A Very Small Form Factor, Multi-Row, Multi-Fiber Connector with Multi-Vendor Interoperability

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Abstract

The paper describes the design, performance, backwards compatibility, and supply chain maturity of a new, very small form factor (VSFF) multi-fiber interconnect variant of the TMT ferrule. The 24-fiber TMT ferrule is designed with two rows of 12 fibers with the same alignment structure as traditional 24-fiber MT ferrules, enabling the TMT ferrule to be directly mated to legacy MT ferrules. The MMC connector format was used to validate the performance of the 24-fiber TMT design. The connectors were tested in accordance with the requirements of Telcordia GR-1435 [1]. Furthermore, the ferrule was tooled by three different component vendors and a random optical intermate was performed to demonstrate interoperability with ferrules and cable assemblies made from different termination factories.

Keywords: MT; TMT; MPO-24; MMC multi-fiber connector; VSFF; density; co-packaged optics; multi-vendor; interoperability; intermateability.

1. Introduction

Advancements in network switching and artificial intelligence technologies deployed in data center applications are outpacing the bandwidth capabilities of optical transceivers resulting in networks with higher optical fiber density requirements. Subsequently, emerging hyperscale data center architectures are demanding cabling solutions which cannot be managed with legacy connector types. A VSFF multi-fiber connector system has been previously demonstrated to improve usable fiber density when compared to the incumbent MPO connector format [2]. This paper addresses a higher density, multi-row variant of the VSFF connector system.

This new, high density connector technology enables unmatched fiber density for cabling, patch panel, card-edge and on-card applications. A single rack unit (RU) with a 19-inch span, typically supporting 72 LC duplex ports, or 144 fibers, can support up to 6336 fibers with granularity of 24 fibers per connector. This 24-fiber VSFF connector format establishes the lowest loss, highest density and optimal granularity for emerging optical link technologies (see Figure 1).

Emerging transceiver formats are now evolving with two multi-fiber connector port interfaces. For example, 800 Gb/s transceivers for artificial intelligence data center clusters are now being deployed with a 2 x 400 Gb/s configuration utilizing two base-8 MPO connectors. OSFP-XD has now specified 2-port MPO and 2-port VSFF transceiver formats. While two vertically oriented MPOs fit within the transceiver footprints, the size of the MPO format drives the vertical interface of the module to be larger, impeding airflow. The vertical orientation also results in more challenging internal fiber routing. Two MMC connectors can be placed in the transceiver in either a vertical or horizontal orientation, enabling a reduced footprint, improved airflow, and improved internal fiber routing for future transceiver formats [3]. Furthermore, as the industry looks to pluggable transceiver formats at 1.6 Tb/s and 3.2 Tb/s, VSFF connector formats with multiple rows of fibers will be needed.

The density explosion is challenging overall fiber management in data center environments, driving reduced size and multi-row connectivity solutions.

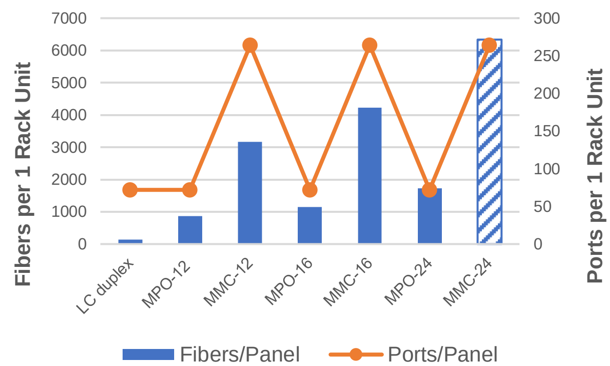

Figure 1. Fiber and Port Density

The 24-fiber TMT ferrule is designed with less than 40% of the material volume used in traditional MT ferrules while supporting two rows of 12 optical fibers on the industry standard pitch of 250 µm. The overall height is reduced by approximately 30%, while the ferrule length is 1/2 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 2.

