100G SWDM4 Transmission over 300m Wideband MMF

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Abstract *Experimental data is presented demonstrating 100GbE (4 x 25.8 Gb/s) SWDM4 VCSEL technology, and SWDM4 transmission over 200m and 300m of wideband OM4 fiber. All SWDM4 channels achieve error free transmission at 200m, and BER < 1.e-9 at 300m.*

Introduction

Multimode fiber (MMF) optical modules based on VCSEL technology provide a low cost and power efficient solution for 100 Gbps data center networks based on parallel multimode fiber[1]. The IEEE recently standardized these systems as 100GBASE-SR4 (100GbE), providing a maximum reach of 100m on OM4 fiber. It would be very desirable to extend the reach to 300m OM4, while also saving on fiber plant costs by reducing or eliminating the need for parallel fiber. One possibility is to employ powerful DSP based modulation and equalization techniques to achieve 50-100 Gb/s VCSEL based MMF systems[2,3]. However for data center applications, DSP technology may incur a prohibitive cost in power consumption. In this work, we demonstrate that extended reach, fiber efficiency, and low-power can all be achieved simultaneously by a combination of 4 x 25.8 Gb/s SWDM (SWDM4) VCSEL technology with novel wideband OM4 fiber[4]. We achieve 100 GbE SWDM4 transmission over 300m MMF utilizing only conventional low-power NRZ electronics, and low-cost SWDM optics.

Experimental Setup

Figure 1 shows the experimental setup. A set of four 25G VCSELs and PDs where designed and fabricated for SWDM application in the 850-950nm band. The VCSELs and PDs are assembled into conventional 25.8 Gb/s TOSA and ROSA packages. For this initial demonstration, we employ separate XFP+ modules for each channel. The modules include conventional 25G NRZ CDR, and there is no DSP or adaptive equalization required. The SWDM mux/demux optics are based on thin-film

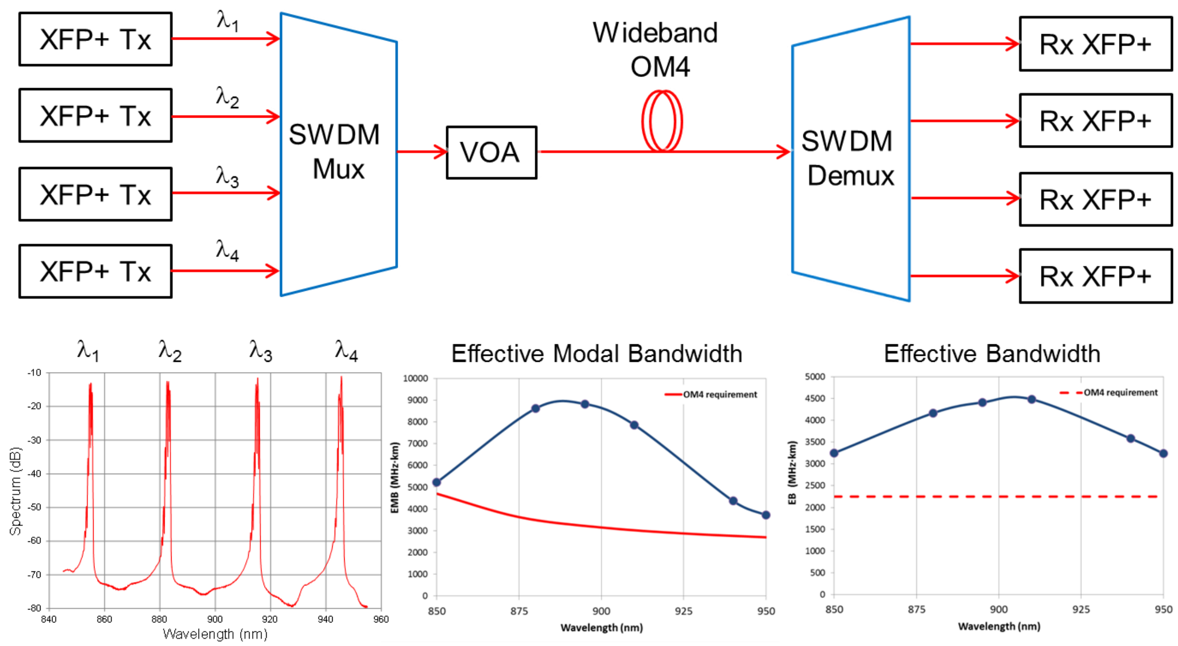

Fig. 1: Experimental setup, including measured SWDM spectrum, and wideband OM4 measured EMB and EB (SBW=0.4nm).

filter technology with a channel spacing of 30nm, and wide pass bands of ~20nm to accommodate the wavelength accuracy specifications for uncooled VCSEL operation. The 4 channel SWDM spectrum measured at output of mux is shown in the inset of Fig. 1. The VCSEL center wavelengths are measured at 855, 883, 915, and 945nm, and RMS spectral bandwidths are in the range 0.34 to 0.41 nm.

