High Bandwidth Large Core Multimode Fibre with High Connector Tolerance for Short Distance Communications

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Abstract *We propose a large core multimode fibre for short distance communications. We demonstrated 24 GHz·km peak modal bandwidth in the 850 nm window, connector offset tolerance up to 10 μm, and 25G error-free multimode VCSEL transmission over 500 m of such fibre.*

1. Introduction

Multimode fibres (MMFs) have been widely used in short distance communications in data centres [1]. Even with the surge of interest in standard single-mode fibre for hyperscale data centres, MMFs along with multimode (MM) VCSEL based transceivers remain the cost-effective solution for distances up to 100 m. Compared to the standard single-mode fibre with approximately a 9-μm core size, existing high bandwidth MMFs have a 50-μm diameter core, which allows easier optical coupling and higher connector offset tolerance.

Over the past few decades, the ever-increasing demand for higher data rates motivates the evolution of fibres toward higher modal bandwidth. Currently, 50-μm core MMFs with around 1% refractive index contrast are used predominantly in the field, among which the highest grades such as OM4 and OM5 have 4700 MHz·km effective modal bandwidth (EMB) at 850 nm. Despite already having a large core size and the ease of optical coupling, there is a continued demand to push the limit further, which has resulted in novel connectivity solutions using lensed connectors with expanded beam [2].

In this paper, we propose a fibre solution that can offer not only higher modal bandwidth, but also higher connector offset tolerance than the 50-μm core MMF. The new MMF, referred to as large core MMF (LCMMF), can find a potential application in the emerging fibre-to-the-server (FTTS) [3], where the technology has evolved to a point that optical links are desired for replacing copper links to meet the high bandwidth requirements while providing low cost, low power consumption and simple connector handling for easy installation. In addition, the long system reach of 25G transmission experiments with the LCMMF makes it a promising candidate for high-speed short-distance data centre applications.

2. Fibre concept and design considerations

The proposed new LCMMF can fulfil the goal of having both higher modal bandwidth and higher connector offset tolerance by a proper design of the core refractive index profile and core size. The relative refractive index profile, or delta profile of the LCMMF takes the alpha graded-index profile, $\Delta(r)=\Delta_0[1-(r/a)^{\alpha}]$. As illustrated in Fig. 1 the fibre has 1% core delta, ~100-μm core diameter and α around 2.1.

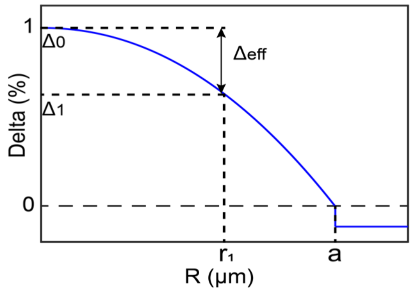

Fig. 1 The delta profile of the LCMMF.

Even though the LCMMF has a larger core, we expect that the light from existing VCSEL transceivers designed for 50-μm core MMF is launched into a fiber core portion much smaller than the 100-μm core diameter. As shown in Fig. 1, under such a underfill launch condition, the excited core portion of the LCMMF has a radius of r_1 and an effective delta of Δ_{eff}. Using the bandwidth of 50-μm core MMF with 1% core delta as a reference, the relative peak bandwidth (BW_{peak}) is [4],

$$BW_{peak} = 1/\Delta_{eff}^2 \quad (1)$$

If we assume the light is launched from a 50-μm core MMF with 1% core delta, using the relationship of conservation of etendue [5], the radius r_1 of the excited core portion can be calculated using the following equation,

$$r_1 = \sqrt{a a_r} \quad (2)$$

Where a and a_r are the radii of the LCMMF and the launch fibre, respectively, so that a=50 μm and a_r=25 μm. Using Eq. (2), we get a radius of r_1=35 μm, or a diameter of 70 μm for the excited core portion. Assuming the same α value, the relative peak bandwidth can be written as,

$$BW_{peak} = 1/[\Delta_0(r_1/a)^{\alpha}]^2 \quad (3)$$

For the excited core portion of 70-μm diameter in the LCMMF, we expect the peak bandwidth to be about 4.3 times of the 50-µm core MMF due to reduced effective core delta Δ_{eff}.

3. Characterization of fibre properties

3.1 Modal bandwidth

The modal bandwidth of the LCMMF is characterized using the standard encircled flux launch condition set by ModCon mode controller from Arden Photonics for 50-µm MMF over a range of wavelengths. The measured modal bandwidth is shown in Fig. 2. As can be seen, the fibre has a peak modal bandwidth of 24 GHz·km around 870 nm, which is much higher than that of a typical 50-µm MMF. The modal bandwidth at 850 nm is 13.6 GHz·km, which far exceeds the modal banwidth requirement of OM4. Notably, the fibre also exhbits high bandwidth over a broader wavelength range. Specifically, the modal bandwidth at 910 nm is around 8 GHz·km, and at 950 nm is around 3.7 GHz·km, which exceeds OM5 bandwidth requirements. Such broad bandwidth feature makes the LCMMF suitable for BiDi [6] and SWDM applications [7].

