

A High Density Optical Blind-Mate Connector System for Data Center Optical Networks

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Abstract

Continued acceleration of hyperscale and artificial intelligence (AI) data center development is driving demand for connector systems that support very small form factor (VSFF), high-density fiber connectivity. This paper presents a novel high-density optical blind-mate system built around the MMC connector platform for data center optical networks. This system targets true blind-mate applications, such as mid-board mounted modules, enabling automatic bulk insertion of multiple high fiber-count connectors while providing independent float of each connector to accommodate misalignment during mating. The design of the blind-mate system is described, along with insertion loss performance results comparing the blind-mate connections to conventional adapter connections. System stability is demonstrated through GR-1435 environmental and mechanical testing with in-situ insertion and return loss monitoring. Endface geometry was also characterized before and after testing to confirm fiber stability.

Keywords: Blind-mate connector; VSFF; MMC connector; TMT ferrule; data center; optical networks; hyperscale; AI; co-packaged optics; insertion loss; return loss; multi-fiber connector; endface geometry; GR-1435; environmental testing; mechanical testing; vibration testing; durability testing; misalignment tolerance

1. Background and Applications

Continued acceleration of hyperscale and artificial intelligence (AI) data center development is driving the need for connector systems that can support very small form factor (VSFF), high-density fiber connectivity. New multi-fiber connectors, such as the MMC connector platform built around the TMT ferrule, have been developed to significantly increase usable connector density in data center applications [1, 2, 3].

High power consumption is synonymous with data centers, especially data centers optimized for AI [4]. The added demand on the power grid is causing some municipalities to slow acceptance of new building permits for data centers. This in turn is generating renewed interest in technologies that reduce data center power consumption.

Currently, data signals in a data center network are transported on copper and optical media. Generically speaking, copper is used for short distance transmission, while optical fibers are used for longer distance transmission. Optical networks also require conversion of the optical signal to an electrical signal at both ends of the optical fiber in order for the ASICs to properly process the electrical data signals. Optical sub-assemblies (OSA) inside pluggable transceivers convert the optical signals to electrical signals at the interface of electronic hardware. The electrical signals then follow copper trace pathways on the circuit board to the ASIC. The copper trace pathways exhibit a higher signal loss than the optical fibers

per distance traveled. The higher electrical signal loss requires additional re-timers to be added to the electrical circuit. Each re-timer requires power thus adding to the overall power consumption of the circuit.

Co-packaged optics (CPO) reduces the overall power consumption by eliminating the pluggable optical transceiver and relocating the optical/electrical interface from the faceplate of the electronic hardware to inside of the electronic hardware. The new location reduces the length of the copper trace pathway between the optical/electrical interface and the ASICs, eliminating many of the electronic signal re-timers and thus reducing power consumption.

While moving the new optical/electrical interface inside of the electronics helps to reduce power consumption, the ability to connect and disconnect the optical fiber becomes more difficult. Most optical fibers are connected at a face plate by hand using a standard optical connector. When the optical fibers of CPO terminate inside of the electronics hardware, using hands to connect each optical circuit is not desired and, in some cases, not possible.

Most modular servers or switches utilize a chassis/card system that allows users to add capacity by adding cards to the system as needed in mid-board applications as well as traditional back-plane applications. Power and electrical signals are easily connected to each card using blind-mate (aka back-plane) connectors as each card is installed into the chassis. These blind-mate connectors contain features to self-align the connectors as the card is installed into the chassis. These connectors typically do not have their own latching system but use the card's latching system to hold the connectors in proper position. For the CPO application, a similarly designed blind-mate connector for optical fiber would provide simple and easy connection to the card as the cards are installed into the chassis.

With the growth of co-packaged optics and scale-up implementations in AI networks, mass installation is becoming necessary in blind-mate VSFF connector applications. Rather than mating one connector at a time, next-generation optical modules and switch trays require simultaneous bulk insertion of multiple high fiber-count connectors, while still accommodating the mechanical misalignment that inevitably occurs between trays or boards during blind mating. Meeting this need requires a system that provides independent float for each individual connector, so that misalignment in one connection does not propagate to, or degrade the performance of, its neighbors. A complementary mass-insertion approach for VSFF MMC connectors, using mechanical-advantage lever arms to reduce the manual force required to simultaneously seat multiple connectors, has also been demonstrated [5]; the blind-mate architecture presented here instead targets applications requiring true blind mating without a manual lever-actuation step.

This paper introduces a novel high-density optical blind-mate system, built around the MMC connector platform, that addresses

these requirements for data center optical networks. The system enables bulk insertion of multiple MMC connectors while providing independent float of each connector to accommodate misalignment during mating, supporting the mass-installation demands of hyperscale and AI data center architectures.

