SENKO® Advanced Components

White Paper

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PReSS: Performance Reliability Scalability Sustainability

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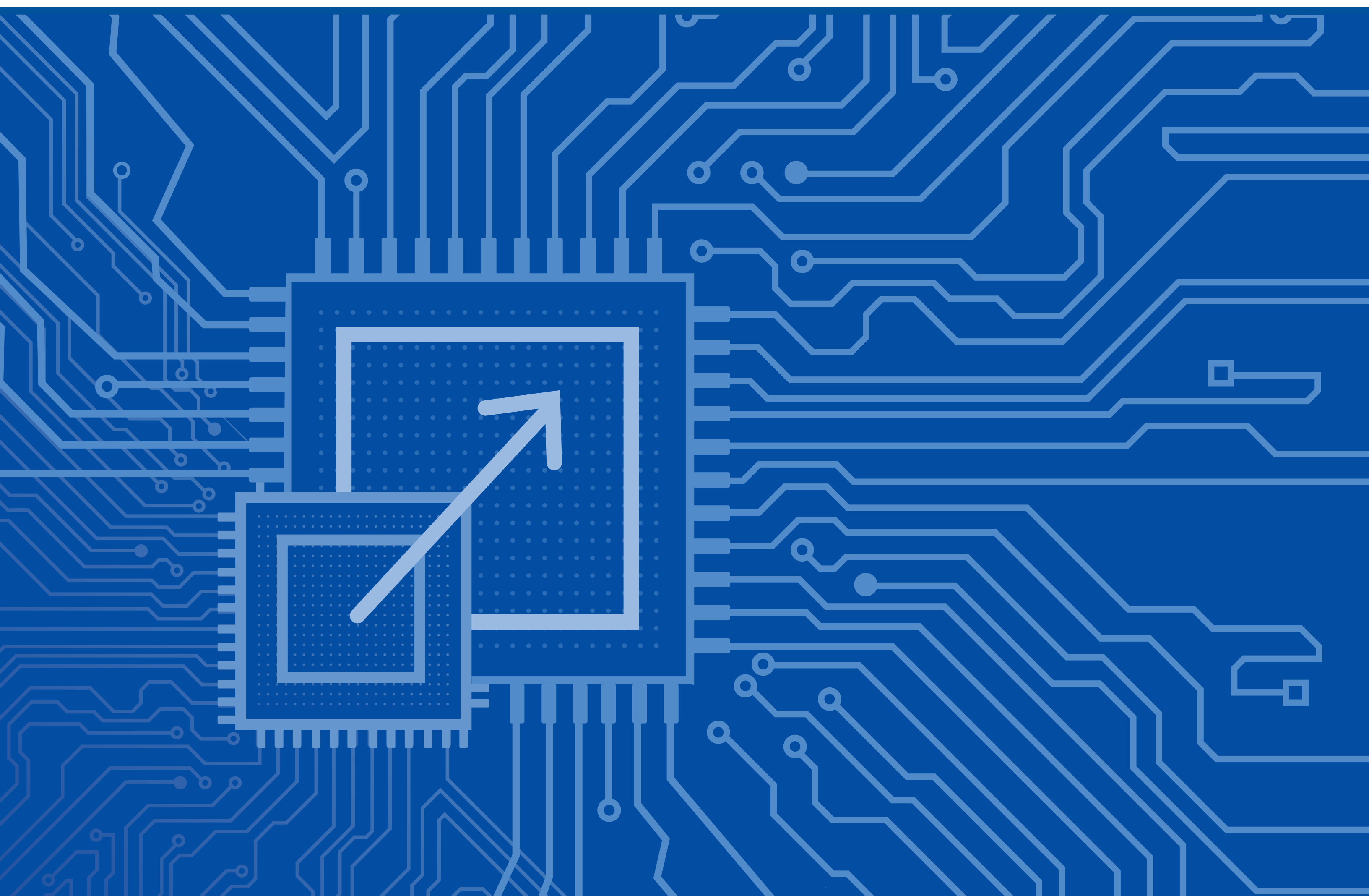

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PReSS: Performance Reliability Scalability Sustainability

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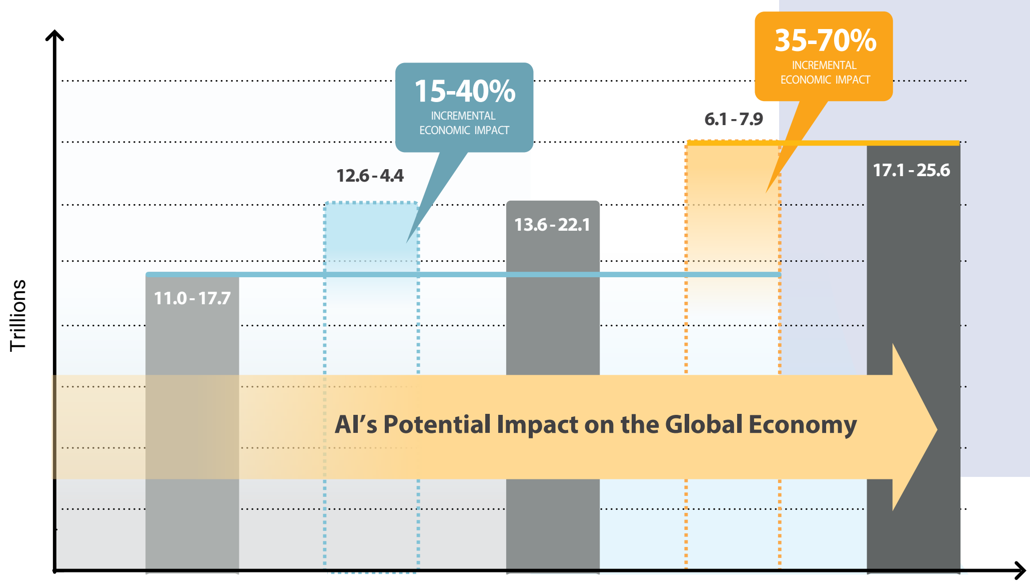
Introduction

Artificial Intelligence (AI) is already a multi-billion-dollar industry and is used in almost every industry ranging from tech, education, healthcare, agriculture, and more. AI has been used by many enterprises for many years in the form of machine learning and data analytics, and the recent rise of Generative AI (Gen AI) that responds to natural language is pushing it to further heights. This means that existing infrastructures managing data must be ready to meet new processing demands from such AI technology. The need for real-time, low-latency processing of Large Language Model (LLM) databases to provide real-time responses demands high performing and reliable networks that can be scaled to meet future demands.

According to a report from McKinsey and Company on the opportunities for Gen AI, organizations that rely on innovation, data analysis, and process automation stand to benefit most from Gen AI. It has incredible potential to accelerate growth and reduce costs by adding intelligence to any data set, which can then be used to inform decision making. As Ai is becoming such an integral part of our lives, the performance, reliability, scalability, and sustainability of the network becomes ever more crucial.