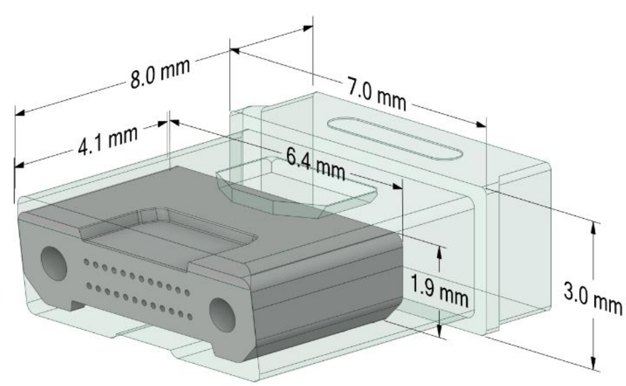

Figure 2. Comparison of the outer dimensions of the MT and TMT ferrules.

This ferrule is designed with the structural integrity required to support industry standard mechanical and durability requirements in push-on/pull-off connector formats. The precision optical and mechanical tolerances are designed to be compliant with the MT optical interface IEC 61755-3-31 for Grade B performance [4]. Nominal optical fiber datum locations and guide hole size and pitch are designed to be compliant with the multi-row MPO as defined in IEC 61754-7-2 [5] (see Figure 3).

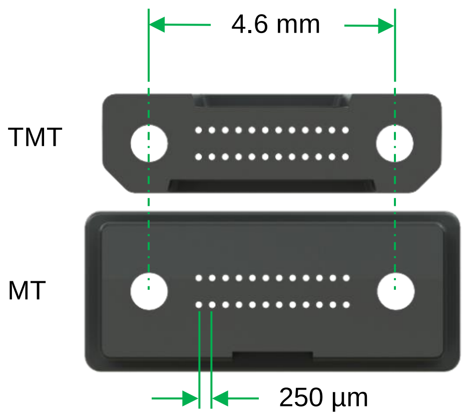

Figure 3. Ferrule structure harmonized to IEC 61754-7-2.

Compliance with MT-based standards allows for the ferrule mating to be compatible with MT ferrules, an important feature for data center infrastructure ecosystems, including cabling, equipment and transceivers.

The TMT ferrule is designed for ease of termination to enable improved yield in cable assembly manufacturing.

The epoxy window in a traditional MT ferrule is eliminated in the TMT ferrule (see Figure 4) which allows for an improved fiber lead-in structure. The chamfered fiber holes of this lead-in design provide 360-degree guidance for each fiber during the termination process. The design offers more forgiveness in the ribbonized fiber-to-fiber pitch tolerance as compared to traditional fiber lead-in designs of MT ferrules.

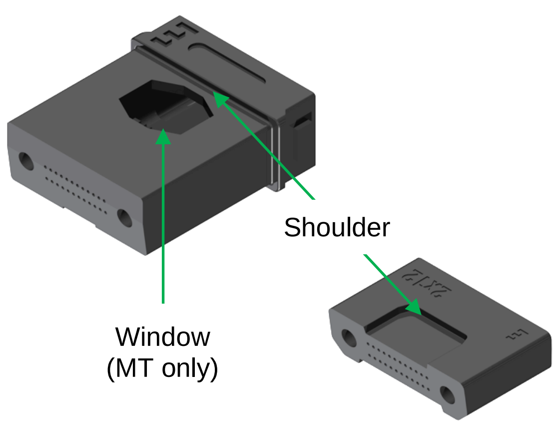

Figure 4. Comparison of external features of TMT and MT ferrules.

The outer profile of the TMT ferrule, including internal shoulders, ensures error-free assembly within the MMC connector due to keying for single-orientation insertion as shown in Figure 5.

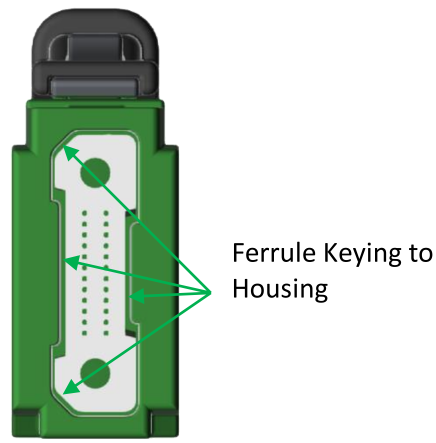

Figure 5. Endface view of a TMT ferrule in an MMC connector.

