A Very Small Form Factor Connector Solution Designed for Space Constrained Applications

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Abstract

Transceivers, cassette modules, and data center interconnect (DCI) applications are all increasingly space constrained and need smaller fiber optic connector systems. This paper presents a new multi-fiber very small form factor (VSFF) connector system, the MMC Jr. connector, designed specifically for such applications. This novel VSFF springless connector uses retractable mating pins both for ferrule mating and to simultaneously induce a centering force on the connector to eliminate pin stubbing during mating. Design considerations for the space constrained connector include a trigger delatching mechanism to reduce the connector footprint, and an asymmetric ferrule to ensure proper ferrule and connector polarity. Environmental and mechanical test data are provided to demonstrate connector performance.

Keywords: Optical; Artificial Intelligence; AI, data center; multi-fiber; connectors; adapters; increased; density; space constrained; MMC; VSFF; GR-1435; environmental performance.

1. Background and Applications

Hyperscale data centers are deploying Artificial Intelligence (AI) systems that are fundamentally changing fiber optic structured cabling. For over a decade, typical data center architecture has included spine, leaf, and top-of-rack (TOR) switches. A layer of spine switches connects downstream to leaf switches that then connect to TOR switches, all connected using fiber optic cable. The TOR switches connect downstream to servers using copper interconnect cables, a more cost-efficient solution (see Figure 1).

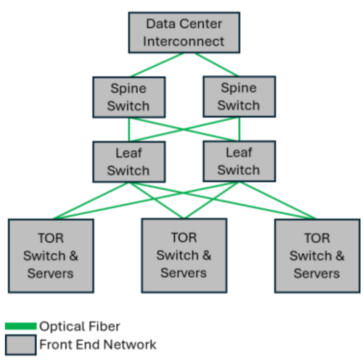

Figure 1. Generic data center architecture prior to artificial intelligence

AI has fundamentally changed this architecture. The number of computations has greatly increased, thus increasing the required resources (e.g. switches, cables, processing units). These added resources are now known as the back-end network (see Figure 2). Due to the AI GPU systems' need for higher bandwidth, longer reach, and lower latency, fiber optic cables are the preferred communication medium to connect the servers and switches. This includes the links between the TOR and GPU/CPUs, previously dominated by copper cables.

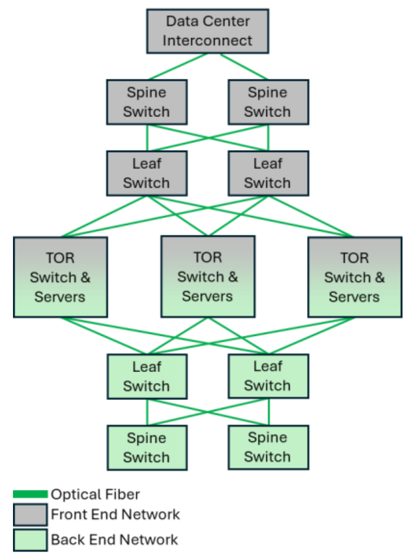

Figure 2. AI data center architecture with additional back-end network

1.1 Patch Panel Density

The direct impact of AI GPU systems is two-fold; more optical fiber is needed, and there is less cabinet (i.e. rack, space) to manage it. The former is the obvious impact of replacing copper interconnect cable assemblies with optical cable assemblies. The latter is due to the scale of GPU clusters, which puts a premium on rack space. AI architecture pushes to maximize the number of compute trays in each rack, which minimizes the space for optical cabling, as shown in Figure 3. This has accelerated the deployment of very small form factor (VSFF) optical connectors, which have far greater fiber density than traditional LC and MPO optical connectors. The MMC Jr. connector [1], a VSFF connector, is presented in this paper as a solution to many of the new industry demands associated with AI architecture demands.

