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White Paper

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MPO Connector Random Mating IL versus IL by Master Jumper

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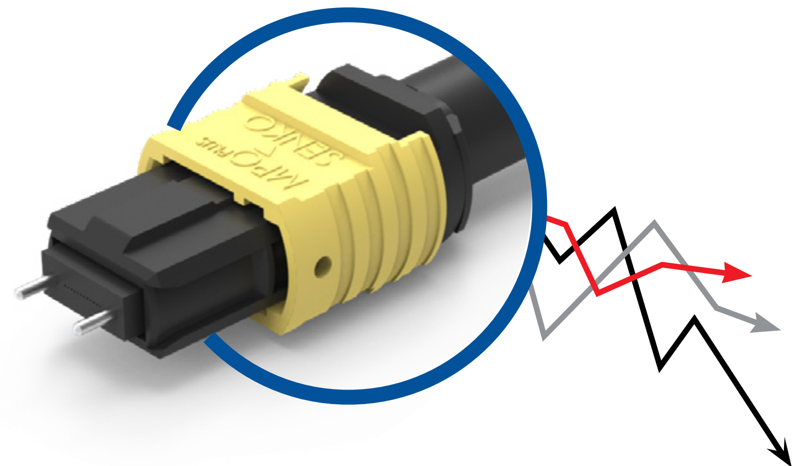
Introduction

Optical connectors are one of the most important components in an optical network as it provides the flexibility to quickly and reliably establish a connection without needing any complex equipment such as fusion splicers. However, they are also one of the components that can cause network failure with high Insertion Loss (IL) and Return Loss (RL). As higher bandwidth networks using 400GbE and 800GbE transceivers are deployed, optical performance of connectors becomes ever more crucial.

The increase in the demand for data intensive and latency sensitive services such as video streaming, machine learning, and AI-driven applications further increases the number of fiber links. This pushes an exponential increase in the deployment of higher density multi-fiber connectors such as the MPO connector.

Unlike the more commonly used LC and SC single fiber connector, multi-fiber connectors house multiple fibers, with some up to 32 fibers within a single connector housing. The failure of a single fiber within the connector housing can have an impact on the rest of the fibers. A high level of connector quality in terms of its material, overall dimensions, fiber positioning, and manufacturing must be of the highest quality to comply with international standards.

As all the components have very tight tolerances in the microns, variability in these tolerances causes increased optical losses, even if the patch cords are produced by the same manufacturer. In addition to controlling the component tolerances, design considerations and testing methods also contribute to optimal connector intermateability.



1.1 Insertion Loss (IL)

As manufacturers need to have a reliable and repeatable method to test their patch cords, a reference or master patch cord and adapter is used as a control to perform these tests. A master patch cord is essentially a near perfect patch cord, specifically in terms of the positioning of the fiber core and its protrusion/undercut from the ferrule. The patch cord test result against this master patch cord is what is measured and reported on the performance report that is provided to the end user.

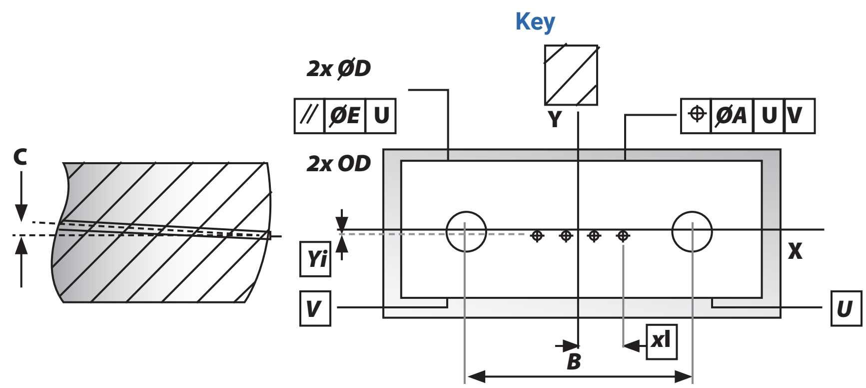
The manufacturer’s IL values can only serve as a guidance on the connector performance in a controlled environment. The IL performance using a master patch cord will not be the same as out in the field and can vary at the installation site where various random patch cords are mated together using generic adapters. The higher loss values recorded in the field is referred to as Random Mating loss. The only way to reduce Random Mating loss is by improving manufacturing consistency and reducing tolerances.

