A Mass Insertion Solution with Reduced Installation Force for Very Small Form Factor Connectors

Pradeep Bembiri, Jennifer Cline, Jeff Hendrick, Jason Higley, William Kettlety, Dirk Schoellner

US Conec Ltd., Hickory, North Carolina

+1-828-323-8883 · jeffhendrick@usconec.com

Abstract

This paper introduces a novel mass insertion mating solution for very small form factor connectors that increases deployment speeds and improves cable routing in mass installations in hyperscale and artificial intelligence datacenters. The new design solution uses two lever arms that employ mechanical advantage to keep the total connector insertion force for multiple simultaneously mated connectors at one-sixth of the total force needed to mate all the connectors conventionally. Once installed in mass, individual connectors are still accessible to be removed and reinstalled using the standard push/pull boot.

After presenting the mass insertion design, insertion loss performance data demonstrates that the very small form factor connectors are not impacted by the mass insertion solution. Stability of the system is demonstrated through mechanical testing, as well as environmental test performance data.

Keywords: MI; TMT; MMC; mass insertion; multi-fiber connector; adapter; VSFF; density; visual inspection; end face geometry; endface; EFG; environmental performance; mechanical testing; hyperscale datacenter; AI; TIA-568-E.

1. Applications and Background

Over the last several years there has been an explosion in the deployment of data center optical ports and associated optical fiber infrastructure. The networks for Artificial Intelligence (AI) computing require many more optical fiber ports than legacy data center architectures. Traditional computing or front-end networks typically have copper connectivity from each server to a Top-Of-Rack (TOR) switch, supported by just a handful of optical uplink ports. With AI computing, in addition to front-end requirements, a back-end network has been added to the architecture [1] that drives parallel optical ports to every GPU; with multiple GPUs per server, this results in hundreds to over a thousand fibers per AI server rack. These ports then get extended into the next switching layer, driving even more optical ports and requirements for optical cabling and connectivity into today's data centers.

The introduction of Very Small Form Factor (VSFF) connectors, such as the MMC connector [1-6], has increased the port density per rack unit by a factor of three as compared to the MPO connector [2]. The reduced connector footprint is achieved by replacing the traditional MT ferrule with the TMT ferrule that is less than 40% of the volume of the legacy MT ferrule [3]. The increased density provided by MMC connectors solves the real estate problem driven by the increase in optical ports required for AI networks; however, these new AI architectures also require increased speed of deployment in order to deliver AI capacity quickly and realize the return on investment associated with AI computing.

For over 30 years, cable systems makers and installers have been using multi-fiber optical connectors for large fiber count cable assemblies that link two common locations. The traditional MPO connector and VSFF MMC connector typically terminates 8 to 32 fibers in a single connector. Aggregating the fibers into a singular connector reduces the cable system installation time because installing one connector activates 8 to 32 fibers instead of only one fiber with a single optical fiber connector, such as the industry standard LC connector.

As the number of fibers terminated in a single optical connector increases, it is more difficult to achieve low insertion loss performance across all channels, which typically limits fiber counts in a ferrule to around 32 fibers, instead of significantly higher counts. Alternatively, to achieve low IL performance, multiple ferrules could be aggregated in a single optical connector housing; however, this presents challenges during both termination and deployment due to lack of individual access. Cable assembly termination yield can be impacted if one of the ferrules within the connector housing needs to be re-worked and once deployed if there is an issue with one ferrule port all ports included in the same optical connector housing will need to be removed from the network. In order to further increase deployment speed and support large-scale fiber aggregation while maintaining low insertion loss, high yield, and operational flexibility in the field, a new method is required, leading to the development of the Mass Insertion (MI) MMC adapter solution.

