A Novel, Low-loss, Multi-Fiber Connector Compatible with Reduced Coating Diameter Fiber

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Abstract
This paper examines the advantages of a new 165 µm diameter fiber with a 125 µm cladding diameter, and a new very small form factor multi-fiber connector with a miniature physical contact multi-fiber ferrule. This combination maintains compatibility with existing ferrule geometries and the fiber handling ecosystem. Environmental and mechanical test data is reported using the new ferrule, connector, and 165 µm diameter fiber.

Keywords: TMT ferrule, MMC connector, multi-fiber connector, VSFF, density, co-packaged optics, reduced coating diameter, 165 µm diameter optical fiber, MPO connector.

1. Introduction
The bandwidth demand of data centers continues to increase faster than optical transceiver speeds can support due to applications such as cloud computing, remote working, machine-learning, the Internet of Things (IoT) and artificial intelligence. This trend is encouraging the development and deployment of small diameter cables and high-density fiber optic connectors to compensate for the transceiver speeds [1].

Inside the rack, high-density optical interconnects are becoming a critical component for switches and servers. Fibers with 200 µm and smaller coating diameters are being tested and implemented for these applications, but smaller cladding diameters have been resisted, partially due to the cost and technical challenges required to change the prevalent infrastructure built around 125 µm cladding diameter fibers.

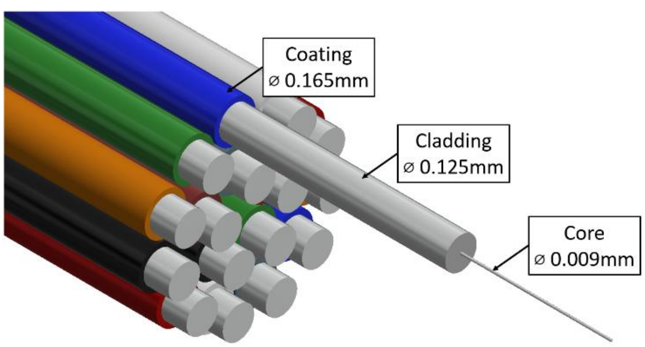

Figure 1. Reduced coating fiber with an overall diameter of 165 µm

Fiber and connector manufacturers have partnered to develop new components that reduce both the fiber coating diameter and the overall cable weight, yet still maintain the existing ecosystem of 125 µm cladding. This paper presents a new very small form factor (VSFF) MMC connector and TMT ferrule that supports a reduced coating fiber with a total diameter of 165 µm. Figure 1 shows the new fiber structure, and Figure 2 shows the accompanying new multi-fiber MMC connector with reduced footprint and support for 165 µm fiber [2]. The new reduced diameter cable and connector are targeted towards several application markets. As will be discussed further below, since the connector maintains a standard 250 µm fiber array spacing, the MMC connector is compatible with existing MPO formats and termination and testing techniques.

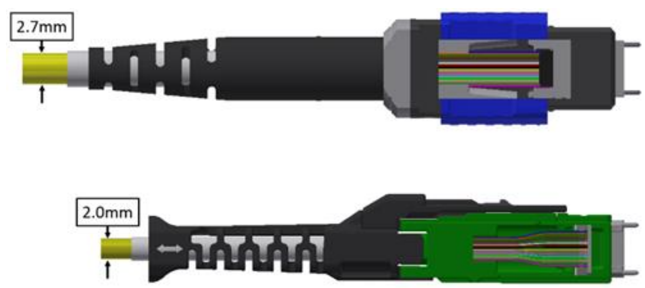

Figure 2. (a) traditional MPO connector with 250 µm coating fiber and (b) new 165 µm diameter fiber and reduced footprint MMC connector

1.1 Structured Cabling

Pluggable transceivers continue to be the primary data center (DC) optical interconnect solution for the foreseeable future. The past few years have seen fiber counts within the transceiver rise to support higher data rates, where schemes such as Dual Duplex LC (four fibers) and Dual MPO8 (sixteen fibers) are popular with hyperscale DCs because they double the module port bandwidth (e.g., 2x400G) [3, 4]. However, Figure 3 (a) shows how little room there is to fit two of these legacy optical connectors into a single pluggable module. Accessing a connector without disturbing its neighbor has proven to be challenging in the field. Often, the entire transceiver module must be unplugged from the panel just to service one optical connector. The smaller footprint of the new MMC connector provides more space for access to the connector body, as shown in Figure 3 (b).

