Multimode Fiber Bandwidth Uniformity and its Impact on Optical links in Hyperscale Datacenters

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Abstract: We characterize multimode fiber bandwidth uniformity and its impact on optical links in data centers, discussing the importance of MMF bandwidth uniformity to data center deployment of the next-generation 100-Gb/s multimode products.

1. Introduction

Vertical Cavity Surface Emitting Laser (VCSEL) based 100G, 200G, and 400G SR4 transceivers are widely used in hyperscale data centers, with operating distances specified up to at least 70 m on OM3 and 100 m on OM4 Multimode Fibers (MMF) [1]. We found a certain percentage of network link failures were caused by inadequate bandwidths of MMF in our data centers, even though all the fibers passed the production test and were graded as OM3 or OM4 class.

Differential Mode Delay (DMD) based Minimum Effective Modal Bandwidth (EMB) tests during fiber production are used to grade MMF class according to IEC standards [2]. Limited by the pulse width of the light source used in the test system and the measurement resolution of the DMD waveform, this test method requires the length of the fiber under test to be longer than a few kilometers, and fiber of about 8000-m length is typically used for EMB test by manufacturers. The whole 8000-m long wool is graded as a specific class based on its minimum EMB results. The long fiber is then cut into short fibers with lengths < 70 m for OM3 and < 100 m for OM4 and assembled as cables for data center use. The bandwidth of the short fibers is assumed to be the average result of the long fiber, but its actual bandwidth is unknown and hard to test in practice.

In this paper, we characterize the bandwidth uniformity of a 7200-m-long fiber by cutting the fiber into 100-m-long pieces and measuring their effective bandwidths. We find there is a significant variation of the effective bandwidths among the segments, and some of the segments do not have sufficient bandwidths. We also test the MMF nonuniformity's impact on the performance of 25.78Gb/s non-return-to-zero (NRZ), 53.125Gb/s 4-level pulse amplitude modulation (PAM4), and 106.25Gb/s PAM4 signals. The importance of MMF bandwidth uniformity in deploying next-generation 100-Gb/s per lane in data center networks is discussed.

2. Short MMF Effective Bandwidth Test Method

Since EMB testing of short MMF is very challenging, we evaluate the effective bandwidth of MMF less than 100 m by testing the Transmission Dispersion Eye Closure (TDEC) over fibers of the typical transceiver. The test setup is depicted in Fig. 1. One channel of a 100-Gb/s SR4 optical transceiver is used as a light source. Its center wavelength is ~850 nm, and the Root Mean Square (RMS) spectral width is ~0.45 nm. A mode conditioner is used to block the launch condition variation of light sources, and it outputs a constant launch condition and is compliant with IEC 61280-4-1 Encircled Flux (EF) [3]. Such a source has a typical launch condition in field applications.

Firstly, we characterize the relationship between the transmission performance of the light source and the channel bandwidth [4]. The light source is directly measured by the Digital Communication Analyzer (DCA) sampling oscilloscope with a 1-m long fiber. The channel response of the System Implus Response Correction(SIRC) filter inside the DCA is set as a Fourth-order Bessel-Thomson response to emulate the dispersion of the multimode fiber channel. The SIRC filter is a so-called fiber emulation filter [5], and its electrical 3-dB bandwidth is adjustable. TDEC parameter is measured to quantify the transmission performance. We sweep the transmission eye diagram and TDEC under different bandwidths of the filter, as shown in Fig. 2. The smaller the bandwidth of the channel, the more closed the eye diagram. Fig. 3 depicts the relationship between TDEC and the fiber emulation filter. As seen, the channel bandwidth is well correlated with TDEC values. Since the TDEC measurement error will exceed the TDEC difference caused by channel bandwidth beyond 22 GHz, in this test system, the upper limit of the bandwidth measurement is 22 GHz.

Then, we replace the fiber emulation filter with actual fibers under test and measure the TDEC after fiber transmission. by checking the curve in Fig. 3, the effective bandwidths of the short fibers under test are obtained.

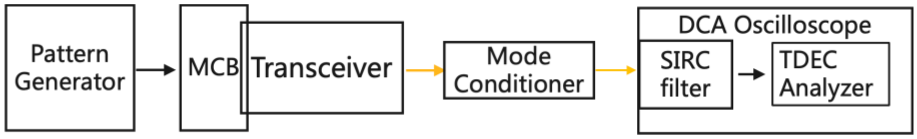

Fig. 1 Experimental setup for transmission performance versus channel bandwidth characterization. MCB: module compliance board.