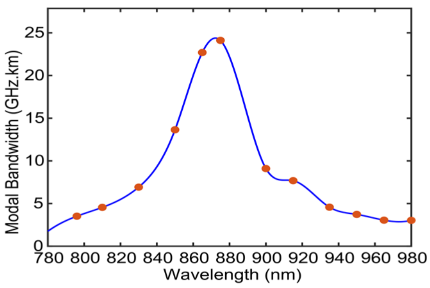

Fig. 2 The measured modal bandwidth for the LCMMF.

3.2 Characterization of connector offset tolerance

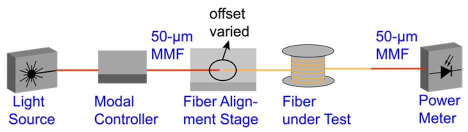

Fig. 3 Schematic of the experimental setup for the connector offset loss measurement.

We further characterized the effect of connector offset on the coupling loss of the LCMMF. The experimental setup is shown in Fig. 3. The ModCon mode controller was used to set the encircled flux launch condition into a 50-µm MMF. The output of the 50-µm MMF and left end of the LCMMF were put onto a fibre alignment stage to control the offset between the two fibres. The output of the LCMMF is directly butt-coupled to a 50-µm MMF and the output optical power is monitored by a power meter. We also measured the relative coupling loss versus offset of a OM4 fiber for comparison.

The experimental results are shown in Fig. 4(a). The vertical axis is the relative coupling loss, which means the additional loss caused by the fibre misalignment compared to the well-aligned case. The LCMMF shows higher connector offset tolerance compared to the OM4 fibre, as the LCMMF has lower additional loss than the OM4 with the same connector offset. Specifically, using the LCMMF with an offset to the launch 50-µm MMF up to 9.7 µm, the additional coupling loss compared to the well-aligned case is lower than 0.3 dB; while for an OM4 fiber, a 1.6 µm offset leads to 0.35 dB additional loss, and a 9.7 µm offset leads to 2.2 dB additional loss. Additionally, when both fibres are connectorized with LC connectors, the coupling loss from the 50-µm MMF to the LCMMF is around 0.2 dB.

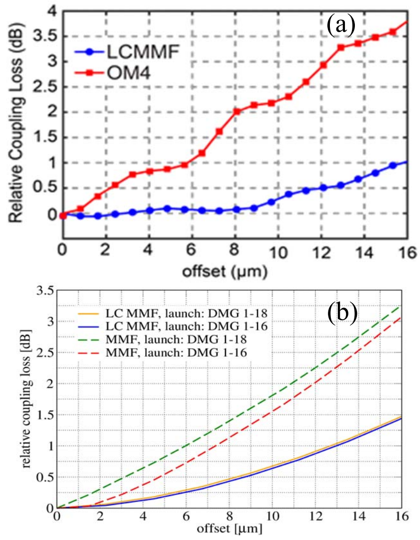

Fig. 4 The relative connector loss of LCMMF and OM4 fibres as a function of offset. (a) Experimental results; (b) Simulated results.

Simulated relative coupling loss for LCMMF and OM4 MMF is shown in Fig. 4(b) for two launch conditions, corresponding to excitation of 18 or 16 degenerate mode groups (DMGs) of input MMF. In both cases the launch power is assumed to be equipartitioned between all modes, resulting in an overfilled launch for DMG 1-18 case, and in a condition similar to an encircled flux standard compliant launch for DMG 1-16. The difference in the coupling loss predicted by the model for OM4 MMF and LCMMF follows qualitatively the experimental curves in Fig. 4(a), and is within <1 dB of measured difference in relative loss for offsets up to 16 µm.

Furthermore, we measured the impact of connector offset on the modal bandwidth of the LCMMF. The experiment was done using a setup similar to Ref. [8] with a vector network analyser (VNA) to obtain the modal bandwidth information, and the setup in Fig. 3 to control the relative offset between two fibers. As shown in

Fig. 5, the modal bandwidth of the LCMMF at 850 nm remains high (above 12 GHz·km) over a large offset range up to 16 μm.