Similarly, optical patch panels are becoming increasingly dense. Hyperscale applications prefer to leverage existing infrastructure and keep their patching within the same rack unit (RU) height. DCs are also concerned with the additional bulk and weight of additional fiber, as next generation patching needs exceed even what MPO connectors can provide.

Table 1 quantifies the additional fiber density the MMC connector provides. Smaller connectors result in smaller pluggable modules, less panel space consumed, and improved air flow. When terminated with 165 µm coating fibers, DCs gain the additional benefit of lower cable weight and size.

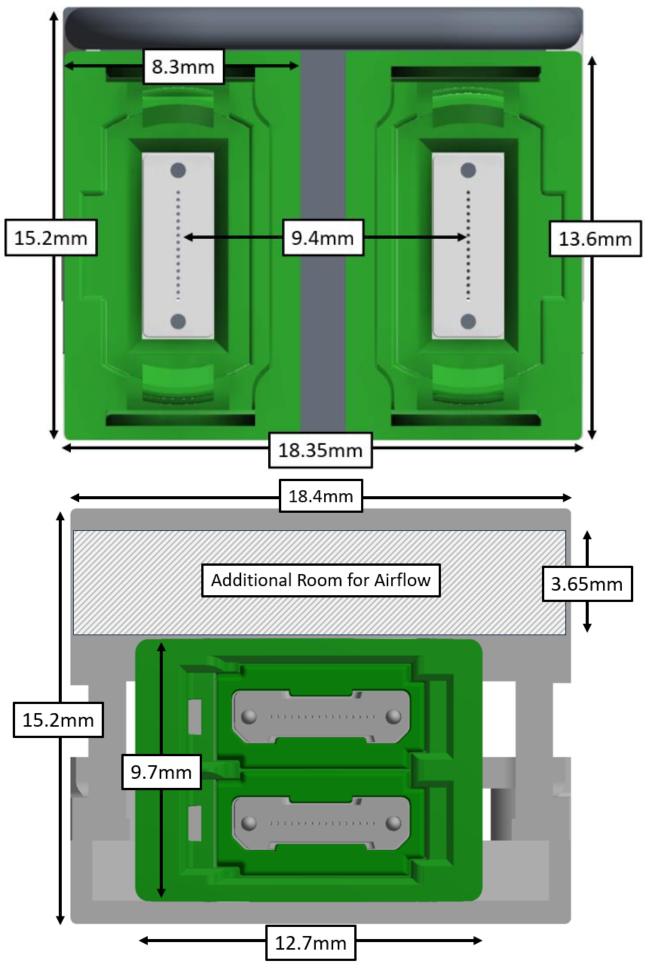

Figure 3. (a) Dual MPO and (b) Dual MMC footprints

Table 1. Number of connectors and fiber a 1RU rack can support by connector type

1RU Panel Max Density			
80 MPO Connectors		264 MMC Connectors	
12f MPO	960	12f MMC	3168
16f MPO	1280	16f MMC	4224
24f MPO	1920	24f MMC	6336
32f MPO	2560	32f MMC	8448

1.2 Co-Packaged Optics

Inside the switch, co-packaged optics (CPO) and silicon photonics use smaller fibers that alleviate the routing and size constraints of conventional 250 µm diameter fibers. Figure 4 illustrates how these optical interconnects were envisioned to eliminate the copper traces to reduce the power consumption latency associated with extracting the clock and data from the electrical signal.

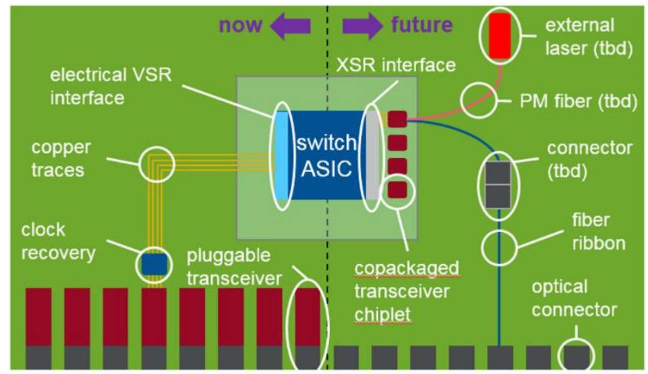

Figure 4. (Left) Traditional copper track layout, and (right) optical interconnects replace the copper for improved latency and power consumption

Optical interconnects are typically accomplished using v-groove arrays to maintain the fiber pitch while providing a bonding surface. Building the v-groove arrays with 165 µm fiber enables the fiber-chip connectivity to have a 33% smaller footprint, as shown in Figure 5. The 125 µm cladding diameter maintains compatibility with the optical connectors currently being integrated into the faceplates of optical switches and transceivers.