2. Design Overview

The blind-mate solution seen in Figure 1 is built around the MMC connector platform and its TMT ferrule. It is configured with the blind-mate connector as the unpinned half and a fixed connector as the pinned half, consistent with typical data center deployment. In this configuration, the fixed pinned connectors are mounted on the back-plane or panel side of the system, while the blind-mate unpinned connectors are carried on the card side or carrier such that multiple carrier sets can be installed simultaneously rather than one at a time.

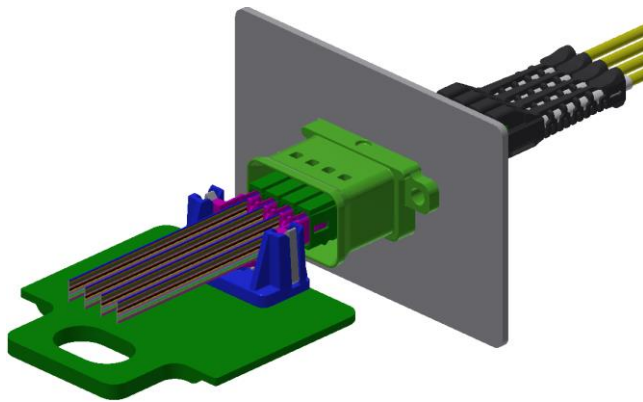


Figure 1. Isometric view of the blind-mate solution

The connector system is designed to have individual cable assemblies that include a spring-loaded connector. These assemblies are then installed onto a common spring push forming a carrier set (shown as 4 connectors with the ability to scale to other connector counts). This carrier set is then inserted into a bracket mounted to the card/tray side of the blind-mate system (see Figure 2).

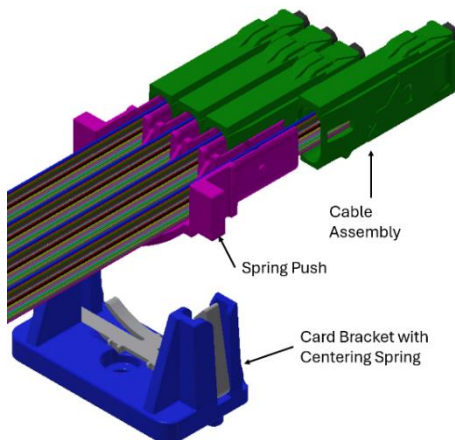


Figure 2. View of the blind-mate connector assembly

The bracket has a captive spring component that functions to retain the spring push as well as center it. The spring push has the ability to float in the X and Y directions to accommodate system misalignment during the mating of the card or tray into the system. Because the connectors are separate parts attached to the spring push rather than a unified housing, each adds a small amount of

individual float on top of the carrier-set float. The adapter in the panel or rack has a tapered lead-in that is wider than a typical adapter to allow the connector system to be captured within the allowable X and Y float and guide the carrier set into the adapter as shown in Figure 3.

Along with X and Y float, a typical card to rack connection requires a float in the Z direction as well. Unlike copper connections, which are very forgiving to the Z direction or axial position of the card, fiber optics have a relatively short mating length. To accommodate various card/tray latching systems, the spring in the connector is used to allow for an increased tolerance in that Z mating position, which results in the independent Z float of each connector. When combined with the X and Y floats of the carrier set, the blind-mate system can handle the 3 directions of misalignment, allowing ± 1 mm of misalignment in each of the X and Y planes and ± 1.25 mm along the Z axis. The Z axis allows 2.5 mm of acceptable travel, and while the nominal location is the center of the range, for the purposes of testing the rest of this paper treats $Z = 0$ as the first engagement point where the ferrules contact suitably.

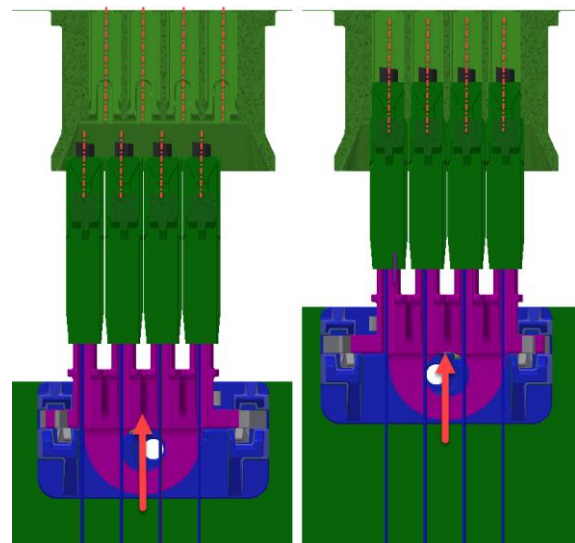


Figure 3. Cross-section view of the blind-mate solution with connector float showing how a misaligned blind-mate connector (left) floats to correct the misalignment (right) when inserted into the adapter

This architecture allows multiple high fiber-count connectors, as seen in Figure 4, to be mated in a single blind insertion event while preserving the insertion loss and return loss performance of a conventional single-port MMC connection.

