A Simple and Compact Fiber Modal Adapter for Upgrading 850 nm Multimode Fibers for Fundamental Mode Transmission at 1310 nm

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Abstract: We propose a simple and compact adapter using specially designed modal conditioning single-mode fiber for fundamental mode transmission through multimode fiber and demonstrate error-free transmission over 1-km multimode fiber using a 100G CWDM4 transceiver. © 2020 The Author(s)

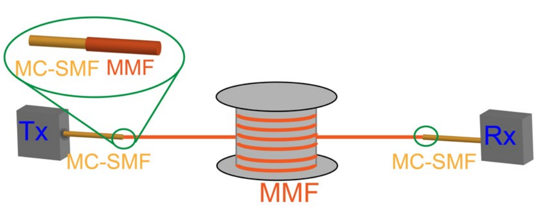
1. Introduction

In short distance communications, both single-mode fibers and multimode fibers (MMFs) are commonly used. Driven by the demand for increasing the data rate and extending the reach especially in hyperscale data centers, more single-mode (SM) transmission systems using single-mode fibers have been adopted. Simultaneously, the low cost of system using multimode (MM) VCSELs over MMFs remains attractive. Various approaches have been proposed to enable the benefits of both SM and MM transmission using one type of fiber. One example is to use universal fiber [1], which is an MMF, but can also be used for SM transmission due to its matched LP_{01} mode field diameter (MFD) to that of standard single-mode fiber, acting essentially as a single-mode fiber when the fundamental mode is launched using a SM transceiver. Another approach is to use existing 50-µm core MMFs for SM transmission by launching the fundamental mode through a single-mode fiber jumper or a mode expansion system [2-4]. Center launch from standard single-mode fiber has been used to improve the bandwidth-distance of an MMF link. However, it is not ideal due to various issues such as mode mismatch and having an extra jumper attached to the transceiver [2]. Various mode expansion techniques have been proposed either to fusion splice a short piece of single-mode fiber with expanded MFD through thermal diffusion of core dopant [3] or use free-space bulk optics [4]. A more complex approach using phase plates [5] has been demonstrated, based on which commercial products are offered [6]. These solutions have significant challenges in either component processing or device packaging and are too costly for cost-sensitive data center applications.

In this paper, we propose a new approach to address the problem by using a specially designed modal conditioning single-mode fiber (MC-SMF), which is a single-mode fiber with LP_{01} MFD matched to that of a 50-µm MMF at 1310 nm and packaged in a compact pass-through adapter.

2. MC-SMF Design Concept and Use of Compact Adapter

We adopt a simple, compact and low-cost fiber-based approach to realize fundamental mode transmission in MMFs. Fig. 1 shows a schematic diagram of the optical transmission configuration. The MC-SMF near the Tx serves as a launch fiber to excite only the LP_{01} mode of the MMF, while the second MC-SMF ensures that only the LP_{01} mode of MMF can pass through, effectively acting as a mode filter.



(a)

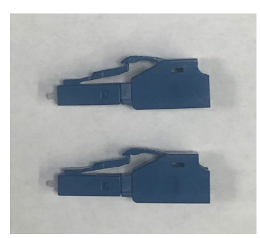

(b)

Fig. 1 (a) The schematic diagram of the optical transmission configuration involving an MMF sandwiched between two MC-SMFs; (b) a picture of two MC-SMF adapters with LC connectors.

At 1310 nm the MFD of LP_{01} mode of a typical 50-µm core MMF is around 14.5 µm, while the MFD of a typical standard single-mode fiber is around 9.2 µm. Such big MFD mismatch can cause high insertion loss, as well as significant multi-path interference (MPI) [7]. To reduce the insertion loss and MPI, we propose to use specially designed single-mode fibers with MFD roughly matched to that of LP_{01} mode of MMF for 1310 nm operation. The design can be accomplished using step-index profile design. We have chosen a fiber core index delta of around 0.13% and core radius of 7.22 μm. Three fibers targeting the design with delta of 0.114 %, 0.127 % and 0.148 % have been made, and their optical properties are shown in Table 1. The fibers have MFDs near the targeted value of 14.5 μm. The fiber cutoff wavelengths are well below 1310 nm so that they are single-mode over very short length. The high macrobend losses make the fibers not suitable for use as jumpers. Instead, we package them in very compact adapters as shown in Fig. 1(b) to avoid high bending loss. The fiber length within the adapter is 16 mm but due to low cutoff wavelengths, the fibers are essentially single-mode over such short length [8]. Standard single-mode fibers have higher cutoff and are not single-mode at adapter length, leading to higher order mode excitation.

