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White Paper

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The Importance of Low Loss MPO and SN-MT Connectivity in Today's and Future Networks

OCTOBER 2023
Rev. 01

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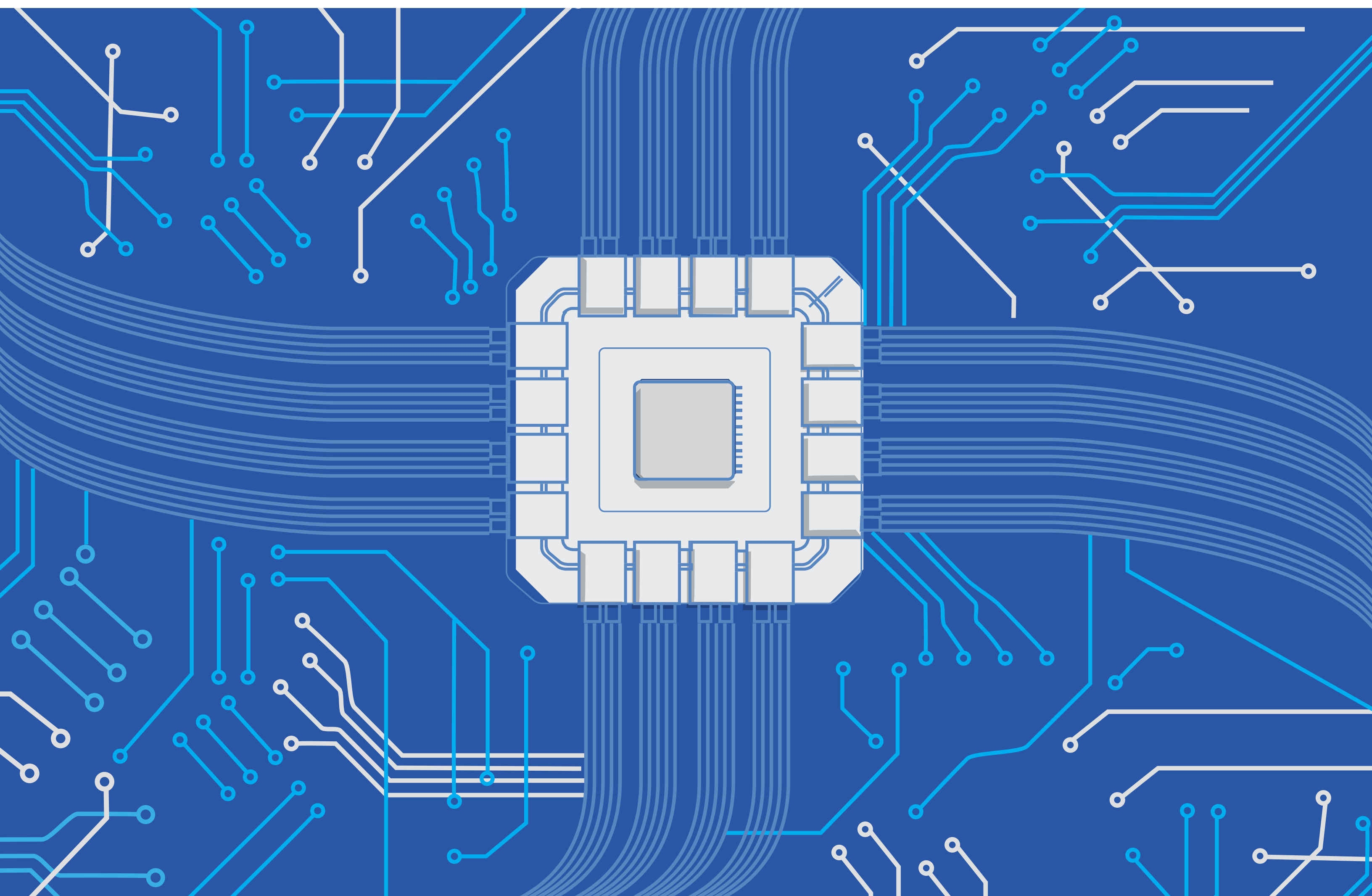

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1.1 Parallel Optics Development

Definition of Parallel Optics

In the late 1980s, Nippon Telegraph and Telephone Corp. (NTT) invented a physical contact connection technology that significantly improved the performance and reliability of fiber optic connectors. These connectors were named Single Fiber Coupling (SC) and Multifiber Push-On (MPO). The compact size and easy push-pull installation were major advantages of both connectors. The SC connector accommodates a single fiber, while the MPO connector can terminate up to 72 fibers simultaneously. Since the early 1990s, MPO connectors have been widely adopted by carriers and data centers. This technology revolutionized global digital communication systems by simplifying interconnect routing. The ability to bundle multiple fibers onto a single connector is the greatest advantage of MPO connectors. In high-density scenarios, MPO connectors save space compared to duplex connectors or other alternatives.

Thus, parallel optics was born as the demand for data increased, leading to a migration from duplex transceivers and interconnects to multi-fiber transceivers with MPO interfaces. Parallel optics with MT ferrule-based connectors refers to a technology that utilizes multiple optical fibers in parallel to transmit data simultaneously. The MPO connector became the connector of choice for parallel optic systems.

Key Features of Parallel Optics Include:

Parallel Transmission	Unlike traditional serial transmission, where a single high-speed signal is transmitted over a single fiber, parallel optics utilize multiple fibers (or multiple lanes within a fiber) to transmit data in parallel. This allows for increased data throughoput.
High Data Rates	Parallel optics is used to achieve very high data rates, such as 100 Gbps, 400 Gbps, or even higher. By splitting the data into multiple channels, each operating at a lower data rate, the overall system can achieve higher aggregate bandwidth.
Multi-Channel Transceivers	Parallel optics requires specialized multi-channel transceivers that include multiple laser diodes for transmitting and multiple photodetectors for receiving. These transceivers are often referred to as "parallel optics modules."
MPO Connectors	To facilitate the connection of multiple fibers between transceivers, parallel optics often use MPO or multi-fiber termination push-on (MTP) connectors. These connectors allow for efficient coupling of multiple fibers, enabling parallel transmission.
Data Center Applications	Parallel optics is particularly well-suited for data center applications, where high-speed and high-capacity connections between servers, switches, and other networking equipment are crucial.

It's worth noting that parallel optics technology is just one approach to achieving high data rates over optical fibers. Another approach is using wavelength division multiplexing (WDM), where multiple data streams are transmitted using different wavelengths of light over a single fiber. The choice between parallel optics and WDM depends on factors such as system architecture, distance requirements, cost considerations, and compatibility with existing infrastructure.

1.2 Advancements in Optical Transceiver Technology and Optical Connectors

An optical transceiver is a vital hardware component responsible for transmitting and receiving data. Since their initial development, optical transceivers have come in various forms, evolving over time. To ensure seamless integration with network equipment and transceivers from different vendors, industry standards have been established to govern all functionalities and characteristics of optical transceivers. Numerous organizations have been actively working on achieving transceiver interoperability. Leading the charge are the Institute of Electrical and Electronics Engineers (IEEE) and Multi-Source Agreements (MSAs), who define a significant portion of the standards for optical transceivers. Over the past 25 years, the market has witnessed the introduction of diverse optical transceiver types, as depicted in Figure 1. These innovations have revolutionized data transmission and reception, making optical transceivers indispensable components in modern networks.

GBIC

In 1995, the Small Form Factor Committee introduced **GBIC** *(Gigabit Interface Converter)*, the first flexible hot-swappable transceiver standard, later revised in 2000.

1995

SFP

SFP *(Small Form-factor Pluggable)* transceivers emerged in 2000, offering the same functionality in a smaller form. LC Duplex and MT-RJ connectors were commonly used.

2000

XFP

XFP *(X Form-factor Pluggable)* was developed in 2002 and adopted in 2003, providing 10G modules denoted by the Roman numeral "X".

2002

SFP+

SFP+ *(Enhanced Small Form-factor Pluggable)* was launched in 2006, delivering higher data rates up to 10 Gbps and supporting various connectors.

2006

QSFP+ and CFP2

In 2012, Enhanced **QSFP+** and **CFP2** were introduced, offering higher performance and density with data rates ranging from 100Gbps to 200Gbps.

2012

QSFP28

QSFP28, based on the same technology as QSFP+, became the standard for 100G applications in 2014, offering configurations from 100m to 80km.

2014

QSFP56

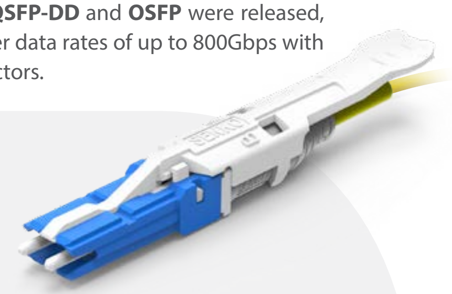
QSFP56 was standardized in 2019, doubling the data rate of QSFP28 to 200Gbps, using parallel fibers or PAM4 modulation.

2019

QSFP-DD and OSFP

Also in 2019, **QSFP-DD** and **OSFP** were released, enabling higher data rates of up to 800Gbps with new CS connectors.