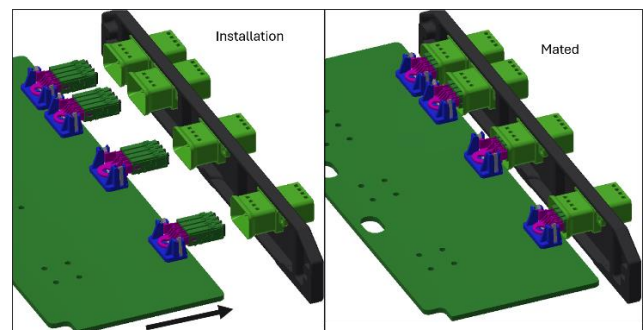


Figure 4. The left image represents the installation of multiple blind-mate systems. The right image shows the fully mated card in the system

3. Performance Characterization

Mating solutions for blind-mate systems are tested in the same traditional manner as connectors, through environmental exposure and mechanical stress testing [6] to validate the repeatability and stability of the mating. For this connector system and expected applications, the following battery of tests was performed to validate the adapter performance:

- GR-1435 [7] controlled environmental exposure with in-situ monitoring:
 - Initial insertion and return loss
 - Thermal aging (96 hrs / 60 °C)
 - Humidity aging (96 hrs / 40 °C @ 95% RH)
 - Thermal cycling (40 hrs (5 cycles) / -10 °C to 60 °C)
 - Dry-out (24 hrs / 60 °C)
 - Post-chamber insertion and return loss
- GR-1435 mechanical testing:
 - Initial insertion and return loss
 - Vibration
 - Impact
 - Durability
 - Final insertion and return loss

Other GR-1435 mechanical testing that is typically performed on connectors, such as flex, twist, and proof loading, was not applicable to the system since that tests the cable to connector retention and is independent of the blind-mate adapter. Therefore, that testing was not performed with the system, but was relied on from previous published qualifications with GR-1435 mechanical testing [8, 9].

Additional testing was performed to validate the system float during mating to ensure that the blind mating ability functioned correctly. A mechanical mating fixture that could create a known offset between the connector and adapter was used to mate connectors with controlled offsets in each axis while validating the stability and repeatability of the adapter components.

For each test sequence that follows, initial endface geometry of the TMT ferrules will be shown, followed by insertion loss performance of the connector mated pairs in the blind-mate system prior to testing. After testing is completed, the final insertion loss performance will be shown. All testing was conducted using connectors terminated with standard factory ribbon, with the blind-mate connector unpinned and the fixed connector pinned, as will typically be used in most applications.

3.1 Insertion Loss Validation

For initial validation of the system compared to traditional adapters used with MMC connectors, two dozen 16 fiber cable assemblies were built and tested to a reference assembly [10] for insertion loss measurement, through a standard single-port MMC adapter as the control for the test. The assemblies were then arbitrarily paired up and measured through the blind-mate system to compare performance and look for systematic performance differences. Figure 5 shows the insertion loss performance to the reference through a conventional adapter compared to the mated pairs through the blind-mate adapter, and Table 1 displays statistics for

both populations, which are nearly identical, demonstrating that nominal use of the blind-mate connector system induces no performance differences in the MMC connectors.

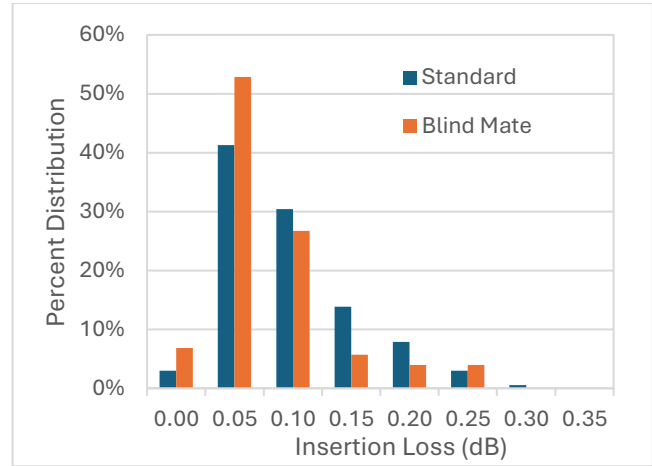


Figure 5. Insertion loss results at 1310 nm of initial blind-mate testing

Table 1. Statistics at 1310 nm of the initial jumpers using standard MMC adapters and a reference assembly compared to mated through the blind-mate adapter

	Reference	Blind-Mate
Average	0.08 dB	0.06 dB
Std Dev	0.06 dB	0.06 dB
97%	0.21 dB	0.22 dB
≤ 0.25 dB	100.0%	100.0%

3.2 Environmental Testing

A set consisting of 8 pairs of MMC 16 fiber assemblies was built for GR-1435 controlled environment testing and were terminated using standard recommended processes [11]. Endface geometry results are shown in Table 2 [12, 13].

