# Transmission of 400GBASE-LR8 Over 15 km Deployed Step-Index 4-Core fiber for Data Centre Interconnects

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**Abstract:** We demonstrate transmission of 400GBASE-LR8 signals over 15 km of installed simple step-index 4-core fiber. Resultant symbol error rate was below the KP4-FEC threshold showing the suitability of multicore fibers as data centre interconnects. © 2022 The Author(s)

## 1. Introduction

As the demand for high-speed Ethernet links continuously grows in data centre interconnects (DCI), IEEE802.3 has commenced to study beyond 400GbE interfaces. Accordingly, technologies for improving accommodation efficiency of data traffic have been considered. Space-division multiplexing (SDM) is envisaged to contribute to the sustainable growth of transmission capacity by improving the spacial density of fiber optic cables and connectors [1]. As a result SDM fibers such as, few-mode fiber and randomly-coupled multicore fiber are being considered; however, these SDM fibers require challenging implementations of complex digital signal processing into real time. Weakly-coupled multicore fiber (WC-MCF) is considered as the most promising candidate to realise SDM transmission systems because of the compatibility with existing transponders. In particular, MCFs with standard cladding diameter of 125 $\mu$m have been attractively studied for its ease of production and reliability [2]. In fact, 400 Gb/s transmissions over various WC-MCFs with the standard cladding diameter have been reported [3,4]. The previous works have been mostly conducted using MCFs with trench-assisted designs. The trench structure supports to suppression of the intercore crosstalk (IC-XT). The benefit of operating an MCF in the O-band is the intrinsic lower IC-XT compared to the C-band. Recently, a simple step-index four-core fiber (SI-4CF) without the trench has been reported [5], in which each core showed a compatibility with the ITU-T G.652.D fiber and supports the full telecommunication band as well as a conventional standard fiber.

In this paper, we rigorously validate 400GBASE-LR8 transmission over an installed SI-4CF testbed for the first time. To show the feasibility of the SI-MCF solution in a DCI application, the transmission performance was estimated after cabling with tens of passive splice/connector points. Although we confirmed deterioration from ideal performance in terms of IC-XT and attenuation from imperfection of splices/connectors, transmission distance reached at 15 km exceeding the applications' requirements of $>$10 km [6].

## 2. Experimental Setup

The 400GBASE-LR8 signals were generated with a QSFP-DD-LR8 module and measured with a 400GbE tester. A PRBS31 stream was used as the base of 26.6 GBd electrical signals. The average at optical power of the eight wavelengths ranged from 1.6-2.2 dBmwith a total transmit power of 11 dBm. This was launched into the core under test. Emulation for LR8 signals in the other cores was used.

LR8 emulation was performed by using 5 DFB lasers and 3 external cavity lasers (ECLs). The lasers at 1273.8, 1277.7, 1282.2, 1286.8 and 1308.9 nm were DFB lasers and the remaining wavelengths 1295.36 1299.88 and 1305.01 nm were ECLs. These were combined together using a 1x8 PM coupler. The resultant WDM signal was sent to an intensity modulator being driven with PAM-4 electrical signals at 26.6 GBd. After modulation the signal were amplified with a praseodymium doped fiber amplifier (PDFA). This is shown as dummy LR8 in Fig. 3(a). The signals were then demultiplexed with a WDM coupler, so that each wavelength band could be attenuated separately and then recombined with another WDM coupler. The attenuation of each band was chosen such that the gain profile of the PDFA could be compensated. The resultant dummy LR8 signals were all within 2 dB. It can be seen that the DFB lasers had slightly different wavelengths that drifted over time but were kept within $\pm$2 nm. In order to mimic simultaneous four cores for transmission the dummy signals were split with a 1x4 coupler and copies were delayed with 20 and 40m of fiber. Each delayed copy was used for a different core.

The installed multicore fiber cable consisted rollable fiber ribbons and accommodated 200 fibers in total. The cable length was 1 km and was installed over various conditions such as tunnels or being suspended between