2. Compatibility with ≤ 250 µm Ecosystems

Designed with a fiber hole pitch of 250 µm, the TMT ferrule is compatible across all existing and future application needs, including environments with 250 µm fiber cabling solutions as well as those leveraging smaller diameter fibers (e.g., 200 µm, 165 µm).

Data center interconnect applications with high fiber count cables that can reach up to 6912 fibers per cable are leveraging small diameter single-mode fibers (e.g., 200 µm) today and likely will migrate to 165 µm diameter optical fibers in the future to meet the requirements for pathway spaces. With growth in other high-density applications such as machine learning, data center back-end networks are driving an increasing number of optical fiber links. Traditional indoor data center pathways can become congested and may not be rated for the loads or space required for the increased volume of cable. In single-mode applications, small diameter fibers, such as 200 µm and future 165 µm or smaller, may be leveraged to reduce the diameter and weight of the cable infrastructure. At the same time, there are short distance machine learning applications driving a resurgence of multimode (250 µm) fiber deployments. With cabling solutions using a mix of fiber diameters including 250 µm single-mode, multimode, and possible future multicore fibers, as well as ongoing decreases in single-mode fiber diameter for some environments, it is critical to have ferrule and connector platforms that do not restrict the ability to terminate optical fiber cables that will be used in current and future applications. While we have previously demonstrated that a fiber hole pitch of 165 µm is achievable in multi-fiber ferrules, maintaining a pitch of 250 µm ensures compatibility with all fiber types and interfaces [6].

To terminate optical fiber cables using small diameter fibers, a method is available to ribbonize fibers on a 250 µm pitch. A tool has been created to enable easy conversion of the small diameter fibers into the correct order and pitch for ribbonization, as demonstrated in Figure 6. The molded plastic tool contains 200 µm (or 165 µm) pitch grooves that fan out to 250 µm pitch on the opposite end. Following application of a quick cure adhesive, the ribbonized fibers can then be removed from the handler, stripped and cleaved for ferrule insertion using industry standard tools.

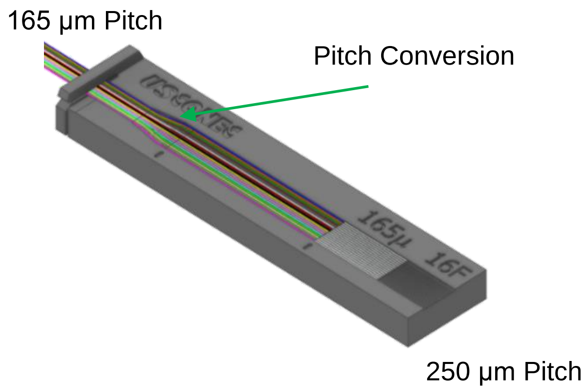

Figure 6. 165 µm Fiber Ribbonization on 250 µm Pitch.

3. Connector Performance

GR-1435 testing of the MMC connector with 24-fiber TMT ferrule has been completed. Figures 7 through 10 show results from tests that are key to optimal performance of connectors in data center applications. The insertion loss results collected for new product measurements (see Figure 7) exceed IEC Grade B requirements.

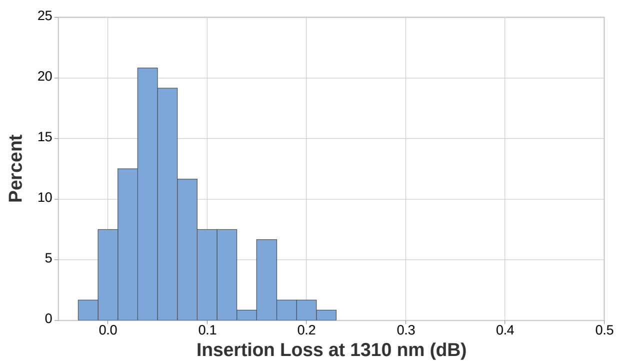

Figure 7. Insertion Loss at 1310 nm prior to environmental exposure.