Table 2. Endface geometry for the MMC 16 fiber assemblies prior to environmental testing

	N	Avg	Std Dev	Max	Min
Minus Coplanarity (nm)	16	104	16.66	139	78
Ferrule X-Angle (°)	16	-0.037	0.057	0.097	-0.123
Ferrule Y-Angle (°)	16	8.13	0.04	8.18	8.05
Fiber Height (nm)	256	2050	107.42	2257	1700
Adj. Fiber Height (nm)	256	31	18.05	84	0
Fiber Tip Radius (mm)	256	4.45	0.72	7.22	3.20
Ferrule X-Radius (mm)	16	9784	1674	12664	7012
Ferrule Y-Radius (mm)	16	161	9	179	148

One active assembly pair was mated into each 4-port blind-mate adapter along with 3 sets of mechanical MMC pigtails, with a total of 8 different MMC blind-mate chassis used to gather performance data. Each active assembly pair was installed on a different port such that each port was represented twice through the GR-1435 testing. Figure 6 shows the initial insertion and return loss performance prior to testing, where the average insertion loss was 0.06 dB with 97% at 0.22 dB, and a minimum return loss of 63 dB at 1310 nm.

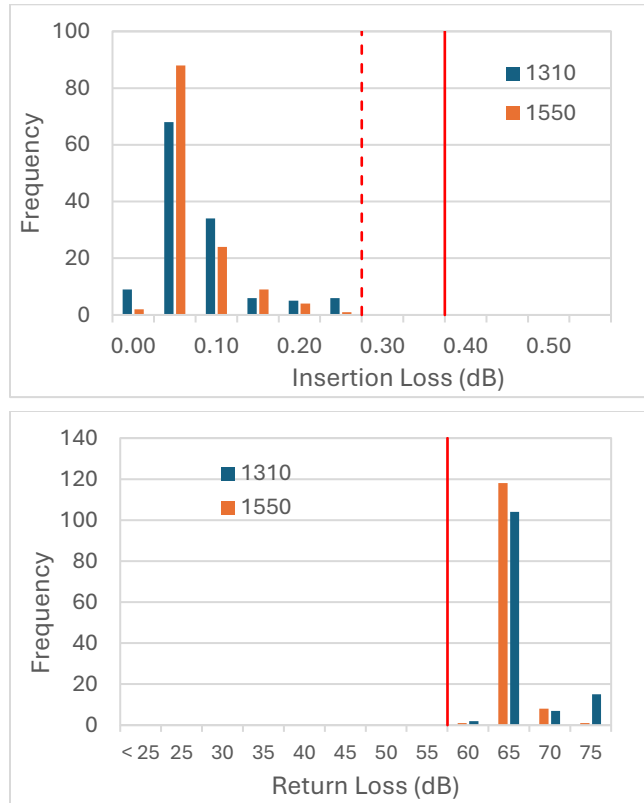


Figure 6. a) Initial insertion and b) return loss of the 8 mated pairs of MMC connectors installed in the blind-mate system prior to testing

All 8 sets of assemblies in blind-mate adapters were then tested to the entire GR-1435 controlled environmental test regime:

- Thermal aging (96 hrs / 60 °C)
- Humidity aging (96 hrs / 40 °C @ 95% RH)
- Thermal cycling (40 hrs (5 cycles) / -10 °C to 60 °C)
- Dry-out (24 hrs / 60 °C)

Figure 7 shows the change in insertion loss from initials and the measured return loss versus environmental exposure through the entire 256-hour test regime. No insertion loss channels changed by more than 0.3 dB, and the average change was 0.07 dB and return loss passed on every channel.

After removal from the chamber, all the systems were retested for final performance, which is shown in Figure 8, where all channels still passed IEC grade B insertion loss and return loss performance [14].