2019



Summary of The Evolution of Optical Transceivers

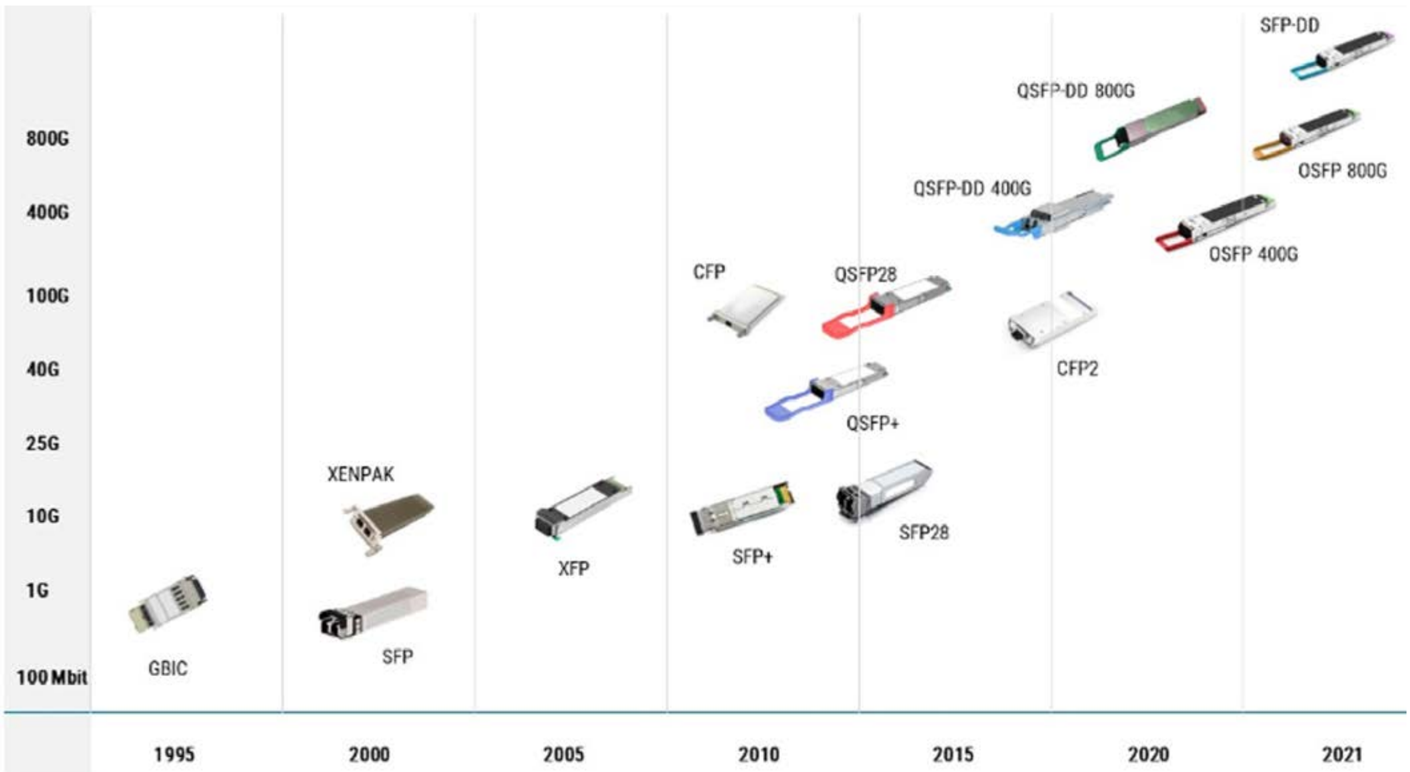


Figure 1 *Optical transceivers development time line.*

The latest standard, SFP-DD, allows data centers to double port density and increase data rates by utilizing OM3 and OM4 optical fibers.

With the evolution from duplex to parallel optics, transceivers now offer higher data rates and increased connectivity density, reducing costs and enabling fast network upgrades.

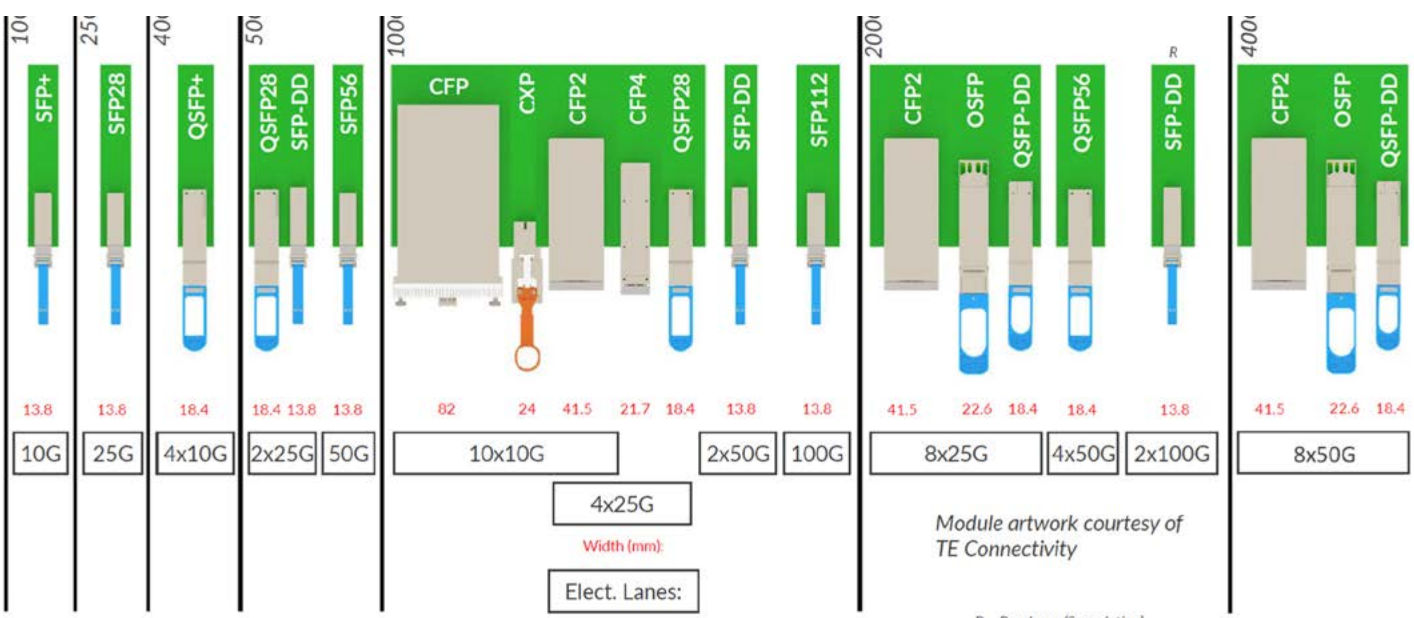


Figure 2 *Transceiver types for parallel optics. Reference: Jeff Maki, Juniper. (2020).*

What Are the Driving Factors For 400G Development?

The driving factors for 400G development are video streaming services and video conferencing services. These services require high data transfer speeds to function smoothly across the globe. A look at the stats reveals that a medium-quality stream on Netflix consumes 0.8GB per hour. See that in relation to over 21 million subscribers. As the traveling costs came down, the savings went to improved quality streams on Netflix like HD and 4K. What stood at 0.8GB per hour rose to 3 and 7GB per hour. This evolved the need for 400G development. Another example is a trend after COVID of working from home. The Bureau of Labor Statistics found that around 27% of the U.S. workforce was working remotely at least part time as of August and September 2022, while a handful of academic surveys have suggested that the number is closer to 50%. As video conferencing took center stage, Zoom, which consumes 0.5GB per hour, saw a huge increase in its user base.

The data transfer that keeps up with bandwidth demand occurs in Hyperscale Data Centers. Hyperscale data centers are large-scale facilities specifically designed to handle massive amounts of data and computational workloads. These data centers are capable of providing high levels of performance, scalability, and reliability to meet the needs of modern internet-based services and applications. The most advanced data centers are moving toward 400G with an eye to 1.6TB of data processing rates. To put it simply, 400G raises the data transfer speed four times over typical 100G. 400G reduces the cost of 100G ports as breakouts when comparing a 4 x 100G solution to facilitate 400GbE with a single 400G solution to do the same. A single node at the output minimizes the risk of failures as well as lower the energy requirement. This brings down operational cost while maintains same redundancy capabilities and more flexible scalability.

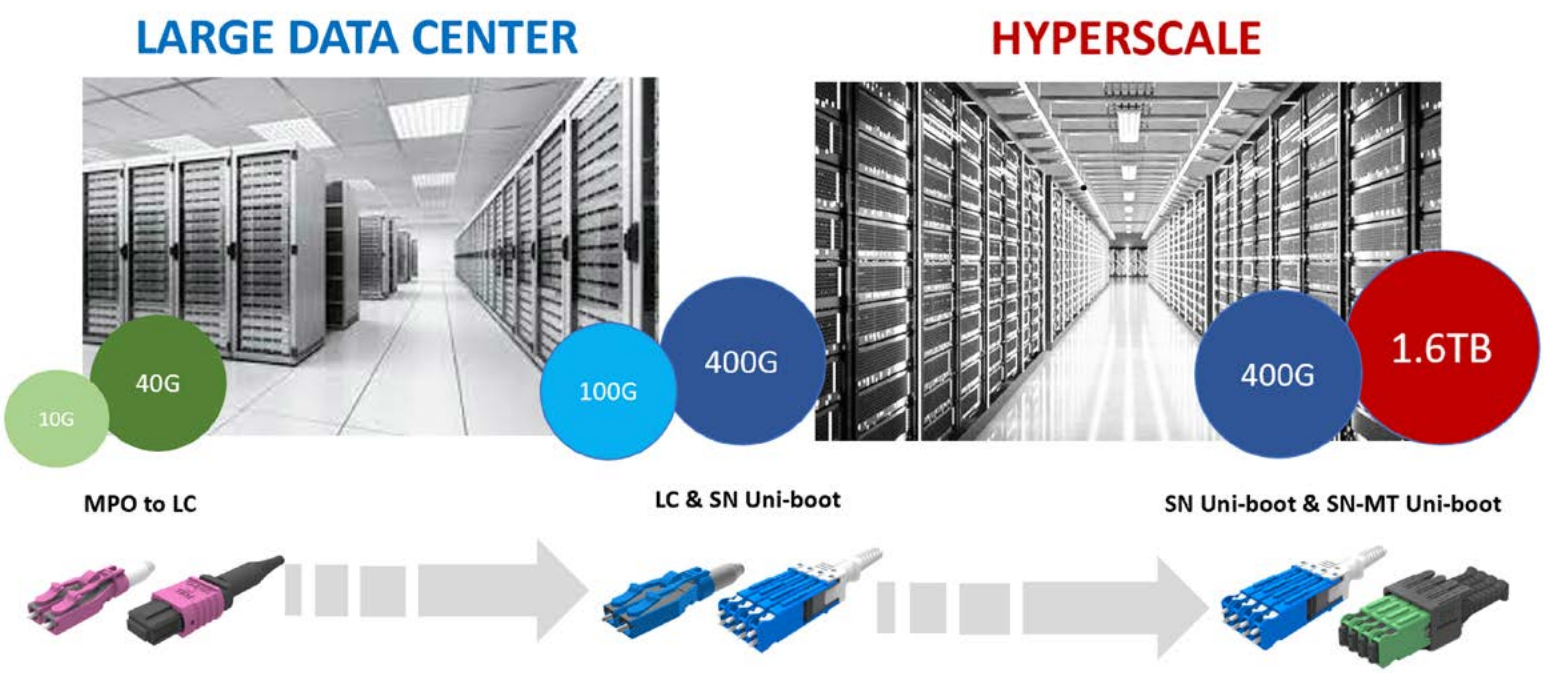


Figure 3 *From Data Center to Hyperscale migration.*

Naturally the optical connector footprint to accommodate all the above requirements should be smaller with and have as many fibers as possible. Duplex SC connectors were replaced by duplex LC connectors in the late nineties. LC connectors feature a 1.25mm ferrule, which is half the size of the 2.5mm ferrules used in SC connectors. LC connectors became known as Small Form Factor (SFP) interconnects. Today, as the migration to Hyperscale Data Centers continues, a new generation of interconnects has been developed, called Very Small Form Factor (VSFF) connectors. These connectors are known as CS and SN connectors. Both connectors feature 1.25mm ferrules, but the pitch between the ferrules is reduced to accommodate more space in the same rack unit area compared to LC or MPO interconnections. Similarly, the MPO footprint is also being reduced in size, opening the way for new SN-MT interconnections. A 1RU patch panel can house a maximum of 80 MPO adapters, which represents 2,560 fibers when using 32-fiber MPO connectors. In comparison, a 1RU patch panel can also house 216 SN-MT adapters, which represents 3,456 fibers when using 16F SN-MT connectors. This is a 25% increase in fiber count in just 1RU.