Physical contact of multi-fiber ferrules is directly correlated to the endface flatness achieved during polishing. The design of the TMT ferrule results in superior endface flatness when the ferrule is polished, illustrated by the minus coplanarity histogram in Figure 8. The IEC minus coplanarity limit for a 12 fiber MT ferrule (400 nm) is shown for reference. There is currently no IEC endface geometry specification for 2x12 MT ferrules.

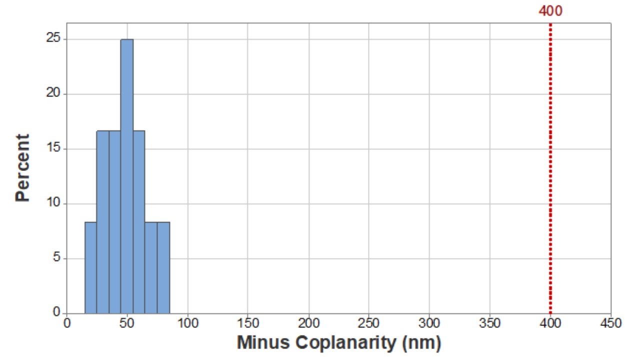

Figure 8. Endface geometry (Minus Coplanarity).

With a reduced size ferrule design that does not utilize an epoxy window, the TMT ferrule has improved symmetry and reduction in epoxy volume needed; subsequently, the insertion loss of the 24-fiber MMC connector is extremely stable during environmental testing. Figure 9 shows the change in loss through GR-1435 controlled environment testing, consisting of thermal aging (60°C, 96 h), humidity aging (40°C, 95% RH, 96 h), thermal cycling (-10°C to 60°C, 40 h), and a dry-out period (60°C, 24 h). The change in loss is < 0.1 dB relative to the start of the test through all environments.

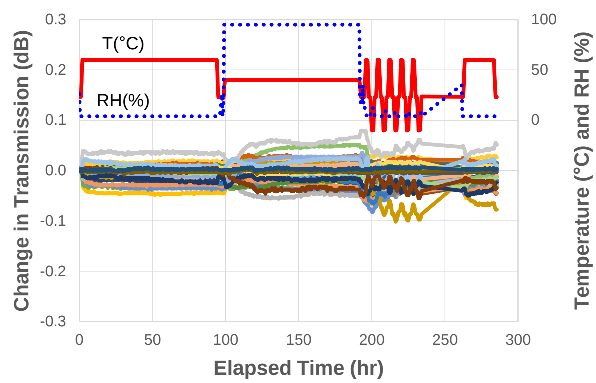

Figure 9. Change in transmission through environments: thermal aging; humidity aging; thermal cycling; dry-out.

Durability testing was completed with MMC connector pairs each mated 50 times per the GR-1435 standard. The durability test results are shown in Table 1. Figure 10 shows images of a female connector end face before and after a male connector was cycled manually 50 times.

Table 1. Durability test results.

Parameter (dB)	1310 nm	1550 nm
Delta IL Max	0.12	0.09
Delta IL Avg	0.03	0.02
IL Max	0.25	0.18
IL Avg	0.07	0.05

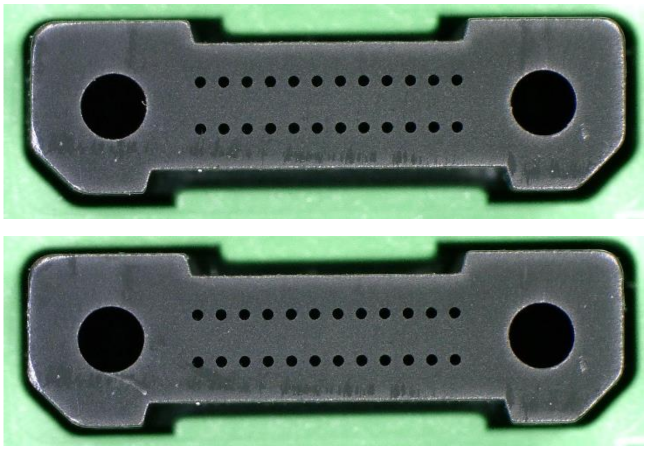

Figure 10. Pre- and Post-durability images of a female connector after manual cycling of a male connector.