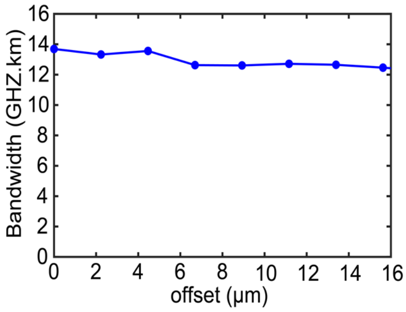

Fig. 5 The measured modal bandwidth of LCMMF as the function of the offset.

4. Transmission Experiment Performance

With the fibre characterized, we conducted transmission experiments using a 25 Gb/s SR transceiver (Hisense LTF8505-BC+), which is based on an MM VCSEL transmitter. The transmitter optical power is -2.1 dBm measured with a 2-m long 50-μm MMF. Using 50-μm MMFs, the link distances of the transceiver are specified to be 70 m for OM3 and 100 m for OM4.

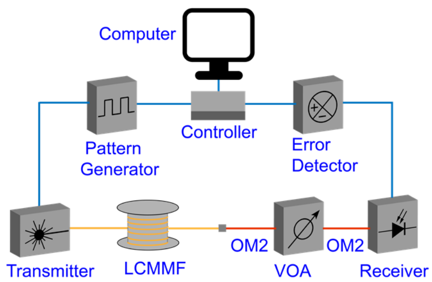

Fig. 6 Setup for the transmission experiments.

The system testing setup is shown in Fig. 6. A Keysight BERT system operating at 25 Gb/s was used to measure the bit error rate (BER). The controller (N4960A-CJ1) controls the pattern generator (N4951B) and error detector (N4952A-E32), which provides 2^{31}-1 PRBS pattern that was used in our experiments. The BER measurements were done with LCMMF having lengths of 0 m, i.e back-to-back (B2B), 200 m, 300 m and 500 m. We obtained the BER versus received optical power for each case. A variable optical attenuator (VOA) connected with 2 pieces of 50-μm MMFs was placed right before receiver port of the transceiver. Since the VOA uses 50-μm MMFs, the LCMMF is coupled to them before reaching the receiver. There is a loss of around 1.5 dB due to the coupling. However, when the LCMMF is directly connected into the receiver as expected in actual application, we expect the receiving optics to capture more light, resulting in lower loss.

As shown in Fig. 7, under the B2B condition, the system reaches error-free performance with received power of around -11 dBm. With 200 m and 300 m lengths, little penalty is observed judged by the optical power needed to reach the 10^{-11} or 10^{-12} BER compared to the B2B case. Only when the fibre length reaches 500 m, a power penalty of 4.5 dB is observed. Nevertheless, the system can work error free for 4 minutes using 500 m LCMMF without the VOA.

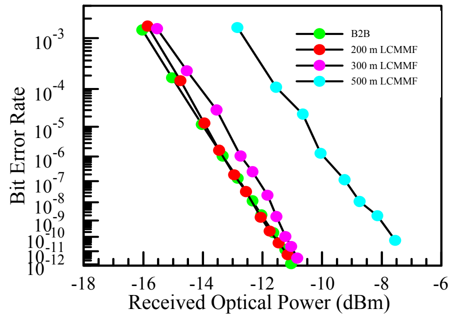

Fig. 7 The BER versus received optical power for the B2B and several lengths of the LCMMF under test.

We also obtained the optical eye diagrams using an Agilent digital communication analyser mainframe (86100D) with a MM optical receiver plugin (86105D). As shown in Fig. 8, with increasing fibre length, the optical eye diagrams become incrementally degraded. With 200 m and 300 m length, the optical eye diagrams become slightly noisier but the eye opening narrows substantially at 500 m length.

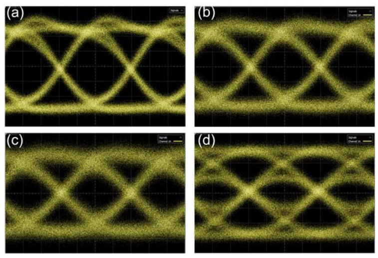

Fig. 8 Optical eye diagrams obtained at (a) B2B, (b) 200 m, (c) 300 m, and (d) 500 m length of LCMMF.

5. Conclusions

We proposed a new large core MMF design with 1% core delta and around 100-μm core diameter. We fabricated a fibre and conducted detailed characterizations. The fibre exhibits a peak modal bandwidth of 24 GHz·km at 870 nm, a wide wavelength window with high bandwidth from 850 to 950 nm, as well as high connector offset tolerance up to 10 μm in terms of both insertion loss and modal bandwidth. Transmission experiments using a 25G SR transceiver show that such fibre can work error free over a length of 500 m and show negligible power penalty over 300 m compared to the B2B case. The LCMMF can potentially offer a fibre solution for data centre applications with easier connectivity and higher bandwidth compared the conventional 50-μm core MMFs.

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