Table 1. Optical properties of three MC-SMFs made.

Fiber	MFD at 1310nm (mm)	Fiber Cutoff Wavelength (nm)	Macrobend Loss @ 40mm Diameter (dB/turn)
MC-SMF1	15.44	1055	47.03
MC-SMF2	14.83	1115	20.38
MC-SMF3	14.02	1204	15.39

3. Insertion Loss and MPI

We conducted detailed measurements of the MPI in various configurations. The SMF jumper, which is not ideal for the modal conditioning, is also studied for comparison. The experimental setup is shown in Fig. 2. The MMF is sandwiched between MC-SMFs or standard single-mode jumpers. The optical power variations over a period of time is subsequently measured. The polarization scrambler is actively engaged, and a portion of the fiber is manually shaken to accelerate the process for the optical power to vary in its full range. The MPI defined in the current study is the peak-to-peak value of the optical power variation, also referred to as P-P MPI. Table 2 shows the measured P-P MPI for four conditioning fibers with three different lengths of 50-μm core MMFs: 2 m, 100 m, and 1 km. It is found that with standard single-mode fiber jumpers as the conditioning fibers, the P-P MPI is around 2 dB for all cases. On the other hand, for all three versions of MC-SMFs, the P-P MPI values are much lower varying from 0.15 to 0. 30 dB. The MPI using MC-SMF is dramatically reduced compared to the case using SMF jumpers.

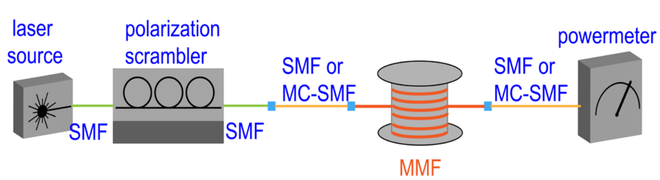


Fig. 2 The schematic diagram of MPI measurement.

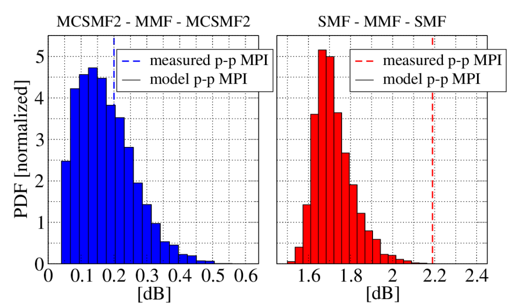


Fig. 3 MPI distribution for two configurations

We also measured the insertion loss of the MMFs with MC-SMFs and show the results in Table 3. It can be seen that the end-to-end insertion loss is between 0.31 and 0.41 dB, much lower than that using SMF jumpers with end-to-end insertion loss of 2.03 dB. The difference also highlights the advantages of using MC-SMFs over SMF jumpers in reducing the insertion loss of the system. Also note that the insertion loss for a commercial LP_{01} launch device is specified at 2 dB typical and 3 dB max [6], much higher than using MC-SMFs here.

Table 2. Measured MPI for several MMFs with four different modal conditioning fibers

Conditioning Fiber	P-P MPI (dB)		
	2m MMF	100m MMF	1-km MMF
SMF	2.19	2.37	1.95
MC-SMF1	0.22	0.26	0.17
MC-SMF2	0.20	0.30	0.22
MC-SMF3	0.16	0.15	0.23

Table 3. Measured link insertion loss for four different modal conditioning fibers

Configuration	Insertion Loss (dB)
SMF-2m MMF-SMF	2.03
MC-SMF1- 2m MMF-MC-SMF1	0.35
MC-SMF2- 2m MMF-MC-SMF2	0.41
MC-SMF3- 2m MMF-MC-SMF3	0.31

Numerical modeling is also conducted to estimate the MPI based on the modal conditioning fiber type and connector offsets using the model in [7]. Fig. 3 shows MPI distributions, i.e. probability density function, computed based on the link setup shown in Fig. 2. Single-mode operation of the launch and receiving fibers at 1310 nm wavelength is assumed in the model, and the transverse offset at each connector is taken to be the dominant source of misalignments. The maximum offset is assumed to be ~1.5 µm. Power coupled into each mode group of MMF is assumed to equipartition between the modes within that mode group, due to their essentially same propagation constants. Results of Monte-Carlo simulations of the link with random variations of connector offsets and random relative phases of the MMF modes are found to correlate well with measured MPI values.