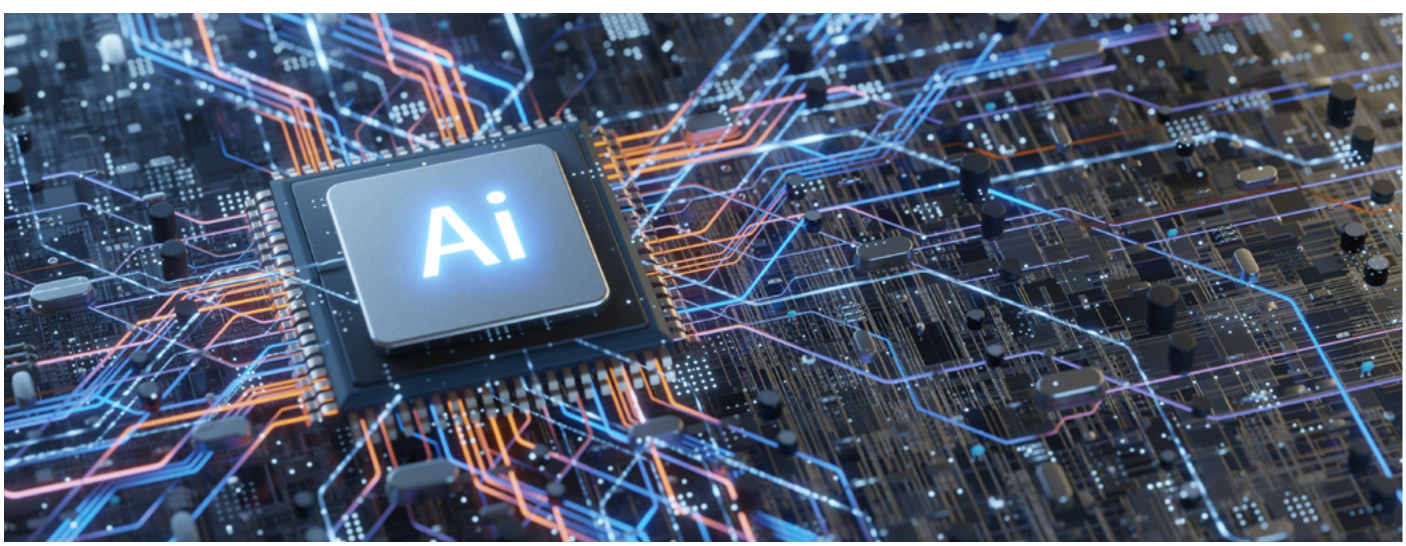


Source: McKinsey & Company, Beyond the Hype: New opportunities for gen AI in energy and materials.

There is an exponential need for scaleable, high performing networks.

PReSS

Performance
Reliability
Scalability and
Sustainability



Performance

Applications such as generative AI uses PAM4 modulation technology, which is commonly adopted by 400G transceivers and above. These networks require excellent Insertion Loss (IL) and Return Loss (RL) performance to ensure transmission quality. One of the most important components in any telecommunications and data center network is the fiber optic connector, which will have the biggest impact on the IL and RL performance.

Even when the connector complies with accepted international standards, performance of the connector can still fall short of the requirements of the network. IL and RL performance shortfalls are typically due to the lack of understanding of the performance standards, lack of care during installation, and connector intermateability. All which can result in poor IL and RL performance.

When connectors from different manufacturers are used together within an interconnect system, the IL and RL performance can significantly vary due to the different connector kits and manufacturing processes. Although all of them may comply with industry standards, the slight variability in the tolerances contributes to the inconsistencies in optical losses, even when the connector is produced by the same manufacturer. Tight manufacturing controls is only one of the factors to maintain consistency of the connector end face finish which has a significant impact on the connector quality. As manufacturers must test connectors in a repeatable and consistent manner, factory tested IL and RL results are usually done with a Master patch cord and adapter in a clean and controlled environment, which will produce an ideal termination. It is common for network operators to assume that the factor IL and RL test results will translate to the same results in the field. However, this is far from the truth as field performance can vary with random patch cords and adapters being terminated. Therefore, the IEC 61753-1, IEC 61300-3-34, and IEC 61300-3-35 standards were issued.

The IEC 61753-1 standard outlines the fiber optic interconnecting devices and passive components. It provides the performance standards for all passive fiber optic products, including connectors. This standard specifies the performance grades for the IL using four grade letters A, B, C, and D, and for RL using four grade numbers 1, 2, 3, and 4. Depending on the network, the required connector performance grades can be specified by the network operator.

Insertion Loss Grade	Specification
Grade A	Undefined
Grade B	Max 0.12dB, ≤ 0.25dB (97% of all connectors)
Grade C	Max 0.25dB, ≤ 0.50dB (97% of all connectors)
Grade D	Max 0.50dB, ≤ 1.00dB (97% of all connectors)

Table 1 *IEC 61753-1 Connector Attenuation Grades*

Return Loss Grade	Specification
Grade 1	≥ 60dB (mated); ≥ 55dB (unmated)
Grade 2	≥ 45dB
Grade 3	≥ 35dB
Grade 4	25dB

Table 2 *IEC 61753-1 Connector Return Loss Grades*

The IEC 61300-3-34 standard outlines the basic test and measurement procedures for the attenuation of random mated connectors. The intention of these procedures is to provide a practical expected optical loss of randomly mated connectors in the field, including worst case scenarios. The complex dependencies between the various factors such as ferrule and fiber dimensions, end-face geometry, and end-face polish quality are taken into consideration. The test methods to measure optical losses of random mated connectors provide a statistically unbiased estimate of the expected average patch cord performance. The following image shows the comparison between a generic patch cord performance when measured against a Master patch cord, and when it is measured by random mating. In the worst-case scenario, the Insertion Loss performance can more than double when randomly mated.

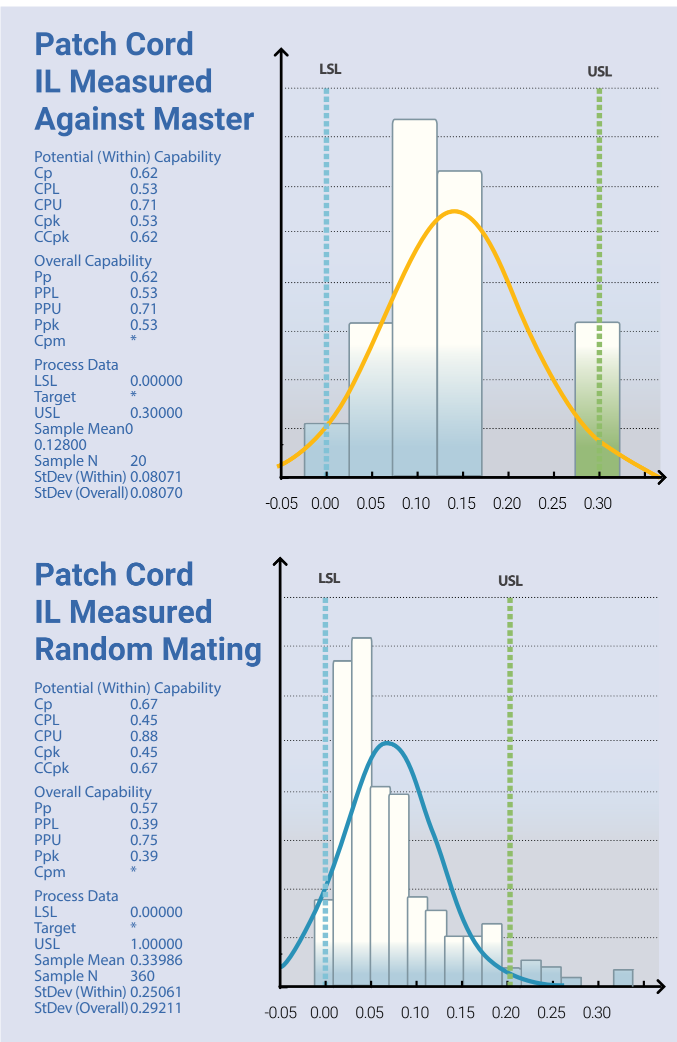
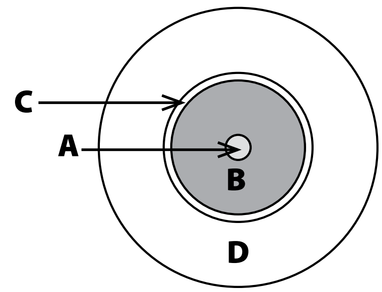


Figure 1 *Patch Cord IL Performance Against Master and Random Mating*

The IEC 61300-3-35 standard is a set of requirements for fiber optic connector quality that is designed to determine the acceptable condition of a connector end face which will impact the IL and RL performance. This standard defines the end face of an optical connector into various zones and sets the acceptable limits of scratches and defects. There are different limits outlined for single fiber connector and multi fiber connector, as well as for single mode and multi-mode fiber. The acceptable limits outlined in the table below is for a single fiber connector with a single mode fiber.



