Universal Fiber for Both Short-reach VCSEL Transmission at 850 nm and Single-mode Transmission at 1310 nm

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Abstract: We proposed a universal fiber and demonstrated its use in 850nm VCSEL based multimode transmission at 10Gb/s and 25Gb/s over 100/50m and 1310 nm single mode 25 Gb/s NRZ and 44Gb/s PAM4 transmission over 2km.

OCIS codes: (200.4650) Optical Interconnect; (060.2360) Fiber optic links and subsystems

1. Introduction

In data centers and short distance optical communications, multimode fiber (MMF) has been the primary optical medium with VCSEL based optical transceivers for low cost transmission systems. In recent years single mode fiber (SMF) and single mode (SM) transceivers have been used more frequently in emerging super- and mega- scale data centers that demand longer system reach than can be achieved with MMFs. While it is possible to use both MMF and SMF in data centers, it is desirable to use a uniform type of optical fiber that can accommodate both types of transmission to simplify fiber cable management.

There has been interest in transmitting through MMF using 1310 nm SM transceivers with restricted launch so that MMF can act as a single-mode link. Because the mode field diameter (MFD) of the fundamental mode of standard 50 μm core MMF is much larger than that of standard SMF at 1310 nm, over 20% of the power is launched into higher order modes when coupled directly from a SMF to a MMF, causing significant system degradation due to multipath interference effects. In addition, higher order mode excitations also deteriorate the tolerance to mechanical perturbations such as the connector offset and fiber bending. Although it is possible to launch the light into only the fundamental mode of MMF using various complicated mode expansion techniques [1-4], the solutions are too costly for cost-sensitive data center applications. Furthermore, the SM receiver can only receive a small portion of the light emitted from the MMF, resulting in significant penalty in optical power.

Instead of using existing 50 μm MMF for SM and MM dual transmissions, in the current paper, we propose a specially designed MMF with smaller core than conventional MMF but with its mode field diameter of the fundamental mode similar to that of standard single mode fiber at 1300 nm wavelength and therefore can readily work with many existing SM transceivers such as LR4 transceivers for DWDM transmission. Because the fiber can be used for both MM transmissions at 850 nm and SM transmission at 1300 nm, we refer to this fiber as universal fiber. While we have taken a design trade-off with smaller core MMF so that some coupling loss may occur when light is launched into the fiber and it may not accommodate the MMF transmission at full length specified by standard, we recognize that a majority of MMF application have a system reach of less than 100 m with average value to be around 50 m [5]. On the other hand, more and more single mode transmission has been preferred in large scale data centers, a universal fiber that can cover majority of use without the need to manage multiple fiber types can significantly simplify the data center infrastructure.

2. Fiber design and properties

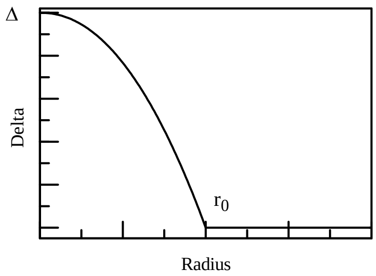

Fig 1. Delta profile of the fiber.

The fiber takes a simple alpha refractive index profile as illustrated in Fig. 1. The refractive index profile is expressed by $n(r) = n_0 \cdot \sqrt{1-2\Delta(r/r_0)^\alpha}$, where α describes the shape of the profile, n_0 is the refractive index in the center of the core, r_0 is the core radius, and $\Delta = (n_0^2 - n_1^2)/(2n_0^2)$ where n_1 is the refractive index of the cladding. When the α value is properly chosen, the modal bandwidth of the MMF can be optimized or maximized at a specified wavelength. For 850 nm operation, the α value is around 2.1. The mode field diameter of the fundamental mode can be designed to match the mode field diameter of standard single mode fiber by properly choosing the core delta and core radius. A fiber was fabricated according to the design concept. The fiber has a numerical aperture of 0.2 similar to OM3 and OM4 MMFs, while the radius a is 11.5 μm, corresponding to a 23 μm core diameter. With the above fiber parameters, the fiber has a mode field diameter very similar to that of a standard single mode fiber at 1310 nm around 9.2 micron. The attenuation of the fiber was measured at 850 nm and 1310 nm to be 2.1 dB/km and 0.41 dB/km. The overfill (OFL) bandwidth of the fiber at 850 nm was also measured to be 1.35 GHz.km.