1.2 Random Mating

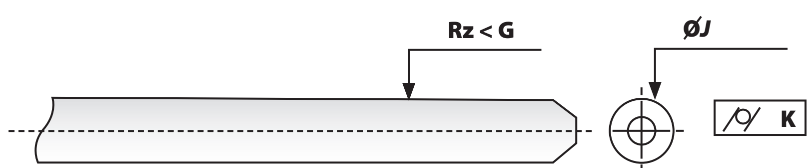
Random Mating is a method of cross-mating patch cords from different manufacturers or manufactured batches from the same supplier without the use of master patch cords or adapters. The IEC 61300-3-34, "Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures" standard, specifies random mating procedures. These procedures are intended to give an accurate expected optical loss in the field, including worst case scenarios, taking complex interactions into account between all factors including ferrule and fiber dimensions, end-face geometry, and polish surface quality. The standard describes test methods of randomly mated connector with randomly selected adapters to provide an estimation of their expected performance.

The IEC 61753-1 standard specifies the random mating IL performance and provides attenuation grades depending on their performance. As multi-fiber connectors have additional design parameters and constraints, another standard was developed. The standard that outlines the IL performance requirements for angled polyphenylene sulphide rectangular ferrules with 2, 4, 8, and 12 fibers, such as the MPO connector, is the IEC 61755-3-31. This standard also outlines the optical interface end-face geometry tolerances and three connector grades which outlines random mating IL performances which are Grade B, Grade C, and Grade D. Like the IEC 61753-1 standard, Grade A has yet to be defined.

Interface Dimensions Related to Lateral and Angular Offset



Alignment Pin Geometry



Ref	Grade B		Grade C		Grade D		Units	Remarks
	Min	Max	Min	Max	Min	Max		
A	-	0.0016	-	0.0024	-	0.0034	mm	Core position
B	4.598	4.602	4.598	4.602	4.597	4.603	mm	Hole pitch
C	-	0.2	-	0.2	-	0.2	o	Fiber angle error
D	0.699	0.6996	0.699	0.7	0.699	0.7	mm	Diameter
E	-	0.012	-	0.012	-	0.012	mm	Hole parallelism
G	-	200	-	200	-	200	mm	RMS roughness
J	0.6984	0.6985	0.698	0.699	0.698	0.6990	mm	Diameter
K	-	0.005	-	0.005	-	0.005	mm	Cylindricity

Figure 1 *EC 61753-1 optical interface enface geometry tolerances.*

Grade B connectors are becoming a common requirement for many telecommunication network and data center operators. This is to reduce the cost of transceivers and power consumption with lower optical budget. In this paper, we focus on the Random Mating IL requirements of a Grade B connector.

Rectangular ferrule connector core alignment specifications are defined at the single channel level. A population of fiber links interconnected with Grade B rectangular ferrules will yield ≤ 0.25 dB IL for ≥ 97 % of all channels with a mean of ≤ 0.12 dB. However, as multiple channels are grouped in a single connector, the theoretical, worst-case connector IL yield percentage for a completely random core alignment distribution can be calculated as follows:

$$\text{Multi-fiber connector attenuation yield \%} = \left[\text{single channel attenuation yield \%}\right]^{n}$$

n= total number of populated fibers per ferrule

As an example, for a 12-fiber MPO connector, the theoretical IL yield % can be calculated as

$$\text{12-fiber MPO yield \% with Attenuation} \leq 0.25\text{ dB} = \left[\begin{array}{c}97.293 \\ \text{or } 71.94\%\end{array}\right]^{12}$$

n= total number of populated fibers per ferrule

The yield % of 4-fiber, 8-fiber, and 12-fiber connectors with various attenuation levels are outlined in the table below.