2. Design Overview

A traditional MMC or MPO connector requires 10N of force to mate under standard conditions to ensure correct physical contact of all the fiber tips. It is often desired to insert as many connectors as possible simultaneously, but the insertion force requirement increases linearly with each additional connector and quickly becomes a limit to how many connectors can be installed by hand. For example, there are international standards for installing automotive connectors, with an upper limit of 45N for a connector that requires a thumb and fingertip to install a connector [7]. Similar guidance would cap simultaneous MPO or MMC installation at four connectors before 45N of force was exceeded.

The mass-insertion approach for MMC connectors using the MI adapter directly addresses this challenge by reducing the overall force required during mating. With the mechanical advantage of the levers in the MI design, in a six-port adapter the total force required to mate all six connectors simultaneously is approximately the same as mating a standard single connector in an adapter.

The mechanical advantage mechanism uses the leverage of two lever arms on the adapter body to draw in the mass-insertion carrier, as shown in Figure 1. This leverage reduces the user's required input force to about one-sixth of the combined spring force of the simultaneously installed connectors. The reduced force and direction of applied force provided by the levers also minimizes potential damage to the installed panels or housings. Connectors are typically installed by exerting force in the direction perpendicular to the thin panel/housing wall. The perpendicular force applied to the panel is virtually eliminated when using the levers to install the connectors in a mass insertion adapter.

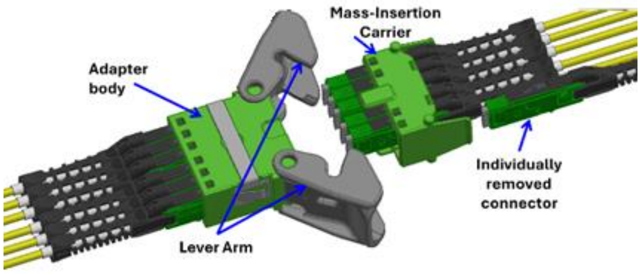

Figure 1. The mass insertion (MI) solution components, shown as a six-port adapter configuration

The two lever arms have been designed to minimize the force required to install multiple connectors, without occupying more room in the panel than necessary. The free body diagram of the force calculations for the applied forces is shown in Figure 2, as well as in equations (1) through (5).

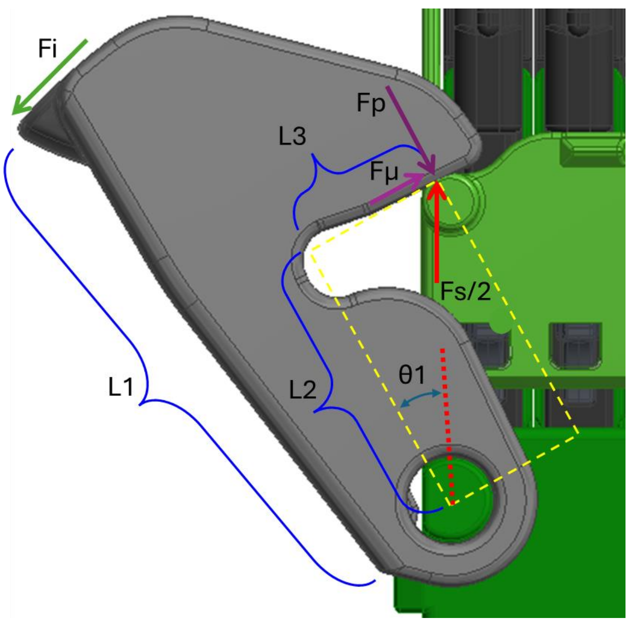

Figure 2. Free body diagram of lever arm showing the applied force and mechanical advantage

The user input force is a

$$\sum M = 0 = Fp * L3 + F\mu * L2 - Fi * L1 \quad (1)$$

$$Fs = spring\ force * number\ of\ connectors \quad (2)$$

$$Fp = \frac{Fs * \cos\theta 1}{2} \quad (3)$$

$$F\mu = Fp * \mu \quad (4)$$

$$Fi = \frac{Fp * L3 + F\mu * L2}{L1} \quad (5)$$

Where the connector spring force F_s in equation (2) acts on two lever arms, each lever experiences only half the load, or $F_s/2$. The user must overcome both the normal force applied to the carrier through the lever, F_p in equation (3), and the corresponding frictional force, F_μ equation (4). By summing the moments about the lever arm axis as shown in equation (1), the resulting user input force F_i can be determined in equation (5).