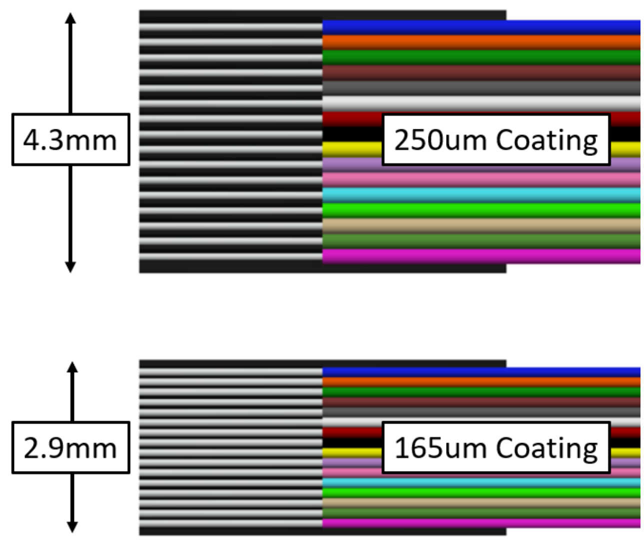

Figure 5. V-groove pitch comparison between the different fiber types

1.3 Artificial Intelligence/Machine Learning

In the past few years, the computing power needed to train the large size artificial intelligence and machine learning (AI/ML) training models has significantly outpaced the performance of the individual Graphics Processing Units (GPUs), resulting in the formation of AI/ML clusters in the hyperscale DCs with 1,000's or 10,000's of GPUs to meet computation demand [5].

It is estimated that the growth of the AI/ML clusters will lead to five to ten times more optical interconnects in AI-centric DCs versus recent hyperscale architectures [6]. Increased connectivity density is becoming a problem for AI/ML system builders that 165 µm diameter fiber cable addresses.

1.4 Data Center Interconnects

Data center interconnects (DCI) use thousands of fibers in small two-to-three inch diameter conduit to connect hyperscale campuses. These links are transitioning from spliced to connectorized solutions to significantly reduce installation time and eliminate the need for special equipment. Reducing the size of the connector and fiber will help maximize fiber counts in these small conduit applications.

2. 165 µm Fiber Design Summary

One of the key concerns in the utilization of smaller diameter optical fibers is microbending sensitivity, which can lead to elevated losses. This limitation was addressed by using a trench-assisted design in which the fiber core is surrounded by a fluorine-doped cladding region which reduces coupling between the optical signal and the cladding modes [7]. A two-layer coating system that includes a low-modulus inner, primary coating helps further suppress the microbend losses that could occur.

A second concern is greater susceptibility to glass damage through perforation of the protective polymer coatings during fiber processing and handling. Puncture of the protective secondary coating is one of the possible failure modes that has been analyzed in detail [8, 9]. While this phenomenon will invariably be higher in small-diameter fibers, an outer, secondary coating with a high modulus provides more damage protection than legacy coatings.