The link includes a mode preserving VOA to adjust the optical power, and various lengths of wideband OM4 fiber. The wideband OM4 fiber (trademark WideCap-OM4) is manufactured by Prysmian Group. The measured effective modal bandwidth (EMB) is shown in the inset of Fig. 1. This fiber is designed for peak EMB at ~ 890nm; note that chromatic dispersion bandwidth tends to shift the peak of net effective bandwidth (EB) to slightly longer wavelengths at ~ 905nm[4,5]. The EB shown in inset of Fig. 1 is calculated from the EMB data and chromatic dispersion bandwidth assuming a VCSEL spectral bandwidth (SBW) of 0.4 nm, without taking into account Modal and Chromatic Dispersion interaction (MCDI)[5].

Measurement Results and Discussion

Figure 2 shows the measured eye diagrams. The top row shows the VCSEL transmitter eyes. The measured transmitter extinction ratios are in the range 3.3 to 3.5 dB. The middle row in Fig. 2 shows the received eyes at the output of demux for 200m, and bottom row shows the received eyes for 300m; note channel wavelength increases from left to right in this figure. We observe wide open eyes at 200m for all channels. At 300m distance, the shortest and longest wavelength channels show the most eye closure, and the channel at 915nm shows the best eye, as expected from the fiber EB data in Fig. 1; all received eyes are still open at 300m, and we anticipate good enough BER to close the link.

The BER is measured simultaneously on the SWDM4 channels using a 4 channel BERT (not shown in Fig. 1.); we use PRBS31 patterns in all tests. Figure 3 shows the measured BER versus received average power measured at the module inputs. For clarity, the BER data is organized into four separate plots, one for each wavelength channel. We show BER waterfall curves measured B2B (black curves), after 200m (blue curves), and after 300m (red curves) for each wavelength channel.

The B2B receiver sensitivities at BER=1.e-12 are approximately in the range -10 to -10.5 dBm. At 200m, we achieve error free transmission on all channels when the received power is > - 8 dBm. The 200m power penalties relative to B2B are modest, approximately ranging from 1 to 2 dB at BER=1.e-12. We believe this SWDM transmission result demonstrates acceptable performance over 200m wideband OM4 without the need for FEC. At 300m, the penalties increase significantly as expected from the measured eye diagrams. Nevertheless, all channels achieve BER < 1.e-9. This BER performance provides more than enough margin

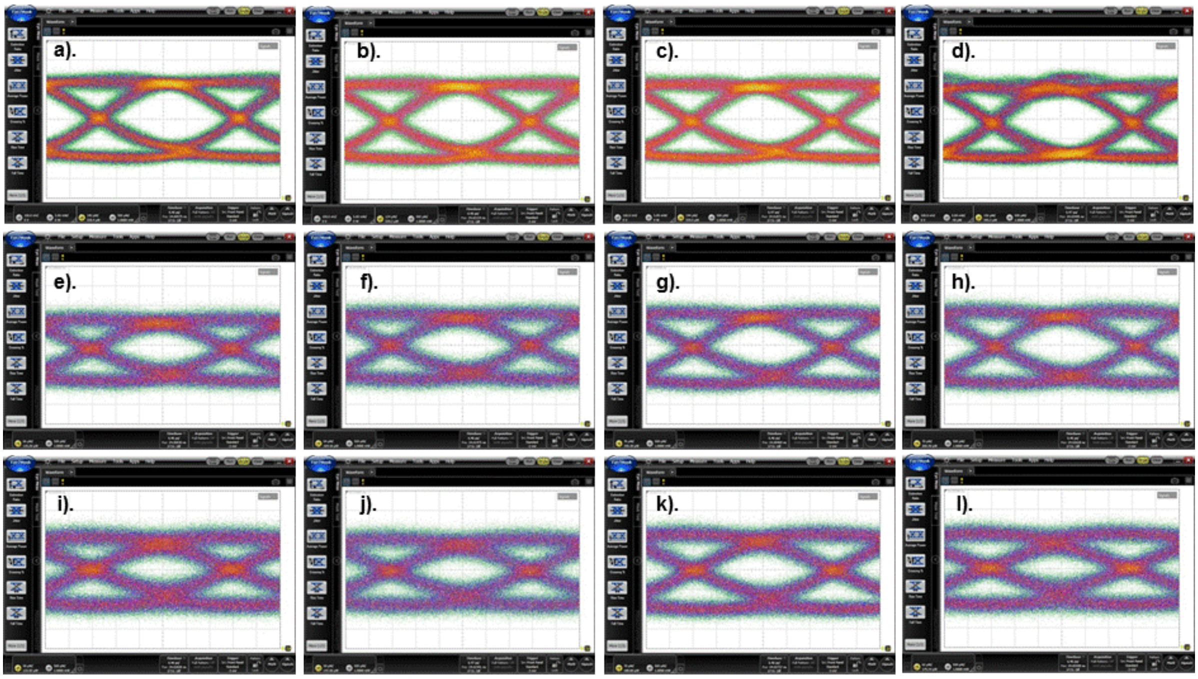

Fig. 2: Measured optical eye diagrams for a)-d). transmitter eyes, e).-h). received eyes for 200m, and i).-l). received eyes for 300m; note leftmost column corresponds to 855nm channel, with increasing wavelength to 945nm for rightmost column.

