A Novel, Low-loss, Multi-Fiber Connector with Increased Usable Fiber Density

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Abstract

In this paper, we describe the design overview and initial trials of a new, high density, Very Small Form Factor (VSFF) multi-fiber connector which exceeds the application and performance requirements of the MPO format. The new connector increases multi-fiber port density by a factor of three with a novel reduced size, low-loss, physical contact ferrule. The new connector is designed to support an array of up to 16 fibers on 250 micron pitch and utilizes the optical and mechanical alignment interface established in the MPO format. Preliminary lab results confirm physical contact of the fiber tips and indicate optical and mechanical performance compliant with industry standards for carrier and data center applications.

Keywords: MT, TMT, MPO-16, multi-fiber connector, VSFF, density, co-packaged optics

1. Introduction

Advancements in data center switching silicon since 2010 have resulted in an increase in switching bandwidth by a factor of 80 while the transmission bandwidth per fiber has increased by a factor of 10. This phenomenon is resulting in optical networks with increasing fiber densities for both pluggable optics and emerging architectures with embedded optics. Increased fiber densities are driving the need for new fiber connector formats and functionality.

A new multi-fiber ferrule referred to as the TMT has been designed with less than 25% of the material volume used in traditional MT ferrules while supporting 16 optical fibers on the industry standard pitch of 250 microns. This ferrule was designed with the structural integrity required to support industry standard mechanical and durability requirements in push-on/pull-off connector formats. The ferrule was tooled to the precision dimensional requirements of IEC Grade-B, Angled Physical Contact (APC) MT ferrules [1].

A new connector based on the MDC duplex connector interface was introduced to house the new ferrule and is referred to as the MMC connector. The new connector enables insertion and extraction with a push-pull strain relief boot facilitating finger accessibility and usability without the need for tools. The new connector employs the same footprint and latching mechanism of the MDC duplex [2] but is keyed such that the duplex and multi-fiber variants are not inter-mateable in order to maintain polarity in the field.

2. Applications

The advent of Co-Packaged Optics (CPO) for 51.2 Tb switching and beyond is driving the need for novel architectures with fiber optic connectivity requirements which cannot be met with current industry standard, high-density connectors. At 51.2 Tb switching for DR (500m) reaches and 100 Gb per fiber, 1024 fibers are needed per switch [3]. This fiber density requires connectivity solutions beyond existing MPO capabilities to fit the optical I/O connectivity within a single Rack Unit (RU) panel.

In addition to CPO, next generation transceiver applications are now requiring multiple 8 fiber MPO ports per transceiver which results in a larger transceiver footprint and limits airflow [4]. In the future, 1.6Tb transceivers at 100 Gb/fiber with two 32 fibers per transceiver. A 2 x 800 Gb variant would subsequently require two 16 fiber connectors. Similarly, a 4 x 400 Gb variant would require four 8 fiber connectors. A higher density connector format enables more connector ports per transceiver while minimizing transceiver size, maximizing transceivers per panel with optimal cooling airflow.

This high density connector technology enables unmatched fiber densities for patch panel, card-edge, on-card or emerging transceiver applications (Figure 1). A single Rack Unit (RU) with a 19 inch span typically supporting 72 LC ports can support up to 3456 fibers with granularity of 16 fibers per connector. This new connector format enables the lowest loss, highest density and optimal granularity for emerging optical link technologies.

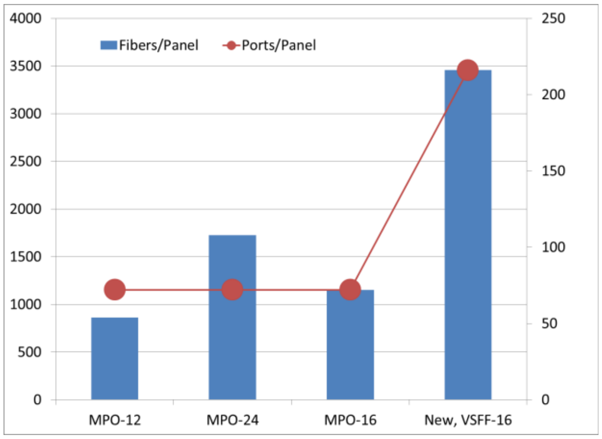

Figure 1. Comparison of fiber and port density per rack unit

3. Design

3.1 Ferrule Design Considerations

The TMT ferrule is designed to support existing and emerging fibers. With an initial fiber to fiber pitch of 250 um and the same nominal guide pin bore diameters and guide bore pitch, the TMT ferrule is mateable to existing 16 fiber MT ferrules, which allows for backwards compatibility with installed base 16 infrastructure. In Figure 2, a comparison of the TMT and MT-16 ferrules is shown, as well as a demonstration of the capability to mate MT-16 ferrules to TMT ferrules.