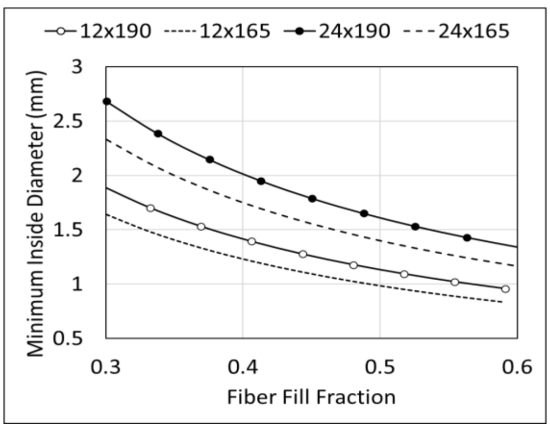

Figure 6. Comparison of fill fractions vs. fiber diameter

The maximum number of fibers that can be incorporated into a buffer tube can be calculated using the mathematical theory of circle packing. For a relatively small number of circles, the maximum bundle (fill) fraction is approximately 75%, but the small amount of free space would result in a very inflexible cable because the fiber positions cannot change when the cable is bent. As a result, fill fractions between 30% and 60% are more typical for the buffer tubes used in optical fiber cables, particularly when aramid yarns are used to enhance the strength. Figure 6 is a plot of the minimum inside diameters of buffer tubes with 12 and 24 fibers as a function of the fiber fill fractions. For both fiber counts, the minimum inside diameter is around 0.2 to 0.3 mm with 165 µm fiber compared to 190 µm fiber. While this difference is small, it is enough to improve the compatibility with the footprints of VSFF multi-fiber connectors.

3. MMC Connector

3.1 TMT Ferrule Design

The TMT ferrule employs the same alignment structure as a traditional MT ferrule. The guide pin bore diameter and guide pin pitch align with MT ferrules defined in IEC 61754-7 series interfaces [10]. This feature allows for the ferrule to be backwards compatible with MT ferrules, an important feature for existing deployed infrastructures. The overall ferrule height is reduced by approximately 30%, while the ferrule length is half of the MT ferrule length. The external MT shoulder is removed, reducing the width of the ferrule to 6.4 mm, as shown in Figure 7. The TMT ferrule has an internal shoulder and an asymmetrical shape, effectively keying the ferrule to the connector for error free assembly. For the testing reported within this paper, a TMT ferrule with two rows of 12 fibers per row was used, but variants with 16 fibers within a row are also available to support Base 8 applications. The TMT ferrule is primarily designed to support existing applications that are using 250 µm fiber pitch, but it can support even higher densities for future applications with tighter fiber to fiber pitch.

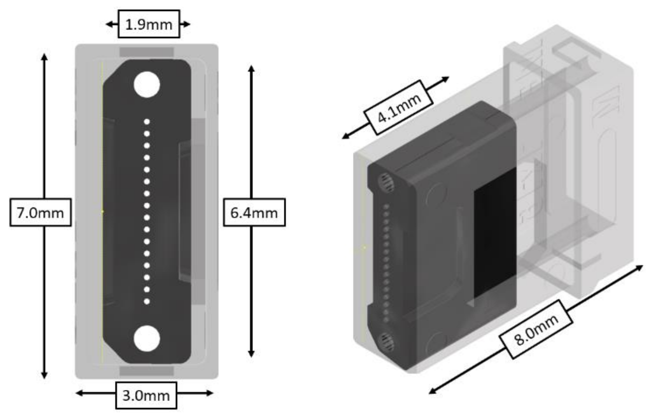

Figure 7. MT (Transparent) and TMT (Solid) comparison

3.2 MMC Connector Format

The MMC connector footprint is also reduced in comparison to the MPO connector footprint. In Figure 8, the footprints of the two connectors are compared. The MMC connector utilizes a rail structure to maintain polarity as shown in Figure 8. This configuration simplifies polarity management within the applications.

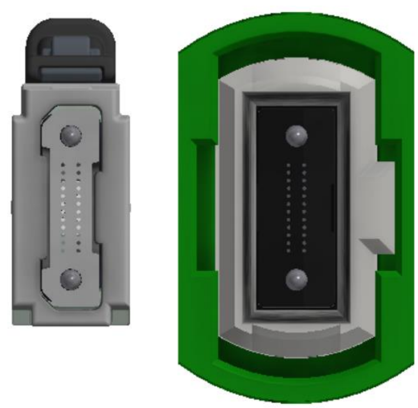

Figure 8. MMC and MPO 24 fiber connector formats

The pitch between connectors is limited by cable outer diameters. The MMC connector can accommodate up to 2.5 mm nominal cable sizes with a connector-to-connector pitch of 3.9 mm. Smaller coated fibers allow for increased fiber counts within the cable diameter.

3.3 Qualification Testing

To validate performance over typical operating ranges, qualification testing was performed according to Telcordia GR-1435 controlled environment requirements [11]. For this testing, 24-fiber cable assemblies were built using traditional 250 µm fibers. The assemblies were exposed to the conditions outlined in Table 2.