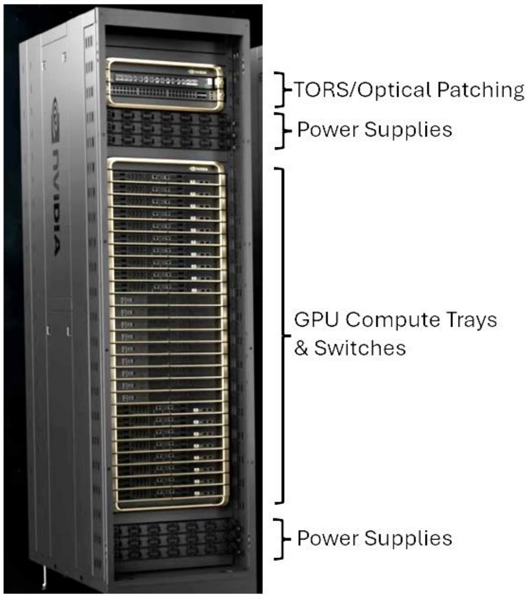

Figure 3. Example AI rack showing majority of rack space dedicated to compute trays and minimal space for optical cabling/patching. Source: NVIDIA

1.2 Cassette Modules

Optical patch panels typically contain multiple cassette modules designed to simplify structured cabling installation by transitioning high fiber count trunk cables to lower fiber count access cables. The advent of VSFF connectors helps achieve higher fiber density at the cassette module. Vendors have the option to triple the number of optical connectors per cassette module or reduce the overall size of the cassette.

1.3 Pluggable Optics

Traditional pluggable optical transceivers primarily use LC or MPO optical connectors. As optical transceiver speeds continue to increase, some variants require additional optical connector ports (e.g. Dual MPO). Due to their small size, transceivers are limited in how many optical connectors they can accommodate. For example, the optical connector receptacle of a QSFP-DD module is limited to an area of 13.5 mm x 19 mm [2]. and current Dual MPO receptacles nearly fill that entire area. Dual VSFF optical connector receptacles allow multiple connectors to reside in a much smaller footprint and thereby provides more panel space for airflow and better overall cooling. Changing the optical connector from an MPO to a VSFF optical connector can generate 100 mm^2 of additional space for airflow per transceiver (see Figure 4).

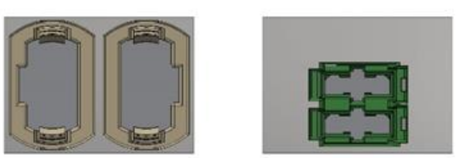

Figure 4. Dual MPO vs Dual MMC QSFP-DD height

Additionally, VSFF connectors can be beneficial to internal transceiver features. Dual MPO variants must be oriented vertically to fit within the transceiver envelope. This requires the internal optical ribbons to twist 90° in a very short distance, which strains the fibers. Dual MMC connectors can fit horizontally, meaning the internal fibers have no twist or strain (see Figure 5).

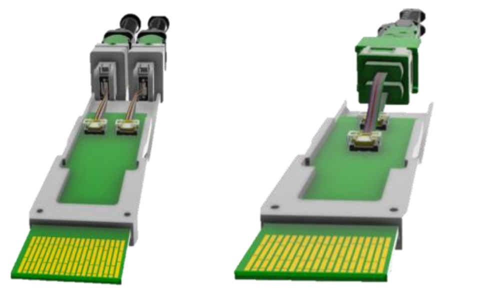

Figure 5. Transceiver internal view: ribbon twist Dual MPO (left) vs no ribbon twist Dual MMC (right)

1.4 Co-Packaged Optics

Co-Packaged Optics (CPO) is an alternate interconnect solution to pluggable optics, as shown in Figure 6. It has the potential to consume less power and decrease link latency, both factors critical to AI GPU systems. CPO chips use small optical engines (OE) that require a small optical connector to take fiber to the card edge. VSFF optical connectors are preferred over standard MPO connectors since they consume less vertical and horizontal space on the board and at the card edge. This is especially critical in smaller form-factor PCB types, such as PCIe and OCP.