Zone	Name	Scratches	Defects
A	Core (0 - 25μm)	None	None
B	Cladding (25 - 120μm)	No Limit ≤ 3μm None > 3μm	No Limit < 2μm Max 5, 2μm to 5μm None > 5μm≥
C	Adhesive (120 - 130μm)	No Limit	No Limit
D	Contact (130 - 250μm)	No Limit	None ≥ 10μm

Table 3 *IEC 61300-3-35 Scratches and Defects Limits*

This standard is used as a reference by Fiber Inspection Probe (FIP) manufacturers as a basis for the pass/fail criteria of connector end faces, while network installers and operators use it as a basis to determine connector end face cleanliness. In a study conducted by NTT Japan, 98% of installers and 80% of network operators reported that issues with connector contamination was the greatest cause of network failure. When a connector is contaminated, the beam of light that travels through the core can be blocked. A contaminant with a size of only 2-15 micron can have significant impact on the signal transmission and can also cause damage to the optical end face. Contaminants that adhere to the core can increase the IL and reflectance. In addition, hard contaminants can cause chips, pits, and scratches in the connector end face under the pressure of the physical connection, while large contaminants can cause air gaps which will result in increased loss. Where high power lasers are used, residue or contaminants can be burnt, causing the optical fiber to melt; and in extreme cases, it can destroy devices and equipment.

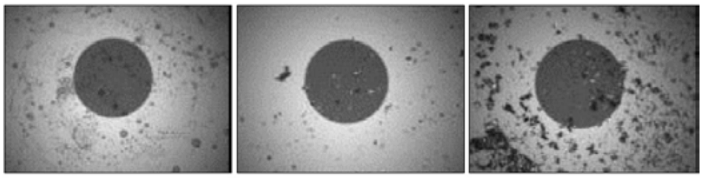
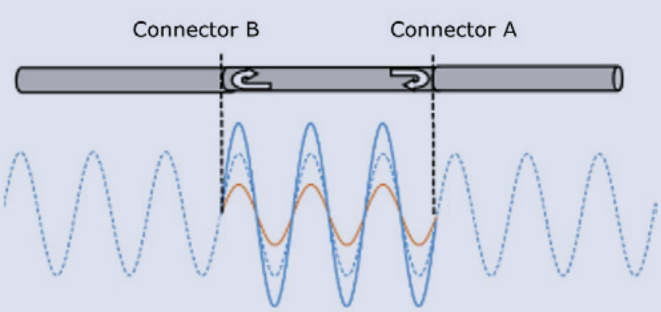


Figure 2 *Connector End Face Contamination*

Connector IL and RL performance including connector hygiene is a critical factor in modern fiber optic networks. As the number of connectors in a link increases, so does the amount of Bit Error Rate (BER). A study by done by NTT AT measured the increase in BER with respect to increasing number of connectors in a fiber link.



(1) Optical reflection occurs at Connector A

(2) Reflected light from Connector A is then again reflected at Connector B

The back-and-forth reflection of (1) and (2) creates a multiple reflections phenomena which collapses the waveform, thus increasing BER.

Thus, the higher the number of connectors in a link, the higher the possibility of multiple reflections occurring. This phenomenon has a much higher impact on higher bandwidth transceivers using the PAM4 modulation compared to NRZ as the normal eye-opening width is significantly reduced. Even with Forward Error Correction (FEC) capability, it is difficult to avoid high BER with more connectors. If a high number of connectors cannot be avoided, especially in long network, the impact of optical reflections in a network can be minimized by deploying connectors with high RL performance.

No. of Connectors	Total Reflectance (dB)	CH Receive Level (dB)	Error Rate
12	12.1	-6.07	5.8E-0.6
11	12.0	-4.09	3.4E-0.5
10	11.9	-4.00	3.2E-0.5
9	12.1	-3.71	2.1E-0.7
8	12.0	-3.72	0

Table 4 *Patch Cord IL Performance Against Master and Random Mating*

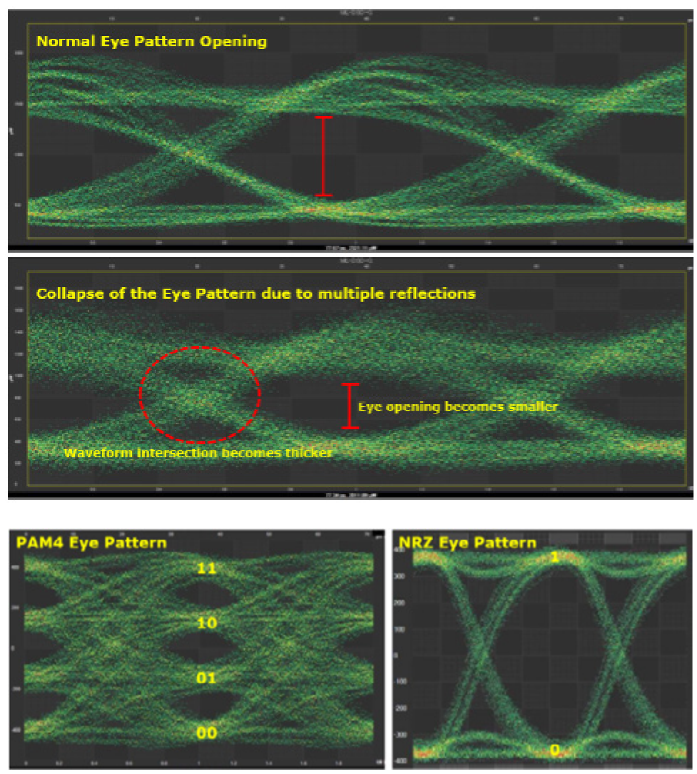


Figure 3 *Eye Pattern*

To keep up with the computing power demands, quantum computers are becoming a fundamental requirement to solve complex mathematical problems. Unlike conventional computers which use binary digits or bits to perform operations, quantum computers use quantum bits or qubits. Although this capability far exceeds classical computing, it inevitably presents a significant threat to cyber security and foundation of today's cryptography. Quantum Key Distribution (QKD) is a means of enabling secure encryption and authentication in the presence of the unbounded computational power to be introduced by quantum information technologies. QKD enables the exchange of secret symmetric keys used for encryption and authentication. These keys are secure, even against eavesdropping attempts powered by quantum computing. The transmission of these keys is done through low powered optics which is very sensitive to sources of IL such as connectors. The performance of optical connectors in QKD networks must have exceptionally IL and RL performance that is comparable to an optical splice.

The rapid adoption of AI technologies has increased the demand trajectory for power, density, and by extension, cooling requirements. According to the European Commission, data centers are expected to consume about 8% of the world's electricity by 2030. A large portion of this power will be dedicated to cooling systems. Conventional air cooling via the hot and cold isles have reached its limits as air flow is insufficient to remove heat from densely packed processors. Compared to air, liquid cooling has 1500 times more cooling capacity, are 25 times better at transferring heat, and require 10 times less energy to move heat. As the processor is in direct contact with the cooling liquid, it does not require any heat sinks and fans, thus allowing higher density circuit boards which increased performance output and enables processor overclocking. Liquid cooling can provide a more stable and lower operating temperature environment, which helps to improve equipment lifespan.