Table 2. Environmental conditions

Test	Condition	Duration
Thermal Aging	60°C	4 days
Humidity Aging	40°C / 95% RH	4 days
Thermal Cycling	-10 ºC to 60 ºC	5 cycles / 40 hours
Dry Out	60°C	1 day

The environmental performance summary for all tests is shown in Table 3 below. A snapshot of the in-situ insertion loss performance during the thermal cycling testing is shown in Figure 9. The MMC exhibits exceptional stable performance over the entire testing sequence.

Table 3. In-situ insertion loss performance during environmental testing

Specification	Performance	1310nm (dB)	1550nm (dB)
New Product	IL Max	0.32	0.26
	IL Avg	0.11	0.08
Thermal Aging	IL Max	0.38	0.27
	IL Avg	0.11	0.07
Humidity Aging	Delta IL Max	0.16	0.07
	Delta IL Avg	0.04	0.02
	IL Max	0.39	0.27
	IL Avg	0.12	0.08
Thermal Cycling	Delta IL Max	0.15	0.07
	Delta IL Avg	0.05	0.02
	IL Max	0.36	0.26
	IL Avg	0.10	0.07
Dry Out	IL Max	0.36	0.25
	IL Avg	0.10	0.06

Overall, the optical performance for the Telcordia GR-1435 controlled environment conditions is well within the acceptable limits dictated by the industry standard.

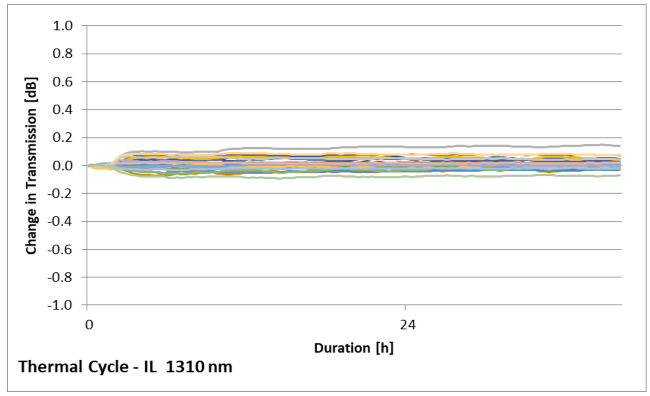

Figure 9. Thermal cycling performance

4. Termination

Multi-fiber connectors are commonly built around a 250 µm fiber pitch to match standard ribbonized fiber. To keep the TMT ferrule backward compatible and intermatable with the MT ferrule and MPO connector, the TMT ferrule is also based around a 250 µm fiber pitch. Therefore, a method is needed to adapt the 165 µm pitch fiber to the 250 µm ferrule pitch. A tool has been created to enable easy sorting of the smaller fibers into the correct order and pitch for ribbonization, as shown in Figure 10. The molded plastic tool contains 165 µm pitch grooves that fan out to 250 µm pitch. The loose fibers can be ordered and placed in the 165 µm end, and by running a finger along the tool, the fibers will seat in the grooves and fan out to the correct ferrule pitch. A ribbonizing cyanoacrylate epoxy, such as Loctite 4861, is then applied and quickly cures to create a temporary ribbon matrix to secure the fibers for handling. The fiber ribbon can then be removed from the handler, stripped, and cleaved for ferrule insertion using industry standard tools [12]. Since the fiber matrix material is smaller than conventional 250 µm fibers, it might be necessary to adjust the blade heights on the tooling to ensure adequate contact with the fiber.

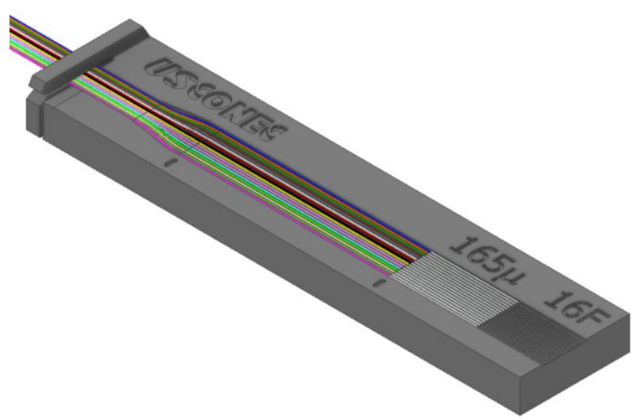

Figure 10. 165µm ribbonization tool for termination

The TMT ferrule is terminated using conventional MT ferrule termination techniques [13]. After the fiber is stripped and cleaved, it is inserted into the ferrule with epoxy and cured. Polishing is also comparable to MT polishing and uses standard MT polishing recipes and films, but since the ferrule surface area is significantly smaller the polishing times need to be reduced by approximately

55%. The TMT ferrule geometry is quantified using standard endface geometry interferometers and the same specifications.