What Are the Driving Factors For 400G Development?

In Hyperscale network architecture, the leaf-spine cross-connection represents a specific design approach utilized to establish an exceedingly scalable and efficient network fabric. The leaf-spine topology embodies a distinct network design aimed at preventing the constraints inherent in conventional hierarchical network architectures. Within this framework, devices (such as servers, switches, and routers) are segregated into two primary tiers: leaf switches and spine switches. Leaf switches serve as the direct connectors to end devices, including servers and other network peripherals. Typically, each leaf switch maintains connections to every spine switch. Spine switches, in contrast, serve as conduits for high-speed, non-blocking interconnectivity among leaf switches. These spine switches facilitate seamless communication between any given leaf switch and any other leaf switch, all while minimizing the number of intermediary hops.

In this particular network design approach, the connection between leaf switches and spine switches is orchestrated to furnish elevated bandwidth and curtail network latency. For scenarios involving a high channel count, the SN-MT connector emerges as the most optimal choice for optical interconnect.

Today, SN-MT is considered the connector with the highest density in the industry.

The benefits of SN-MT are:

- Up to 16-fibers in a single row
- Same connector footprint as SN connector
- 2.7x denser than MPO-16F
- 1.3x denser than MPO-32F
- Low insertion loss across all channels
  – maximum 0.35dB max (IEC Grade B)

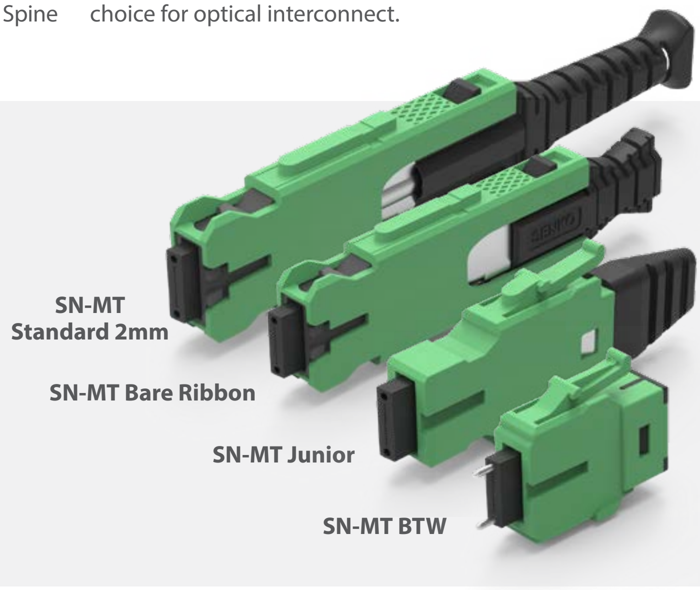


Figure 4 *SN-MT designs.*

What other factors should be considered? The innovation in fiber and specifically fiber ribbon design. The standard 250µm pitch used in multi-fiber ferrules with 125µm cladding diameter optical fiber is physically too large to support the quantity of optical lanes that will be coupled inside the coming switching platforms. That's why SN-MT has a next generation MT-style ferrule designed for smaller acrylate coating fiber ribbons on a pitch of 200µm. By decreasing the pitch from 250µm to 200µm, up to 50% rack unit (RU) space can be saved. *See figure 5.*

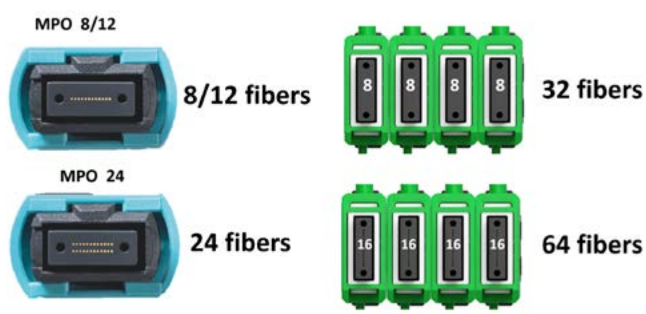


Figure 5 *Footprint comparison to scale between MPO and SN-MT fiber count.*

What Are the Driving Factors For 400G Development?

This tighter pitch enables higher fiber densities coupled directly to or in Tx/Rx lines. The new MT ferrule also needs to be "new and improved" over standard MT ferrules in terms of optical loss and reliability and we discuss it further in Chapter 2.

6a

Connector type	LC	CS	SN	MPO-12	MPO-16	MPO-24	MPO-32	SN-MT
Fiber count/connector	2	2	2	12	16	24	32	16
Fiber count/19 inch 1RU panel	144	336	528	960	1280	1920	2560	3456

6b *16F in one row*

6c

Figure 6 *VSFF Connectors with MT Ferrules are enabling unprecedented fiber density: a) graph depicting different fiber counts on a 1 RU panel for different optical connector types, b) SN-MT connector with 16F per row, c) MPO and SN-MT connector comparison.*

1.2 Onboard Optics, Backplane MT Based Connection and BTW

Another trend that necessitates smaller and more reliable MT ferrules is On-Board Optics (OBO). The fibers are being brought closer to the optical chip. Achieving the transmission of data by light to the point where it is processed stands as one of the ultimate goals of optical networks. Progress in implementing optics into electronics is indicating a trend of minimizing the distance between the optical and electrical components on the active PCB. There is a drive to bring the optical connector to the same level as the location of the Tx/Rx chip and create a unified component.

Currently, the standard solution is based on pluggable modules in the form of backplane connections or BTW (Behind the Wall). However, this solution has several disadvantages, including larger dimensions and high energy consumption and cooling requirements. The second generation of solutions involves OBO modules, where the opto-electrical converter is already integrated at the PCB level but remains a separate part. The fully implemented optical part, known as the co-packaged solution, will be covered by the 3rd generation, which is still under final development. In all cases, the power requirements for cooling are significantly reduced.

Presently, companies like Cudoform, Ranovus, and many others are actively working on developing solutions in this field.

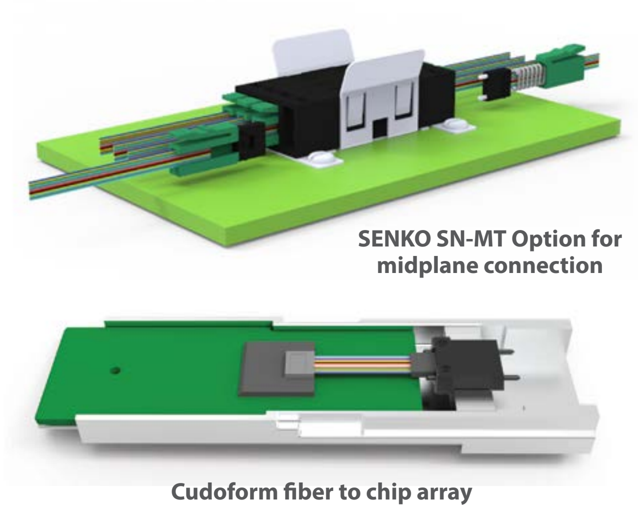


Figure 7 *Midplane and onboard optics with SENKO MT ferrule.*

The primary option for coupling fiber to the chip involves using standard MT ferrules, but the superior option is a smaller and denser SN-MT ferrule. The MT approach relies on the physical contact principle, whereas the fiber alignment from a chip can utilize a focal lens principle.

Moving the fiber to the chip significantly reduces energy consumption for cooling (*see Figure 8*). By directly integrating the function of transceivers onto a substrate with the IC switch, there is no need for electrical signal travel over the PCB. Consequently, this eliminates heat generation resulting from optical-to-electrical conversion, which is performed immediately without the need for wiring transceiver.

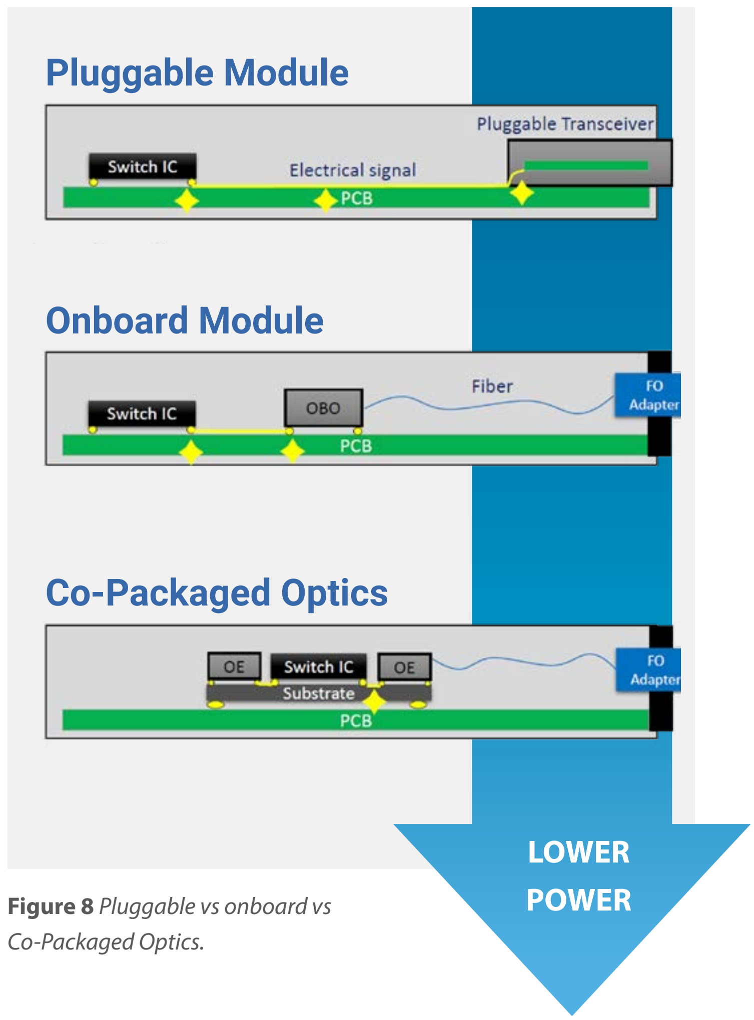


Figure 8 *Pluggable vs onboard vs Co-Packaged Optics.*

2.0 Link Budgets With MPO

2.1 Low Loss Requirements

The optical link budget for MPO transceivers can vary depending on the specific application, data rate, and distance of the link. The link budget is a calculation that takes into account various parameters such as transmitter power, receiver sensitivity, fiber attenuation and connector losses to ensure that the received optical power is sufficient for error-free data transmission. For example, in a typical 40 Gigabit Ethernet application over OM3 or OM4 multimode fiber, the link budget for MPO transceivers might be around 3 to 4 dB. This means that the overall optical loss in the system should not exceed 2 to 3dB in order for received optical power at the receiver be at guaranteed sensitivity level to account for losses in the fiber link. For longer-distance applications, such as 100 Gigabit Ethernet over OM4 multimode fiber or single-mode fiber links, the link budget for MPO transceivers could be slightly higher depending on the specific requirements.

