FlexAirConnecT – Dust Insensitive Multi-Fiber Connector with Low Loss and Low Mating Force –

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Physical contact (PC) optical connectors are commonly used for their favorable connection characteristics. However, PC connectors have some drawbacks such as the necessity of careful end face cleaning and an increasing mating force as the number of fibers increases. To overcome these drawbacks, we have developed a new multi-fiber connector that has an air-gap between its end faces. Eliminating the need for PC connection, this connector offers good optical characteristics and high reliability. This paper reports on the optical characteristics and reliability test result of the new connector.

Keywords: multi-fiber connector, dust-insensitive, air gap, reliability

1. Introduction

Data traffic on the internet is increasing due to cloud and video-streaming services, which have been rapidly rising in popularity. As a result, there is a growing demand for optical communication capable of fast and high-capacity data transmission at data centers that handle the information traffic.

Currently, at data centers, dominant device-to-device optical connection systems use a lucent connector (LC) as a single-fiber connector and a multi-fiber push-on (MPO) connector*1 as a multi-fiber connector. These connectors are connected by physical contact (PC). In the PC connection, optical fibers come into direct contact with each other under pressure so that the cores come in close contact with each other with no gap between them that can attenuate the optical signals, as shown in Fig. 1. The PC connection ensures favorable optical characteristics such as low connection loss and high return loss.

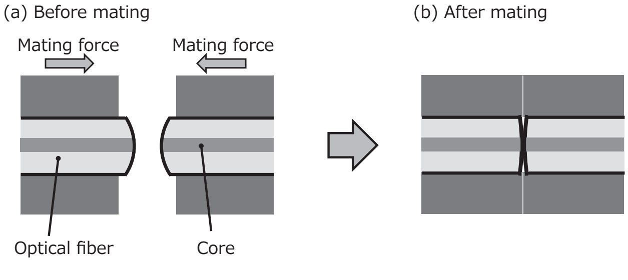


Fig. 1. Schematic diagram of PC connection

However, PC connectors have the following issues. One is the need to increase the mating force. With the increase in the fiber count per connector, because of the connecting principle governing the PC connection, it becomes necessary to raise the mating force. The MPO connector has been standardized by the IEC.*2 The specifications state that the mating force shall be 9.8 N(1) for connectors with fibers arranged in a row, such as with a fiber count of 12, and 20 N(2) for connectors with fibers arranged in two rows, such as with a fiber count of 24. As the demand for optical communication grows, the need for higher fiber counts is expected to rise. To keep in line with this trend, the MPO connector needs to be fitted with a higher mating force, which will probably result in an increase in the cost incurred by the strengthened connector housing, making the connector more difficult to work with. Another issue is the need to keep the connector end faces clean. The core size of a multimode fiber is small at 50 µm. At this size, trace amounts of dust and other contaminants can block the light path, causing increased losses at the connection. Moreover, because the PC connection requires the cores to come into direct contact with each other to transmit light, mating fiber end faces with contaminants present between them may result in the contaminants being pressed against the end faces and adhering to them.

To solve these issues, vigorous efforts are being made to explore and develop an optical connector that avoids the PC connection principle. One idea is for a lens connector(3)-(6) that expands the beam of light by a lens attached to the connector. One feature of this design is that the expanded beam reduces the effect of contaminants blocking the light path. Additionally, unlike with the PC connection, the lens connector no longer needs the optical fibers to come into direct contact with each other. This implies that the mating force can be constant, independent of the fiber counts, and it avoids the problem of the contaminants in the light path adhering to the ends of the fibers under pressure. In developing a lens connector, alignment between the fibers and the lens attached to the connector is a very important factor because a misaligned lens will directly lead to losses.

Providing a slight clearance between the mated connectors is another method of avoiding a PC connection. The air gap connector designed based on this idea also has a similar effect to the lens connector. Although it does not differ much from the PC connector in its susceptibility to contaminants blocking the light path because the light beam is not expanded, the air gap connector offers the advantages of a reduced mating force and no contaminants adhering to the light path because there is no need for direct contact between the connector end faces. This method differs from the lens connector in that the only optical component that requires alignment is the optical fiber. Consequently, the effects of manufacturing variations that result in misalignment are minimized, contributing to a low insertion loss. Reference (7) describes how to form concave fiber end faces by a special polishing process to produce an air gap when the connectors are mated. With this method, optical interference between the connector interfaces is reduced by an antireflective (AR) coating.

Sumitomo Electric Industries, Ltd. has developed an air gap connector (FlexAirConnecT) that has a film on the connector end face to form an air gap. This method has an advantage over the design described in Reference (7) in that the connector gap can be selected more flexibly. Because of this advantage, we have been able to reduce both the optical interference and the insertion loss even without the use of an AR coating.(8)

2. Structure

Figure 2 illustrates the structure of the newly-developed air gap connector. The geometry of the connector differs from the conventional MPO connector, and the air gap connector has a film attached to the ferrule end face of the male connector. As a result, it can be manufactured using almost the same process as the MPO connector. The only additional step needed is to attach the film to the ferrule end face of the male connector. The film and the ferrule are made of the same material and therefore have the same coefficient of thermal expansion (CTE). Consequently, this design ensures high reliability by reducing the stresses arising from different CTE values and temperature changes. When mated, the connector has a gap between the ferrules equal to the film thickness. The film is attached to the outer body of the ferrule end face, out of the fiber area. Light beams pass through the air at the connector interface. Since this structure avoids direct contact between the fibers, the connector avoids the problems of a PC connection.