The analysis yields an approximate 6:1 mechanical advantage, meaning the user input force is one-sixth of the total spring force of all the combined connectors installed. For instance, in a six-port carrier with springs providing a combined force of 60 N, the required input force is approximately 10 N. Experimental measurements confirmed this value: the closing force for a six-port system was around 10 N. Similarly, for a four-port system with a total spring force of 40 N, the measured input force was about 7 N, aligning with the theoretical calculation.

While increasing the lever arm length would further reduce the required input force, spatial constraints limit this option. Therefore, the chosen lever design represents a compromise between user effort and system compactness.

The angle θ_1 is determined by the required connector displacement during mating. The length L_2 must be shorter than the hypotenuse, L_h, by the insertion distance necessary for proper engagement. In this MI system, the required displacement is approximately 1 mm, as illustrated in Figure (3). The figure shows that D_1 is about 1 mm greater than D_2 when the connectors are fully mated.

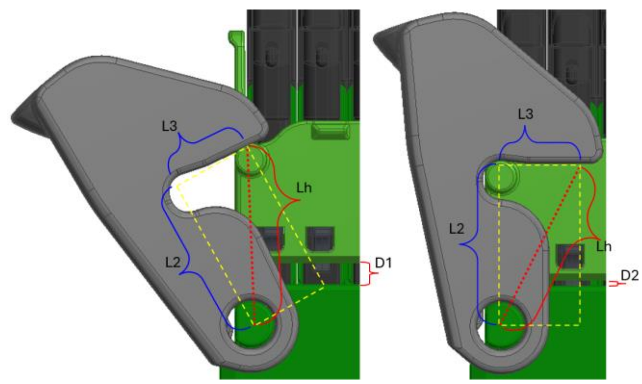

Figure 3. Travel distance of the connector from an unmated state to a fully mated state

Second, to facilitate troubleshooting after installation of large connector assemblies, the system allows individual connectors to be removed without disassembling the entire group. This modularity minimizes disruption, reduces maintenance time, and shortens downtime during diagnostics and repair. As each MMC connector is mated initially into the MI carrier, it can be individually removed using the convenient push-pull boot located behind the carrier once the entire carrier and connector have been mated into the adapter body. This design, where each individual connector can easily be removed and reinstalled, allows for simple cleaning or swapping of individual connectors once the bult installation has occurred.

3. Performance Characterization

To validate the MI adapter performance, MI adapters were populated with functional MMC connectors and were put through a battery of industry standard environmental and mechanical tests. Unless specified otherwise, all the testing below was performed using TMT ferrules installed in MMC Mini ribbon hardware configuration after being terminated with standard 16 fiber factory non-peelable ribbon. By using ribbon, cable performance was removed from the testing as a potential factor, as the connector and adapter performance were being evaluated. The non-device under test (DUT) ends of the jumpers were all terminated with traditional MPO connectors.

3.1 Endface Geometry

Two dozen MMC connectors were built using conventional multi-fiber termination and test procedures [2]. After termination and polishing [8], endface geometry was measured on all ferrules; one set of twelve ferrule measurements is shown below in Table 1 that was typical of all the results. While an IEC 61755-3-31 standard has not yet been established for TMT ferrules, it is sufficiently similar to MT ferrules in MPO connectors that similar algorithms, grading criteria, and region of interests are used [1, 9, 10].