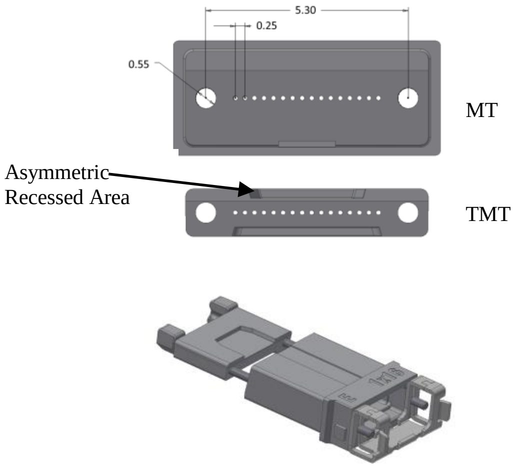

Figure 2. Mating dimensional comparison of MT-16 and TMT ferrules

For emerging fiber with smaller cladding layers, pitch transition termination methods can be utilized to transition fiber pitches to 250 micron. In addition, the TMT ferrule is adaptable for fiber pitches of less than 250 enabling fiber counts of up to 24 in a single row on a 165 micron pitch. [5]

While the TMT ferrule was developed with the mechanical integrity for connector applications where insertion and extraction occur via push and pull hardware, it is also suitable for on board and hardened packages where smaller ferrule geometries are beneficial. Both multi-mode and single-mode ferrules are designed for angled polish with a pre-angled end face to support the higher return loss requirements for new applications.

The new ferrule design is half the height and length of the traditional MT ferrule geometry at 1.25 mm X 4 mm, yet uses the same proven alignment configuration as 16 fiber MT ferrules. The external shoulder structure of the MT ferrule was eliminated, and a recessed feature was added to serve as the x-angle polishing datum and internal connector seating feature. The resulting geometry improves mechanical integrity over traditional MT ferrules with the external shoulder. A comparison of the ferrule geometries is shown in Figure 3. The asymmetric ferrule design simplifies assembly and polarity management when integrated into the connector, which be further discussed in the next section.

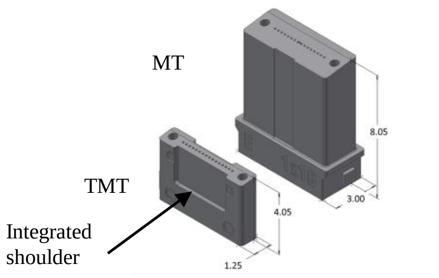

Figure 3. Overall geometry of MT-16 and TMT ferrules

3.2 Connector Overview

The MMC optical connector housing is based around the VSFF MDC two fiber optical connector. Instead of two ceramic optical ferrules containing one fiber per ferrule, the MMC connector contains the new TMT ferrule that can hold up to 16 optical fibers. A comparison of the two connector formats is shown in Figure 4.

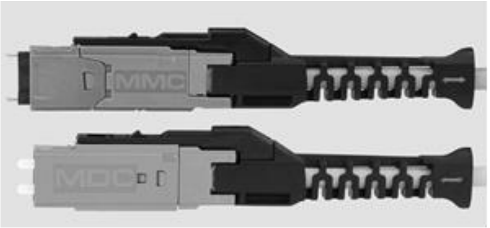

Figure 4. Comparison of MMC and MDC formats

The smaller ferrule and connector embodiment allows three MMC optical connector mated pairs to fit in the same space as one traditional MPO-16 optical connector. As shown in Figure 5, the MMC connector increases patch panel density significantly, minimizing the patch panels, hardware and physical infrastructure needed as the consumer demand for bandwidth continues to grow.