3. VCSEL transmission at 850nm

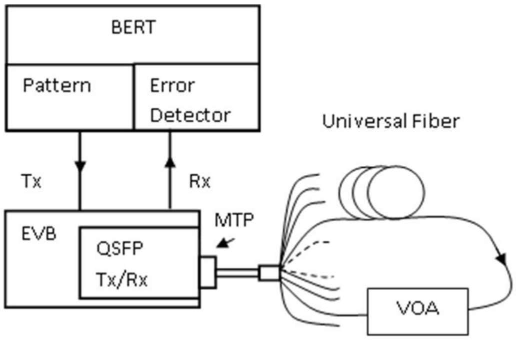

Fig. 2. The layout of experimental setup using 25Gb/s VCSEL based transceiver operating at 850nm.

We tested the fiber at 850 nm using a VCSEL based transceiver using experimental layout shown in Fig. 2. The transceiver is a commercial 100G transceiver with QSFP form factor operating at 25.78125 Gb/s in compliance with IEEE 802.3bm standard as driven and error detected by an Agilent BERT. Only one transmitter (Tx) and one receiver (Rx) channel were used. The transceiver has a port with MTP connector. A fan-out cable with a MTP connector at one end and 12 pigtail fibers with LC connectors at the other end was used. The fiber samples were prepared in 30 m and 50 m lengths. We measured BER vs. received optical power as shown in Fig. 3 for the back to back (B2B) and with 30 m and 50 m fiber samples. The optical power launched into the fiber under test was -0.3 dBm. The received optical power was controlled by a multimode variable optical attenuator (VOA). We can reach 2.3×10^{-11} and 2.0×10^{-8} BER at 30 m and 50 m, which exceeds the forward error correction (FEC) threshold of 5×10^{-5} set by IEEE 802.3bm standard and the link is error free after FEC. In the setup, we had around 4.25 dB and 4.55 dB insertion loss through the 30 m or 50 m fiber under test, which were spliced with a short pigtail cable with LC connector that was interfaced with the fan-out cable. The fan-out cable and short pigtail cable utilize 50 μm core MMF. The light from the VCSEL transmitter was first coupled into the 50 μm core MMF before coupling into the specially made universal fiber. This caused more insertion loss. If the fan-out cable and pigtail cable are also made from the universal fiber, the insertion loss will be reduced significantly. A length of 50 m is right around the average link length of MMF used in the data center covering a large percentage of usage.

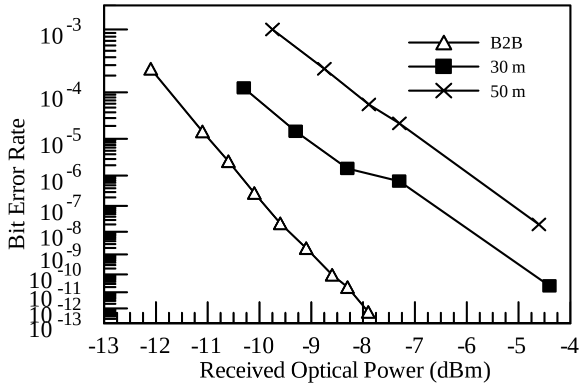

Fig. 3 The BER vs. received optical power curves for VCSEL at 25.78125Gb/s transmission at 850nm.

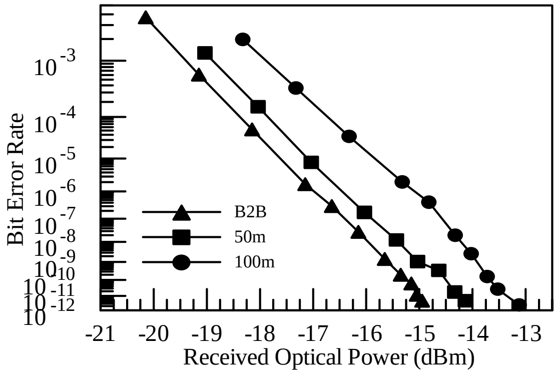

Fig. 4. The BER vs. received optical power curves for VCSEL at 10.3125Gb/s

We also conducted the experiment using 10Gb/s VCSEL based transceiver with SFP+ form factor. The transceiver optical interface uses LC connectors. We were able to have error free system performance at 50 m and 100 m respectively as shown in Fig. 4. For this experimental setup the insertion losses for 50 m and 100 m fiber under test were 2.8 dB and 3.2 dB, respectively.