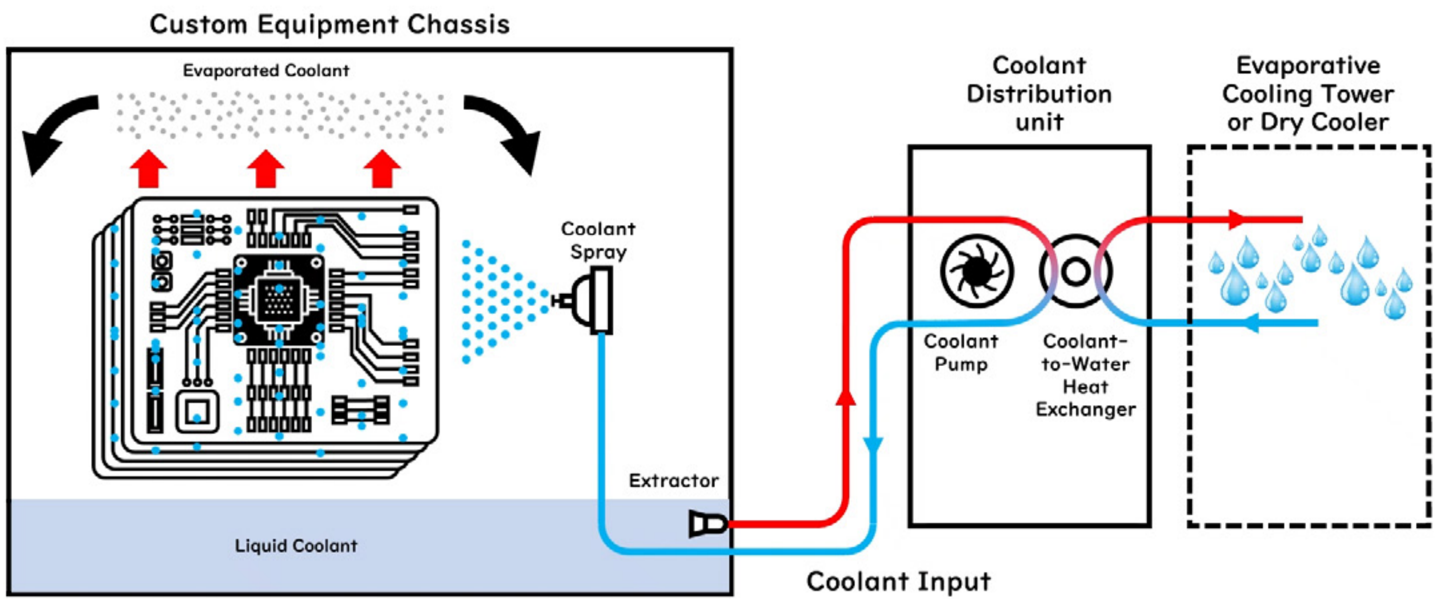


Figure 4 *Evaporative Liquid Cooling Solution*

Reliability

According to Straits Research, global optical interconnect market size is projected to reach $35.76 billion by 2030, growing at a Compound Annual Growth Rate (CAGR) of 13.29%. Hyperscale data centers are one of the major investors in the global optical connectivity market to support the growing cloud-based services. Almost all modern data centers adopt server architectures based on optical fiber technologies and the optical connector is one of the fundamental components of an optical communication network. The fiber optic connector market was valued at $4.35 billion in 2022 and is projected to register a compound annual growth rate of 9.4% up to 2028.

The GR-326-CORE is one of the most popular standards which provides the generic requirements for single mode optical connectors and jumper assemblies. This standard outlines a comprehensive testing regime which will not only test the connectors' material and manufacturing precision but also the quality of workmanship. The tests are divided into two main tests which are the Service Life Test, and the Extended Service Life Test. These tests function to simulate the stresses a connector may experience while also accelerate the effects of aging on the connector assembly.

The Service Life Test is further divided into environmental tests and mechanical test. Some of the environmental tests simulate prolonged exposure to high temperatures and temperature fluctuations which are commonly experienced in data centers. The mechanical test is performed to simulate the stresses the connector assembly may experience. As the number of connections required within a standard rack footprint increases, so does the number of connectors, cords, and cables. The connectors may be twisted, flexed, pulled, or knocked when it is installed or while in operation. The standard also outlines Extended Service Life Test includes exposure to a variety of environments such as high dust or airborne contaminants that may be present in data centers.

As higher bandwidth transceivers technologies such as 400G, 800G, and above continue to be deployed, multi-fiber connectors are becoming the predominant connector to be deployed in telecommunication exchanges and data centers. However, the higher the number of connectors housed in a single ferrule, the higher the probability of quality challenges. Like the GR-326 standard, the GR-1435 standard outlines the requirements, features, and characteristics of single mode multi-fiber optical connectors through a series of environmental and mechanical qualification tests.

The GR-326 and GR-1435 require multiple samples to be put through the series of tests when it is initially qualified. If the product samples pass the test requirements, the manufacturer is certified, and a periodic product re-qualification is performed to ensure that any changes over time in the manufacturing process does not adversely impact the product quality and reliability.

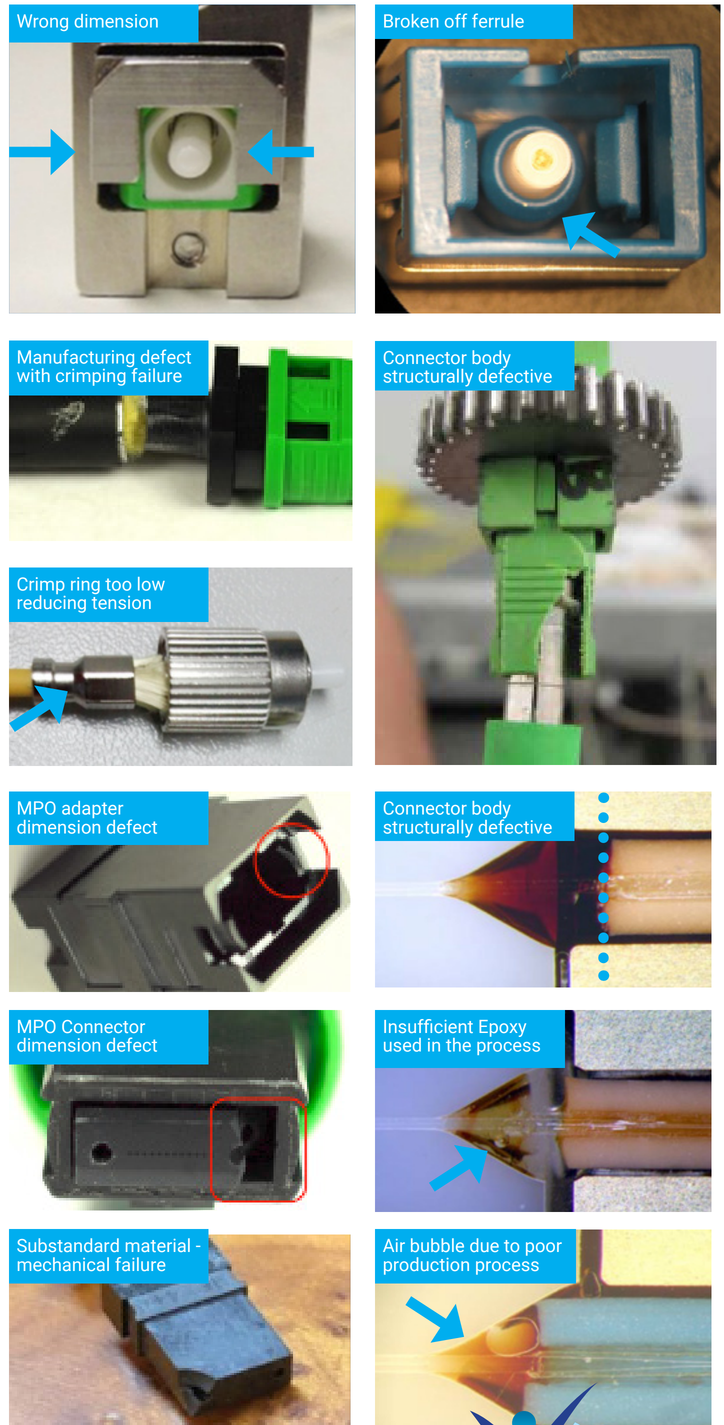


Figure 5 *Non-compliant to standard dimension examples*

GR 326 COMPLIANT

Scalability

One of the most important resources in telecom exchanges and data centers is rack space. Photonic Integrated Circuits (PIC) and Quantum Photonic Integrated Circuits (QPIC) are now widely used in optical communications, routers, signal processors, and Artificial Intelligence (AI). As PIC and QPICs are further miniaturized, more connections can be terminated into a single microchip. These connections will need to be managed through a network of optical connector cross-connects which will need to be manageable throughout the lifecycle of the equipment.