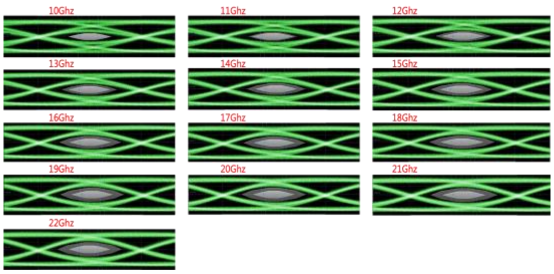

Fig. 2 Eye diagram versus channel bandwidth.

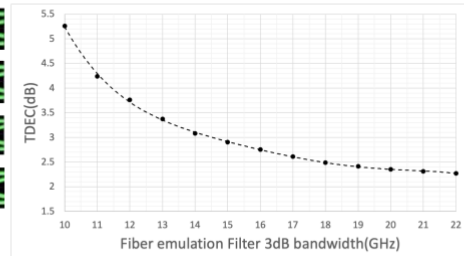

Fig. 3 TDEC versus channel bandwidth.

3. Multimode Fiber Bandwidth Uniformity Characterization

An OM4 MMF with a minimum EMB of 4725 MHz.km and a length of 7200 m is selected for bandwidth uniformity characterization. The 7200-m long fiber is cut into 72 segments of 100 m each and terminated with FC connectors, numbering the positions in sequence along the fiber axis. Eye diagrams and TDEC of signals transmitting over these 100-m fibers are measured according to the method in Chapter 2. The test setup is shown in Fig. 4.

We plot the test results the TDEC and the effective bandwidth versus the position number of the fiber, as shown in Fig. 5. Note that since the upper limit of the bandwidth measurement of the test system is 22 GHz (corresponding to EMB of about 4930 Mhz.km) [6], The dots at 22 GHz in the figure represent their bandwidth is greater than or equal to 22 GHz. It can be seen from Fig. 5 that the 7200-m long fiber has a significant fluctuation in effective bandwidth at fiber positions from 4600 m to 5400 m, and the fiber effective bandwidth in 100 m length is as low as 12.9 GHz in this range (corresponding to EMB of about 2048 Mhz.km), while higher than 22 GHz in other places. Fig. 6 compares the transmission eye diagrams of 3 typical 100-m fibers with high, medium, and low bandwidths, respectively. Table 1 summarizes the transmission performance and bandwidth of these three 100-m fibers. It can be seen from the data that the transmission eye is closed for the low-bandwidth fiber, while the transmission eye is open for the high-bandwidth fiber. Although the 7200-m fiber has a minimum EMB 4725Mhz.km and is graded as OM4 class, the 100-m fiber segments have a significant bandwidth variation, and some segments have a bandwidth that does not meet OM4 class.

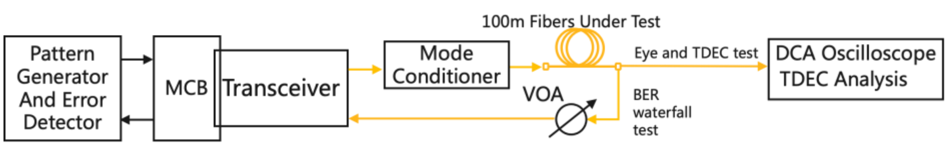

Fig. 4 MMF effective bandwidth and impact on the optical links test setup. VOA: variable optical attenuator.

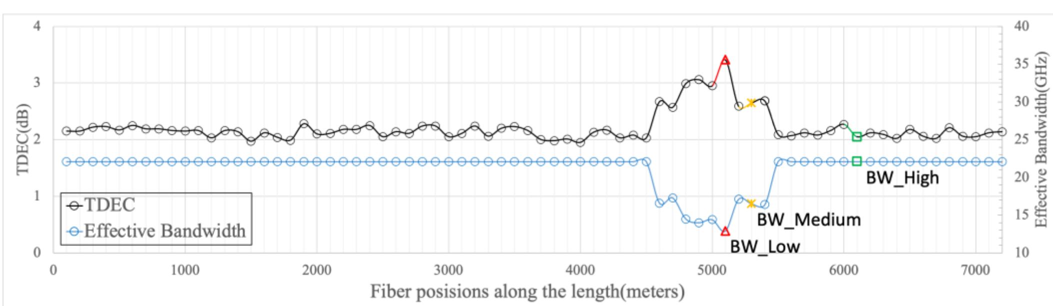

Fig. 5 TDEC uniformity and fiber effective bandwidth uniformity along the length.