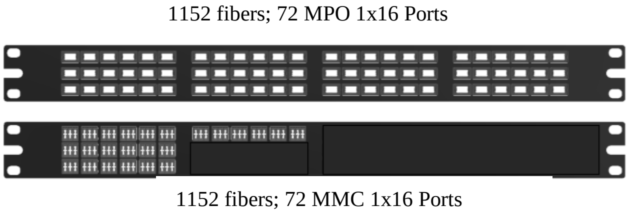

Figure 5. 1,152 fibers in 1RU panel using 72 MPO-16 adapters and same capacity using 24 MMC adapters

3.2.1 Push-pull boot

While increasing optical connector density at the patch panel minimizes the required physical infrastructure, it also increases the difficulty of individual optical connector access due to the increased number of cable assemblies in front of the patch panel. The MMC connector incorporates a boot and integrated latch release mechanism employed on the VSFF 2-fiber MDC optical connector [2]. The connector strain relief boot maintain proper cable bend radius while serving as the push-pull insertion and extraction handle.

3.2.2 *Ferrule/Connector design for easy assembly*

Standard MT ferrules incorporate an elevated shoulder on the rear portion of the ferrule that seats into the MPO connector housing to maintain the pre-loaded spring force. (Figure 3.) The front rectangular face of the MT must pass through the shoulder seating area of the MPO connector during the assembly process which can require special tools or timely processes.

The TMT ferrule design does not incorporate an elevated rear shoulder, but instead includes asymmetrical recessed geometry on the top and bottom outer surface of the ferrule, as could be seen in Figure 2. The connector housing for the MMC incorporates shoulder seating geometry on the inside surface of the connector complementary to the recesses on the TMT ferrule. Eliminating the elevated ferrule shoulders from the TMT ferrule design allows the TMT ferrule to enter the connector front shroud without obstruction and completely removes the need for any type of ferrule guide reducing connector termination time and increasing efficiency (Figure 7).

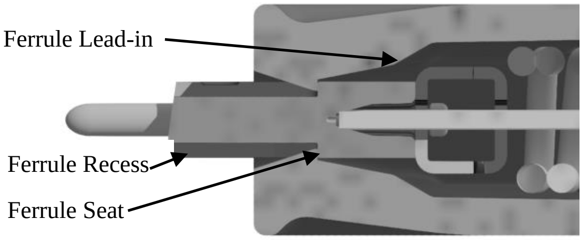

Figure 7. Ferrule – Housing Interface for assembly and polarity management

3.2.3 Ferrule Float

Optical connectors and adapters are designed to maintain ferrule contact of the two mated connectors to ensure a consistent insertion loss at the connection point. If ferrules separate during optical transmission, the insertion loss at the connection point will increase. To ensure stable optical connection, the ferrule endfaces and fiber tips must remain in contact when external loads are applied to the connector or cable. To maintain contact, the TMT ferrules to housing interface was designed to allow the connector bodies to translate axially while the ferrule float ensuring stable contact. A similar design tactic, a floating ferrule, used with the ceramic ferrules of the MDC was incorporated into the MMC connector housing and TMT ferrule designs (Figure 8). 'The connector housing can be designed to allow the [ferrule] to rotate within the connector housing at a larger rotational angle than the connector can rotate within the adapter. Conversely the ferrules can remain stationary while the housing rotates about the ferrules. This 'ferrule float' relative to rotational translation between two connector plugs ensures proper axial alignment of the ferrules and ultimately optical stability of the connector system.' [2]

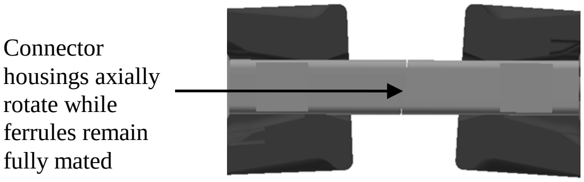

Figure 8. Connector Float

3.2.4 Ferrule is keyed to the housing

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. Maintaining gender requirements of individual communications system components will ensure the optical links will be able to connect with one another to build the entire system.

The same asymmetrical ferrule recessed features correspond to asymmetrical protruding geometry on the internal ferrule seating portion of the connector body. This design results in a keyed housing to ferrule engagement for ease of assembly and ensuring that the TMT ferrule is inserted into the MMC connector housing in one, and only one, orientation. Inserting the angled ferrules of two MMC optical connectors into both sides of an aligned adapter properly aligns the angled ferrule endfaces. (Figure 9).