Optical connectors have a long history since its introduction to now being the predominant solution for network connectivity in data centers. As the number of connections increases, the multifiber MPO connector was introduced by Nippon Telegraph and Telephone (NTT) in the 1990's based on the MT ferrule technology. Following the trajectory of optical connector miniaturization is the introduction of the LC connector, which is the first Small Form Factor (SFF) connector. A series of Very Small Form Factor (VSFF) connectors were introduced in 2016, starting with the CS connector to the SN®-MT Uniboot connector, which is the highest density connector in the market. These connectors were introduced in support of the latest high bandwidth pluggable transceivers and on-board optics.

Multi-Fiber Push On (MPO) Connector

1990s

Lucent (LC) Connector

Late 1990s

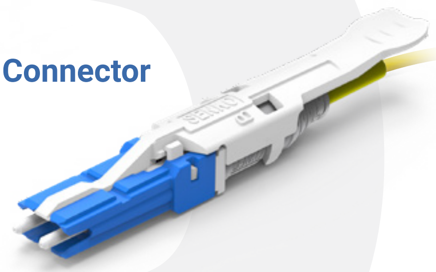
SN®-MT Connector

2019

SN® Connector

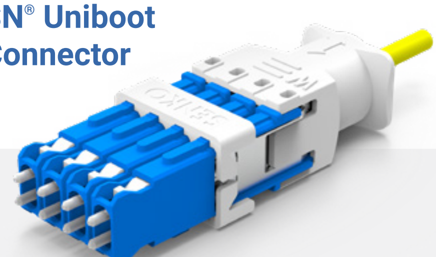
2017

CS Connector



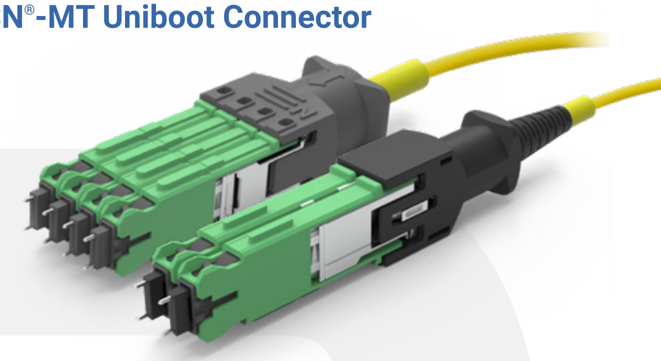
2016

SN® Uniboot Connector



2019

SN®-MT Uniboot Connector



2021

The two-layer, fully-meshed leaf-and-spine architecture is the most commonly deployed architecture in data centers. The leaf layer is composed of switches that connect to end devices such as servers, while the spine layer can be a layer 3 switch that serves as the spine of the network. This architecture improves scalability, redundancy, and increases bandwidth availability.

As data centers swap out older transceivers for higher bandwidth transceivers at a higher rate to keep up with bandwidth demand, data centers must plan the fiber optic connectivity infrastructure with the changes in mind. Network interconnect is a simple and fundamental point-to-point way of connecting equipment in different locations. It can either be a direct connection between the equipment, or it can be a trunk cable terminated into a distribution panel mounted on each rack. Connection to the equipment can then be routed locally in the rack from the distribution panel. Although simple when it is first deployed, network connectivity becomes complicated and potentially disastrous when individual equipment needs to have their connectivity changed. This may be due to a change in customer requirement, maintenance, or equipment lifecycle change.

A more future-proofed architecture is the cross-connect topology. This method requires the use of one or multiple racks in a central location housing distribution panel. Trunk cables are routed from this central location to all the equipment racks with their own distribution panel mounted at the top of the rack. This allows easy connectivity between any equipment through the cross-connect racks. However, this design will require more fiber with the high cross-connection cable runs since each leaf must be connected to every spine device.

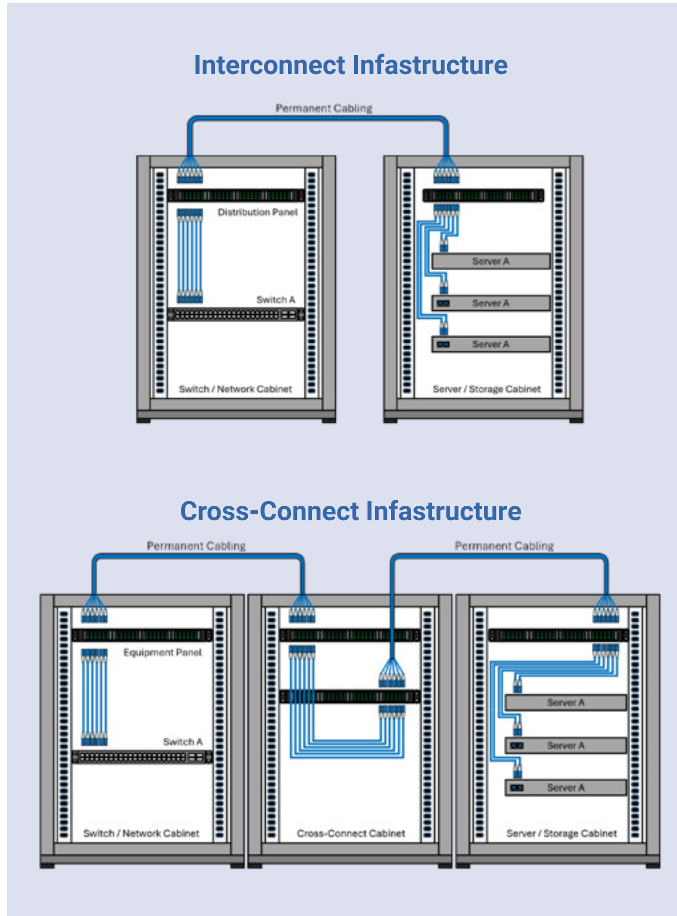
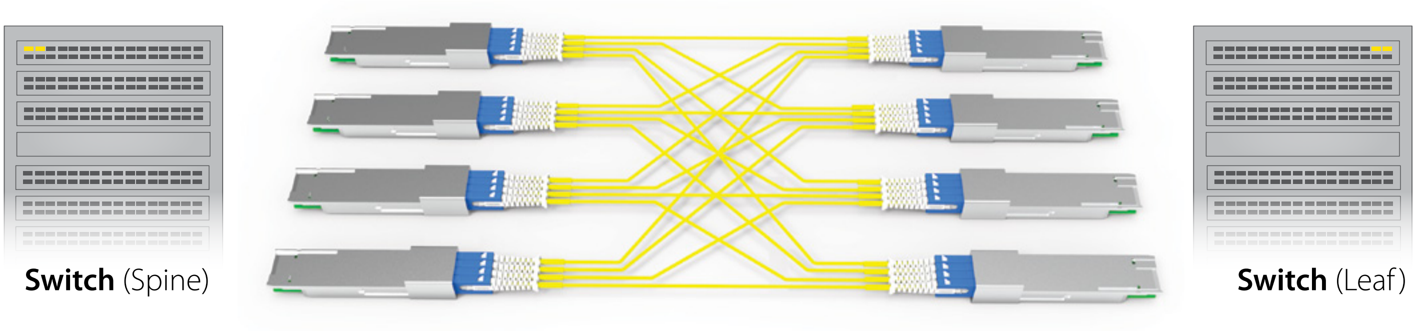