Table 1. Endface geometry parameters for MMC

	N	Avg	Std Dev	Max	Min
Minus Coplanarity:	12	71	33.78	126	32
Ferrule Surface X Angle:	12	0.047	0.042	0.119	-0.016
Ferrule Surface Y Angle:	12	7.97	0.08	8.1	7.85
Fiber Height:	192	1836	98.68	1991	1628
Adjacent Fiber Height:	192	26	16.53	77	0
Fiber Tip Radius:	192	5.87	0.73	7.84	3.47
Ferrule Surface X-Radius:	12	-17858	42950	31218	-106735
Ferrule Surface Y-Radius:	12	170	12.94	196	151

3.2 Insertion Loss Performance

As the MI adapter allows connectors to be installed both in ganged fashion as well as individually, both techniques needed to be tested to validate insertion loss performance. Twelve MMC jumpers were built as described above, and then intermated into a standard MMC adapter to establish a baseline of 20 connector mates for a total of 320 fibers. Figure 4 shows the insertion loss distribution at both 1310 nm and 1550 nm, which passes IEC 61753-1 Grade B specs [11], with an average 1310 nm insertion loss of 0.06 dB and a 97% value of 0.21 dB.

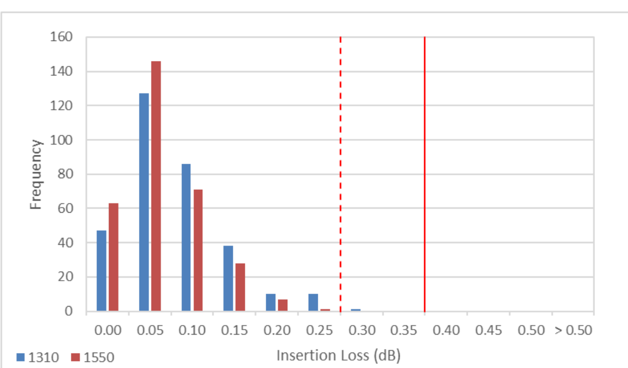

Figure 4. Insertion loss histogram of MMC connectors mated in standard MMC adapters, with IEC 61753-1 grade B performance. The vertical dashed line indicates the 0.25 dB 97% threshold, and the solid vertical line indicates the 0.35 dB value

The same connectors were then tested in MI MMC adapters in two different installation configurations. First, all the female connectors were installed in the MI adapter non-latch side, and the male connectors populated into the MI carrier. Each connector was cleaned during installation into the carrier. Using the MI latches, the carrier containing all the female connectors was installed simultaneously. Figure 5, below, shows the insertion loss histogram of the simultaneous mating of the connectors; since twelve mated pairs were used, the data contains measurements from four different adapters for 320 fiber measurements. The results of Figure 5 match the initial readings of the standard adapters in Figure 4 almost identically, both sets of data had average insertion loss performance of 0.07 dB. Simultaneously mating all the connector pairs has no impact on insertion loss performance.

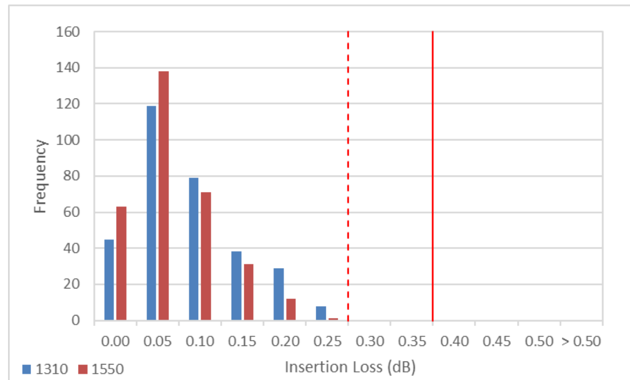

Figure 5. Insertion loss histogram of MMC connectors mated in MI adapters using the carrier and latches to mate four connectors simultaneously

Secondly, since the MI adapter allows individual connectors to be removed after the ganged mating, each female connector was then individually demated, inspected, cleaned, remated, and remeasured. As previously, the insertion loss measurements in Figure 6 mirror the initial measurements, as both ganged and individual mating of connectors provide identical performance to a standard adapter, but significantly more efficiently.