To demonstrate connector performance with the reduced 165 µm fiber, 10 jumpers were built using the 2.0 mm 24-fiber cable described above. Each jumper was terminated on one end with a 24-fiber MPO connector, and with a 24-fiber MMC connector with TMT ferrule on the other end; half of the jumpers were male connectors, and the other half were female. Table 4 shows the endface geometry results for the set of TMT ferrules, along with the current grading range used for acceptable ferrules.

Table 4. Endface geometry results for TMT ferrules

	Average	Std Dev	Min	Max
Minus Coplanarity (nm):	57	27.18	-	150
Ferrule X Angle (deg):	-0.03	0.01	-0.15	0.15
Ferrule Y Angle (deg):	7.91	0.03	7.8	8.2
Fiber Height (nm):	2236	55.86	1000	3500
Adj Fiber Height (nm):	61	38.73	0	300
Fiber Tip Radius (mm):	3.30	0.22	1	-
Ferrule X-Radius (mm):	49251	95720	2,000	-
Ferrule Y-Radius (mm):	204	20	5	-

Connectors were then intermated to measure insertion loss performance at 1310 nm and 1550 nm wavelengths. Each male connector was used as a launch and every female connector intermated to the launch connector, producing 600 mated fiber measurements. The histogram of all the insertion loss measurements is shown below in Figure 11. The average insertion loss was 0.08 dB at 1310 nm, and 0.06 dB at 1550 nm. The 97% insertion loss values were 0.26 dB and 0.20 dB respectively.

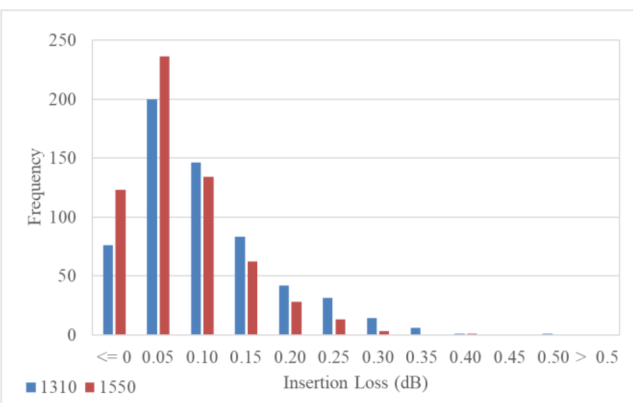

Figure 11. Insertion loss histogram for 600 connections with reduced coating diameter fiber

The above jumpers were then mated into pairs and tested to the Telcordia GR-1435 controlled transmission with applied load (TWAL) media type II 90° standard to ensure that the smaller diameter fiber cable and connector could still perform to required mechanical standards. For each connector pair, insertion loss was measured initially. A 2.2 N force was then applied on the cable perpendicular to the connector directly behind the connector boot, and insertion loss measured again. Finally, the weight was removed, and insertion loss was measured a final time. The GR-1435 specification requires that loss does not change more than 0.50 dB with the applied load. Figure 12 shows the insertion loss histograms of the measurements initially, during load, and after load removal where it is evident that there was no significant change in the performance. The average change with the load applied was 0.003 dB, which is well within the measurement repeatability of the testing, and no measurements changed by more than 0.18 dB, well under the 0.5 dB specification.

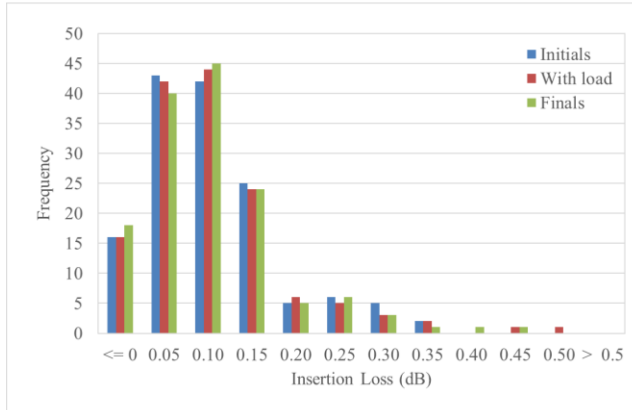

Figure 12 Insertion loss histogram at 1310 nm of GR-1435 TWAL 90° testing.