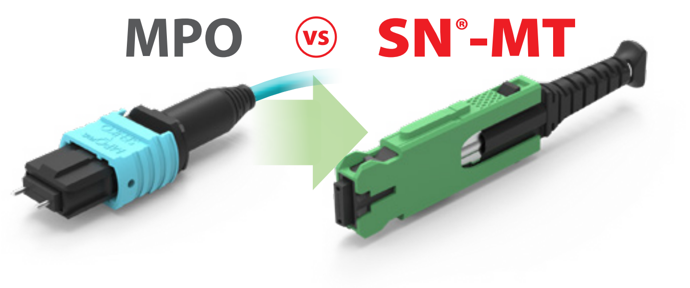
Figure 6 *Interconnect vs. Cross-Connect Infastructure*



The MPO connector was adopted to support such a highly dense network, but it created new problems with how fibers are distributed. As all the fibers are housed within a single ferrule, additional components are needed to breakout the fibers which takes up more rack space and increases network attenuation.

The SN® connector was specifically designed to overcome these complications while maintaining the high-density feature. In addition to simplifying network designs, it also reduces the overall optical attenuation and cost. Using SN® connectors that can be independently managed at the transceiver interface without the need for fan-out cable assemblies or cassette modules as each of the SN® connectors can be mated and de-mated separately without affecting the adjacent connections.

Higher density patch panel is also needed to support the increased number of connections. The fiber density of MPO connectors is reaching its practical limits with 16-fibers in a single ferrule. Although higher fiber count MPO connectors are available, it becomes highly complex, costly, and increases the possibility of failure. In comparison, the SN®-MT connector has a higher fiber density while minimizing connector complexities. To compare the fiber density of legacy single fiber connectors and multi-fiber connectors, a 19" mounted patch panel designed to accommodate 4 cassettes within 6 slots with various connector and adapter types are compared.



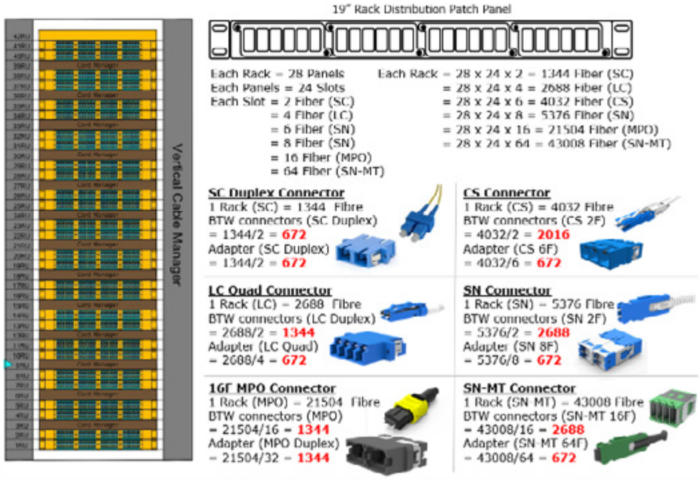
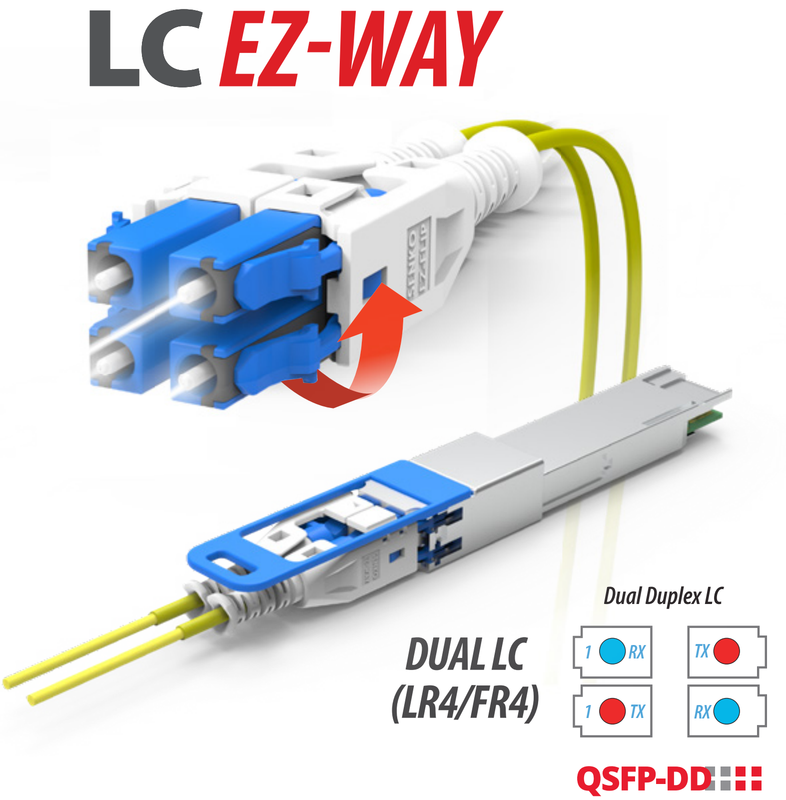
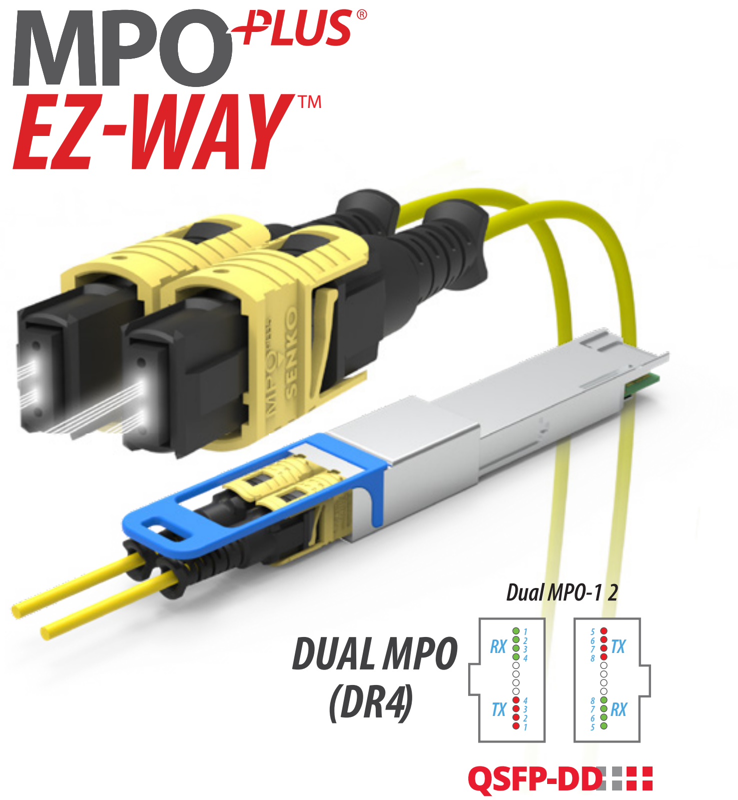


Figure 7 *Connector Count in 19" Patch Panel*

Backbone Connectivity





The development of optical connectors is usually influenced by the need to lower the Total Cost of Ownership (TCO), increase fiber density, or to align with the requirement of new transceivers. Conventional MPO and LC connector bodies were redesigned to suit the size requirements of QSFP-DD and OSFP transceivers to establish additional transmission lanes. Conventional MPO and LC designs can only accommodate one MPO connector or a duplex LC connector. To double the connector density, the connectors were redesigned to have a slimmer profile, thus allowing a belly-to-belly pitch that fits within the transceiver footprint.