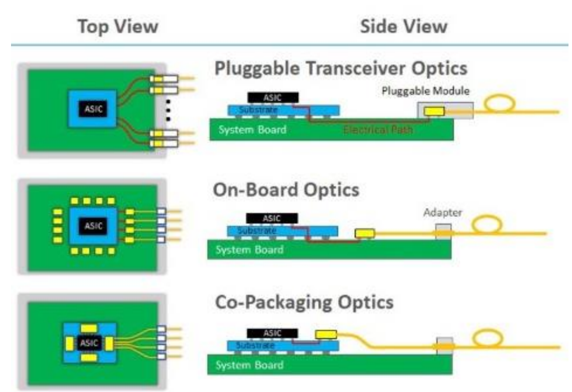

Figure 6. Comparison of pluggable, on-board, and co-packaged optics. Source: Semiconductor Engineering

1.5 Data Center Interconnects

Large-scale data center operations often connect multiple campus locations via high fiber count cables (e.g. 6912 fibers) inside small pre-installed conduit only a few inches in diameter. These fiber links are referred to as Data Center Interconnects (DCI) and can extend as far as a few kilometers. Connecting these bulk cables to the in-building networks has traditionally involved mass fusion splicing, a reliable but not necessarily scalable technology. Data center operators are showing an increasing preference for connectorized DCI cables to reduce the project expenses associated with highly involved skilled labor. As DCI fiber counts increase, installing connectorized cables in small conduit space becomes increasingly challenging. VSFF connectors are becoming a preferred alternative to MPO due to their smaller size.

2. Design

2.1 Connector Envelope

The most obvious design consideration for space constrained optical connectors is minimizing the overall size, or connector footprint. Relative to legacy multi-fiber connectors, such as the MPO connector, VSFF multi-fiber optic connectors, such as the MMC connector, already provide a large degree of miniaturization in panel footprint of the connectors (x and y axes indicated in Figure 7). A major factor in the size reduction is the use of the smaller TMT ferrule versus the industry standard MT ferrule. The TMT ferrule design is two-thirds the height and half the length of the traditional MT ferrule geometry at 1.95 mm x 4.1 mm [3]. The smaller ferrule and connector embodiment allows three MMC connectors to fit in the same space as one traditional MPO connector. Although the MMC connector is smaller than MPO connectors, the MMC connector does not fit space constrained applications due to its length (Figure 7). A variant of the MMC connector, known as the MMC Jr., has been developed for space constrained applications and will utilize the small TMT ferrule to minimize its envelope in the panel, but also has a significantly reduced length.

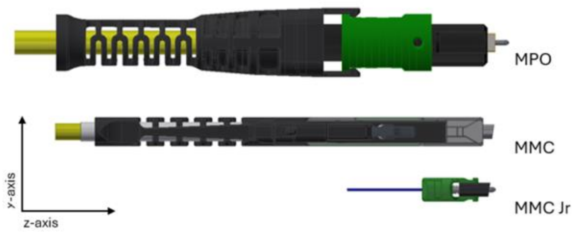

Figure 7. MPO, MMC and MMC Jr. connectors

Reducing the connector length requires removing design elements from a full size VSFF connector. Boots, crimp bands, and crimp bodies are typical optical connector components which interface with jacketed cables having strength elements, all necessary for front plane connectors which are exposed to stress associated with handling throughout its lifetime. Most of the space constrained applications previously discussed are internal to an enclosure or housing. The enclosure not only provides added protection for the connector and cable assembly, but it also limits accessibility to the connector, thus limiting the number of insertions/removals the connector will see during its product lifetime. With this, temporarily ribbonized coated optical fiber and factory ribbonized optical fiber are most common for space constrained connector applications. Since some of the design elements of the full size VSFF optical connectors are not required for these space constrained applications, these elements can be removed, minimizing the length of the connector.

By eliminating the push-pull boot from the full sized VSFF connector design, the length is effectively shortened by 45%. Removing the crimp band and crimp body design elements from the same connector design further reduces the length by another 22%, as can be seen in Figure 7.

The spring also occupies significant length in traditional MPO and MMC connectors. Since a spring is used to maintain fiber end-face physical contact during mating, removing the spring for a space constrained connector does come with a cost. With no spring force to maintain fiber end face physical contact, the space constrained connector must be mated to a connector that contains a spring for fiber end face physical contact, such as the MMC connector. For many applications, this is not an issue since the mating connector is an external optical connector. The elimination of the spring will further reduce the space constrained connector length by another 15%.

2.2 Retractable Pins

Although the MMC Jr. connector does not require a spring for fiber end face physical contact, it is not a spring-less connector. The connector contains two small round coil springs installed over the pins between the connector housing and TMT ferrule. The pins contain a clip at the rear of the pin. The two coil springs exert a small force on the ferrule and the pin clip in opposing directions. This spring force maintains separation of the ferrule from the connector housing, essentially retracting the pins into the ferrule in a non-mated state.