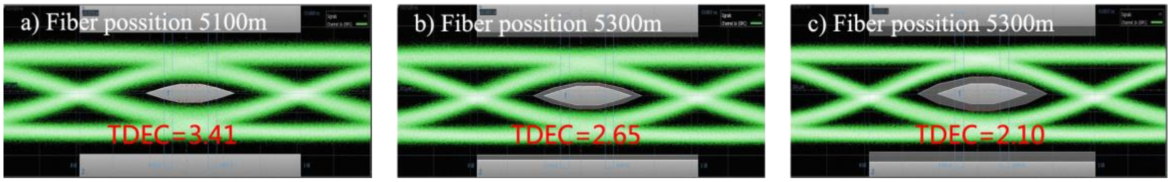

Fig. 6. Eye-diagrams of 25-Gb/s NRZ signal after transmission over 100-m low, medium, and high bandwidth MMF.

	Eye Mask Margin at Hit Ratio 5.0E-5	TDEC(dB)	Electrical Effective BW (GHz.100m)	Estimated EMB(MHz.km) [6]
BW_High(position#6100)	21.8%	2.10	≥22.0	≥4930
BW_Medium(position#5300)	15.7%	2.65	16.7	2923
BW_Low(position#5100)	1.1%	3.41	12.9	2048

Table 1. Transmission performance and bandwidth results for three typical 100m fibers.

4. MMF Bandwidth uniformity's impact on the optical links

We test the transmission performance by the BER waterfall curve of 25.78Gb/s NRZ, 53.125Gb/s PAM4, and 106.25Gb/s PAM4 signals over the above three 100-m fibers of high, medium, and low bandwidths. The test setup is shown in Fig. 4. The transceivers used in the test are 100G QSFP SR4, 200G QSFP SR4, and 400G QSFP SR4 respectively. The test results are shown in Fig. 7. Table. 2 lists the transmission penalty of the fibers with high, medium, and low bandwidths compared to the back-to-back at the bit error ratio (BER) of 1.0E-5. It can be seen that the higher the data rate, the greater the penalty caused by insufficient fiber bandwidth. The low-bandwidth fiber can even cause receiver Loss of Lock in the case of 106.25-Gb/s signaling, and the link cannot work.

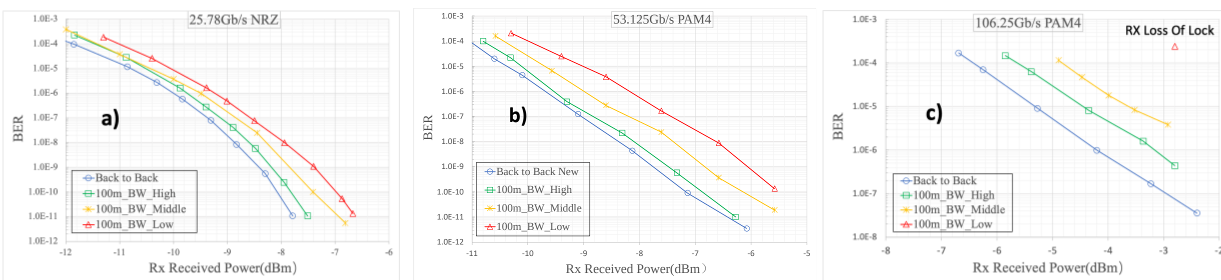

Fig. 7. BER waterfall curve comparison between fibers with bandwidth low, medium, and high at a) 25.781-Gb/s NRZ, b) 53.125-Gb/s PAM4, and c) 106.25-Gb/s PAM4.

Penalty to B2B at 1.0E-5	25.78Gb/s NRZ	53.125Gb/s PAM4	106.25Gb/s PAM4
100m_Bandwidth High	0.3 dB	0.3 dB	1.0 dB
100m_Bandwidth Medium	0.4 dB	0.7 dB	1.7 dB
100m_Bandwidth Low	0.8 dB	1.4 dB	>4 dB

Table 2. Fiber transmission penalty compared to B2B at the BER 1.0E-5.

5. Summary

We characterize the bandwidth uniformity of multimode fiber and found that some long fibers with minimum EMB conforming to OM4 grade have non-uniform bandwidth distribution along the length. After they are cut into short fibers, some fibers fail to meet the specification. MMF bandwidth uniformity is essential to data center deployment of multimode products, especially for the next-generation 106-Gb/s PAM4 transceivers. Multimode fiber manufacturers should not only focus on improving the minimum EMB of multimode fibers but also focus on improving the uniformity of fiber bandwidth.

References

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