The MPO EZ-WAY and LC EZ-WAY were designed to have a lower profile with push-pull boot rather than push-pull tabs, as high volume of fiber cords can obscure push-pull tabs. Using push-pull boots allows connectors to be mated or demated without the risk of disrupting connectors in proximity. Although the EZ-WAY series of connectors were designed to support QSFP-DD and OSFP transceivers, they can also be used to increase patch panel density.

Another method of scaling the network is by optimizing the time-of-use of the network. As the requirement for a physical network connectivity outpaces the network availability or when the connectivity between the various equipment need to be changed at regularly, the operation of re-routing patch panels become complicated. Connector wear-and-tear, end face hygiene, cord management, route accuracy, and records update are some of the crucial aspects that must be considered and managed. One way to accurately manage the operations of a physical connection is through the deployment of an automated patch panel.

Like the concept of a Software Defined Network (SDN) which virtualizes the Local Area Network (LAN) and Wide Area Network (WAN), An automated patch panel is the network switching of the physical layer, providing an optimized low-cost method to manage the core functionality of a cross-connect. The ability to switch fiber links on demand via a software driven process eliminates human contact with the physical network which minimizes potential network fault due to human error. In addition, the handling of fiber connector cleaning, patching, and cord management becomes a simple software command.

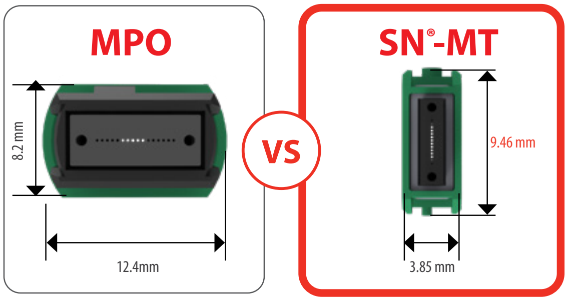
As the network is built using an automated patch panel system, the network build and service activation can be performed simultaneously via software scripts to create fiber links, test, and commission networks autonomously. Troubleshooting can also be simplified with the automated patch panel linking test equipment such as an OTDR to test faulty network to compare the trace with its reference trace when it was commissioned, thus reducing the potential extended network down-time while waiting for a technician to arrive on site, identifying the port corresponding to the network fault, performing a test, and evaluating it.

Sustainability

As more data centers are deployed and existing ones are expanding their capacity, the deployment of additional fiber optic components increases the consumption of plastic materials that makes up the connector, adaptor, and cabling. Plastics generate carbon emissions during production and even after disposal, depending on the type of plastics, it takes about 20 to 500 years to decompose and risk leeching into the environment. In addition, since fiber connectors must have excellent thermal and environmental properties to operate in varying conditions, manufacturers use high grade amorphous plastics, such as Polyetherimide (PEI), which has a higher environmental impact than most other plastics.

The deployment of VSFF connectors and adapters increase connector density and minimizes plastic content in addition to supporting the deployment of ultra high-density cables with reduced sheath coating. Deploying the SN® and SN®-MT connectors instead of the LC duplex and MPO connectors can significantly reduce the plastic amount.

Comparing the SN®-MT connector with the more commonly used MPO connector, the SN®-MT connector achieves a plastic content reduction of 43%. The smaller footprint of VSFF connectors becomes significant to material consumption reduction when millions of connectors are deployed globally. Plastic content is further reduced in the network as the use of VSFF solution does not require the use of MPO to LC breakout modules.



1 x SN®-MT (16-fibers)

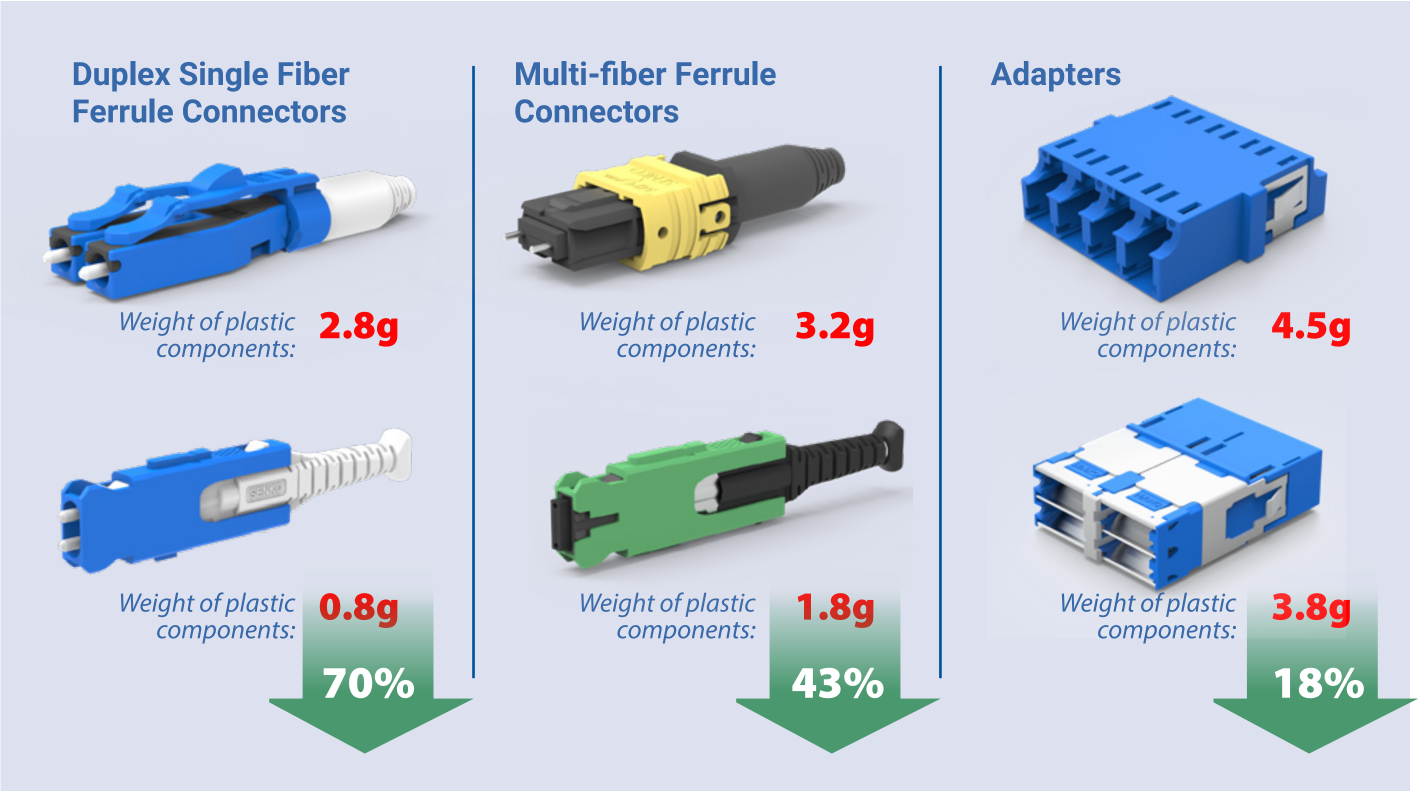
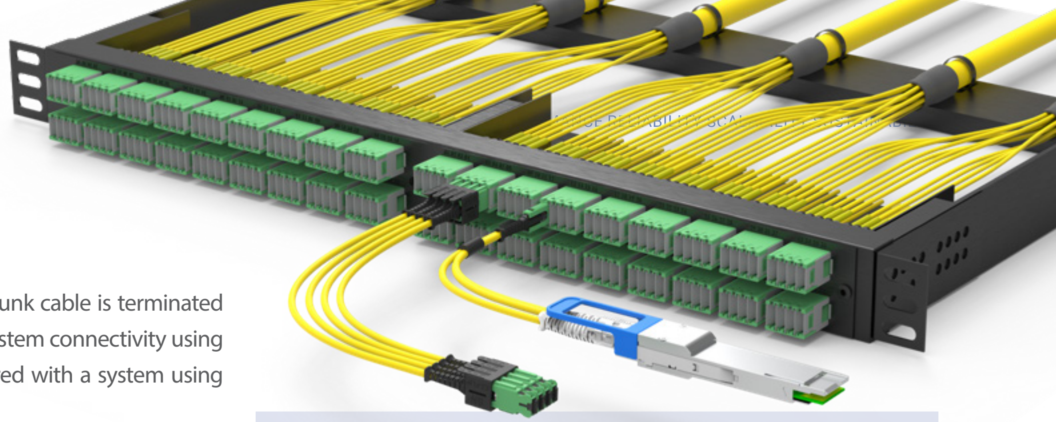