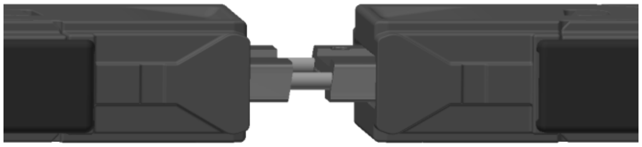

Figure 9. MMC angled ferrule orientation

3.2.5 Small Pitch Results in Cable Challenges

Mult-fiber cables are typically larger in outside diameter (OD) than single fiber cables to accommodate the space required for the additional fibers. The reduced connector format of the MMC optical connector increases the connector density at the patch panel, however it also reduces the interface with the optical fiber cable. For tighter connector spacing at the patch panel or transceiver, a connector pitch of 3.9 mm is used. The connector assembly process and rear portion of the connector body was designed to support the smaller connector and tight pitch of the applications with wall thicknesses supporting cables diameters of up to 2.8 mm maximum (approximately 2.5mm nominal) could be maintained while meeting standard MPO cable loading requirements (Figure 10). This supports 16 fiber cables with standard 250 micron fibers.

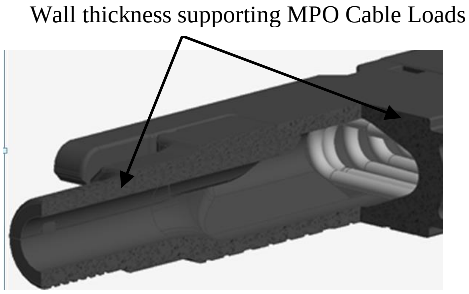

Figure 10. Connector body crimping area

4. Ferrule and Connector Performance

As with all standard multi-fiber ferrules, the MMC connector and TMT ferrule rely on correctly molded ferrule geometry and polished endface geometry to obtain IEC grade B insertion loss performance [1]. The TMT ferrule, while significantly smaller than traditional MT ferrules, still uses similar assembly, termination, and polishing procedures and requirements to mate successfully. TMT ferrules were terminated with single mode fiber. The ferrules were then polished on a standard MT polishing machine with a polishing plate designed to interface with the TMT ferrule polishing datums. Since the TMT ferrule surface is 40% smaller than that of an MT-16, polishing parameters were adjusted accordingly, minimizing polishing processing times and materials. MMC connector hardware was added prior to insertion loss and mechanical testing.

4.1 Endface Geometry

Since the TMT ferrule has a significantly smaller endface and modified geometry compared to an MT ferrule, the repeatability of endface geometry interferometry measurements was verified prior to characterizing the TMT ferrules used for testing. A subset of TMT ferrules was measured on an interferometer 10 times, removing from the fixture and reinstalling between each measurement. Standard

IEC MT endface geometry standard parameters such as ferrule angles and minus coplanarity were studied and compared to MT-16 ferrules that were terminated and measured in accordance with standard MT endface geometry requirements [1]. Other than adjusting the region of interested to scale for the newer smaller ferrule endface of the TMT ferrule, no other interferometry settings were changed. Measurement variations between the MT ferrules and the TMT ferrules were comparable and in accordance with normal MT variation over ten measurements. The TMT standard deviation was less than 0.04 degrees for the ferrule y-angle, and less than 3nm for the minus coplanarity.

With repeatable measurement capability, 14 TMT ferrules were then characterized for endface geometry and results are summarized in Table 1. The y ferrule angle of the entire population is slightly lower than the desired 8 degree nominal goal, but is due to needed optimization of the polishing processes. For this preliminary study, the ferrules are intra-mated and therefore compatible with complementary angles. Similarly, the ferrule y radius is smaller than traditionally used in MT connectors, but will naturally flatten as the polishing process is optimized. However, the minus coplanarity and fiber heights of all 224 fibers are well within expected to provide ample physical contact during connector mating. Despite the very small ferrule face and preliminary polishing process, the total range of the measured parameters is acceptable per standard allowable MT endface geometry ranges [1].