As the MMC Jr. connector is inserted into the adapter port, the ferrule, along with the connector, will align until the ferrule is seated. Once seated in the adapter port, the connector housing will depress the two coil springs and push the pins through the ferrule, as can be seen in Figure 8.

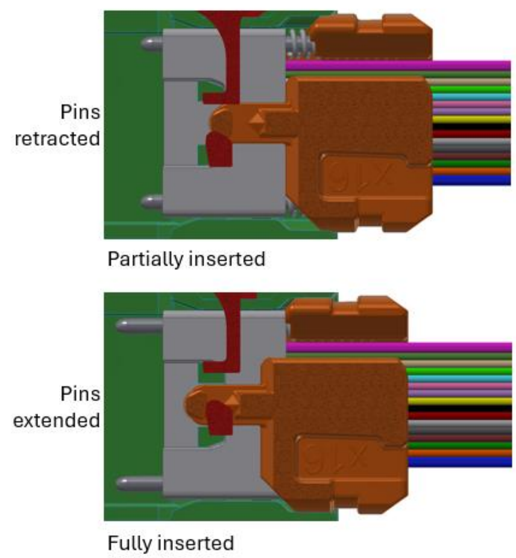

Figure 8. Retractable pins and adapter latching

The delayed pin extension greatly minimizes pin stubbing against the mating ferrule by providing the ferrule a longer engagement length, which vastly improves the ferrule and pin alignment before the pins can contact the opposing ferrule end face.

2.3 Ferrule Keying

Maintaining polarity of a multi-fiber optical communications system is necessary to ensure individual transmitters on each fiber are communicating with the proper receiver on the other end of the system [4]. Keying components of the optical fiber system help to ensure proper polarity. Pre-existing optical connectors, such as the MPO connector, use a symmetrical ferrule and key the housing to the adapter, but do not key the ferrule to the housing. The MMC connector uses an asymmetrical ferrule and key the ferrule to the housing and key the housing to the adapter [5]. The space constrained MMC Jr. connector takes a slightly different approach. The asymmetrical ferrule of an MMC Jr. connector is not directly keyed to the connector housing. Therefore, the ferrule can be installed into the connector housing in one of two 180° opposed orientations (Figure 9).

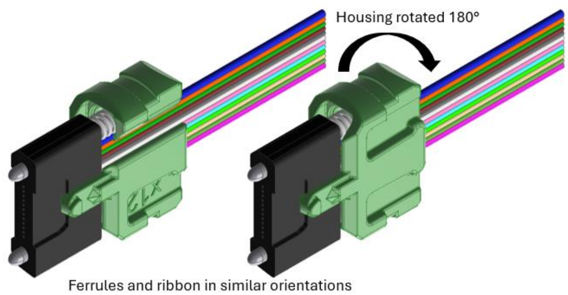

Figure 9. Ferrule not keyed to housing

The MMC Jr. connector housing is also not keyed to the adapter port and (with no ferrule installed) can also be installed in one of two 180° opposed orientations in the adapter port. However, the ferrule of the MMC Jr. connector is keyed directly to the adapter port. Figure 10. The ferrule to adapter keying eliminates potential system polarity issues due to improper connector housing installation during the connector termination process and/or improper connector installation during system installation.

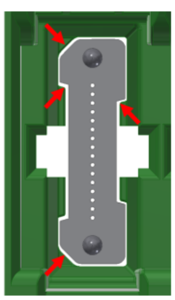

Figure 10. Ferrule keyed to adapter port

2.4 Adapter Latching

Although the push-pull latching functionality of external optical connectors is a favorable optical connector design element, the force required to remove the connectors can be abrupt in delicate applications and the components and space needed to access them is relatively large. Since a latching mechanism is required for proper connector operation and configuration, the latching mechanism for a space constrained connector will require a new design.

Instead of the space constrained optical connector containing a push-pull latch, latch arms were added to the MMC Jr. connector, and a novel trigger mechanism was added to each port of the adapter to assist with connector removal. Removing the movable latch release operation from the connector to the adapter not only reduced the connector size, it also reduced the lateral force required to remove the connector.