Grade B Single Channel vs. Multi-fiber Connector Performance

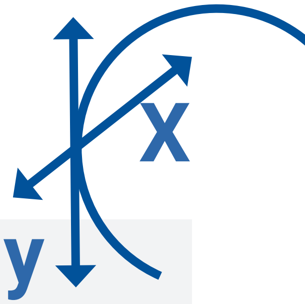
Attenuation (dB)	Single Channel Cumulative %	4-Fiber Cumulative %	8-Fiber Cumulative %	12-Fiber Cumulative %
0.25	97.29	89.60	80.29	71.94
0.30	98.71	94.92	90.10	85.53
0.35	99.41	97.66	95.37	93.14
0.40	99.72	98.90	97.81	96.74
0.45	99.87	99.49	98.98	98.48
0.50	99.94	99.75	99.49	99.24
Note: Mean = 0.07 dB	*IL_{max} <0.25 dB for 97.29% of channels*	*IL_{max} <0.25 dB for 89.60% of channels*	*IL_{max} <0.25 dB for 80.29% of channels*	*IL_{max} <0.25 dB for 71.94% of channels*

Figure 2 *Grade B single channel vs. multi-channel connector performance.*

1.3 Low-Cost MT vs Super-Low-Loss MT Evaluation

The dimension of the connector is not only crucial to ensure the proper alignment of the connector, but it also has an impact on the assembly and polishing processes. The specifications of a generic low-cost MT ferrule and SENKO's super-low-loss MT ferrule are evaluated for the 12-fiber MT ferrules.

The fiber hole eccentricity is one of the most crucial attributes of a fiber ferrule as it determines the position of the optical fibers that are will be terminated to establish a connection. The generic low-cost MT ferrule is observed to have the X-axis eccentricity being shifted to the center of the ferrule, hence the fiber holes on the outer side has a much larger eccentricity error. It also has a much larger variation in the Y-axis eccentricity. The high variability in eccentricity will result in a higher IL.