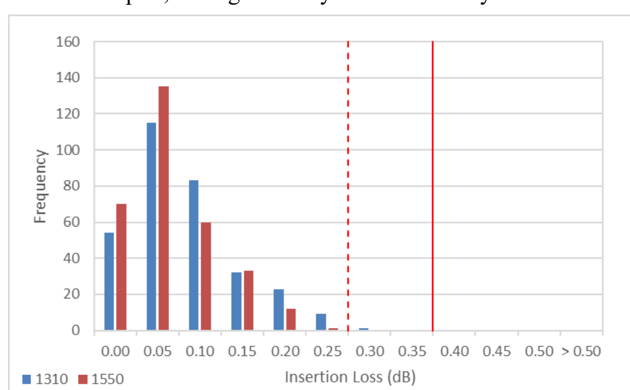

Figure 6. Insertion loss histogram of MMC connectors mated in MI adapters after individual installation in the carrier instead of ganged insertion

Since multiple MI adapters were used during the testing, results can also be examined by port in addition to the bulk histogram charts above. Figure 7 shows the data from Figure 5 separated out by port, with each line representing the average of 5 mated pairs tested in a port. The average values of each port ranged from 0.06 dB to 0.07 dB, with a total deviation of the average port performance of less than 0.015 dB.

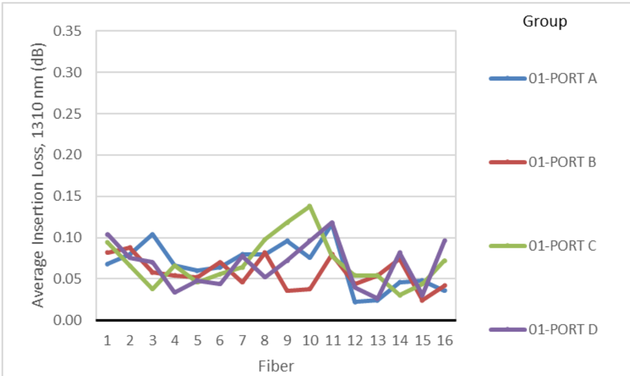

Figure 7. Average insertion loss performance plotted by each port of the four-port MI adapter

3.3 Environmental Testing

To evaluate environmental performance and stability, twelve of the jumpers from the population above were mated as pairs and put through the ANSI/TIA-568.3-E [12] environmental exposure tests shown in Table 2. All mated pairs were monitored in situ for insertion loss and return loss during testing; the change in insertion loss for each mated pair is shown in Figure 8 and then summarized in Table 2. Each pair was mated with an MI adapter in a different port, such that each port location had a live jumper pair in it during the testing (i.e., adapter 1 has mated pair in port 1, adapter 2 has mated pair in port 2, etc.). The remainder of each of the adapter ports were populated with mechanical mated pairs such that the full spring force of all connectors was present during the testing. This arrangement was done such that every port combination in the adapters was tested under worst case scenarios and a larger sample count of adapters was tested.

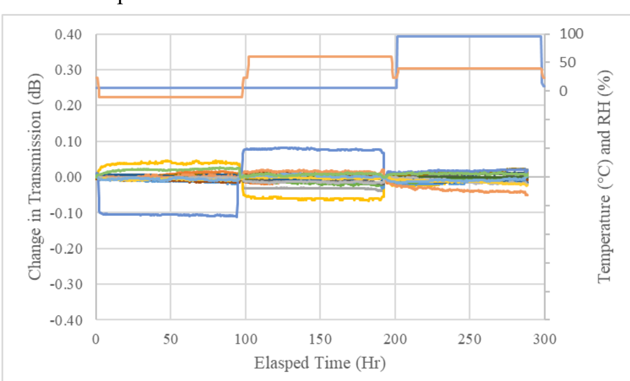

Figure 8. Change in transmission at 1310 nm through TIA-568.3-E. The upper orange and blue lines represent temperature and humidity respectively during testing

The results in Table 2 show the change in insertion loss during each test, as well and the final return loss and insertion loss after the pairs came out of the chamber. After almost ten days of environmental exposure, the average insertion loss change was only 0.01 dB when comparing the final post chamber measurements to the initial pre-chamber measurements. The in-situ measurements during exposure changed an average of 0.01 dB with the single largest swing only 0.11 dB, well under the 0.4 dB limit established by the TIA-568.3-E standard. Throughout all environmental exposure, all channels in every port maintained a return loss of 69 dB or better.

