400 Gbps Transmission over 4-core Single Mode Multicore Fiber for Datacom Applications

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Abstract

We fabricated a 4-core single mode multicore fiber (SM-MCF) with a standard 125 µm glass cladding. We demonstrated 4×100Gbps parallel transmission using a 400GBASE-DR4 transceiver through four cores simultaneously and 400GBASE-FR4/LR4 transmission through individual core indicating the feasibility of supporting 1.6 Tbps ethernet signals for datacom applications.

Keywords: 400 Gb/s; 400GBASE-DR4; 400GBASE-FR4; 400GBASE-LR4; Datacenter; Datacom; Multicore SMF; PAM4; 4-level Pulse Amplitude Modulation

1. Introduction

The exponential growth of data traffic generated within and between data centers by cloud computing, streaming video, and machine learning are driving the continuous increase of SERDES speed and switch bandwidth. Switch bandwidth is projected to reach 51.2 Tbps and beyond within next five years [1]. To reduce total power consumption, modules of co-packaged optics (CPO) at 1.6 Tbps or 3.2 Tbps based on 400GBASE-DR4 and FR4 are proposed [2,3]. For a 51.2 Tbps switch using 1.6 Tbps or 3.2 Tbps CPO modules based on 400GBASE-DR4 or FR4, the total fiber count is 512 or 128 pairs, respectively. 102.4 Tb switch will double the fiber counts. The large number of fiber pairs need to be packaged in an area of less than 150 by 150 mm around the switch ASIC.

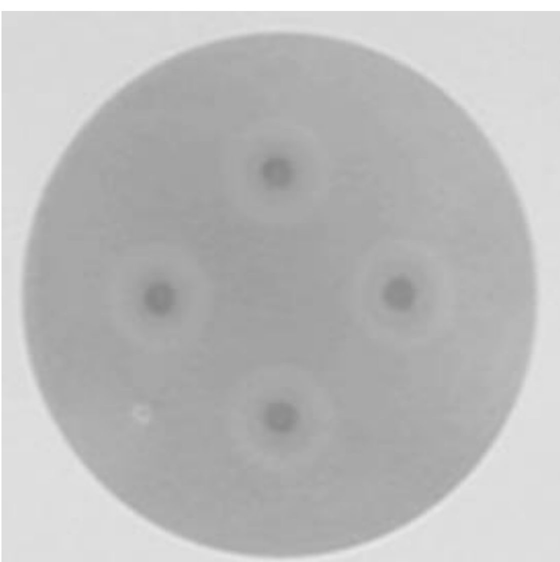

Figure 1. The cross view of the 4-core SM-MCF.

IEEE 802.3 specifies duplex or MPO cables of standard SMF as physical medium in 400G DR4, FR8/FR4, 400G LR8/LR4 for intra- and inter- data center optical interconnects covering < 10 km [4]. For emerging applications such as ultra-high-density data center interconnects (DCI) and optical interconnects to ASIC, a 4-core multicore fiber (MCF) promises to provide 4 × footprint compression than parallel fiber cable for 400G transmission. Thence, it offers a very good solution both to reduce congestion of expensive ducts for high density DCI and to improve heat dissipation for switch capacity beyond 51.2 Tbps. MCF has been intensively researched for various applications in recent years [5]. In the range < 10 km covering the optical interconnects for intra- and short reach inter-data applications, cross talk between adjacent cores of MCF is not severe and a multicore amplifier is not required.

In this paper, we report fabrication and system testing of a four-core single mode multicore fiber (SM-MCF). We achieved error free transmission using an off-shelf 400GBASE-DR4, 400GBASE-FR4 and 400GBASE-LR4 transceivers over a 5 km and 10 km 4-core SM-MCF.

2. Description of the 4-core SM-MCF and FIFO Assembly

The glass cladding of the 4-core SM-MCF is 125 µm in diameter (Figure 1). The pitch between adjacent cores is 40 µm. The cross talk between neighboring cores is < -60 dB over a 10 km spool at 1310 nm. The fiber parameters of each individual core meet ITU-T G.657.A1 specifications. The 4-core SM-MCF spools for system testing are terminated with SC connectors at each end. A fan-in (FI) and fan-out (FO) with four ITU-T G.652 single mode fibers combined and spliced to a short piece of the 4-core SM-MCF are built

		Tx1	Tx2	Tx3	Tx4
400G DR4	λc (nm)	1312.0	1311.7	1312.1	1312.4
	power (dBm)	0.7	1.1	2.1	2.3
400G FR4	λc (nm)	1273.8	1293.5	1312.9	1333.9
	power (dBm)	1.4	2.5	2.7	2.7
400G LR4	λc (nm)	1273.6	1292.8	1311.8	1331.0
	power (dBm)	2.4	2.4	1.5	2.3

Table 1. Characteristic of the 400GBASE-DR4, FR4 and LR4 transceivers.