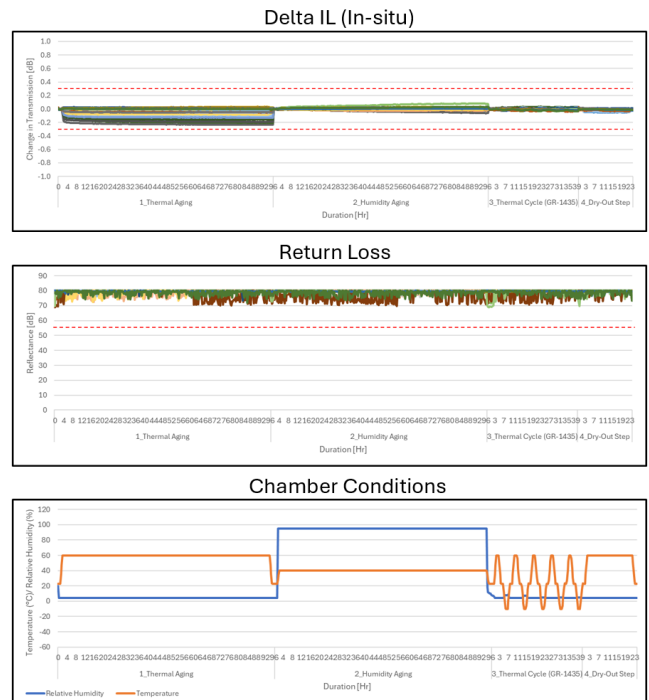


Figure 7. In-situ change in insertion and return loss of the MMC connectors through GR-1435 controlled environment

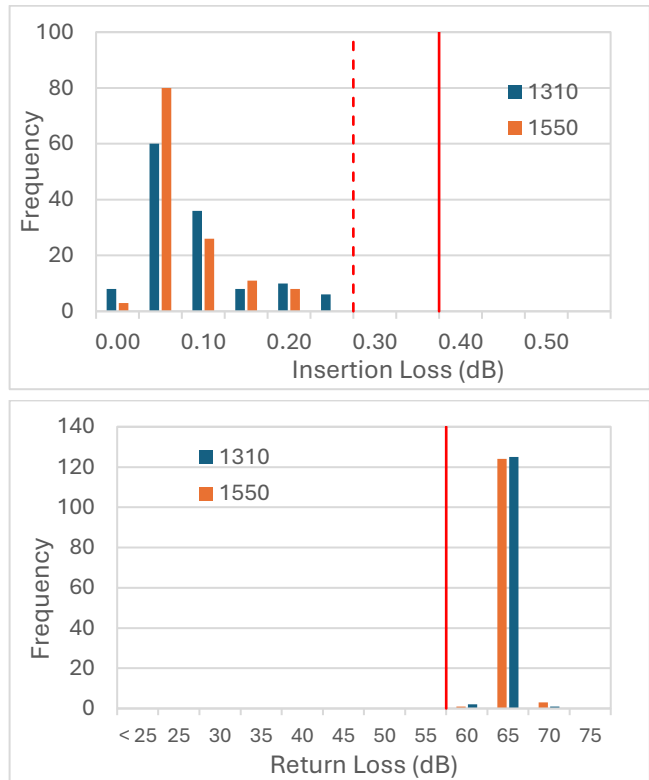


Figure 8. Post-chamber insertion and return loss of the 8 mated pairs of MMC connectors installed in the blind-mate system

Endface geometry was then remeasured on all connectors and compared to the initial post-polishing results. From Figure 9, which shows the change in fiber height data for all fibers, it can be seen there was no significant change in fiber position throughout the entire test regime.

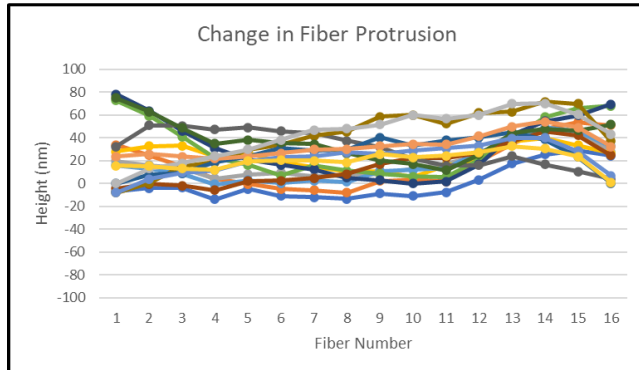


Figure 9. Change in measured fiber height of the post-chamber connectors compared to the initial post-polishing endface geometry measurements

3.3 Mechanical Testing

The MMC connector has been tested to multiple standards and has become widely adopted across the fiber optic industry [15, 16]. To gather as much data as possible, MMC connectors with 32 fiber ribbon hardware were used on the back side of the system and the new blind-mate connectors were used on the card side of the system. Twelve blind-mate adapters were populated each with one active mated pair per system with remaining ports populated with mechanical connectors. A different active port was used in each system so that all port locations had active test data. Table 3 shows the specific GR-1435 mechanical tests that were performed. These were selected as relevant to the expected data center applications for blind-mate solutions. Since the solution is installed on the mid-board of a switch or server, or in the optical back-plane, other GR-1435 tests such as flex, twist, and proof loading are neither applicable nor possible with the adapter. The base MMC connector and TMT ferrule have both passed those tests previously [8, 9].