It's important to note that the link budget also considers factors such as system margin, temperature variations, and other potential losses in the link. However, the biggest contributing factor is connector loss. Guaranteed low connector loss ensures reliable and error-free data transmission in optical communication systems. The actual link budget should be determined based on the specific connector loss and the environmental conditions to which the connectors are exposed.

2.2 Random Mating Loss and SN-MT Interconnect

As mentioned earlier, MT-based connectors are the future for Hyperscale Data Centers. The optical loss of any fiber optic connector is highly dependent on the lateral misalignment. The higher the misalignment, the more mismatch will be observed between the fiber cores. The relationship between the fiber core misalignment and optical loss is calculated.

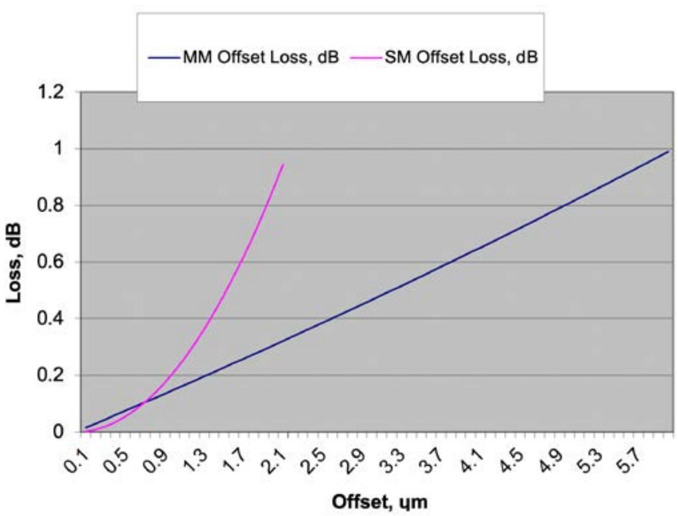


Figure 9 *MM and SM laterlal offset graphs.*

$$Loss,\ dB = -10 \log \left[1 - \frac{8x}{3\pi r} \right]$$

r = fiber radius   x = offset amount

Figure 10 *Theoretical calculation formula for laterla offset cores misalignment.*

Random Mating Loss and SN-MT Interconnect

The tolerance of the MT ferrule's guide pin and fiber holes holds great significance. SENKO offers two types of ferrules in their MPO kits: Standard and Super Low Loss. The primary differences between these two lie in the tolerances for individual fiber holes [1] and guide pin holes [2]. See figure 11. Notably, the Low Loss grade adheres to much stricter tolerances.

In MPO connectors with MT ferrules, the misalignment of fiber cores along the axis stands as the main contributor to connection loss. Theoretical calculations suggest that to achieve a target connection loss of, for example, ≤ 0.5 dB, the total misalignment of fiber cores must be ≤ 1.6µm, with an allowable stackable tolerance for fiber positions and guide pins of ≤ 0.8µm per ferrule. Based on the tolerance analysis results, the practically permissible axis misalignment that meets the target loss of ≤ 0.5dB has been set at ≤ 0.9µm per ferrule.

In the past, manufacturing techniques for MT Ferrules and the sizes of fiber ODs were limited by available materials and molding technology. Consequently, the tolerances were not as tight as they are today, which presented challenges in achieving low optical losses. However, advancements in technology have significantly improved the tolerances between the fiber ODs and the MT ferrule IDs.

These tighter tolerances now allow for successful termination, with insertion losses expected to be below 0.35dB per channel in random mating scenario, regardless of the number of channels. To achieve this, it is crucial to ensure that the ferrule axis misalignment between the fibers is ≤ 1.40µm, in addition to employing proper termination and polishing techniques. Specifically, for individual Low Loss MT ferrules, the overall fiber misalignment should be ≤ 0.70µm.

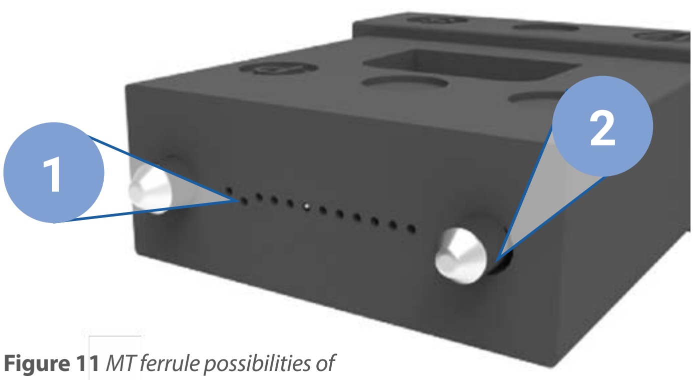


Figure 11 *MT ferrule possibilities of lateral misalignments between fibers.*

Random Mating Loss and SN-MT Interconnect

SENKO believes that the criteria for Insertion Loss (IL) should be based on random mating, as described in the document IEC 61753-1 titled "Attenuation of Random Mated Connectors." This document defines a minimum number of channels below the allowable maximum IL value in percentage (97%) for randomly mated connectors in a field setting and categorizes them into four different grades: A, B, C and D. It is important to note that the IEC 61753-1 categorizes connection performance grades for single-mode and multimode jumpers in a controlled environment and for ceramic ferrules only at the time of publishing this work.

The standard provides four grades for IL, ranging from A (best) to D (worst), as well as grades for Return Loss (RL), ranging from 1 (best) to 4 (worst). Although Grade "A" is not officially ratified by the IEC document, it is likely to have similar optical performance, as reflected in Table 1 below.

Table 1 *IEC 61753-1 proposed ceramic ferrule grades.*

Attenuation Grade	Attenuation Random Mated IEC 61300-3-34	
Grade A*	≤ 0.07 dB mean	≤ 0.15 dB maximum for >97% of samples
Grade B	≤ 0.12 dB mean	≤ 0.25 dB maximum for >97% of samples
Grade C	≤ 0.25 dB mean	≤ 0.50 dB maximum for >97% of samples
Grade D	≤ 0.50 dB mean	≤ 1.00 dB maximum for >97% of samples

Return Loss Grade	Return Loss Random Mated IEC 61300-3-6
Grade 1	≥ 60 dB (ated) and ≥ 55 dB (unmated)
Grade 2	≥ 45 dB
Grade 3	≥ 35 dB
Grade 4	≥ 26 dB

Specification	Each-to Each Values	Budget for 10 Connections
0.1 dB Connector	approx. 0.2 dB *(possibly higher if different manufacturers are combined or unadjusted connectors are used)*	approx. 2 dB, unclear range of tolerance
Grade C	Mean ≤ 0.25 dB, Max ≤ 0.50 dB	≤ 0.25 dB
Grade B	Mean ≤ 0.12 dB, Max ≤ 0.25 dB	≤ 1.2 dB
Grade A*	Mean ≤ 0.07 dB, Max ≤ 0.12 dB	≤ 0.70 dB

* *Note: Grade A is not specified at time of writing, but is assumed to be as shown*

Random Mating Loss and SN-MT Interconnect

It is important to note that the IEC 61753-1 document was developed specifically for ceramic ferrules and not for MPO connectors. However, we believe that its principles can be applicable to MPO testing. MPO connectors typically have a minimum fiber count of 12. When a connector manufacturer states that the MPO connector's maximum loss is, for example, 0.5dB, it is more practical to consider the mean result among the same interconnect with an allowable double value from 0.5dB, which would be 1.00dB in a few channels. This approach allows for greater production efficiency, as it accounts for the possibility of a few channels slightly exceeding 0.5dB while remaining below 0.5x2=1.00dB in over 97% of the readings. By using this method, it offers a more practical approach while considering the production efficiency and the fact that in real-world scenarios, with today's transceivers' dynamic ranges, it is more likely that such a tested MPO connector will perform reliably.

Below is another example of the random mating study. Let's assume that MPO Grade B specifies a maximum loss per channel of 0.35dB, while Grade C specifies a maximum loss of 0.50dB. In Grade B, a few channels exceeded the maximum stated loss of 0.35dB, but over 97% of the channels measured were under 0.35dB, with the mean value below 0.35dB.

Table 2 *Example of compilation of Random Mating data.*

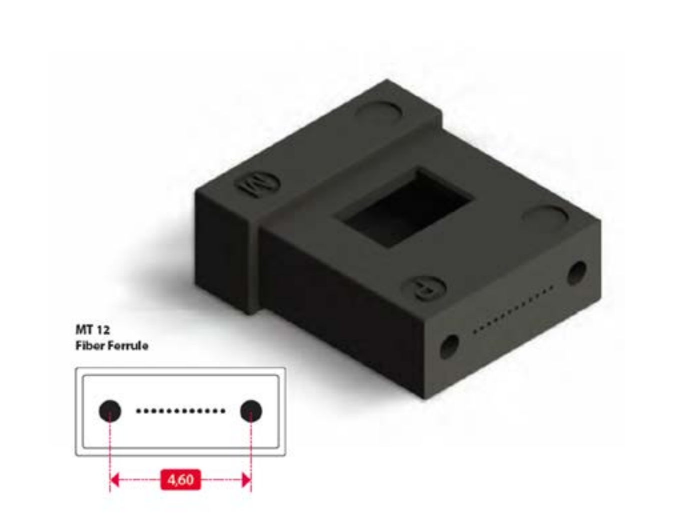
Grade	IL (dB)				Result
	Pass Rate		**Mean**		
	1310 nm	1550 nm	1310 nm	1550 nm	
Grade B Mean ≤ 0.35 DB Minimum 95% < 0.35 dB	98.06%	97.08%	0.15	0.11	**PASS**
Grade C Mean ≤ 0.50 DB Minimum 95% < 0.50 dB	100.00%	100.00%	0.15	0.11	**PASS**