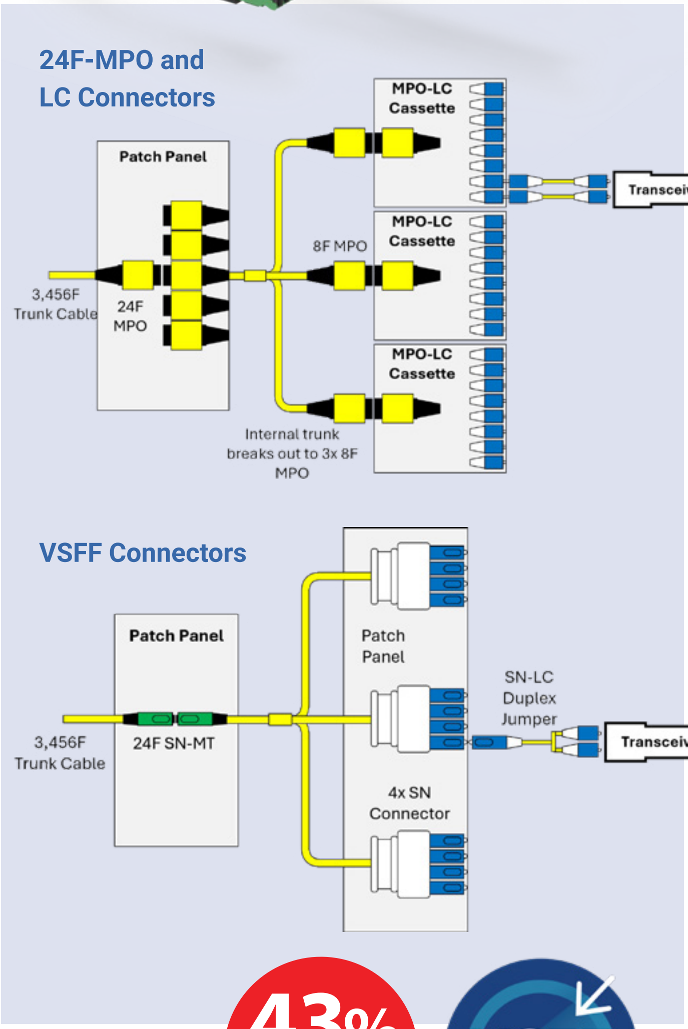
Figure 8 *Plastic reduction*



As a case study, a 3,456 fiber intra-data center trunk cable is terminated to a system of 200GBASE-LR4 transceivers. The system connectivity using conventional MPO and LC connectors is compared with a system using VSFF connectors.

24 fiber SN®-MT connector is terminated in a patch panel which is then connected to an SN®-MT to SN® Uniboot breakout cable which splits the 24 fibers into three SN® Uniboot connectors. As four individual SN® connectors can be separately mated directly to the SN® Uniboot connectors, a cassette module is not needed, which more than halves the number of LC connectors. SN® to LC duplex patch cord will then be used to connect the LR4 transceiver.

The total connector count and total plastic weight of the legacy solution and the VSFF solution from both sides of the trunk cable are shown in the table. By deploying the VSFF solution, 20.09kg or 55.7% of plastic material can be reduced in the entire network. This is equivalent to a reduction of 366.424 CO2eq/kg. In addition, this solution also eliminates the need for cassette modules.

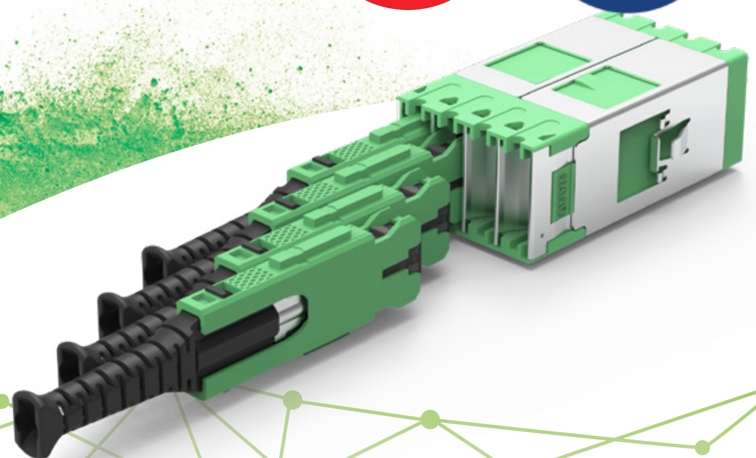


Connector Type	Legacy Solution		VSFF Solution	
	pcs	Plastic Weight (kg)	pcs	Plastic Weight (kg)
LC Duplex	10,368	29.03	3.456	9.68
MPO Qty	2,184	6.97	-	-
SN® Qty	-	-	6,912	5.25
SN®-MT Qty	-	-	576	1.01
Total Qty and Weight	**12,552**	**36.03**	**10,994**	**15.94**

Table 51 *Cassette Legacy vs VSFF Solutions*

43% Reduction in plastic

VSFF VERY SMALL FORM FACTOR



Summary

By using the PReSS design concept, network designers and operators can ensure a highly functional network that can support the requirements of the latest transmission equipment. It is also important to maintain system uptime, especially for critical and essential services. As the change in network connectivity becomes more common with changing technologies, the responsiveness to these changes requires a highly scalable design. Having a scalable design also reduces waste as network components can be repurposed for a more sustainable network.

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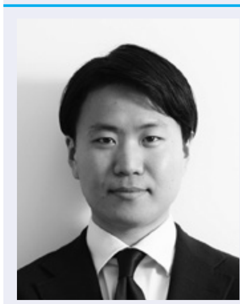
Biography

Bernard is currently the Director of Technology & Innovation at SENKO Advanced Components. He started his career in optical communications when he was a Senior Research Office for the European Union IST project known as DAVID in 2000. In 2003, he joined Telekom Malaysia R&D where he has held various technical and management positions there including the Head of Photonic Network Research and Head of Innovation and Communications. Bernard then joined the parent company, Telekom Malaysia (TM) in 2010 as the Assistant General Manager at the Group Business Strategy Division. Bernard is also an Expert at the International Electrotechnical Commission (IEC), a Chartered Engineer (CEng) accredited by the Engineering Council of UK, a Professional Engineer (PEng) registered with the Board of Engineers Malaysia and a BICSI Registered Communications Distribution Designer (RCDD).



Naoki is currently a Business Development for Telecommunications, Data Center, and Silicon Photonics market at SENKO Advance Co., Ltd in Japan. He joined SENKO in 2021 after graduating from Lindenwood University and started his carrier in optical communications at SENKO's Fiber Optic Division in Tokyo. He started his current position in 2023 and has been engaged in activities to familiarize end uses, system venders, transceiver venders, and installers with the importance of optical connectors in the current network infrastructure. Naoki currently represents SENKO at IOWN Global Forum and Quantum ICT Forum.

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