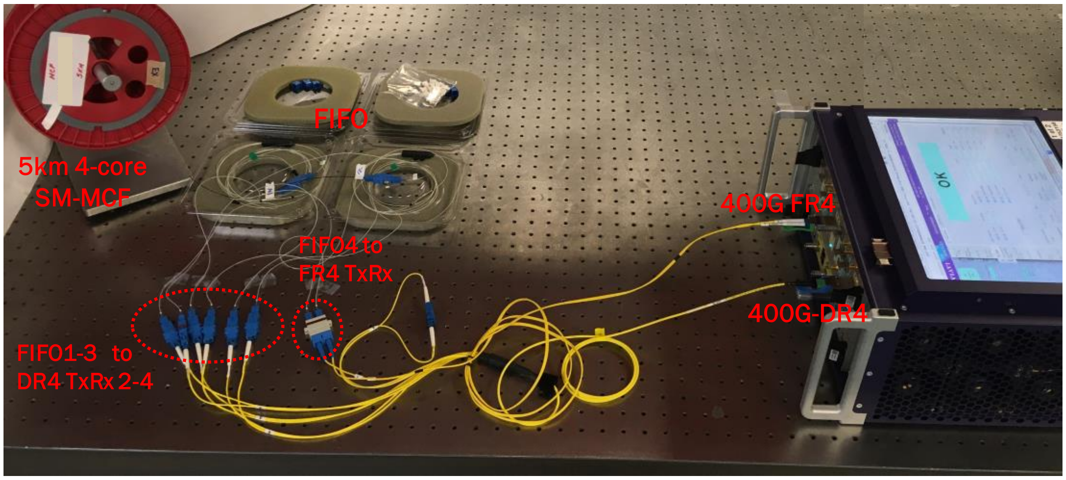

Figure 2. Image of the system setup for 400GBASE-DR4 and 400GBASE-FR4 transmission over a 5 km SM-MCF.

to interface between the SM-MCF under test and 400 GbE transceivers. The FIFO are terminated with SC at the end interfacing to SM-MCF.

3. System Transmission over the 4-core SM-MCF

3.1 Characteristics of the 400 GbE Transceivers

Three off-shelf 400 GbE transceiver modules in QSFP-DD form factor were used in the system testing of the 4-core SM-MCF. The spectral content and average optical power from the transmitters are summarized in Table 1. The reach supportable by the 400G DR4, 400G FR4 and 400G LR4 are specified up to 500 m (2 km for a proprietary 400G DR4+ version), 2 km and 10 km, respectively.

3.2 400GbE System Transmission Setup

A two-ports Viavi 800G Optical Network Tester (ONT-804D) was used to generate 400 GbE and/or 4 × 100 GbE layer 2/3 ethernet traffic. As shown in Figure 2, a 400G DR4 module was plugged in port1 and a 400G FR4 module was plugged in port 2. The 4 × 100 GbE layer 2/3 Ethernet traffic was loaded to the 400G DR4+ transceiver and 400GbE signals were loaded to the 400G FR4 transceiver.

For the 400GBASE-DR4 transmission, the 4 × 106.25Gbps optical signals were simultaneously coupled to the four cores of a 5 km or 9.73 km 4-core SM-MCF using the fan-in/fan-out device. A single mode MPO8 to eight SMF breakout assembly was used to interface between the 400G-DR4 transceiver and the 4-core MCF fan-in/fan-out assembly.

For the 400GBASE-FR4 transmission, one of the four ports of the fan-in/fan-out (FIFO) was disconnected from the 400GBASE-DR4 transceiver and replaced with the 400 Gbps optical signal of 400G FR4, resulting in total > 700 Gbps aggregated signals loaded in the 5 km 4-core SM-MCF under test. A standard single mode duplex jumper was used to interface between the 400G-FR4 transceiver and one of the four ports of the FIFO of the 4-core SM-MCF. 400G FR4 was replaced by the 400G LR4 for transmission over the 9.73 km 4-core SM-MCF.