Table 3. Mechanical tests for blind-mate system

Mechanical Test / Standard	Test
Vibration – X, Y, Z Axis / GR-1435	2 hrs 1.5 mm peak 10 Hz to 55 Hz per axis
Impact: Carrier Only / GR-1435	1.5 m drop: 8 times
Impact: Blind-Mate Connector / GR-1435	1.5 m drop: 8 times
Durability: Card Side Only / GR-1435	50 mates

Twenty-four MMC connectors were terminated and polished using standard recommended processes [11]. The initial endface geometry results are shown in Table 4, followed by Figure 10 with the initial insertion loss for the connectors in mated pair format through the blind-mate adapters. The average insertion loss was 0.09 dB for 384 fibers at 1310 nm.

Table 4. Endface geometry results for the MMC 32 fiber connectors used for mechanical testing

	N	Avg	Std Dev	Max	Min
Minus Coplanarity (nm)	24	152	32.32	200	51
Ferrule X-Angle (°)	24	-0.022	0.045	0.093	-0.087
Ferrule Y-Angle (°)	24	7.96	0.05	8.06	7.85
Fiber Height (nm)	768	2053	75.22	2217	1814
Adj. Fiber Height (nm)	768	74	47.53	255	5
Fiber Tip Radius (mm)	768	5.43	0.49	7.07	3.26
Ferrule X-Radius (mm)	24	21667	14541	67974	9431
Ferrule Y-Radius (mm)	24	260	39	322	197

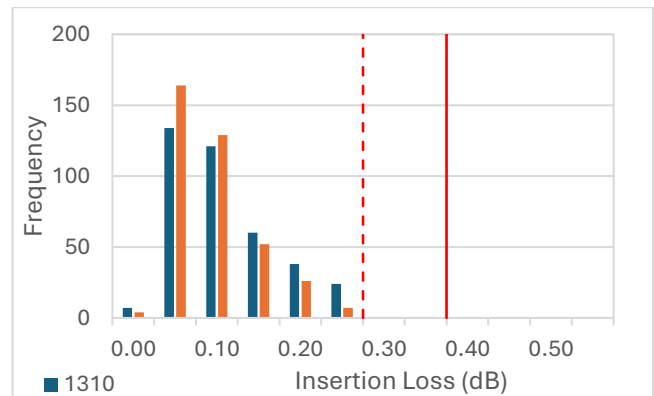


Figure 10. Insertion loss of initial blind-mate system prior to the mechanical testing

All connectors were then tested through all the mechanical tests of Table 3 in their mated state, and insertion loss was measured after each mechanical test. Figure 11, below, shows the performance after all the testing was complete. The end results showed an average insertion loss of 0.08 dB across the 384 fibers tested, with all jumpers still passing the IEC grade B specification. No connectors or fibers showed any visual damage due to any of the mechanical testing or multiple mates [17].

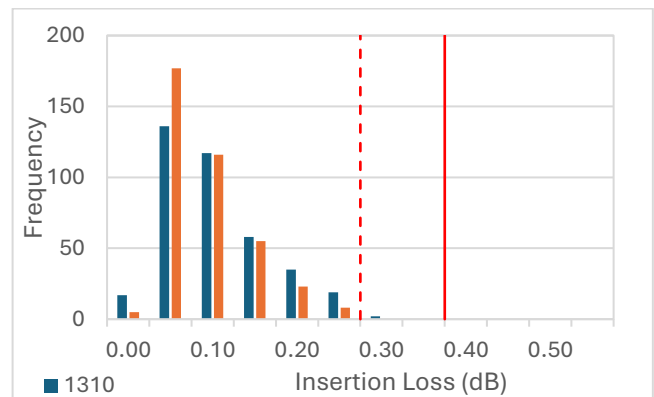


Figure 11. Insertion loss of blind-mate system after all mechanical testing

3.4 Offset Testing Fixture

A custom offset testing fixture was built to allow for loss and insertion force testing across the float design specification of the system. Horizontal and vertical adjustments could be made using stacked linear stages with the 4-port adapter mounted to the vertical stage. Figure 12, below, shows a CAD view of the fixture assembly.

The entire fixture was assembled on a coordinate measurement machine such that all components were installed at nominal positions, and the reference points for the linear stages and dial indicators calibrated during installation.