Table 2. Summary of the insertion loss results at 1310 nm through environmental testing

Test	Procedure		Δ IL in situ	RL End of Test	IL End of Test
Low Temp	-10°C 96 hours FOTP-4	Avg:	0.01	80	0.09
		Max:	0.11	80	0.24
		Min:	0.00	75	-0.04
Temp Life	60°C 96 hours FOTP-4	Avg:	0.01	80	0.10
		Max:	0.07	80	0.30
		Min:	0.00	79	-0.01
Humidity Aging	40°C 95% RH 96 hours FOTP-5	Avg:	0.01	80	0.09
		Max:	0.05	80	0.30
		Min:	0.00	80	-0.01

3.4 Mechanical Testing

Mechanical testing of the MI adapter was performed in a similar manner to the environmental test approach, using 2.5mm riser cable. Six MI adapters were populated with one live mated pair per adapter, with mechanical connectors in the remaining ports. Different port locations were populated in each adapter. All the live mated pairs in adapters were then tested to mechanical tests based around the standard cited in Table 3 in order to cover all the conventional tests required in a variety of standards.

Table 3. Mechanical tests used for testing the MI adapters with live mated pairs of jumpers

Mechanical Test / Standard	Load
Flex / TIA 568	4.9 N (1.1 lbf)
Twist / TIA 568	15 N (3.4 lbf)
Proof 0 / GR-1435	44 N (9.89 lbf)
Proof 90 Key Up & Key Right / GR-326 (SFF)	14.7 N (3.3 lbf)

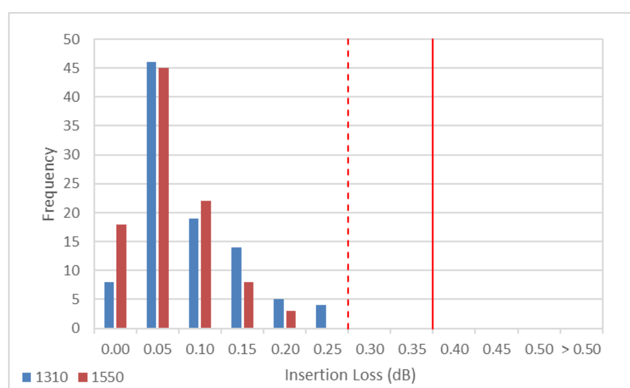

Figure 9. Insertion loss of the initial MMC jumper pairs installed in MI adapters prior to the mechanical testing

Figure 9 shows the initial insertion loss performance of the mated pairs across the six mass insertion adapters; the average insertion loss was 0.06 dB for 96 fiber measurements. Every jumper and MI pair was then subjected to every mechanical test listed in Table 3 in sequential order, and then insertion loss measured again. Figure 10 shows the results after the testing, where the insertion loss remained IEC Grade B and the average value was 0.07 dB.

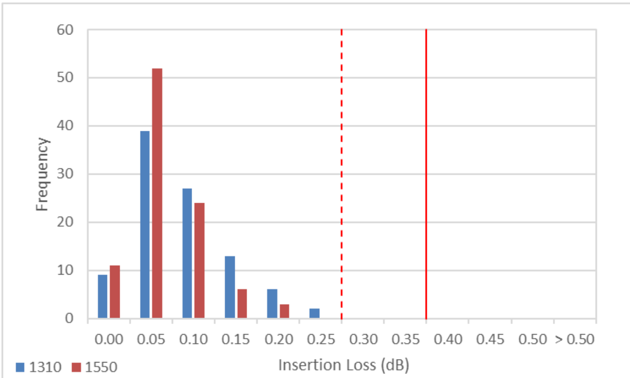

Figure 10. Insertion loss of the MMC pairs in MI adapters after flex, twist, and proof mechanical testing