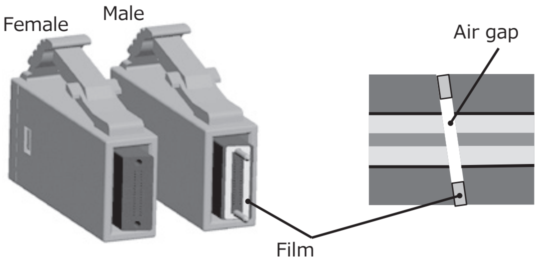
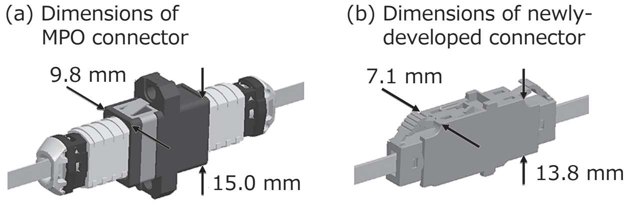


Fig. 2. Perspective and cross-sectional view of FlexAirConnecT

With this design, the mating force of the connector is constant, independent of the fiber count. The mating force of FlexAirConnecT has been set at 3 N, which is sufficient to stabilize the mated connectors. The load is approximately one-seventh of the mating force of standard 24-fiber MPO connectors. The lower mating force has allowed us to simplify the housing. The cross-sectional area of the adapter is 13.8 mm by 7.1 mm, as shown in Fig. 3, which is a 35% reduction over the MPO adapter.


(a) Dimensions of MPO connector

(b) Dimensions of newly-developed connector

(c) Dimensional comparison of rows of four adapters

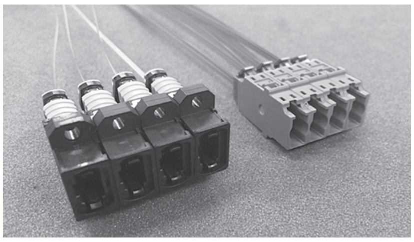


Fig. 3. Dimensional comparison

3. Optical Design

As described in the previous section, FlexAirConnecT features an almost identical design with the MPO connector except for the film affixed to the end face of the male ferrule. Therefore, the basic optical design of the air gap connector follows the optical design of the MPO connector, with the film thickness and the angle of the ferrule end face optimized. The goals of this optical design were to avoid optical interference even without the use of an AR coating and to reduce the connection loss to 0.75 dB or less, which is as low as that of a standard grade MPO connector.

Optical interference is caused by multiple reflections at the connector interface. More specifically, in addition to the intended transmitted light, light is propagated by reflection between the two connector end faces. This reflection can be repeated several times, resulting in optical interference. Optical interference results in unstable optical characteristics because the light intensifies or decays depending on the relationship between the connector gap and the wavelength of the light. Optical interference is eliminated by preventing multiple reflections from reaching the receiving component. To achieve this, reflected light is either reduced by an AR coating or deflected to a spot away from the light-receiving core. The former technique, used in Reference (7), requires large equipment, which is a disadvantage. In contrast, the latter technique can be implemented by optimizing the film thickness and the angle of the ferrule end faces.

MPO connectors designed for single-mode fibers generally adopt end faces ground to an angle of 8°. We decided to use this angle for the ferrule end faces because the 0° grinding used with MPO connectors designed for multimode fibers is ineffective in controlling interference. Next, the relationship between the ferrule-to-ferrule gap and insertion loss was determined by experiment. A mechanical transferable (MT) connector was fabricated with multimode fibers set in MT ferrules, and the end faces ground to an angle of 8°. Insertion losses were measured while varying the gap between the end faces using an aligning device. The value of the insertion loss varies drastically in response to changes in the gap at the interface as a result of optical interference. We decided to select a range that would avoid this variation. The measurement results are shown in the graph in Fig. 4. The smallest connector gap in the measurement was 5 μm. The insertion loss varied significantly with changes in the gap at the interface for a connector gap of less than 14 μm, indicating optical interference. The variation in the insertion loss decreased as the gap at the interface increased. However, the loss itself gradually increased. To meet the target connection loss of 0.75 dB, we divided the loss into its elements. By using a low-loss grade ferrule, the insertion loss due to ferrule is less than 0.35 dB. In addition to that, a loss of 0.3 dB is generated at the two ferrule end faces due to Fresnel reflection[*3]. Taking this into account, the allowable limit for the loss resulting from the gap was 0.1 dB or less.