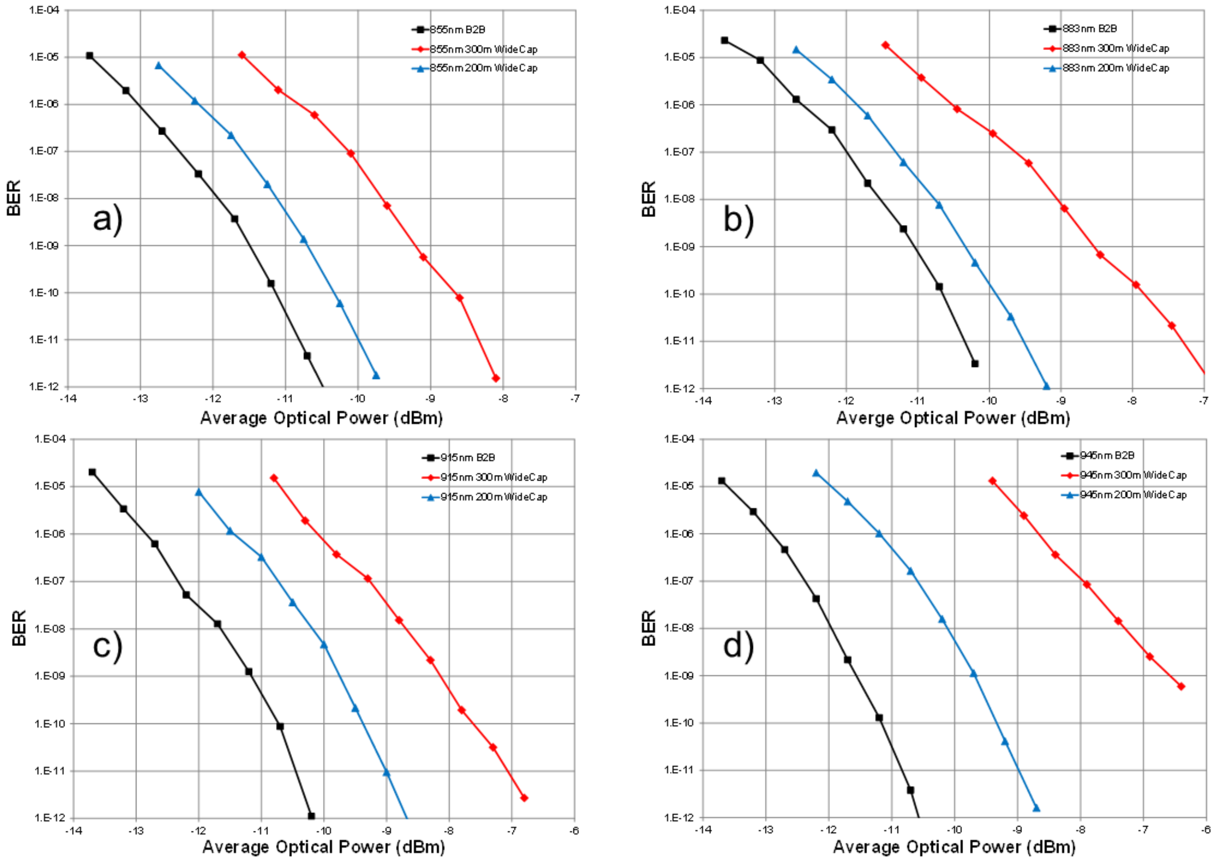

Fig. 3: Measured BER B2B (black), 200m (blue), and 300m (red) for a). 855nm, b). 883nm, c). 915nm, and d). 945nm channels.

to achieve error free transmission in data center systems employing IEEE standard KR4 FEC with a BER threshold at 5.e-5.

The 300m BER measurements show the largest transmission penalty at 945nm, consistent with the received optical eye diagrams. However, the 855nm channel shows better BER performance compared with 915nm channel, an unexpected result based on fiber EB, and measured optical eye diagrams. We speculate that differences in receiver PD and TIA frequency responses between the channels may contribute to some discrepancy between optical eye diagrams and BER measurements.

In this experiment, no attempt was made to optimize the receiver TIA bandwidth and CDR threshold voltages; such optimizations may improve the results. Employing transmitter pre-emphasis techniques would also be very interesting to investigate for extending the reach further in future work. A more accurate computation of EB considering MCDI should provide additional physical insight[6].

Conclusions

We presented initial experimental data on a 100 GbE SWDM4 system prototype, demonstrating successful transmission over 200m and 300m of wideband OM4 fiber. The SWDM4 VCSEL technology, combined with novel wideband OM4 fiber, provide an efficient low-power solution for scaling data center switch density while increasing reach and minimizing fiber count.

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