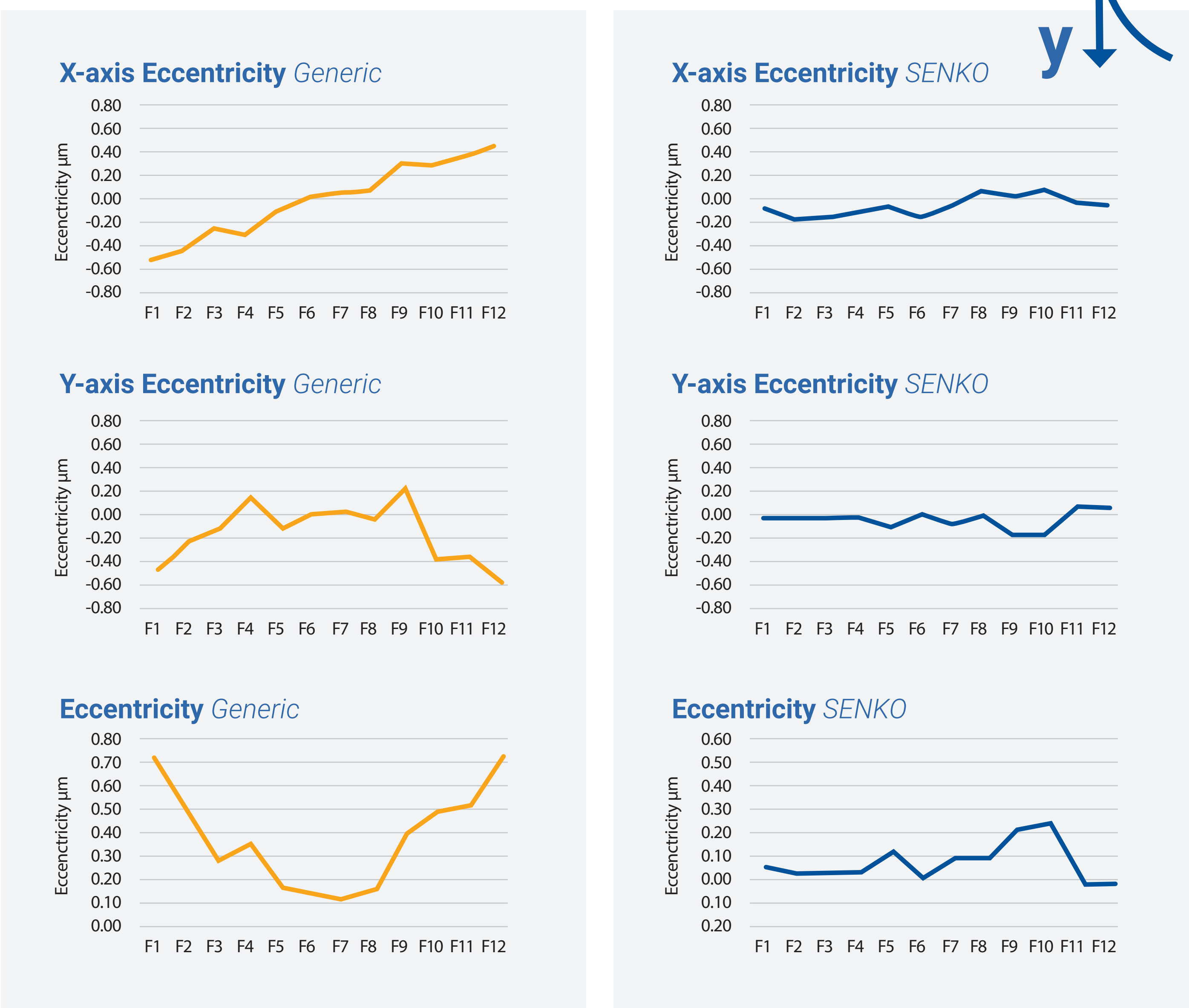
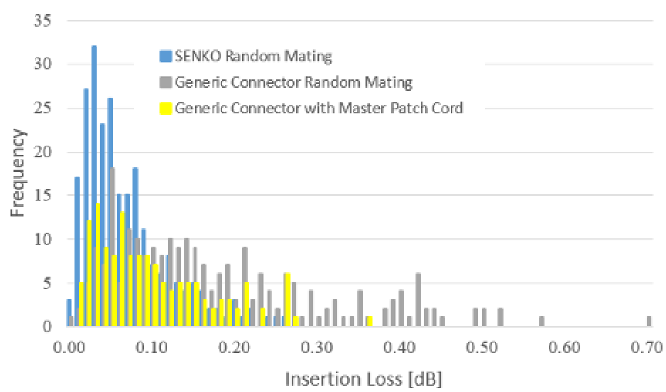


Figure 3 *A comparison between generic low-cost MT and super-low-loss SENKO MT geometrical data.*

The table below shows three tests which are the generic low-cost connector random mating, generic low-cost connector with master patch cord, and SENKO's super-low-loss connector random mating measured in the 1310 nm wavelength. The reason for choosing 1310 nm is because it is more sensitive to misalignment than longer wavelengths would be.