5. Sustainability

With the reduced connector footprint and smaller cable diameters, there is a significant reduction in raw materials. Lowering the material usage can be correlated to a decrease in the overall weight, as well as in the energy used to produce the raw materials, supporting green initiatives. Table 5 shows the material reductions of MMC connectors.

Table 5. Reduction in raw materials used for the new MMC connector

MPO	MMC	Reduction
Mass (g): 2.37	Mass (g): 0.89	62%

When examining 3,456-fiber DCI cables, reducing the fiber to a 165 µm diameter allows for a different cable structure with a smaller total cable diameter that reduces the total cable mass by 36% per unit length [14, 15].

6. Conclusions

The MMC connector with TMT ferrule is compatible with new 165 µm diameter fiber. The combination of these new developments allows for a decreased overall footprint for high density applications with significant size and weight savings. The new connector is intermatable with existing MPO connectors and the traditional 250 µm pitch ecosystem. Connector test results through GR-1435 environmental and TWAL testing show excellent performance.

7. References

[1] Lightcounting, "AI Creates a New Wave in Demand for Optical Connectivity," https://www.lightcounting.com/newsletter/july-2023-mega-data-center-optics-204 (Accessed August 18, 2023).

[2] D. Childers, *et al*., "A Novel Low-Loss Multi-Fiber Connector With Increased Usable Fiber Density," *Proc. 70th IWCS,* (2021).

[3] QSFP-DD MSA, "QSFP-DD/QSFP-DD800/QSFP112 Hardware Specification," *QSFP-DD/QSFP-DD800/QSFP112 HW Rev 6.3*, http://www.qsfp-dd.com/specification/ (2022).

[4] OSFP MSA, "OSFP-XD, Octal Small Form Factor Extra Dense Pluggable Module," *OSFP-XD Specification Rev 1.0,* https://osfpmsa.org/specification.html (2023).

[5] J. Sevilla, *et al*., "Compute Trends Across Three Eras of Machine Learning", *IEEE 2022 International Joint Conference on Neural Networks,* (2022).

[6] A. Alduino and R. Stone, Optical Interconnects for AI/ML. *Open Computer Summit,* (2022).

[7] Y. Gu *et al*., "Evaluation of 165 Micrometer Reduced Coating Diameter Fibers for High Density Cable Applications," *Proc. 72nd IWCS,* (2023).

[8] G.S. Glaesemann and D.A. Clark, "Quantifying the Puncture Resistance of Optical Fiber Coatings," *Proc. 52nd IWCS*, pp. 237-245 (1993).

[9] S.R. Bickham *et al*, "Microbend Performance and Puncture Load Resistance of Reduced-Clad Fibers," *Proc. 71st IWCS* (2022).

[10] International Electrotechnical Commission, "Fibre optic interconnecting devices and passive components - Fibre optic connector interfaces - Part 7-3: Type MPO connector family," *IEC 61754-7-3:2019,* (2019).

[11] Ericcsson Inc., "Generic Requirements for Multi-Fiber Optical Connectors GR-1435 Issue 02," (2008).

[12] US Conec, Ltd., "US Conec Recommended MTP® Brand Multifiber Connector Production Equipment," *US Conec AEN-1801* (2020).

[13] US Conec, Ltd., "MTP® Brand Connector Installation Onto One Row Jacketed Round Cable with Loose Fibers," *US Conec AEN-1407,* (2023).

[14] A. Sullivan, P. Tandon, R. McCool, A. Diaz and C. Hermann, "A Sustainable Future with Optical Fiber", *Corning Incorporated White Paper WP1000*, March 2023.

[15] A. Sullivan, P. Tandon, M. Srygler, E. Hudson and C. Stroup, "Reducing Costs and Environmental Impact of Data Center Interconnects with Novel Pre-Terminated High-Fiber Density Cable Solutions", Paper #3-8, *Proc. 71st IWCS Conference,* (2022).

8. Authors

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