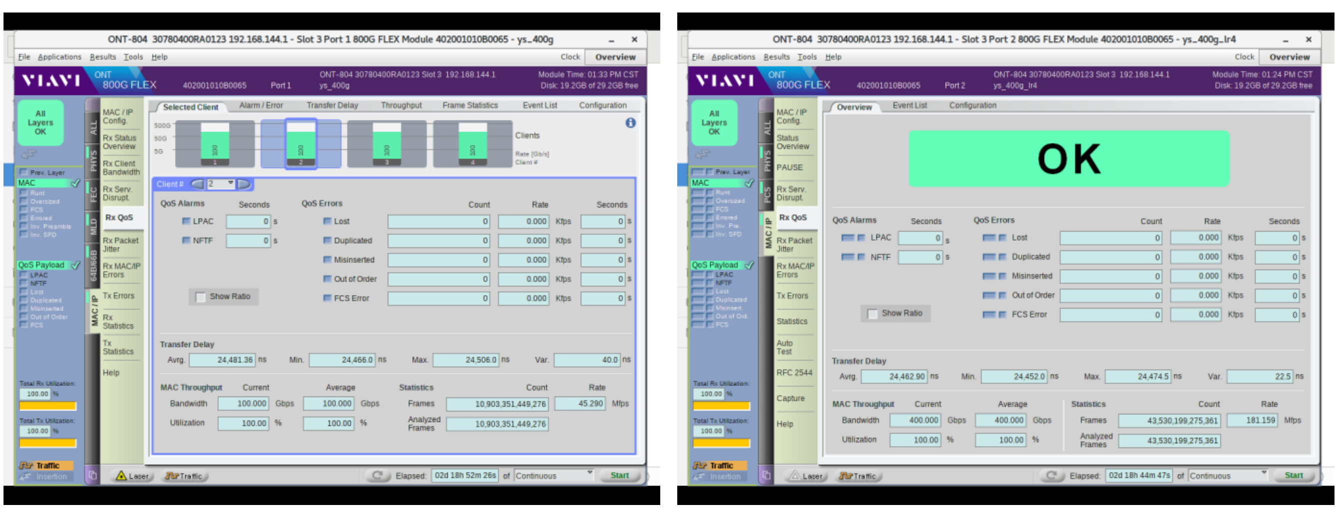

Figure 3. Screen capture of the Rx QoS of the 4 × 100GbE-DR4 (left) and 400G-FR4 over 5 km SM-MCF after > 2 days and 18 hours of continuous transmission.

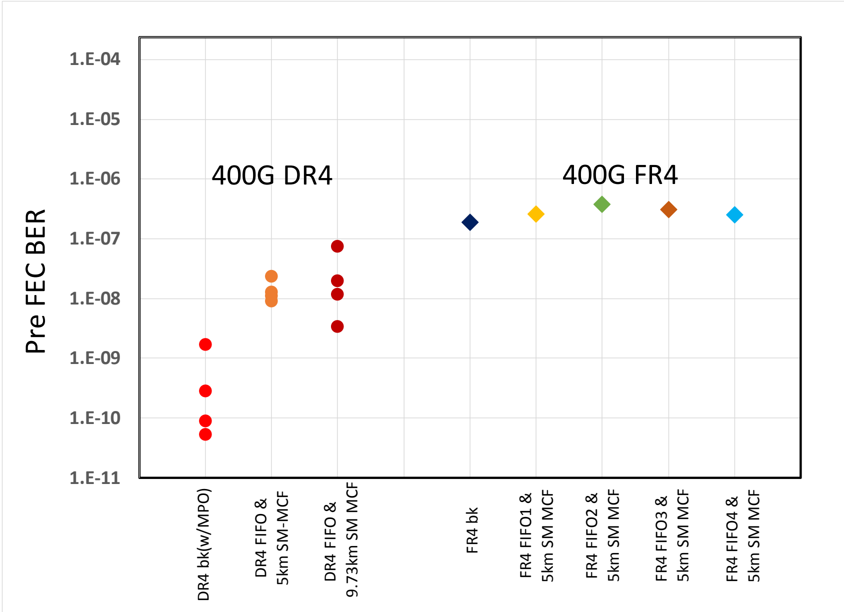

Figure 4. Pre-FEC BER of the 4 × 100GbE-DR4 (left) and 400G-FR4 over 4-core SM-MCF over long duration of continuous operation.