	Wavelength	Max.	Avg.	≤0.25 dB	≤0.30 dB	≤0.35 dB	≤0.40 dB	≤0.45 dB	≤0.50 dB
IEC 61755-3-31 Grade			≤ 0.12	≥ 71.94%	≥ 85.53%	≥ 93.14%	≥ 96.74%	≥ 98.48%	≥ 99.24%
Generic Connector Random Mating	1310 nm	0.70	**0.179**	72.8%	**80.8%**	**85.9%**	**90.6%**	**96.2%**	**98.1%**
	1550 nm	0.62	**0.170**	75.2%	**83.8%**	**88.7%**	**93.7%**	**96.8%**	**99.1%**
Generic Connector with Master Patch Cord	1310 nm	0.36	0.097	94.4%	99.3%	99.3%	100%	100%	100%
	1550 nm	0.33	0.092	97.9%	99.3%	100%	100%	100%	100%
SENKO Super Low-Loss Random Mating	1310 nm	0.26	0.067	99.6%	100%	100%	100%	100%	100%
	1550 nm	0.20	0.060	100%	100%	100%	100%	100%	100%

Comparison IL distribution of 12-fiber MPO connectors @1310 nm, random mating



Comparison IL distribution of 12-fiber MPO connectors @1550 nm, random mating

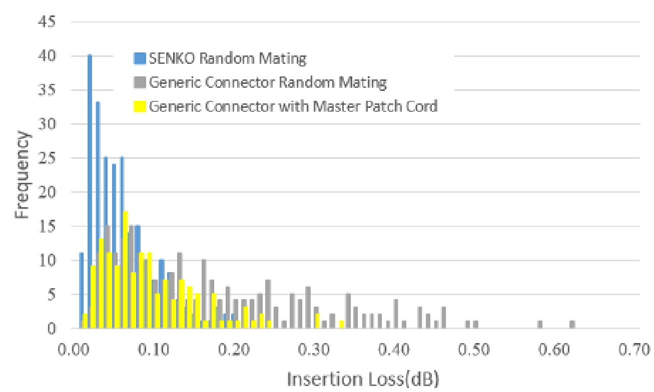
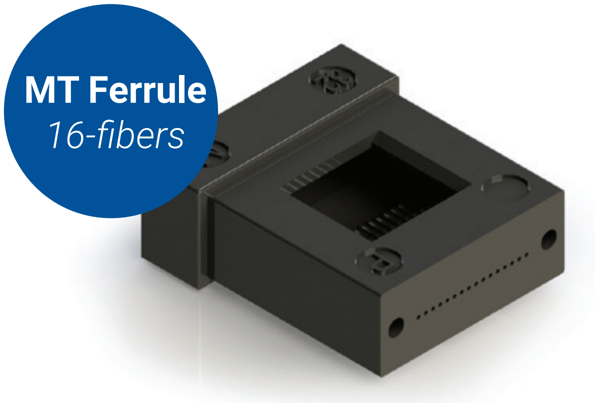


Figure 4 *Comparison IL distribution of 12-fiber MT @1310/1550 nm, random mating between SENKO and Generic MPO connectors.*

Comparing the test results with the IL standards outlined in the IEC 61755-3-31 standard performance grades, the generic low-cost connector does not meet the Grade B standard with the average insertion loss being greater than 0.12 dB for the 1310 nm and 1550 nm wavelengths. In addition, the yield of connectors with IL below 0.30 dB, 0.35 dB, 0.40 dB, 0.45 dB, and 0.50 dB fall short of their respective yield requirements.

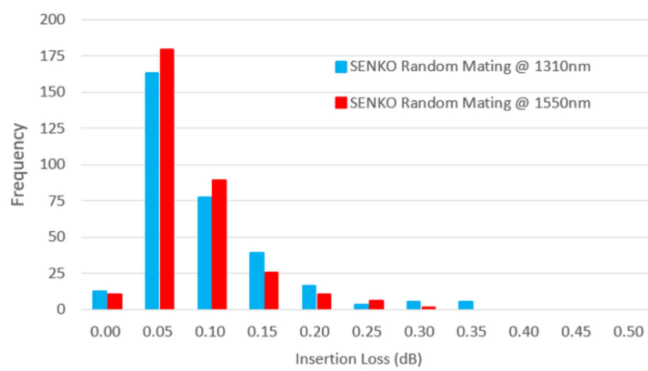
Comparatively, the SENKO super low-loss connectors under test fully comply with the IEC 61755-3-31 standard performance grade with only one connector having an IL of 0.26 dB at 1310nm, which gives it an almost perfect result. In addition, the average IL at 0.067 dB at 1310 nm and 0.06 dB at 1550nm, are significantly lower than the requirement. It is also observed that this result also passes the requirement under the IEC 61753-1 standard for single-fiber ferrule Grade B connectors.