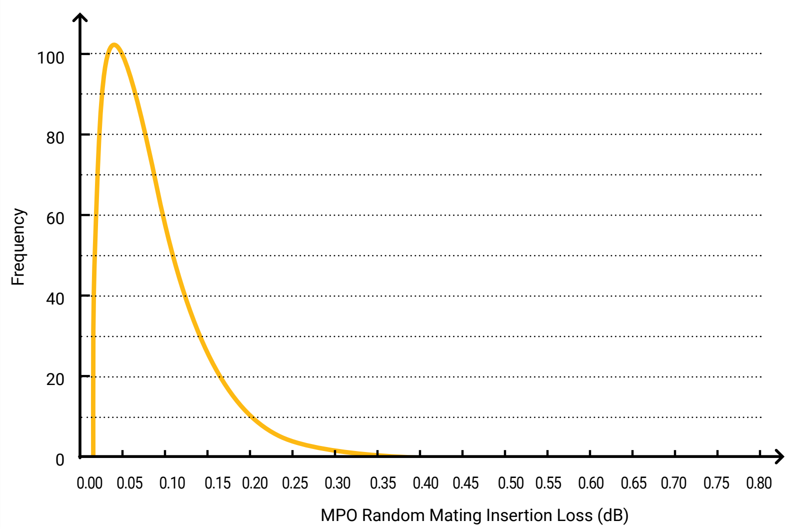
Random Mating Loss and SN-MT Interconnect

At SENKO, we are conducting a study to evaluate the optical loss performance of connectors in a randomly mated scenario, simulating real-world field performance per the IEC 61753-1 document. The most common and statistically meaningful approach for this study is typically carried out in a 10x10 configuration.

In a 10x10 configuration, multiple sets of 10 MPO connectors are randomly mated with each other one at a time, resulting in over 100 different combinations. The purpose of this study is to assess the performance and reliability of optical connections when subjected to random mating. Additionally, it aims to understand the impact of different connector types on insertion loss in such scenarios. As mentioned earlier, MT-based connectors come in various varieties and fiber counts. They can be categorized as SM Low Loss, SM Standard, MM Low Loss, and MM Standard. The studies were conducted with all categories of SENKO MT ferrules.

Below are the results from the study performed at SENKO for the 12F MPO connector:



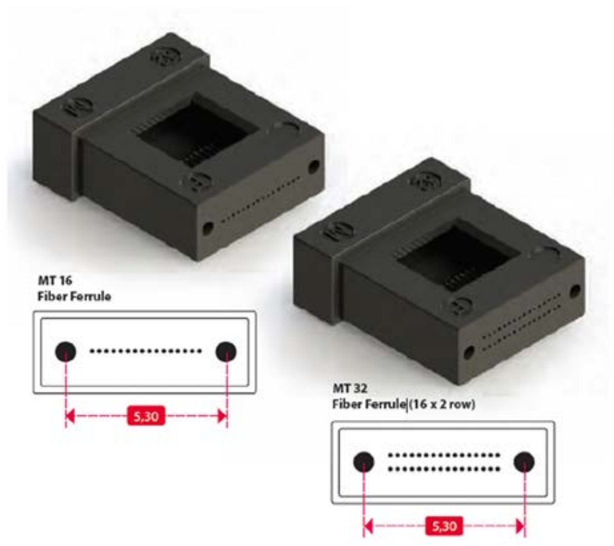


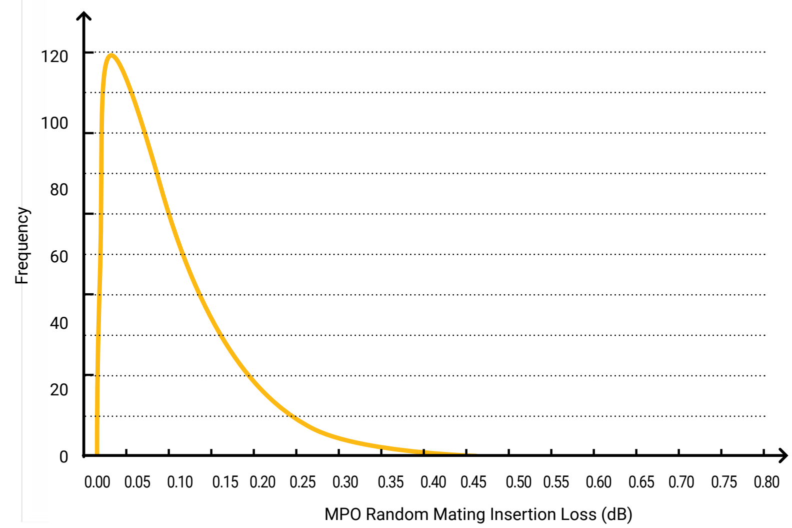
Specification	SM Low Loss	SM Standard	MM Low Loss	MM Standard
IL Typical vs Reference Connector	0.10 dB	0.20 dB	0.08 dB	0.15 dB
IL Max vs Reference Connector	0.25 dB	0.70 dB	0.25 dB	0.5 dB
Random Mating Grade IEC 61755-3-31	Grade B	Grade C	n/a	n/a
Return Loss	60 dB	60 dB	25 dB	25 dB
Recommended PIn Used	SM Low Loss Pin	SM Pin	SM Pin	MM Pin

Figure 12 *Performance of 12F MPO Connector.*

Random Mating Loss and SN-MT Interconnect

Below are the results from the study performed at SENKO for the 16/32F MPO Connector:



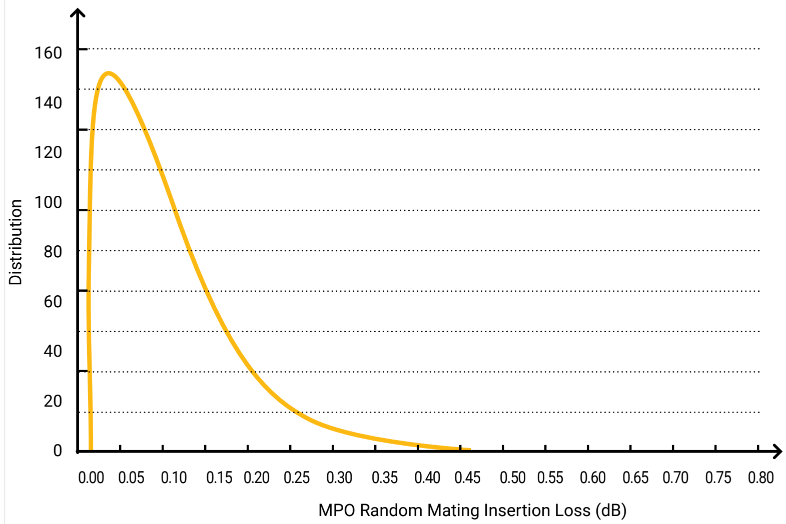


Specification	SM Low Loss	SM Standard	MM Low Loss	MM Standard
IL Typical vs Reference Connector	0.15 dB	0.15 dB	0.20 dB	0.25 dB
IL Max vs Reference Connector	0.35 dB	0.35 dB	0.60 dB	0.60 dB
Random Mating Grade IEC 61755-3-31	Grade B*	n/a	n/a	n/a
Return Loss	60 dB	25 dB	25 dB	25 dB
Recommended PIn Used	SM Low Loss Pin	SM Pin	MM Pin	MM Pin

Figure 13 *Performance of 16F MPO Connector.*

Random Mating Loss and SN-MT Interconnect

Below are the results from the study performed at SENKO for the 24F MPO Connector:

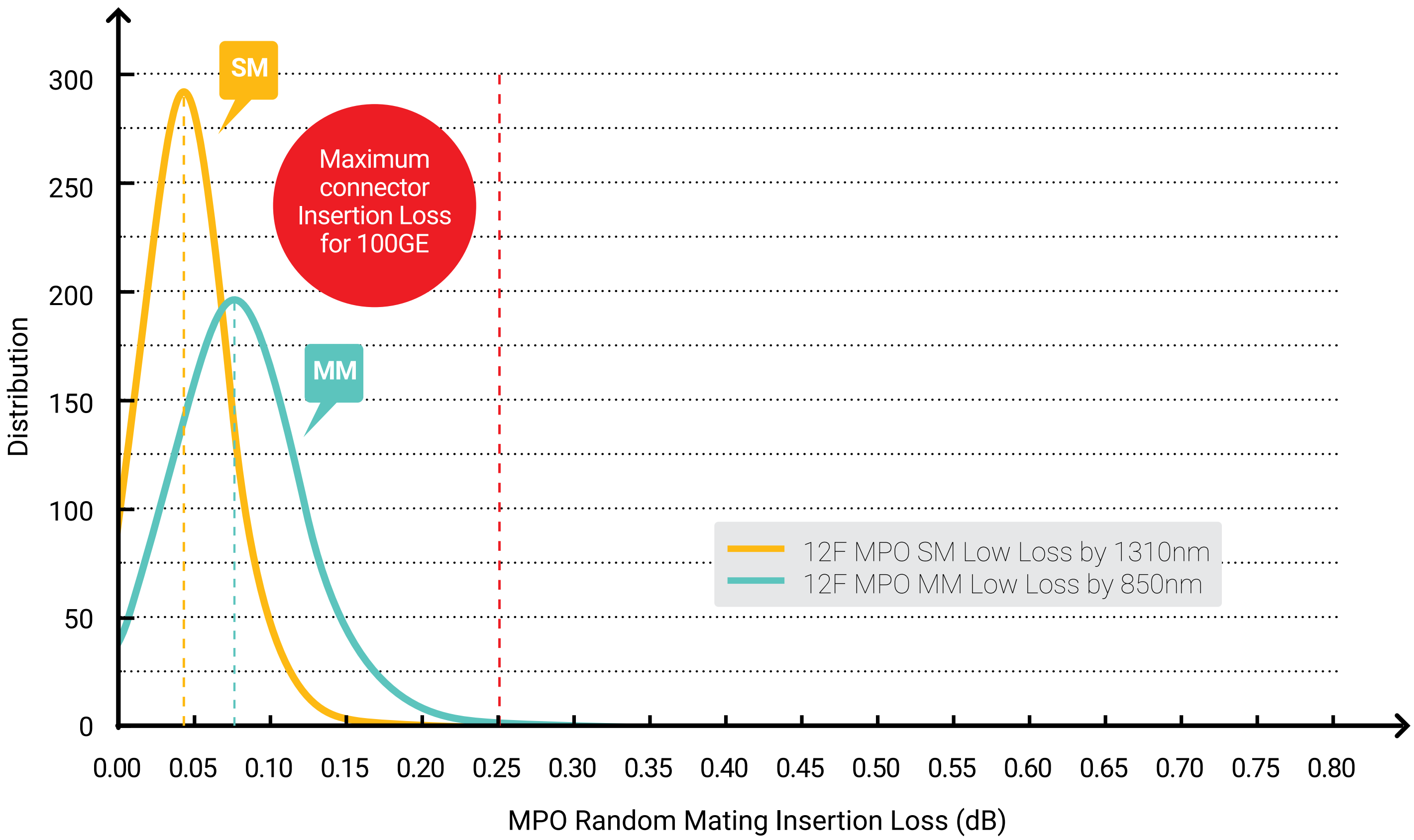


Specification	SM Low Loss	SM Standard	MM Low Loss	MM Standard
IL Typical vs Reference Connector	0.15 dB	0.25 dB	0.15 dB	0.20 dB
IL Max vs Reference Connector	0.35 dB	1.00 dB	0.35 dB	0.50 dB
Return Loss	60 dB	60 dB	25 dB	25 dB
Recommended PIn Used	SM Low Loss Pin	SM Pin dB	SM Pin	MM Pin