4. Single mode transmission at 1310 nm

We also conducted system testing for 1310 nm single mode transmission at 25.78125 Gb/s with NRZ modulation. The transmitter was made from a narrow linewidth 1310 nm CW laser (Santec TSL-510) as modulated by an intensity modulator from Photline (MX1300-LN-40) at 1310 nm. The launch optical power was -2 dBm with an extinction ratio of 11 dB. The optical receiver was the Discovery Semiconductor (DSC-R409) connected with SMF pigtail. Two 1 km universal fiber samples were prepared with each end spliced with standard single mode fiber with LC connectors. Fig. 5 shows the BER vs. received optical powers obtained from B2B, 1 km and 2 km lengths. The three curves are essentially on top of each other, which means there is little power penalty coming from the universal fiber. This implies that, despite the nature of the fiber being multimoded, the transmission is essentially single moded. We also manually shook the fiber in areas near the ends where we had access and saw neither any noticeable change in BER performance nor optical eye diagrams, suggesting there was little mode coupling happening toward higher order modes during the perturbation. The measured insertion loss of the 1 km fiber as sandwiched between SMF pigtail cables were between 0.9 and 1.2 dB, which also included the fiber attenuation of around 0.4 dB/km at 1310 nm.

We also conducted an experiment with PAM-4 transmission at 22Gbaud rate using the same transmitter and receiver setup. The PAM-4 signal was generated with a 64 GSa/s digital-to-analog converter (DAC) with a root-raised cosine pulse shape with 0.75 roll-off factor. The DAC has an analog bandwidth of about 13 GHz and the waveform was pre-emphasized to mitigate the low-pass frequency response of the DAC. The detected signal after transmission was captured with a real-time oscilloscope with maximum bandwidth of 20 GHz and the received waveforms were processed offline to calculate BER as shown in Fig. 6. The performance with 2km of universal fiber is essentially the same as in the back to back setup, similar to those obtained with NRZ transmission above. The BER data in Fig. 6 were calculated without any digital equalization, which has similar capability to those reported in [6] using post-processing of data from real-time oscilloscope.

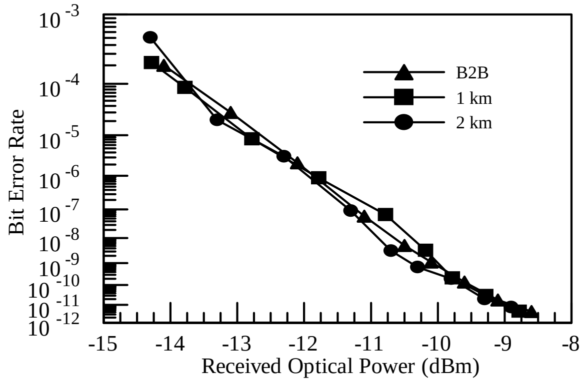

Fig. 5. The BER vs. received optical power curves for three experimental conditions, B2B, 1km and 2km with NRZ modulation.

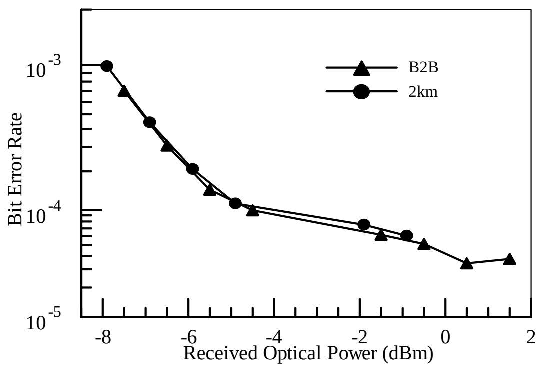

Fig. 6. The BER vs. received optical power curves for, B2B, and 2km conditions with PAM4 transmission.

5. Conclusions

We proposed a universal fiber with a smaller core than conventional MMF but with the mode field similar to that of a SMF around 1310 nm. The design takes into account both the VCSEL based transmission needs around 850 nm and the SM transmission around 1310 nm to make it a fiber for universal use. We have fabricated a universal fiber and conducted system testing. We demonstrated that the system can reach 100 m and 50 m respectively in 10 Gb/s and 25 Gb/s 850 nm VCSEL based transmission. At 1310 nm, we showed a system reach up to 2 km with single mode transmission with both NRZ modulation at 25 Gb/s and PAM-4 modulation at 22 Gbaud with little power penalty except for the insertion loss. Therefore, we would expect the system can have much longer system reach. Because the mode field diameter of the proposed fiber matches that of SMF, it is compatible with SM transceivers as is. The fiber used in the experiments is the result of initial design iterations and the modal bandwidth at 850 nm can be further improved. We believe the proposed universal fiber can cover majority lengths in data centers and its use can reduce the number of fiber types to simplify the data center infrastructure.

6. References

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