Table 1. Endface geometry results for 14 TMT ferrules after polishing

	Ferrule X angle (°)	Ferrule Y angle (°)	Ferrule Y radius (mm)	Minus coplanarity (nm)	Fiber Height (nm)
Avg	-0.04	7.19	12.30	158.91	2782.5
Max	0.05	7.39	14.89	236.16	3585.1
Min	-0.33	6.94	9.24	76.90	2281.8

4.2 Ferrule Geometry

The molded ferrule geometry itself must be accurate in order for ferrules and connectors to perform as expected; endface geometry cannot correct for the lateral fiber alignment locations. Therefore the fiber hole eccentricity was measured on a subset of parts to verify that fiber holes were positioned correctly with respect to the guide line alignment holes. Since ferrules are mated in a key-up/key-down orientation, any x-misalignment in the eccentricity will cancel, but y-misalignment will compound in the final fiber alignment. Therefore, it is critical that ferrules be molded with accurate fiber holes across the entire array. Figure 11 shows the deviation from nominal eccentricity of the fiber holes for several ferrules; where no fiber hole deviates from the expected y-position by more than 0.3 microns. This accuracy in molding the TMT ferrule helps ensure that the fiber core true position locations are complaint with the IEC grade B definition [1]. The ferrule fiber hole location accuracy is highlighted in Figure 11.

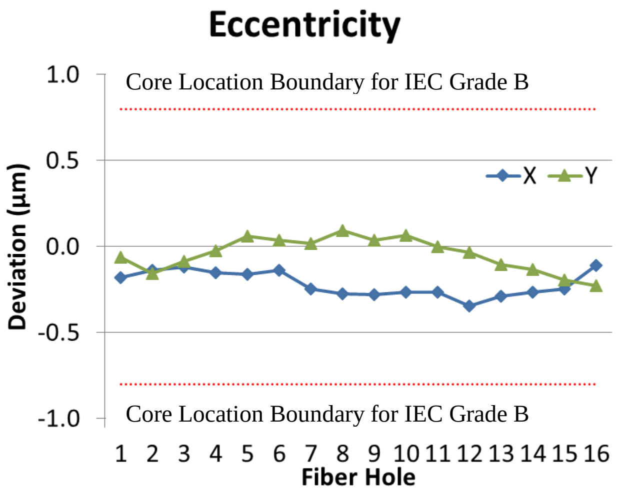

Figure 11. The deviation of the molded fiber holes from expected nominal positions. IEC grade B core locations are shown as dashed lines at 0.8 microns.

4.3 Fiber Tip Physical Contact

When multi-fiber connectors are mated together, proper endface geometry is critical in order to obtain effective alignment and contact between all of the fiber cores. However, in addition to correct endface geometry, in angle polished connectors (APC) the spring force mating the ferrules together must match the fit between the guide pins and guide pin holes of the ferrules. It has been shown previously that as APC ferrules are mated together, the ferrules slip by dimensions of the guide pin and guide pin bore mating datums, in addition to system deflection, leading to an offset of the alignment of the fibers [1]. The amount of translation of the two ferrules is a function of the connector spring force which must be accounted for in the ferrule and connector design. Reducing the spring force creates less ferrule translation, but also reduces the contact forces on each fiber tip necessary to overcome any irregularities in endface geometry. Subsequently, there is a trade-off in the optimization of the spring force selection in the connector design. Previous work with MT ferrules has shown that a 10N spring is sufficient for 16 fiber ferrules to maintain adequate physical contact between the fiber tips of the ferrules, and that the ferrule slip can be accounted and corrected for in such a ferrule design [6]. The new TMT ferrule and MMC connector have been designed around the previous work, and therefore use 10N springs to ensure proper physical contact. Standard single mode fiber optic connector loss attributable solely to axial alignment of the fiber cores results in a ratio of the 1550 nm loss to the 1310 nm loss of 0.78, as the mode field diameters at the respective wavelengths have slightly different coupling efficiencies [7,8]. When the insertion loss data for the two wavelengths are plotted against each other, if the correct ratio is found, then it can be concluded that proper physical contact between the fibers has been achieved; if an air gap were present then the ratio would be substantially different. Figure 12 shows the channel by channel ratios of the connectors tested. The slope of the linear fit through the data confirms physical contact and indicates that the 10N spring is achieving physical contact.