Figure 14 *Performance of 24F MPO Connector.*

Random Mating Loss and SN-MT Interconnect

Below are the results from the study performed at SENKO for the 12F MPO Low Loss Connector:



SPECIFICATION	SM LOW LOSS	SM STANDARD	MM LOW LOSS	MM STANDARD
IL Typical vs Reference connector	0.10dB	0.20dB	0.08dB	0.15dB
IL Max vs Reference connector	0.25dB	0.70dB	0.25dB	0.50dB
IL Typical Random Mating	0.12dB	0.20dB	0.10dB	0.15dB
Random Mating IEC Spec: IEC61755-3-31	Grade B (0.25)	Grade C (0.5)	n/a	n/a
Return Loss	60dB	60dB	25dB	25dB
Recommended PIN Used	SM Low loss Pin	SM Pin	SM Pin	MM Pin

** Above number is only achievable when using SENKO Recommended Reference Jumper, Polishing process and testing method*

** SM Low loss and MM Low loss Max IL 0.25dB to be 95% of all fiber*

Figure 15 *SENKO study for the 12F MPO Low Loss Connector.*

Based on the data, SENKO achieves an insertion loss distribution of a maximum of only 0.25dB across all 12 channels for super low loss connectors which is remarkable.

Below are the results from the study that shows random mating losses mating SENKO MPO with leading MPO brands:

Random Mating Loss and SN-MT Interconnect

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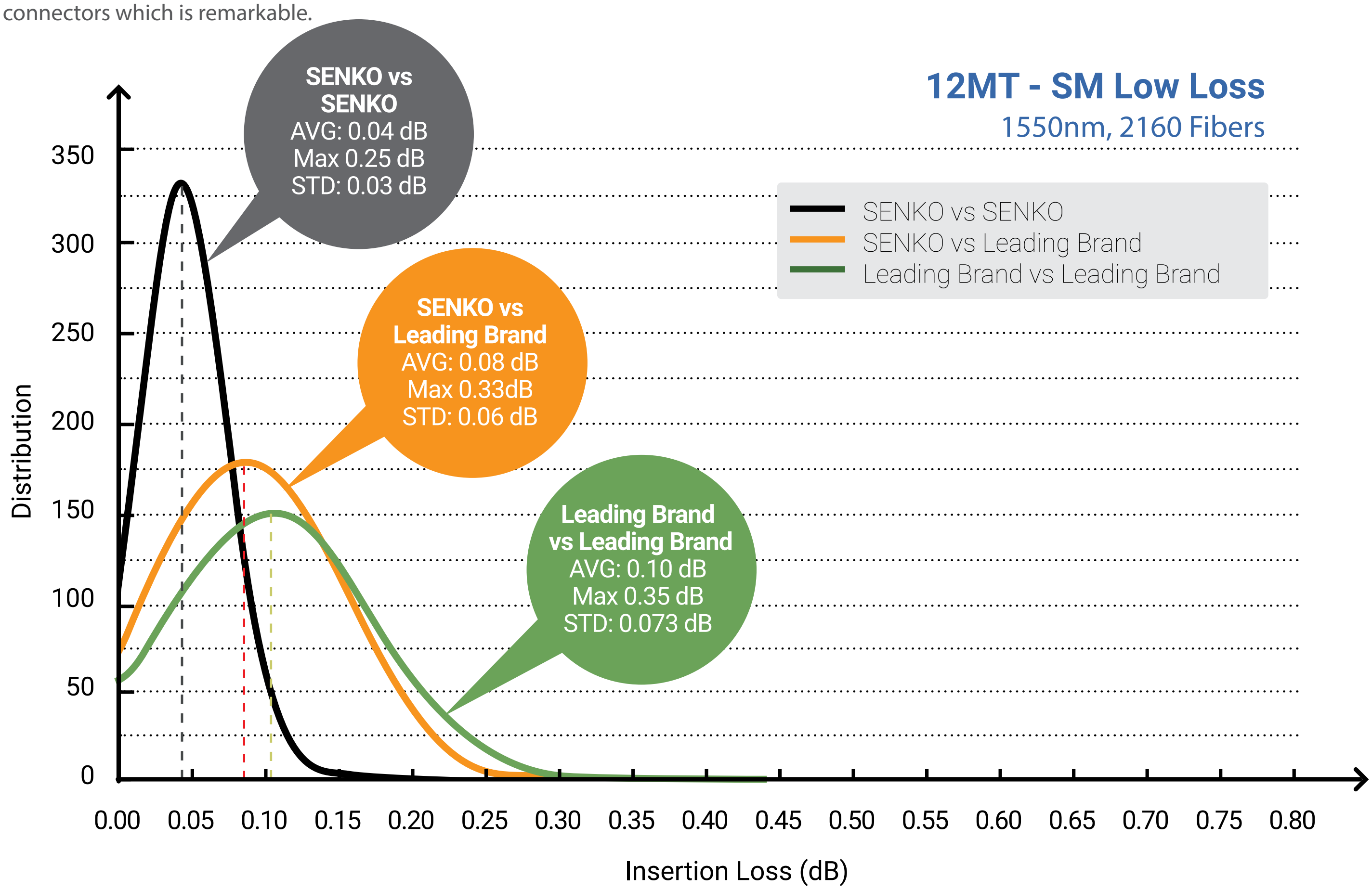


Figure 16 *SENKO MPO optical loss performance against leading MPO brands.*

The data suggests that SENKO MT ferrule tolerances are superior to those of competitive MPO connectors. When comparing SENKO MPO connectors mated with SENKO MPO connectors to the scenario where they are mated with leading brands, the average insertion loss (IL), maximum IL, and standard deviation are slightly higher in the latter case. It is essential to remember that lateral misalignment is the main contributing factor for insertion loss, and it is apparent that the ferrule hole, pins, and guide hole tolerances are superior in SENKO MT ferrules. The newest generation of MT ferrules, known as SN-MTs, has recently been developed for smaller footprint MPOs. These SN-MTs hold the potential to become the prime choice for Hyperscale Data Centers. The new ferrule is smaller than the traditional MT with a reduced guide pin bore diameter and guide pin bore pitch. Figure 17 illustrates the MT and MT- 16 dimensional differences.

Random Mating Loss and SN-MT Interconnect

The newest generation of MT ferrules, known as SN-MTs, has recently been developed for smaller footprint MPOs. These SN-MTs hold the potential to become the prime choice for Hyperscale Data Centers. The new ferrule is smaller than the traditional MT with a reduced guide pin bore diameter and guide pin bore pitch. Figure 17 illustrates the MT and MT- 16 dimensional differences.

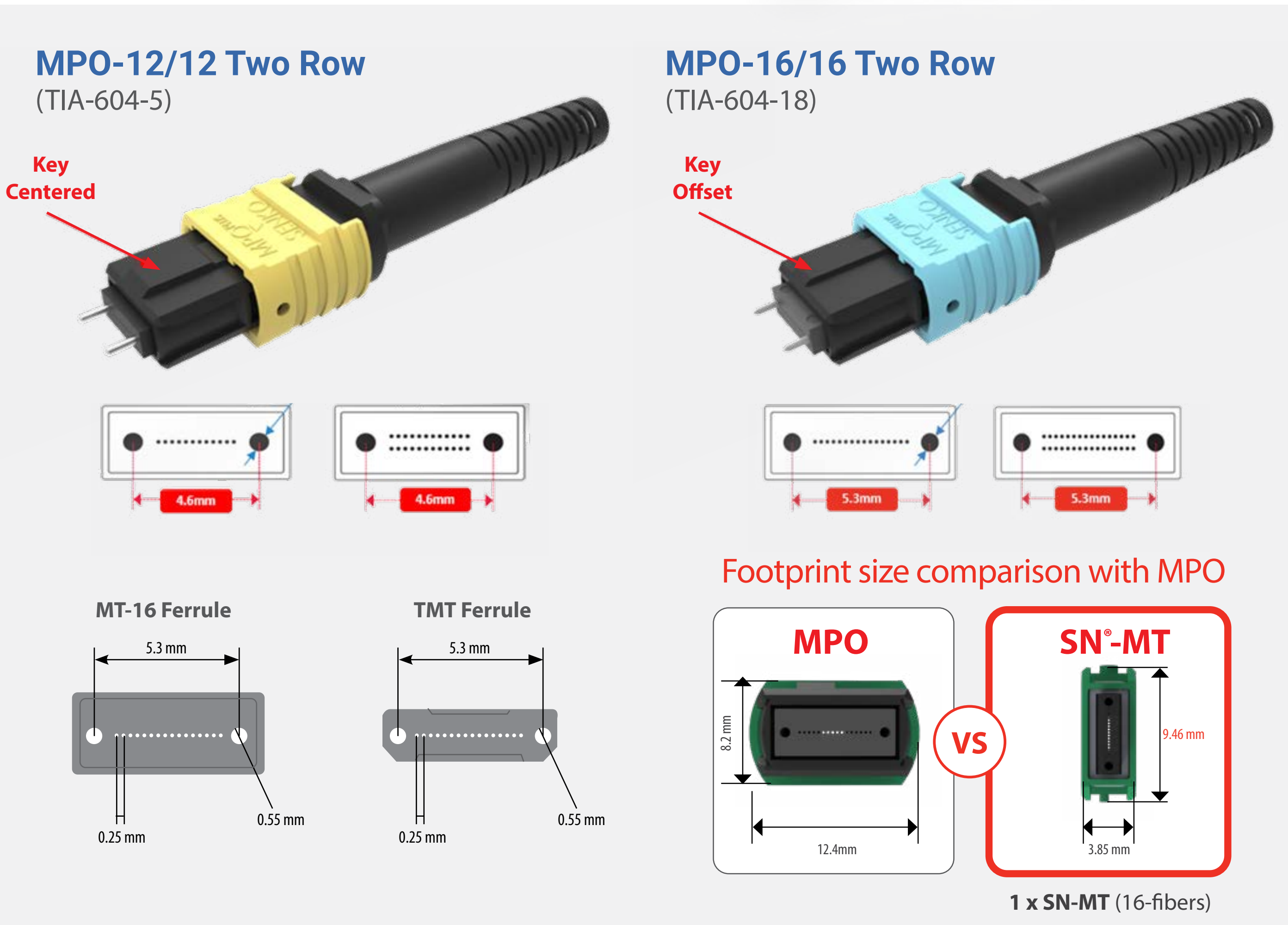


Figure 17 *Comparison between MPO and SN-MT dimensions.*

The SN-MT ferrule is designed with less material, smaller guide pin holes, and a tighter pitch between the fibers. It is specifically intended for use with smaller ribbons of 200µm, rather than the traditional 250µm protective acrylate buffer coating. The traditional MT ferrule is standardized in multiple standards, including IEC 61754-5, which defines the overall size and footprint of the typical rectangular ferrule used in ferrule-to-ferrule applications. The mechanical mating interface requirements of the traditional MPO connector format are defined in the IEC 61754-7-1 and 61754-7-2 series. Additionally, the IEC Optical Interface specification series 61755-3-31 specifies the precision terminated ferrule dimensions required to achieve various optical performance grades. For the one fiber row MT-16 ferrule mating interface, the standard is covered in the IEC 61754-7-4 document.