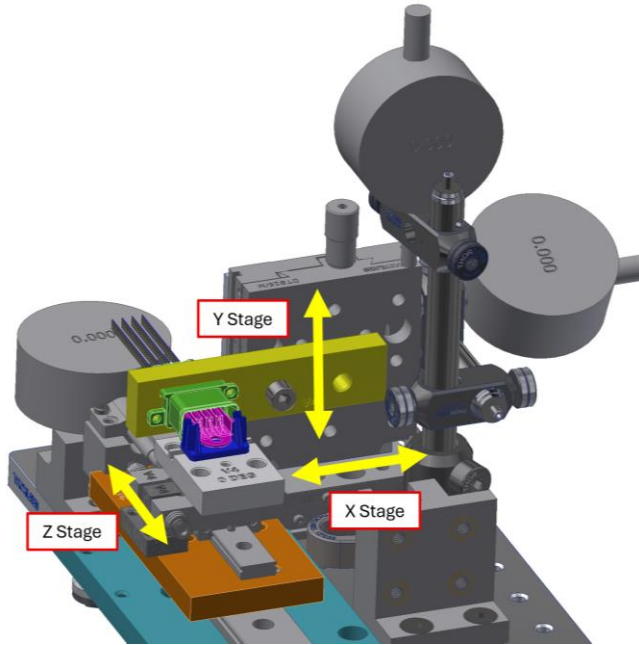


Figure 12. Offset testing fixture layout

Each system was tested across a combination of X (horizontal), Y (vertical), Z (installation depth), and Y-rotation offsets. X, Y, and Y-rotation were tested at the extremes of the design tolerances, and the installation depth was tested at three points across the design tolerance including the extremes. Table 5 shows all the orientations tested; each test began with the blind-mate connectors and adapters fully disconnected. The fixture was adjusted to the desired offsets, and the blind-mate connector was slid into the adapter to the desired Z depth.

Offset testing was performed with three different blind-mate systems using 32 fiber MMC assemblies. Eight MMC connectors were terminated and polished using standard recommended processes [11]. Endface geometry results are shown in Table 6.

Four mated pairs were tested in each of three systems through all the offset positions shown in Table 5, with insertion loss measurements at each indicated position. Figure 13 shows insertion loss results from all tests with all fibers. All the measurements, regardless of offset, passed the IEC grade B specification.

Table 5. Blind-mate connector offset positions

32 fiber Blind-Mate Offset Testing					
Test Number	Axis Settings (mm or Degrees)				
	X	Y	Z	Degree	Fixture Angle
1	0	0	0	0°	0°
2	1	0	0	0°	0°
3	0	1	0	0°	0°
4	0	-1	0	0°	0°
5	1	1	0	0°	0°
6	-1	-1	0	0°	0°
7	1	0	-1.25	0°	0°
8	0	1	-1.25	0°	0°
9	0	-1	-1.25	0°	0°
10	1	1	-1.25	0°	0°
11	-1	-1	-1.25	0°	0°
12	1	0	-2.5	0°	0°
13	0	1	-2.5	0°	0°
14	0	-1	-2.5	0°	0°
15	1	1	-2.5	0°	0°
16	-1	-1	-2.5	0°	0°
17	0	0	0	0°	90°
18	0	0	0	1°	0°
19	1	1	0	1°	0°
20	1	1	-1.25	1°	0°
21	1	1	-2.5	1°	0°
22	0	0	0	1°	0°
23	0	0	0	1°	90°
24	1	1	0	1°	90°
25	1	1	-1.25	1°	90°
26	1	1	-2.5	1°	90°
27	0	0	0	1°	90°

Table 6. Offset fixture testing initial endface geometry

	N	Avg	Std Dev	Max	Min
Minus Coplanarity (nm)	8	147	25.92	185	118
Ferrule X-Angle (°)	8	-0.030	0.025	0.012	-0.075
Ferrule Y-Angle (°)	8	7.96	0.05	8.05	7.91
Fiber Height (nm)	256	2003	72.44	2136	1813
Adj. Fiber Height (nm)	256	68	43.27	198	3
Fiber Tip Radius (mm)	256	5.51	0.46	6.72	4.42
Ferrule X-Radius (mm)	8	23642	11137	43610	13245
Ferrule Y-Radius (mm)	8	241	19	268	206