When the MMC Jr. connector is inserted into the adapter port, the springs of the MMC Jr. connector are compressed, the ferrule seats into the adapter and the connector housing actuates the adapter trigger latch. To remove the connector, simply depress the adapter trigger. The two compressed connector springs (along with the ferrule spring of a mating connector, if installed) will exert a lateral force, pushing the MMC Jr. connector from the adapter port, minimizing external force and eliminating lateral force needed to remove the connector from the adapter port. Figure 8.

3. Performance Testing

To quantify the performance of the new connector and ferrule designs, testing was performed to the Telcordia GR-1435-CORE Issue 2 [6] environmental and mechanical test standards. Connectors were terminated using MMC standard published practice with a polishing process similar to industry standard MPO multi-fiber polishing processes [7]. Two different combinations of test jumpers were built; the first set was terminated into standard MMC connector hardware on 2.0 mm diameter riser cable with 24 200-micron diameter A1 single-mode fibers. As only 16 fiber ferrules were used for the purpose of this paper, eight fibers were omitted from termination and left unterminated inside the cable. The second set, using MMC Jr. hardware, was terminated with 250-micron A1 non-peelable standard ribbonized fiber. Prior published results have demonstrated that the TMT ferrule yields exceptional polishing results for a multi-fiber ferrule [8], when measured to IEC 61755-3-31 end face geometry standards [9]. The IEC standard was developed for MPO connectors up to 12 optical fibers. Table 1 displays the IEC parameters used for TMT ferrule grading, and the average values measured for the samples built above.

Table 1. IEC end face geometry standards and resulting measurements

Parameter	Min	Max	MMC Jr. Average
Minus Coplanarity (mm)	-	400	36
Ferrule Surface X-angle (deg)	-0.15	0.15	0.02
Ferrule Surface Y-angle (deg)	7.8	8.2	7.91
Fiber Height (nm)	1000	3500	2146

Samples were then assembled as MMC/MMC Jr. connector pairs using an MMC from set one from above as one side of the mated pair and an MMC Jr. from the second set to investigate the performance of the new VSFF connector. Mated pairs of connectors were then tested for insertion loss and return loss performance prior to being run through a battery of tests. Results of the initial testing can be seen in Figure 11 for the MMC/MMC Jr. pairs. The full 8 mated pair population all met the IEC 61755-1 Grade B [10] specifications for insertion loss performance.

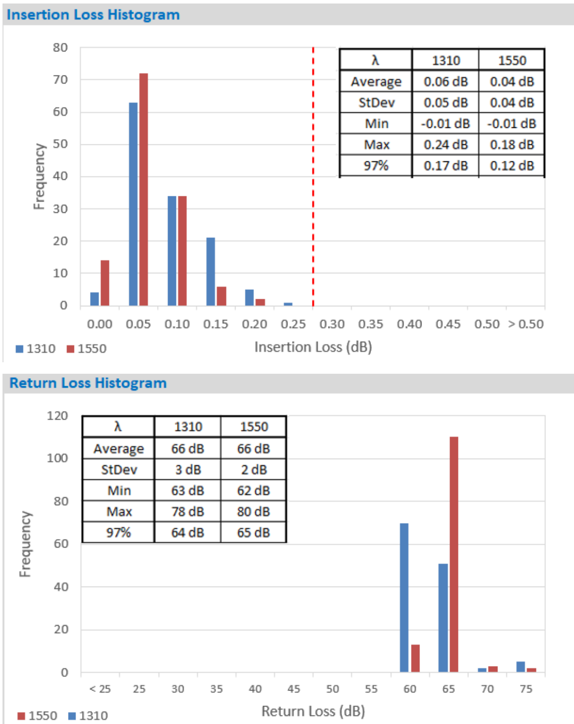

Figure 11. Initial (a) insertion loss and (b) return loss for the MMC/MMC Jr. mated pair connector testing

Environmental and mechanical testing of all the connectors was structured around GR-1435 controlled qualification testing as shown in Table 2. For the connectors where the MMC cable side was tested to flex and twist, the GR-1435 Cable Type II standard applied, and 8.9 N and 13 N loads were applied, respectively. However, when the MMC Jr. bare ribbon side was the applied load side, Cable Type I standard applies and the loads were therefore reduced to 2.2 N, as noted in the table. This is reasonable for the expected applications as noted above, such as in transceivers and co-packaged optics, where loads may be applied to the ribbon cable during installation and fiber routing, but the connector and bare fiber will be packaged and protected in the final application space.