Random Mating Loss and SN-MT Interconnect

As the IEC standards are catching up with dimensional ferrule requirements, SENKO has taken a leading role in developing and testing the new SN-MT ferrule, which is incorporated into the SENKO SN-MT connector. Similar 10x10 studies were performed for MM and SM assemblies, all featuring the SN-MT ferrule, and the results are very positive. Below is the data from the studies.potential to become the prime choice for Hyperscale Data Centers. The new ferrule is smaller than the traditional MT with a reduced guide pin bore diameter and guide pin bore pitch. Figure 17 illustrates the MT and MT- 16 dimensional differences.

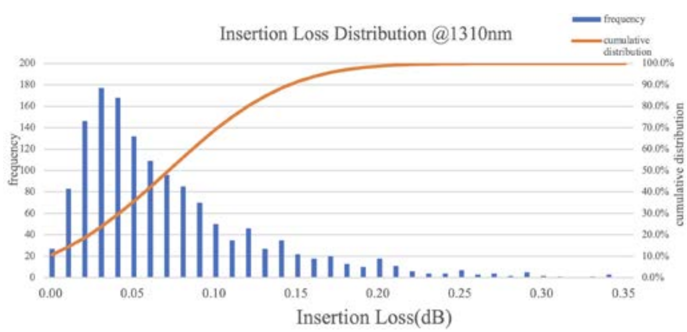
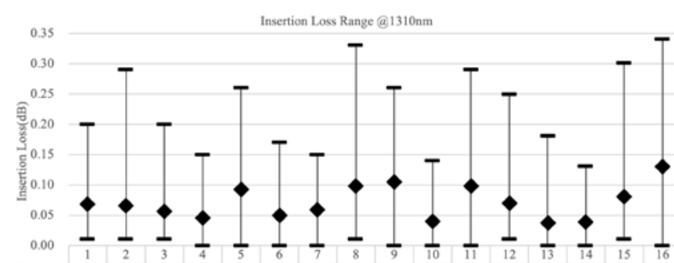


Figure 18 *IL Distribution at 1310nm.*



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
−MAX	0.20	0.29	0.20	0.15	0.26	0.17	0.15	0.33	0.26	0.14	0.29	0.25	0.18	0.13	0.30	0.34
−MIN	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
◆AVG.	0.07	0.07	0.06	0.05	0.09	0.05	0.06	0.10	0.10	0.04	0.10	0.07	0.04	0.04	0.08	0.13

Figure 19 *Average IL per channel at 1310nms.*

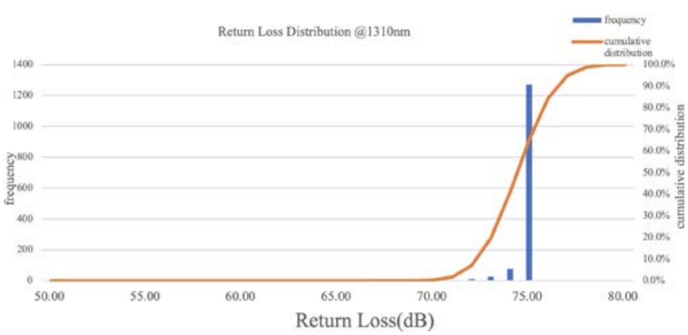


Figure 20 *RL Distribution at 1310nm*

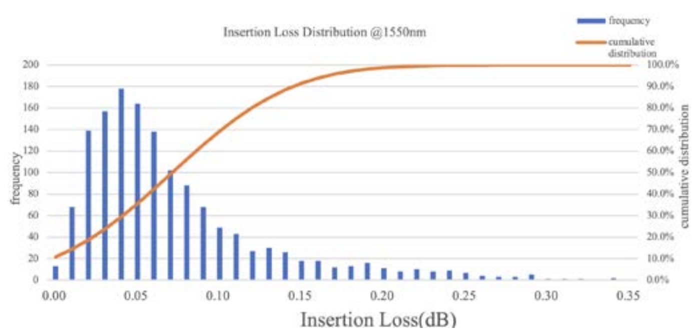
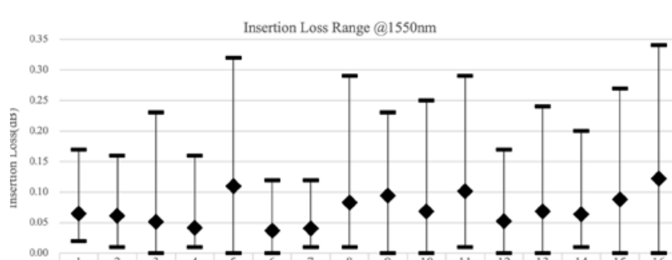


Figure 21 *IL Distribution at 1550nm*



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
−MAX	0.17	0.16	0.23	0.16	0.32	0.12	0.12	0.29	0.23	0.25	0.29	0.17	0.24	0.20	0.27	0.34
−MIN	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
◆AVG.	0.06	0.06	0.05	0.04	0.11	0.04	0.04	0.08	0.09	0.07	0.10	0.05	0.07	0.06	0.09	0.12

Figure 22 *Average IL per channel at 1550nm.*

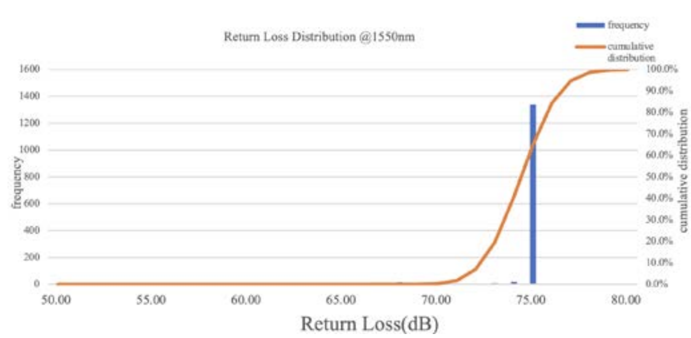


Figure 23 *RL Distribution at 1550nm*

Random Mating Loss and SN-MT Interconnect

In addition, SENKO compared the cumulative Gaussian IL distribution across all channels between the 10x10 study on 16-fiber MPO standard connectors and the study on 16-fiber SN-MT connectors. It should be noted that the MPO ferrule dimensions, pins, pin hole, and spring compression force differ from those of the SN ferrule. However, we believed it would be meaningful to compare the two similar data sets since they both originated from identical 10x10 studies. The results are presented in a Table 3 below:

Connector Type	Total Count	Mean	St Dev	Minimum	**Maximum**
SN-MT16 SM	1440	0.084	0.068	0.00	0.35
MPO-16 SM	1440	0.087	0.074	0.00	0.34

Table 3 *IL comparison summary between MPO-16 and SN-MT-16 SM.*

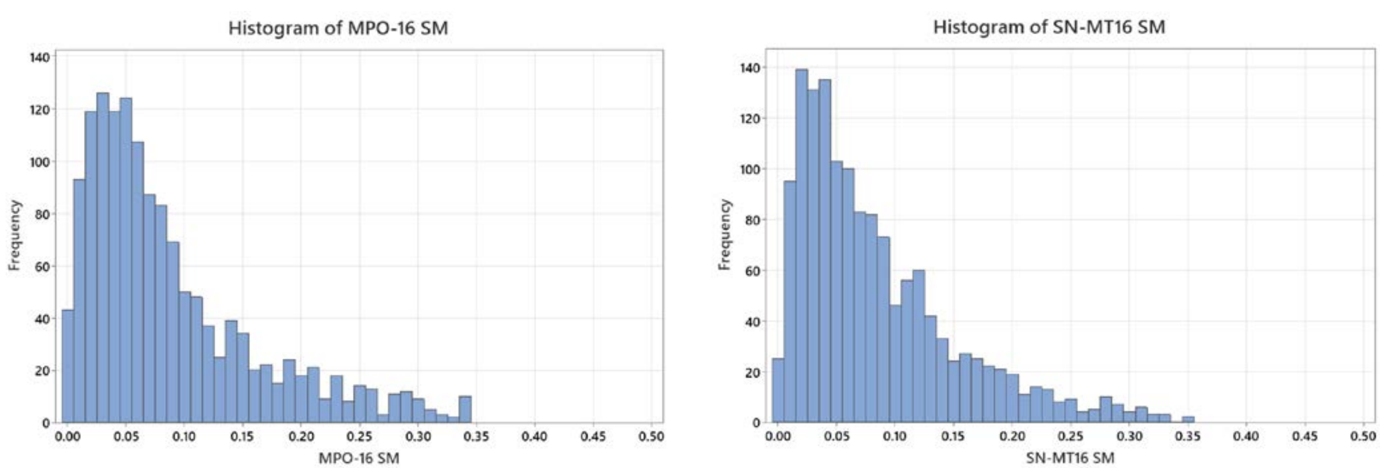


Figure 24 *IL comparison between MPO-16 and SN-MT-16 SM*

The optical losses between MPO-16 and SN-MT-16 SM are very similar regardless of the ferrule differences.