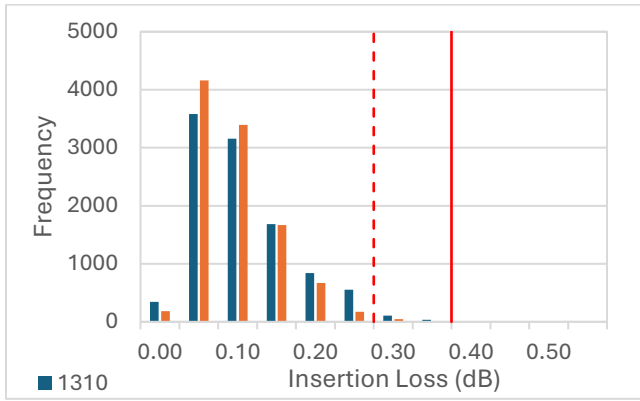


Figure 13. Insertion loss of blind-mate system across all systems and all offsets

Figure 14 shows that there were minimal changes in average loss across all three systems for all offsets. Average insertion loss across the three systems was 0.09 dB at 1310 nm.

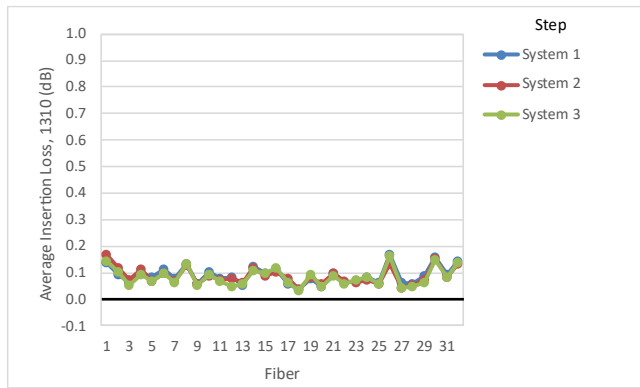


Figure 14. Average insertion loss of blind-mate system per system across all offsets

4. Future Work

While this paper has focused on 16 fiber and 32 fiber MMC connector configurations, the blind-mate adapter architecture and independent per-connector float mechanism described in Section 2 are not tied to a specific fiber count or port count. Future work will extend the system to additional port counts and connector densities to support a broader range of switches, pluggable modules, and co-packaged optics form factors.

The blind-mate system is compatible with lensed MMC connector products, such as the PRIZM-TMT, which build on the expanded beam ferrule designs demonstrated in [18, 19] to eliminate physical contact between mating fiber endfaces. Because the blind-mate system accommodates connector-to-connector misalignment mechanically through independent float, this approach extends directly to other MMC variants, including non-contact lensed interfaces, offering a path toward blind-mate solutions suited to co-packaged optics and extremely high fiber count, contamination-sensitive applications.

5. Summary

This paper presented a new high-density optical blind-mate system for data center optical networks built on the MMC connector

platform and demonstrated its performance across a full battery of applicable GR-1435 qualification testing. Initial insertion loss measurements validated that mating through the blind-mate system produced performance equivalent to a conventional single-port MMC adapter. GR-1435 controlled environmental exposure testing showed stable performance throughout thermal aging, humidity aging, thermal cycling, and dry-out, with an average insertion loss change of only 0.07 dB and no channel exceeding a 0.3 dB change, while return loss and endface geometry remained stable throughout. Vibration, impact, and durability testing likewise showed no meaningful degradation, with a final average insertion loss of 0.08 dB, all channels passing IEC grade B performance and no visible damage to any connector or fiber. Controlled offset testing further confirmed that the connector float system accommodates misalignment between the connector and adapter while maintaining stable, repeatable mated performance. Together, these results demonstrate that the blind-mate system is a robust, high-density solution suitable for mass-insertion blind-mate applications in hyperscale and AI data center optical networks.

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7. Author Biographies

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

Devin Coburn is a senior at the University of North Carolina at Charlotte pursuing a Bachelor of Science in Mechanical Engineering with a minor in Mathematics. He joined US Conec as a Research and Development engineering intern in 2025.

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

Jason Harwood received a Bachelor of Science in Mechanical Engineering from the University of North Carolina at Charlotte in 2007 and an Interdisciplinary Master of Science in Engineering from Purdue University in 2022. He has served as a Senior Metrology Engineer since joining US Conec in 2025.

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. He received a Bachelor of Science 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 fiber optic connectors. He received a Bachelor of Science in Mechanical Engineering from the University of Utah and a Master of Science in Mechanical Engineering from the University of Central Florida.

William Kettlety received a Bachelor of Science 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 a Master of Science in Electrical Engineering from The Ohio State University in 1999. He has been involved in research and development in fiber optics for 25 years. He joined US Conec Ltd. in 2007 as a Senior Development Engineer in the Research and Development Department. He is currently the Manager of Connectivity and Testing at US Conec.

Nathaniel Schwiebert is a senior undergraduate student studying Mechanical Engineering at the University of North Carolina at Charlotte. He has worked at US Conec for the past two summers as an R&D engineering intern.