In normal use, the mass insertion adapter should not experience significant multiple mates since the populated carrier is installed into the data center rank and then individual connectors are removed as needed for cleaning, inspection, etc. However, to demonstrate the MI adapter can handle multiple mates and different arrangements, testing was performed in two different configurations. Four sets of MMC connector pairs were installed into an MI adapter. The first individual connector was removed, referenced for insertion loss measurement, and reinstalled. The entire carrier was then removed and reinstalled for ten consecutive mates without cleaning or inspection. Insertion loss was then measured again at the same port. The next port was then tested identically, followed by the remaining ports. This test method means each before/after measurement has ten mates in between it, but the fourth connector pair and adapter port has a total of 40 mates. No cleaning was conducted during or after any of the matings until the end, when each connector was cleaned and remeasured. Testing was performed in this order such that if any debris was generated it would be present during the intermediate insertion loss testing and visible in the data.

The initial single connector measurements using the MI adapter are displayed in Figure 11; these are the baseline measurements of the connector and adapter performance prior to the repeated matings. After ten durability mating cycles of each set of jumpers without cleaning, the insertion loss was measured, and the results are shown in Figure 12. The average insertion loss performance after durability testing was less than 0.02 dB different from the initial measurements, demonstrating that the MI adapter system is capable of handling repeated matings without cleaning. Finally, each connector pair was cleaned individually and then remeasured through the MI adapter once more to find any change after repeated matings. The average insertion loss of 0.06 dB and histogram, shown in Figure 13, are identical to the initial histogram of Figure 11. This indicates no changes despite multiple matings of the ganged connectors.

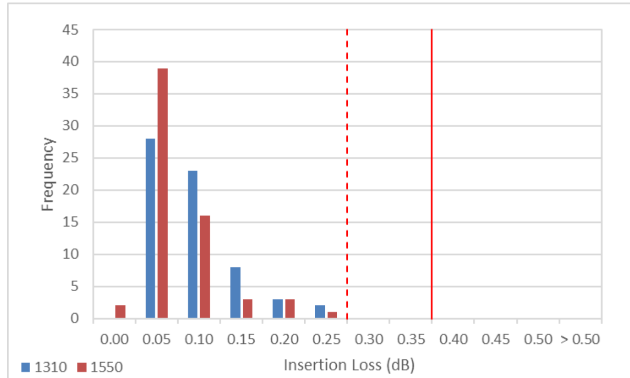

Figure 11. Initial insertion loss of the MMC pairs installed in MI adapters prior to durability testing

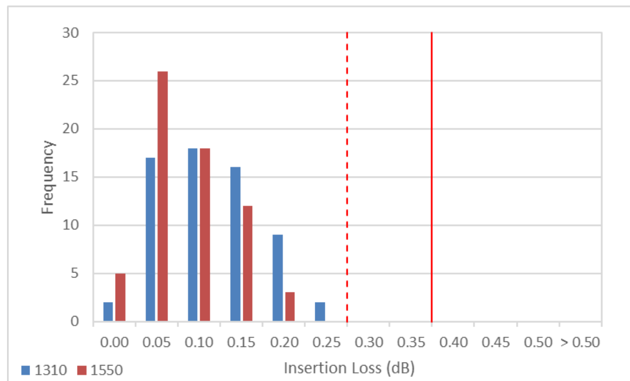

Figure 12. Insertion loss after ten carrier mass insertion mates of four connectors without any cleaning