3.0 Advancement in Cable Construction Technologies

As mentioned earlier, ribbon constructions are also becoming smaller and smaller. Fiber manufacturers are exploring new designs and conducting tests on newer fiber and cable configurations to achieve reduced 250-micron fiber coating down to 200 microns while maintaining the standard 125-micron cladding diameter for optical fibers. Currently, the development is nearing completion for an even smaller design, featuring an 80-micron glass cladding layer diameter, and utilizing fiber coated with as low as 165-micron outer diameter.

Figure 25 compares the dimensional implications of 24 fibers arranged in a linear array with an 80-micron cladding and 165-micron protective layer to that of 16 traditional fibers with 125-micron cladding and 250-micron protective layer. Furthermore, using smaller diameter optical fibers bundled in cables results in reduced cable diameters, which, in turn, reduces space consumption in cable routing areas where space is at a premium.

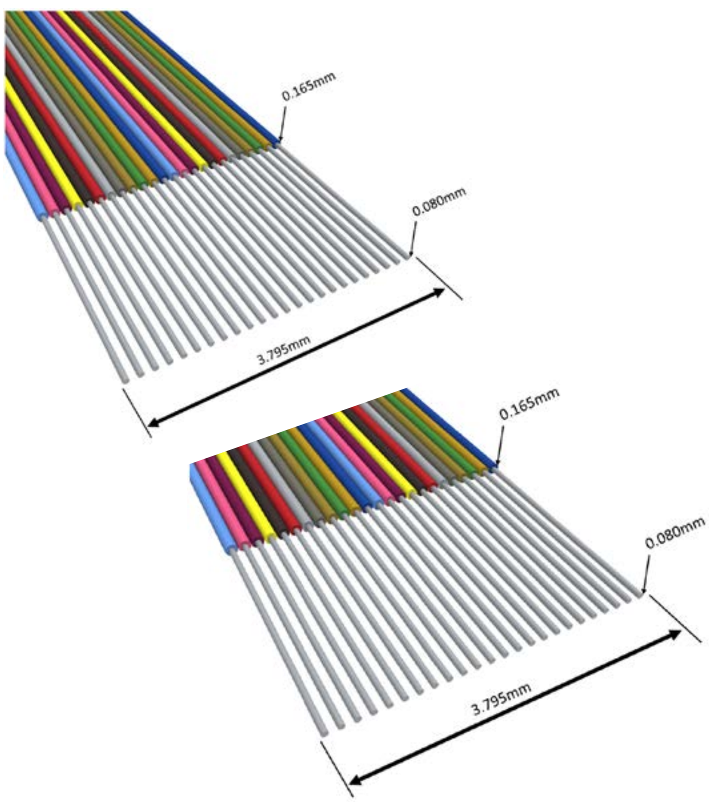


Figure 25 *Compares the dimensional differences of 24 fibers arranged in a linear array with an 80-micron cladding and 165-micron protective layer to 16 traditional fibers with 125-micron cladding and 250-micron protective layer.*

Likewise, the cables themselves are now becoming more compact. Smaller cable diameters allow for more fibers to be placed inside, thanks to new types of ribbon technology called rollable ribbon. Rollable fiber optic ribbon technology, also known as SpiderWeb Ribbon® (AFL Trademark), is an emerging development in the fiber optics industry. Rollable ribbon technology aims to address the challenge of reducing cable size while maintaining high fiber counts. In traditional ribbon cables, multiple fibers are stacked on top of each other with a protective matrix, which can make the cable bulkier and less flexible. Rollable ribbon technology, on the other hand, arranges the individual fibers in a rollable and flexible ribbon-like structure, allowing for easier cable management, a faster termination process, and smaller cable outer diameters. By employing rollable ribbon technology, cable manufacturers can double the fiber count in a cable without increasing its size. This technology has the potential to provide higher fiber density and more efficient use of available space in cable routing areas, especially in high-density data centers or tight installation spaces. Logically, with this type of new ribbon, smaller array connectors will be required, such as SN-MT.

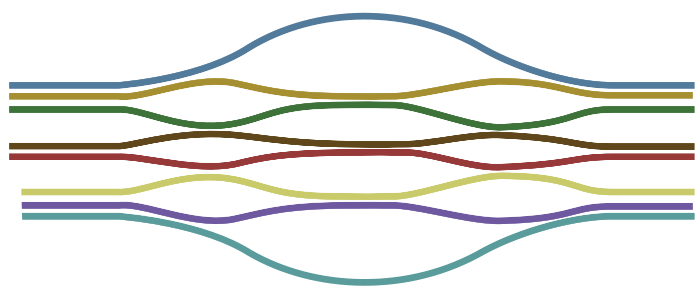


Figure 26 *Rollable ribbon section example.*

4.0 Recognized Industry Standards

There are three standards that define the MPO connector. To ensure MPO compatibility among suppliers, there is TIA-604-5, also known as FOCIS-5: Fiber Optic Connector Intermateability Standard - Type MPO. This standard is developed by a North American TIA committee.

MPO connectors are internationally defined by the IEC 61754-7 international standard, which outlines the mechanical and optical specifications for MPO connectors used in optical fiber communication systems. This standard covers the basic requirements for MPO connectors, including their physical characteristics, dimensions, and optical performance.

Finally, there is a testing standard defined by Telcordia GR-1435. This standard provides generic requirements and characteristics required of single-mode multi-fiber optical connectors. It includes performance tests to compare products against connector requirements and performance objectives. These tests supplement standard service life performance tests and are intended to identify potential weaknesses in connector assembly, design, or materials. Typically, these tests are conducted on a set of 15 samples from the manufacturer to establish a statistically valid sample size. The GR-1435-CORE standard defines the requirements, features, performance criteria, and characteristics of single-mode multi-fiber optical connectors. The standard outlines qualification testing in two phases: initial product qualification/certification and periodic verification to ensure that the product performs within established parameters. The GR-1435 standard is an established industry specification for MPO-type fiber optic connectors. For connector designers and manufacturers, passing GR-1435 testing is important for several reasons:

Quality Assurance	Meeting GR-1435 testing standards is a hallmark of high-quality manufacturing. By passing these tests, manufacturers demonstrate that their connectors are designed and manufactured to stringent quality benchmarks, reducing the likelihood of defects and failures.
Interoperability	GR-1435 compliance ensures that connectors from different manufacturers are compatible and can reliably interconnect with each other. This interoperability is crucial in building complex optical networks using components from various sources.
Reliability	Connectors that pass GR-1435 testing are more likely to have reliable and consistent performance over time, minimizing the risk of signal loss, data corruption, or network downtime.
Customer Confidence	Compliance with a recognized industry standard like GR-1435 builds trust and confidence among customers, who can rely on the connectors' performance and compatibility.
Market Acceptance	Many industries and markets require adherence to established standards like GR-1435. Compliance enhances a manufacturer's credibility and makes their connectors more widely accepted in the marketplace.
Reduced Risk	Rigorous testing helps identify and address potential design flaws or manufacturing defects early in the production process, reducing the risk of field failures and costly recalls.
Long-Term Viability	Connectors that meet GR-1435 standards are likely to remain viable and compatible as network technologies evolve and higher data rates are adopted.
Global Reach	GR-1435 compliance ensures that connectors can be used in international projects and installations, as the standard is recognized and accepted globally.

In summary, passing GR-1435 testing is crucial for connector manufacturers to ensure the quality, performance, and compatibility of their products within the broader optical communication ecosystem. It helps manufacturers meet industry requirements, build customer trust, and contribute to the overall reliability of optical networks.

Summary

At SENKO, we are continuously dedicated to pushing the boundaries of our MT ferrule technology to achieve lower losses. When determining your network budget requirements, understanding the necessary optical losses is of paramount importance. By utilizing SENKO MT and SN-MT low-loss ferrules in comparison to standard alternatives and those of the competition, you can effectively reduce average loss in random mating by half.

SENKO offers an extensive range of MPO interconnects designed to adhere to the GR-1435 requirements for multi-fiber optical connectors. Our MPO kits incorporate a multitude of technological features that position them as industry leaders in both design and performance. These connectors feature SM and MM super low-loss as well as standard MT ferrules, meticulously manufactured in Japan by our partners who are pioneers in MT ferrule technology.

SENKO provides an all-encompassing lineup of MPO and SN-MT connectors and solutions catering to various applications and operational environments, spanning from Hyperscale Data Centers to challenging outdoor conditions. Our MPO connector design integrates patented features that facilitate easier termination and installation, heightened precision, proven reliability, and substantial performance enhancements compared to competing solutions.

The multi-fiber SN-MT connectors are at the forefront of paving the way for future high-bandwidth transceivers. By significantly increasing connector fiber density and concurrently supporting the highly adaptable leaf and spine network distribution design, these connectors are instrumental in enabling robust performance. Our well-established connector ferrule technology empowers SENKO to manufacture connectors boasting exceptional optical performance. The user-friendly operation and ease of maintaining end face cleanliness make the transition to SN-MT connectors effortless for network operators. The SENKO SN-MT connector offers several benefits, including:

High Density	The SN-MT connector boasts industry-leading high density, accommodating a significant number of fibers in a compact footprint.
Performance	The SN-MT connector provides a resilient and consistent performance, exhibiting random mating losses of less than 0.35dB per channel. It facilitates high-speed data transmission while preserving signal integrity effectively.
Space Efficiency	Its compact design and small form factor help optimize limited rack space, making it ideal for installations where space is at a premium.
Ease of Installation	The connector's user-friendly design and features contribute to simplified and efficient installation processes.
Reliability	SENKO is known for its commitment to quality and reliability, ensuring that the SN-MT connector maintains a high level of performance over time.
Flexibility	The connector is suitable for various applications, providing flexibility in network designs and setups.
Future-Proofing	Its advanced technology and capabilities contribute to future-proofing
Scalability	Its design allows for scalability, enabling network expansions and upgrades as needed.

Overall, the SENKO SN-MT connector offers a range of advantages that make it a valuable choice for modern fiber optic networking solutions.

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Biography

Andrei Vankov, is an Application Engineer at SENKO Advanced Components. He received his BS from Thomas Edison State College and his MSEE from Pennsylvania State University. He began his career in 1993 at Sumitomo Electric Lightwave Corp as a Fiber Optic Manufacturing Engineer where he worked on active and passive components using Kaizen methods in Yokohama, Japan. As a Senior Optical Design Engineer in Franklin, MA (founded as Advanced Interconnect) Andrei Vankov developed various passive optical components and packaging integration to meet Telcordia industry standards. He designed optical interconnects, including optical backplanes (MTP, HBMT, PHD, OGI), and a fiber optic SMPTE compatible Broadcast Connector for HD applications. In 2013-2020 Andrei worked at Nokia division Radio Frequency Systems (RFS) where he provided leadership for an LTE RAN launch project team. Andrei holds several US and European Patents in fiber optics interconnect technology.

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