4. System Testing

We conducted system experiments to test the performance of fundamental mode transmission using MC-SMF adapters and a 100G CWDM4 transceiver [9] for 4×25G transmission operating at 1270 nm, 1290 nm, 1310 nm and 1330 nm, respectively. The transceiver utilizes only two fibers with two LC connectors. Using either SMF jumpers or MC-SMF adapters as modal conditioning fibers with MMF in the middle, they all show error-free performance over 1-km MMF for more than 5 hours as tested with Viavi 100G optical network tester (ONT). The MMF used here is OM3 but it can be any grade of 50-µm core MMF. The optical eye diagrams using SMF and MC-SMF 3 are shown in Fig. 4. With MC-SMF 3, the optical eye diagrams are less noisy than those using SMF jumpers, indicating more robust performance. Other MC-SMFs also illustrated similar system performance to MC-SMF 3. The system works with SMF jumpers as conditioning fibers but comes with significant penalties due to insertion loss, MPI and degraded eye diagrams. We also made compact adapters using standard single-mode fiber. They fail the system test since the fiber within the adapter is not single-mode.

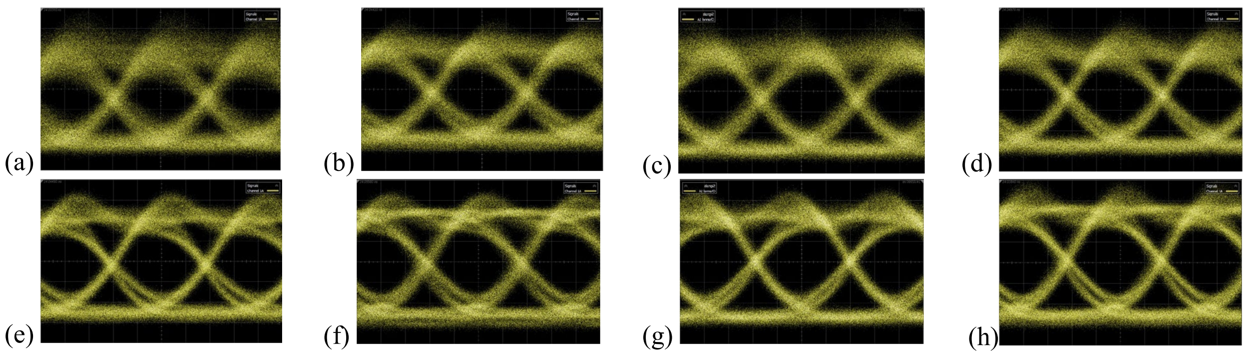


Fig. 4 Measured optical eye diagrams for all four channels with (a-d) for SMF jumpers and (e-h) for adapters using MC-SMF 3.

5. Conclusions

We have proposed a specially designed modal conditioning fiber that is single-mode with mode field diameter matched to the LP_{01} mode of a 50-µm core MMF for fundamental mode transmission. Three MC-SMFs were made and packaged into compact adapters with LC connectors. They show superior MPI and insertion loss performance, which is critical to meet the power budget requirement [9]. Numerical modeling shows reasonable agreement with the experiment. We also verified that the system performs error free using MC-SMF adapters over 1-km 50-µm core MMF using a 100G CWDM4 transceiver. Using the proposed adapter with special MC-SMF is a simple and robust approach for SM transmission around 1310 nm over MMFs. It is potentially a cost-effective solution that enables data centers to benefit from cost and energy efficient 850nm MM transceiver solutions now while having a pathway to upgrade to high data rate systems with 1310 nm SM transceivers in the future.

6. References

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