All connector pairs were monitored during all environmental testing for changes in insertion loss or return loss performance. The in-situ performance of all eight mated pairs of the MMC Jr. connector pairs is shown in Figure 12, as traditionally thermal cycling is the most difficult test for multi-fiber connectors to pass and shows the largest changes in connector performance. All connectors passed all environmental exposure testing, with no channel ever changing by more than 0.11 dB during any of the monitored environmental tests listed in Table 2. After the environmental tests (post chamber), all the connectors were tested again, and then retested after each subsequent mechanical test. Tables 3 and 4 show the average insertion loss and return loss performance of the MMC Jr. connectors after each of the tests.

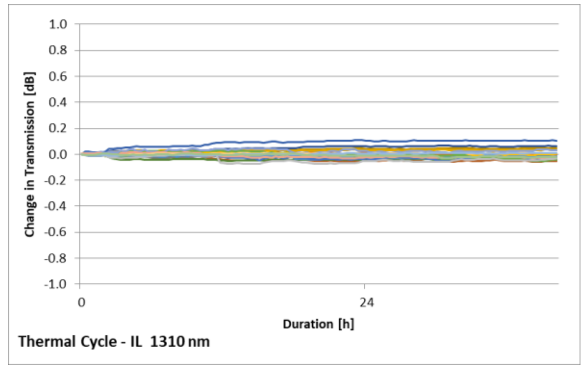

Figure 12. Environmental performance of the MMC/MMC Jr. connector pairs through GR-1435 controlled thermal cycling between -10 °C and 60 °C in one-hour intervals

Table 3. Insertion loss performance at 1310 nm after each environmental and mechanical test performed from Table 2

	Jr. **DUT (N=128, 8 pairs)**
	1310 nm
Initials	0.06
Post Chamber	0.10
Vibration (Post Z)	0.13
Flex	0.12
Twist	0.18

Table 4. Return loss performance at 1310 nm after each environmental and mechanical test performed from Table 2

	Jr. **DUT (N=128, 8 pairs)**
	1310 nm
Initials	66
Post Chamber	67
Vibration (Post Z)	68
Flex	68
Twist	67

4. Future Work

Work is being performed on several space constrained connector variants based on various application needs. Currently, all MMC Jr. connectors are male gender. Some applications, including cassette modules will require a female version due to system configurations. Simply removing the pins will not create a female MMC Jr. connector because the pins are an integral component for spring alignment. The male pins are substituted with a female spacer with short, molded pins. Figure 13. The features, size and performance of the female MMC Jr. connector will be similar to the male counterpart.

Currently the MMC Jr. connectors are designed for optical ribbon applications in order to provide the smallest possible connector footprint. Some optical fiber ribbons contain preferential bends due to their manufacturing process. Preferential bends that are perpendicular to planned optical fiber routing, especially over very short distances, can increase optical fiber stress and potentially reduce long term reliability. Because of this, some cable system manufacturers and cable assembly manufacturers prefer to use round optical fiber subunits because the round subunits do not have a preferential bend and are easier to route. Work is being performed on an accessory funnel attachment that connects to the rear of the MMC Jr. connector. The added functionality of the funnel comes at a slight cost to connector length, almost doubling its length.

Figure 13. Female MMC Jr. and MMC Jr. connector with funnel

Testing on another space constrained VSFF connector design is also in progress. Figure 14. While this miniature MMC connector is slightly longer than the MMC Jr. connector, it also excludes the push-pull boot, crimp band and crimp body of external VSFF connectors, shortening its overall length. This connector will contain a spring utilized for fiber end face physical contact. This design element allows this connector to mate to itself or another external or space constrained optical connector proving beneficial for on-board optics connectivity. Two different connector housings will allow the connectors to accommodate ribbon or non-strain relieved round subunits depending on the application.