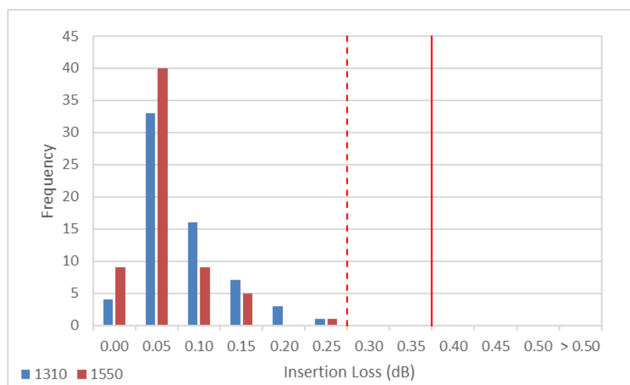

Figure 13. Final insertion loss after cleaning indicates no changes from the initial Figure 11 performance despite repeated matings without cleaning

All the previous testing was performed with MMC connectors populated in every available port. The case may occur that in some applications ports are left open for later use. Therefore, the mass insertion adapters were tested with a variety of unpopulated ports to demonstrate the stability of the MI adapter even if not all ports are used. Six mated pairs were populated in a six-port MI adapter and insertion loss was measured on all jumpers. Then the jumpers in port six were removed, the carrier remated, and all mated pairs remeasured. The testing continued with each remaining pair removed until only the single pair in port one remained, with five empty ports. Table 4 shows the average insertion loss value across all the installed jumpers; since the number of jumpers is changing, it is not expected that the average value will remain the same, but if the adapters and connectors are mating correctly, the performance should always remain acceptable. It can be seen that from the first row where all the ports are populated to the last row where only one port is populated that the MI adapter can be used in any configuration with any number of populated ports and insertion loss performance is not impacted.

Table 4. Average insertion loss performance as different numbers of adapter ports are populated

Number of Connectors	Average IL
6	0.08
5	0.05
4	0.10
3	0.12
2	0.09
1	0.09

4. Future Work

Design has already begun on future variants of the MI adapter solutions. These new designs will be able to connect up to 16 connectors at once. In order to accommodate 16 connectors, a dual row MI adapter design has been created. The dual row design minimizes the carrier width in order to eliminate any possible deflection of the carrier walls during latching with the higher forces.

5. Summary

This paper presents a novel mass insertion (MI) adapter solution for very small form factor (VSFF) connectors to aid in the speed of deployment in hyperscale and AI data centers. The design uses dual lever arms to reduce the user's insertion force to one-sixth of conventional methods while maintaining accessibility for individual connector removal and reinstallation. Insertion loss testing confirms that MI connectors perform equivalently to standard MMC adapters, with minimal impact from simultaneous mating. Mechanical and environmental testing, including repeated matings, flex, twist, and temperature/humidity exposure, demonstrate robust stability and reliability. The system supports flexible port configurations without affecting performance. Overall, the MI solution enables faster, ergonomic, and scalable installation of high-density fiber networks in modern data centers.

6. References

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7. Author Biographies

Pradeep Bembiri is a Process Engineering Manager at US Conec, Ltd. He has over 15 years of experience in plastic component manufacturing with expertise in scientific molding. He received his M.E. in Mechanical Engineering from McNeese State University and has contributed to the development of fiber optic connectors at US Conec since 2024.

Jennifer Cline is the Director of Business & Technology Development at US Conec. With nearly 25 years of experience in the fiber optic telecommunications industry, Jennifer has held roles in engineering, commercial and product management, with a predominant focus on data centers throughout her career. Jennifer holds a Bachelor of Science in Mechanical Engineering from North Carolina State University and Master of Business Administration from Purdue University.

Jeff Hendrick is a Product Manager at US Conec, Ltd. He has over 24 years of technical and commercial experience in the fiber optic industry. Jeff received a Bachelor of Science degree in Electrical Engineering from North Carolina State University.

Jason Higley is a Connector Development Manager at US Conec, Ltd. He has over 19 years of technical experience as a mechanical engineer in the fields of optomechanical systems and fiberoptic connectors. He received a B.S. in Mechanical Engineering from the University of Utah and a M.S. in Mechanical Engineering from the University of Central Florida.

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.

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.