4. Compatibility with MT/MPO

While the TMT ferrule structure can support a fiber hole pitch of less than 250 µm to enable 24 fibers in a single row [6], ferrule geometries designed for a reduced fiber hole pitch (e.g., 200 µm) would not be compatible with standard MT ferrules. To maintain backward compatibility and intermateability with standard MT ferrule and MPO connector deployments and ecosystems, the TMT ferrule leverages a 250 µm fiber hole pitch design. In addition to leveraging the advantages of a standardized 250 µm fiber hole pitch, the guide pin bore size and pitch are compliant with the multi-row MPO as defined in IEC 61754-7-2 (Figure 11).

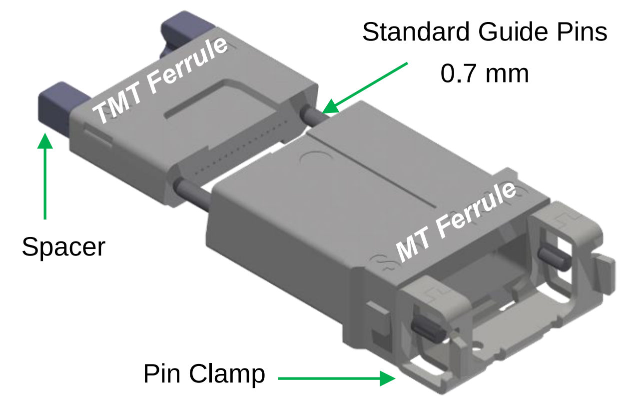

Figure 11. TMT / MT Ferrule Compatibility.

To validate the optical intermateability of the TMT and MT ferrule technologies, testing was completed consisting of 2x12 MT/MPO single-mode connectors mated to 2x12 TMT/MMC single-mode connectors. The MMC and MPO connectors were mated to each other using a hybrid adapter (Figure 12).

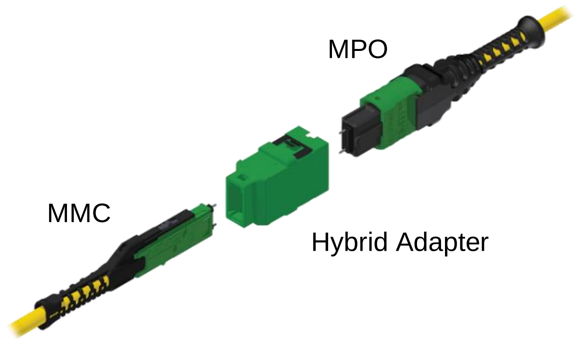

Figure 12. Hybrid adapter for mating MMC (TMT ferrule) to MPO (MT ferrule).

The intermateability results shown in Figure 13 demonstrate loss performance with an average IL of 0.12 dB and a maximum IL of 0.32 dB.

Figure 13. Insertion loss distribution of intermated MPO and MMC connectors.

TMT ferrule to MT ferrule intermateability reduces risk in both legacy and future cabling builds. With demonstrated optical performance when mating MMC connectors to MPO connectors, a migration to the VSFF platform for retrofits in brownfield environments is made easy by enabling backward compatibility with existing structured cabling while still maintaining flexibility for future cabling and technology choices.

5. Multi-Vendor Interoperability

The MMC ecosystem has continued to mature with multi-vendor component supply and termination capabilities. Previously, interoperability testing of 1x16 MMC connectors was completed with TMT ferrules molded independently by both US Conec and Fujikura [7].

US Conec and two additional optical component vendors have independently tooled and molded 2x12 TMT ferrules with a 250 µm fiber hole pitch. An intermateability study was conducted which included ferrules molded by US Conec and the two additional component suppliers, as well as four cable assembly factories, each terminating assemblies at an independent location. The cable assemblies were manufactured with cable using ≤ 200 µm optical fibers. Results from the study demonstrate low insertion losses (see Figure 14) and establish a baseline for optical performance across three ferrule molding vendors and four cable assembly vendors.