Figure 14. Miniature MMC round and ribbon optical connectors

5. Conclusions

As optical fiber density increases, the hardware space allocated to the connector continues to decrease. The number of space constrained connector applications also continues to increase. A new VSFF optical connector, specifically designed for constrained space applications, has been developed. Optical transceivers, cassette modules, pulling grips for DCI applications, etc. can all be reduced in size due to the smaller connector envelope provided by the MMC Jr. optical connector. This new connector has been manufactured and tested to industry standard mechanical and environmental requirements. Results from mechanical and environmental testing show stable, low insertion loss throughout the test sequences making it an ideal candidate for these space constrained applications.

6. References

[1] S. Lutz, S. Mendenhall, T. Mitcheltree, L. Schmidt, S. Bickham, K. Li, S. Raney, P. Tandon. "A Novel, Low-loss, Multi-Fiber Connector Compatible with Reduced Coating Diameter Fiber," International Wire and Cable Connectivity Symposium, (2023).

[2] QSFP-DD MSA, QSFP-DD Hardware Specification for QSFP Double Density 8X Pluggable Transceiver, Rev. 7.1, 2024.

[3] H. Asada, D. Childers, M. Hughes, T. Ishikawa, S. Lutz, D. Schoellner, K. Shindo, Y. Wada. "Next generation multi-fiber ferrule using 165 micron pitch optical fiber," International Wire and Cable Connectivity Symposium, (2023).

[4] D. Childers, J. Hendrick, J. Higley, M. Hughes, D. Kurtz, S. Lutz, D. Schoellner. "A Novel, Low-loss, Multi-Fiber Connector with Increased Usable Fiber Density," International Wire and Cable Connectivity Symposium, (2021).

[5] I. Dancel, S. Field, M Good, M Kader-Kallen, S. Lutz, D. Schoellner, C. Stroup. "A Study of End Face Geometry and Visual Inspection of a Very Small Form Factor Ferrule," International Wire and Cable Connectivity Symposium, (2024).

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

[7] US Conec, "PI-1002_MMC, Rev. 2.0, MMC Connector Process Instructions for Termination on 2.0 mm OD Cable," https://www.usconec.com/products/mmc-connector-process-instructions-for-termination-on-20-mm-od-cable, September 2024.

[8] M. Hughes, J. Cline, I. Dancel, M. Kadar-Kallen, W. Kettlety, S. Lutz. "A Very Small Form Factor, Multi-Row, Multi-Fiber Connector with Multi-Vendor Interoperability," International Wire and Cable Connectivity Symposium, (2023).

[9] "Fibre optic interconnecting devices and passive components – Connector optical interfaces, Part 3-31: Connector parameters of non-dispersion shifted single-mode physically contacting fibres – Angled polyphenylene sulphide rectangular ferrules", IEC 61755-3-31, Edition 1.0, June 2015.

[10] "Fibre optic interconnecting devices and passive components - Connector optical interfaces for single-mode fibres - Part 1: Optical interfaces for dispersion unshifted fibres - General and guidance," IEC 61755-1:2022, Edition 2.0, September 2022.

7. Author Biographies

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Sharon Lutz has 22 years of experience in fiber optic interconnects with US Conec and is currently the Product Manager over precision optical components. Sharon has served as a technical expert for various industry standards including IEC, IEEE, and TIA. She is currently an active member within IEC and serves as convener of the IEC SC 86B WG6 for the development of fiber optic connector standards. Sharon received her Bachelors of Science degree in Mechanical Engineering from the University of North Carolina at Charlotte in 2004 and her Master of Business Administration from Wake Forest University in 2019.

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Dirk Schoellner received his Master's degree in Electrical Engineering from The Ohio State University in 1999. He has been involved in research and development in fiber optics for twenty-five years. He joined US Conec, Ltd. in 2007 as a Senior Development Engineer in the Research and Development Department. Currently Dirk is the Manager of Connectivity and Testing at US Conec.

Charlie Stroup has worked in a variety of engineering roles in the telecommunications industry since 2011. He received a Bachelor of Science in Physics from Guilford College in 2006 and a M.S. in Mechanical Engineering from University of North Carolina at Charlotte in 2008. Charlie has served as a technical expert for WG4 and WG6 of IEC SC86B and is currently the Applications Engineering Manager for US Conec, Ltd.