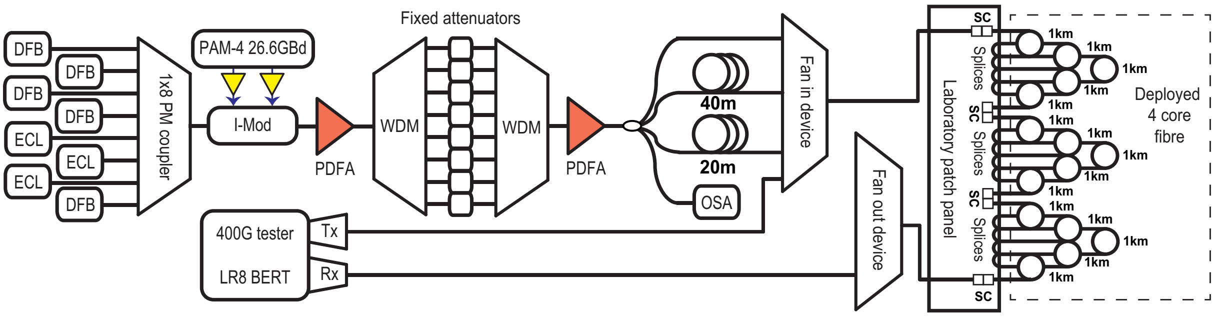


Fig. 1. Experimental setup for LR8 transmission over 4 core fiber, showing dummy LR8 signal generation and deployed fiber

poles [7]. For estimating the transmission performance over different distances, the fibers were concatenated and looped back. Each time the fiber looped back to the access point either a splice was made or it was terminated with SC-type connector. The splicing and connectorisation methods were conventional. The splice method was based on functions for polarisation-maintaining fibers, which was utilises only passive procedures. This results in various lengths available for use. In this experiment 3 spans of 5 kms was chosen. This consisted 5 multicore connectors, one between each span and another to both the fan-in and fan-out devices.

The main limiting factors of IM/DD systems are the accumulated dispersion and received optical power. The attenuation profile and dispersion of the link was measured over the full 50 km available before being normalised per km and is shown in Fig. 2. The markers correspond to the wavelengths of the LR8 transceiver. Each splice or connector in the setup can contribute to higher loss, showing a higher link loss rather than just that of the fiber, hence the higher than expected average loss of 0.76 dB/km. This loss and dispersion profile was found to be within 1% across all four cores of the fiber. The zero dispersion wavelength was found to be 1304 nm.

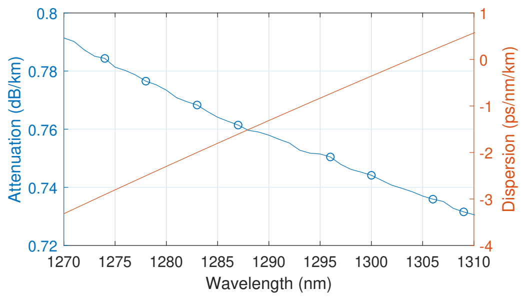


Fig. 2. Dispersion and attenuation measured over the full length shown as a function of wavelength for the installed 4 core fiber

The IC-XT of the 15 km link and the FIFO were also measured. The inputs to core 2, 3, and 4 were dummy LR8 and the input to core 1 was turned off. An OSA trace with a resolution of 0.2 nm was taken of the input dummy LR8 signal and the output of core 1. These were subtracted from each other and then the IC-XT for each of the LR8 wavelengths was calculated, the average values for the fiber and FIFO were, -38.3 and -58.9 dB, respectively.

## 3. Results

The launch power into fiber was matched for all cores at 10.6 dBm. After 15 km of transmission the total received optical power for each cores 1, 2, 3, and 4 was -2.1, -1.2, -2.0 and -1.3 dBm respectively, this can be seen for each wavelength in Fig. 3(b). The PAM-4 symbols on each of the wavelengths were demultiplexed as two electrical lanes of 1bit symbols and the symbol error rate (SER) for each lane was calculated. In order to verify the performance of the fiber link, the tester was run for 24 hours on core 4 with no light being launched into any of the other cores and achieved a total SER of $1.62\times10^{-6}$. The light into each of the other cores was then turned on and measurement continued for another hour, resulting in an SER of $1.67\times10^{-6}$. This insignificant increase in SER shows that the dynamic nature of IC-XT is not a significant source of noise even over 24 hours.