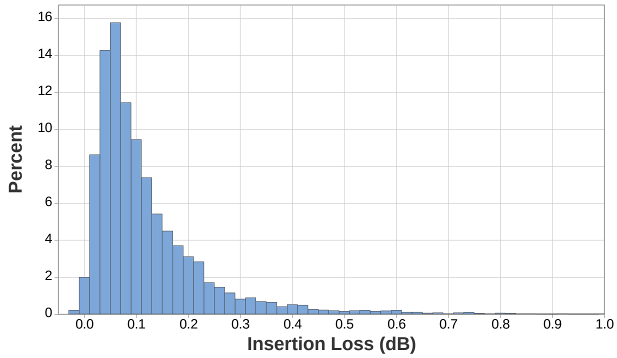

Figure 14. Histogram of the insertion loss measurements at 1310 nm for the multi-vendor interoperability test.

In Figure 15, the insertion loss data is grouped according to whether the mating connectors are from the same vendor (within a vendor) or from different vendors (between vendors). The insertion loss distributions are similar, validating the interoperability performance between suppliers.

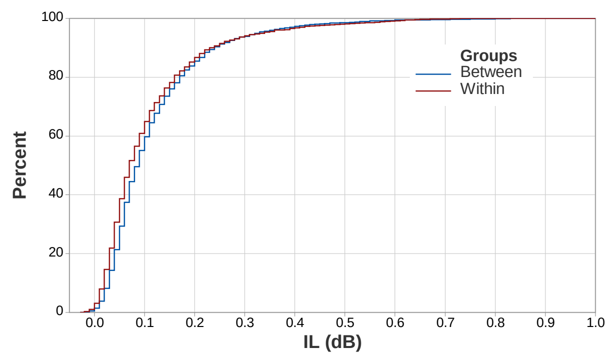

Figure 15. Cumulative distribution functions for the multi-vendor interoperability test, comparing mating between/within vendors.

6. Conclusions

A new, 24-fiber, VSFF TMT ferrule has been developed and tested to the controlled environment requirements of GR-1435. A termination and polishing process was developed in which the endface geometry far exceeds the flatness tolerance requirements defined in the MT optical interface IEC 61755-3-31. US Conec and two additional optical component vendors have tooled the new ferrule design with independent tooling and molding process designs. Ferrules produced from the three component vendors were mated to establish multi-vendor interoperability with cable assemblies produced in four different termination factories. In addition, the new connector format was mated directly to traditional 24-fiber MPO cables establishing backwards compatibility with existing cabling infrastructure. The new, multi-row TMT ferrule format is compatible with existing and emerging small diameter fiber formats and interfaces and enables fiber interconnect densities necessary to support next generation, high fiber-density networks.

7. Acknowledgments

We thank the following companies who participated in the multi-vendor interoperability study: AFL; Corning Optical Communications; Fujikura, Ltd.; Sumitomo Electric Industries, Ltd. [8].

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9. Biography

Mike Hughes is the Vice President of Product Management at US Conec Ltd. He has over 30 years of experience in copper and fiber optic connectors and cabling products. Mike has held engineering and commercial positions in high density optical interconnect technology for 22 years. Mike holds a Bachelor of Science in Mechanical Engineering from North Carolina State University and Master of Business Administration from Wake Forest University.

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Ian Dancel received a Bachelor of Science degree in computer engineering from the United States Military Academy at West Point in 1997. He has been involved in telecommunications and network engineering in field and laboratory environments for 19 years. He joined US Conec in 2016 and is currently focused on fiber optic components as the Process Development Engineering Supervisor.

Michael Kadar-Kallen received a B.S. in Physics and B.A. in Mathematics from the University of Rochester in 1985, and a Ph.D. in Physics from Princeton University in 1992. Michael has been working in the fiber optics industry since 1994, after completing postdoctoral work in atomic physics at Wake Forest University. He is currently a Senior Principal Engineer at US Conec.

William Kettlety received a Bachelor of Science degree in mechanical engineering from North Carolina State University in 2022. He joined US Conec in 2022 and is currently focused on fiber optic components as a Process Development Engineer.

Sharon Lutz has over 21 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 Bachelor of Science degree in Mechanical Engineering from the University of North Carolina at Charlotte and her Master of Business Administration from Wake Forest University.