For some tests, a single mode variable optical attenuator (VOA) is inserted between the ports of the fan-out in interest and the input jumper to the receiver of either 400G-DR4 or 400G-FR4 (or LR4) to further stress the link for assessment of the robustness of the system performance.

3.3 400 GbE System Transmission Results and Discussion

Error free transmission over a 5 km and even a 9.73 km 4-core SM-MCF was achieved using the 400GBASE-DR4 transceiver. 100% of the 4 × 106.25 Gbps bandwidth was utilized. After more than 16 hours of continuous operation, no un-correctable bit or frame errors were detected. The pre-FEC BERs of PHY layer 1 to 4 (corresponding to transmission through core 1 to 4) after the 5 km and 9.73 km MCF were below 10^{-7}, one to two orders worse than the pre-FEC BER of the bk2bk, however, still three orders of magnitude better than the FEC threshold. The link attenuation including FIFO and the 9.73 km MCF were 4.3 dB, 4.8 dB, 4.4 dB and 4.1 dB, respectively. After more than 19 hours of continuous operation using a 400GBASE-DR4+ transceiver, the pre-FEC BERs for transmission over the 9.73km MCF and FIFO were 1.97×10^{-9}, 5.54×10^{-9}, 3.89×10^{-10} and 1.77×10^{-9}, for PHY layer 1 to 4, respectively, four to five orders of magnitude better than the FEC threshold. Note that all cores of the 4-core SM-MCF were transmitting signals simultaneously in co-propagating directions, which was the worst scenario in crosstalk impact. The reach far exceeded the specified 500 m for 400G-DR4 and 2 km for 400G-DR4+. It can be understood by the difference between the parameters of the specific transceivers used in the testing and the worst limit (e.g. minimum transmitter optical power) in standard specification. It also clearly showed the potential of the 4-core SM-MCF in our report to support 400 Gbps transmission in reach suitable for both intra-datacenter and DCI applications.

Limited by the availability of the 400G FR4 module, only one of the four cores of the MCF could carry the 400G FR4 signals each time. However, the degradation caused by crosstalk was considered by transmitting 106.25Gbps signals from the 400G-DR4 transceiver through FIFO to the other three cores of the MCF. Thus, an aggregated 700 Gbps layer2/3 ethernet traffic with 100% bandwidth utilization was co-propagating in the 4-core SM-MCF. After more than 2 days 18 hours of continuous operation over the 5 km SM-MCF, no frame loss or error were recorded for either 400G FR4 or 400G DR4, as shown in the screen capture of Receiver Quality of Service (Rx QoS) in Figure 3. Error free transmission of 400G FR4 was repeated in all four cores one at a time. The pre-FEC BERs of all core of the 5 km MCF were below 10^{-6}, two order of magnitude better than the FEC threshold. It was only slightly worse than the pre-FEC BER of the bk2bk, indicating a negligible penalty due to the 5 km SM-MCF. The robustness of the system performance was further validated by introducing 2 to 3 dB additional attenuation before failing the Rx QoS. The result indeed indicates the potential of 4-core SM-MCF to support 1.6 Tbps up to 5 km allowed by four 400G FR4 transceivers. The reach was extendable to 10 km using the 400G LR4 transceiver instead. Details of the results using the 400G LR4 module will be reported in [6].

4. Conclusions

In conclusion, we demonstrated a 4-core SM-MCF with a standard cladding supporting 425 Gbps ethernet traffic up to 10 km using commercial 400G DR4 transceivers. We also achieved > 700 Gbps transmission over a 5 km MCF using both a 400G FR4 and DR4 transceivers. Pre-FEC BER were several orders of magnitude better than the FEC threshold. Co-propagating of signals through the four cores showed the negligible impact of the cross talk in intra- and inter-datacenter DCI applications up to 10 km.

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6. Picture of authors

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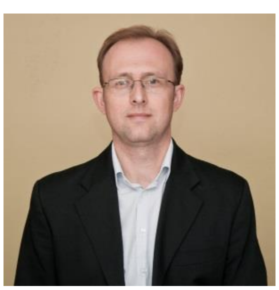

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