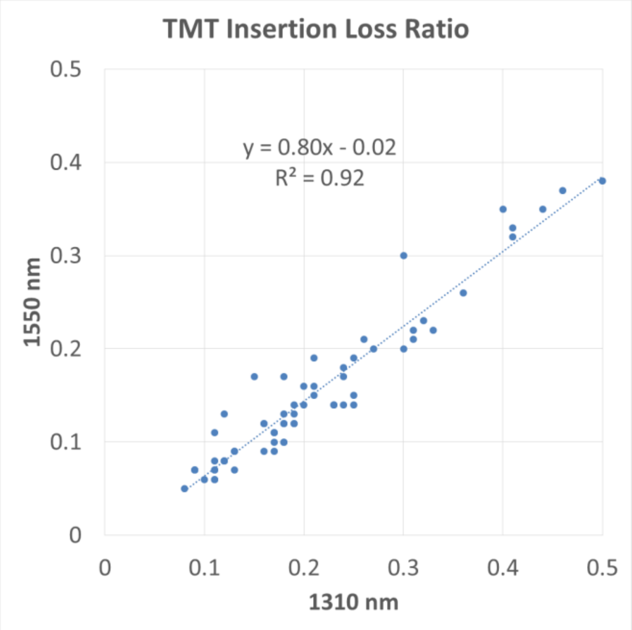

Figure 12. Ratio of insertion loss performance at 1310nm and 1550 nm. The expected slope of the curve predicted by the respective mode field diameters indicates physical contact has been achieved.

4.4 Mechanical Testing

Preliminary mechanical testing of the new ferrule and connector system was performed on the new multi-fiber VSFF format. MMC connectors were terminated, polished and visually inspected before being mated. The connectors were then mated 50 times with insertion loss remeasured between each mate. Connectors were cleaned using standard fiber optic cleaners as needed during the testing. Figure 13 shows the average change in insertion loss from the initial mate through all subsequent 49 mates for a typical connector. The typical insertion loss change during durability testing was less than 0.1dB. A representative sample result is displayed in Figure 13.

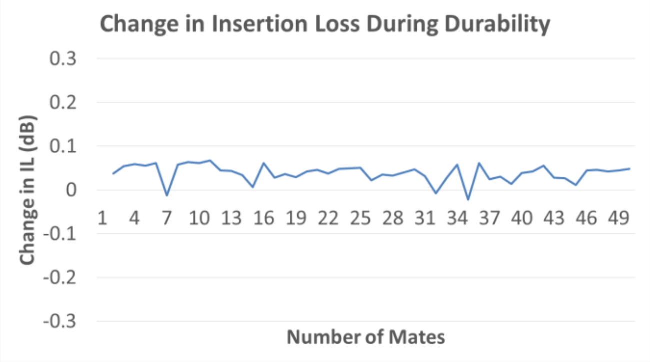

Figure 13. Change in insertion loss during 50 mate/demate durability test

Initial testing has also been completed on testing with applied load GR-1435 uncontrolled media type I requirements [9]. Jumpers were tested to 2.2N in both the 0 degree and 90 degree load conditions while insertion loss was monitored before, during, and after the test. Typical connector results are shown in Table 2, where the connectors remained within acceptable ranges for the Telcordia requirements.

Table 2. Transmission with applied load testing per Telcordia GR-1435 specification

	Average Loss	Average Change
Initial	0.18	
0º load	0.24	0.05
0º no load	0.18	-0.06
90º load	0.20	0.02
0º no load	0.27	0.01

5. Summary and Next Steps

A new, high density, VSFF multi-fiber connector was developed for emerging optical link architectures. The new connector format was designed to offer optimal performance, granularity and usable density in applications where existing connector technology is not adequate. The new connector format utilizes the existing MPO-16 optical alignment structure while reducing the overall connector embodiment size by a factor of 3 over existing the existing MPO-16 format..

The optical alignment technology for the new connector format is based on a reduced size, physical contact, low-loss ferrule designed to exceed the mechanical limits of MT technology. The new ferrule was tooled and confirmed to exceed the dimensional requirement of industry leading IEC Grade B interconnect technology [1]. Preliminary endface geometry was studied on prototype termination processes while physical contact of fiber tips was confirmed for an array of 16 fibers at 10N of connector spring force.

The overall connector system was tested for preliminary mechanical robustness with durability and transmission performance with applied cable loading.

The next steps for this new connector format is finalization of termination processes for optimal overall performance along with formal definition of endface geometry requirements. Formal carrier grade performance qualification will follow.

6. References

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7. Authors

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