The core under test was then rotated and each core was tested for 5 mins, the results can be seen in Fig. 3(a). It is noted that the specification of LR8 requires transmission over 10 km, and this was exceeded in this case at

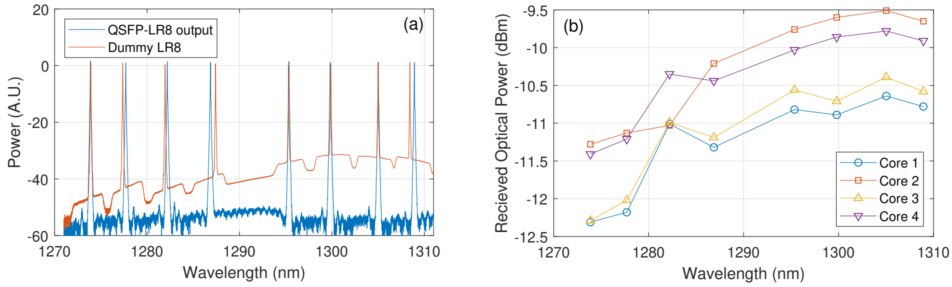


Fig. 3. (a) Spectrum of LR8 and dummy signals, (b) received optical power per wavelength per core

15 km. The number of corrected errors was below 3 for all cores, well within the 400GBASE-KP4 FEC limit of 15 errors. This shows that there is quite a margin left, potentially enabling longer transmission distances or MCFs with higher IC-XT levels. The total symbol error rate across all lanes for cores 1, 2, 3 and 4 was $1.15\times10^{-6}$, $8.75\times10^{-6}$, $5.58\times10^{-6}$ and $1.68\times10^{-6}$, respectively.

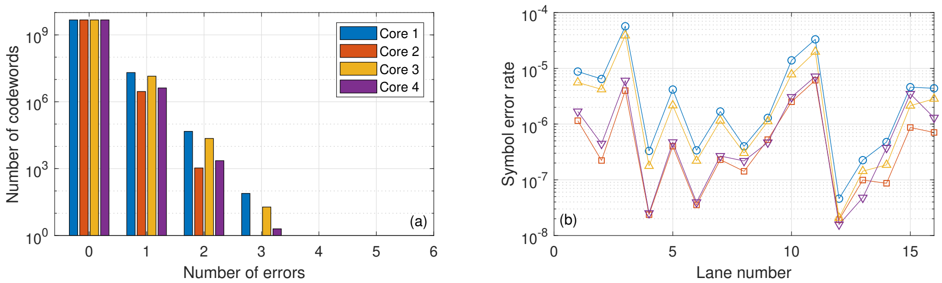


Fig. 4. (a) Histogram showing the number of errors corrected per codeword for each core of the 4CF, (b) symbol error rate (SER) of each lane for each core core of the 4CF

## 4. Conclusion

In this paper, we have verified performance of 400GBASE-LR8 signals for all cores of an installed 4-core MCF. This is the first demonstration to show weakly-coupled step-index multicore fibers as a suitable transmission medium for applications where space is at a premium. Although the standard assumes use of a traditional single-core fiber, the symbol-error rate was low enough to maintain margin for operation as a data centre interconnection.


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## References


1. B. J. Puttnam, G. Rademacher, and R. S. Luís, “Space-division multiplexing for optical fiber communications,” *Optica*, vol. 8, pp. 1186–1203, Sept. 2021.
2. T. Matsui, Y. Sagae, T. Sakamoto, and K. Nakajima, “Design and applicability of multi-core fibers with standard cladding diameter,” *J. Light. Technol.*, vol. 38, pp. 6065–6070, Nov. 2020.
3. S. Beppu, H. Takahashi, T. Gonda, K. Imamura, K. Watanabe, R. Sugizaki, and T. Tsuritani, “56-gbaud pam4 transmission over 2-km 125-$\mu$m-cladding 4-core multicore fibre for data centre communications,” in *41st European Conference on Optical Communication (ECOC)*, p. Th.2.A.2, 2017.
4. N.-P. P. Diamantopoulos, H. Nishi, T. Fujii, K. Shikama, T. Matsui, K. Takeda, T. Kakitsuka, K. Nakajima, and S. Matsuo, “4×56-GBaud PAM-4 SDM transmission over 5.9-km 125-$\mu$m-cladding MCF using III-V-on-Si DMLs,” p. W1D.4, OSA, OFC, 2020.
5. T. Matsui, T. Sakamoto, and K. Nakajima, “Step-index profile multi-core fibre with standard 125 $\mu$m cladding to full-band application,” in *45th ECOC*, p. M.1.D.3, 2019.
6. IEEE 802.3bs-2017, “IEEE standard for ethernet amendment 10: Media access control parameters, physical layers, and management parameters for 200 Gb/s and 400 Gb/s operation,” IEEE Standard, 2017.
7. D. Soma, S. Beppu, H. Takahashi, Y. Miyagawa, N. Yoshikane, and T. Tsuritani, “Optical characterization of installed step-index profile standard cladding multi-core fiber with multiconnection,” in *26th OECC*, p. S4C.3, 2021.