Although the IEC 61755-1-31 standard does not outline multi-fiber ferrules with more than 12 fibers, the 16-fiber and even 32-fiber MPO connectors are widely used in data centers. As the number of fibers in a single-ferrule housing increases, so do the challenges in maintaining a reliable and low-loss connector. As a challenge, SENKO put the super-low-loss 16-fiber MPO connector through the same random mating IL tests.

The results show that even with the higher fiber count, SENKO's super-low-loss MPO connector fully complies with the IEC 61755-3-31 and almost even passes the IEC 61753-1 standard for single-fiber ferrule Grade B connectors that requires 97% of tested connectors having ≤ 0.25dB.

IL distribution of 16-fiber MPO connectors with random mating @1310 nm and 1550 nm



SENKO Super-Low-Loss 16-Fiber MPO						
	Max.	Avg.	≤0.25 dB	≤0.30 dB	≤0.35 dB	≤0.40 dB
IEC 61755-3-31 Grade B requirement		≤ 0.12	≥ 71.94%	≥ 85.53%	≥ 93.14%	≥ 96.74%
SENKO Random Mating @ 1310nm	0.330	0.069	96.88%	98.44%	100%	100%
SENKO Random Mating @ 1550nm	0.300	0.057	99.69%	100%	100%	100%

Figure 5 *SENKO's super-low-loss 16-fiber MPO random mating, surpasses the IEC 61755-3-31 Grade B requirements.*

Summary

SENKO has refined the designs and manufacturing processes on its range of super-low-loss MPO connectors to improve performance during random mating to exceed the requirements outlined in the IEC 61755-1-35 standard. Optimizations have been made to the overall dimensions, fiber hole eccentricity, and fiber hole tilt angle to improve the IL performance repeatability. These design improvements manifest themselves as lower and tighter optical losses during random mating scenarios.

SENKO connectors have demonstrated their superiority over competitors by successfully passing the rigorous GR-1435 standards, ensuring a reliable Multi-Fiber Optical Connector. GR-1435 sets stringent requirements for MPO interconnects, subjecting them to various environmental and mechanical stresses. Consequently, it is advisable for end-users to request such data from their MPO provider to guarantee reliability in the field. SENKO is ready to support with test setup configurations and advise on how to replicate your own Random Mating test at your facility.

In addition to meeting industry standards, a thorough interoperability study revealed that, when testing MT-based connectors against master cables, optical performance often remains high regardless of connector type. However, the real-world scenario in the field differs from laboratory conditions due to two key factors. First, technicians may lack sufficient knowledge, proper end-face cleaning gear, and visual inspection equipment. Second, connecting connectors from different manufacturers and not against master cable results in higher losses than those reported in controlled laboratory environments.

SENKO's MT super low-loss ferrules address these challenges effectively by minimizing the impact of these factors. This is achieved through superior guide pins alignment and meticulous attention to fiber hole geometrical parameters, refined through years of experience and continuous improvement in Japan. As a result, SENKO connectors offer a reliable solution that significantly reduces the loss associated with interconnection in practical field applications.

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.

Bernard HL Lee is currently the Regional Technology Director at SENKO Advanced Components. He started his career in optical communications when he was appointed as 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 also Head of Innovation and Communications. Bernard then joined the parent company, Telekom Malaysia (TM) in 2010 as the Assistant General Manager of the Group Business Strategy Division where he oversees the company's business direction. Bernard is also a member of the International Electrotechnical Commission (IEC), the Institute of Engineering and Technology (IET) and is also the Director of the Board of the Fiber-To-The-Home Council APAC.

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