Optical interference was controlled when the gap was 14 μm or above, while the increase in loss caused by the gap remained below 0.1 dB when the gap was 30 μm or less. Consequently, we selected a design value of 25 μm as the ferrule-to-ferrule gap, taking into consideration manufacturing tolerances and other factors. We used these parameters to construct a prototype.

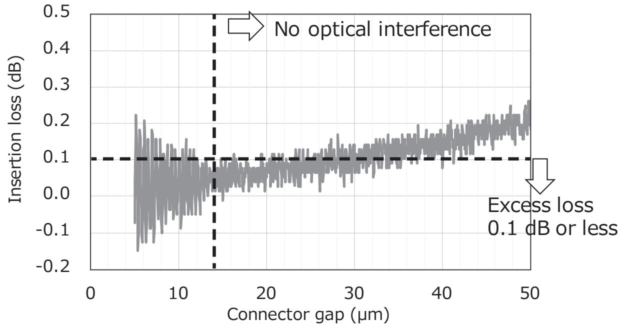


Fig. 4. Insertion loss vs. connector gap

4. Optical Characteristics

A prototype 24-fiber multimode fiber connector was manufactured based on the structure and optical design described above. The optical characteristics of this connector were measured. This connector was the same as the standard MPO connector in that one row of fibers was arranged with a 0.25 mm pitch and the rows were arranged with a 0.50 mm pitch. The wavelength used for the measurement was 850 nm.

4-1 Insertion loss

Figure 5 presents the insertion loss measurement results for the prototype connector. The graph represents the results for 288 channels. Six male connectors were mated randomly with six female connectors twice to form 12 sets of connection. The average insertion loss was 0.49 dB, while the maximum insertion loss was 0.58 dB, thus achieving the target loss of 0.75 dB or less.

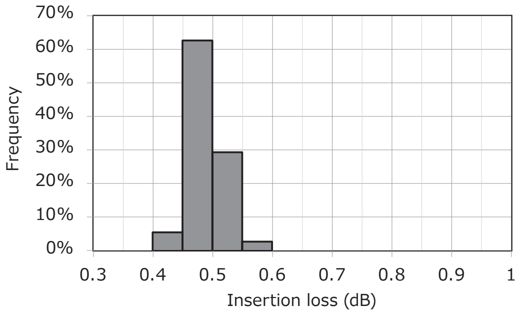


Fig. 5. Insertion loss measurement results

4-2 Return loss

The return loss measurement results for the prototype connector are shown in Fig. 6. The minimum return loss was 38 dB. Light was reflected because it was not a PC connection and there was no AR coating on the connector interface. However, grinding the end faces at 8° proved to be an effective way of avoiding light being reflected to the emitting side of the connector, and gave favorable values for the return loss.

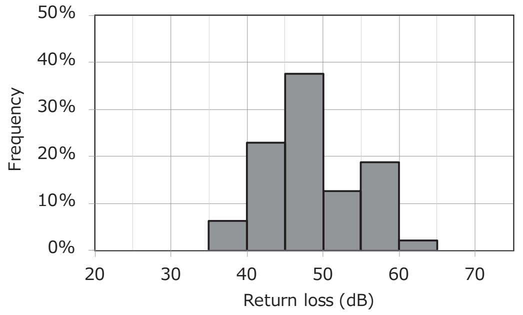


Fig. 6. Return loss measurement results

5. Reliability Testing

Next, the reliability of the prototype air gap connector was tested. In all the tests, a limit of not more than 0.3 dB was set for the insertion loss variation.

5-1 Durability test

A durability test was conducted to evaluate the effect of contaminants produced by the connector or ferrule and the durability of the film.

The test included observing the condition of the end face before and after the test and insertion loss measurement on all the fibers after every 50 cycles. The end faces were cleaned with a simple airblow cleaning tool, which makes cleaning easier than with a conventional cleaning tool that makes contact with the surface. This system can easily be adapted for multiple configurations. The end faces were cleaned every five cycles. Figure 7 shows the test results.

Over a total of 1,000 cycles, the insertion loss variation was good at 0.08 dB or less. No changes in appearance or flaws were observed in the film over the end face.

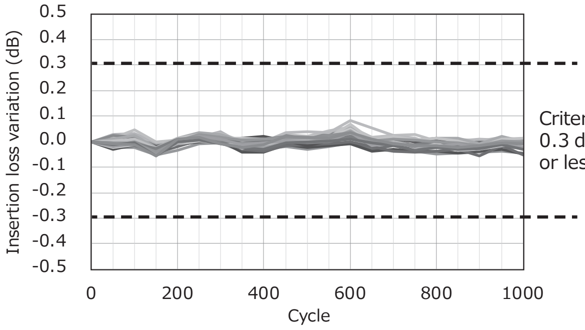


Fig. 7. Durability test results

5-2 Service life tests

We conducted another series of reliability tests based on Telcordia GR-1435-CORE, Issue 2, which is a widely-known standard for environmental testing of multi-fiber connectors. Table 1 presents a list of the tests conducted. The list was compiled for the "Uncontrolled Environment" in Telcordia GR-1435-CORE, Issue 2. The tests were performed consecutively.

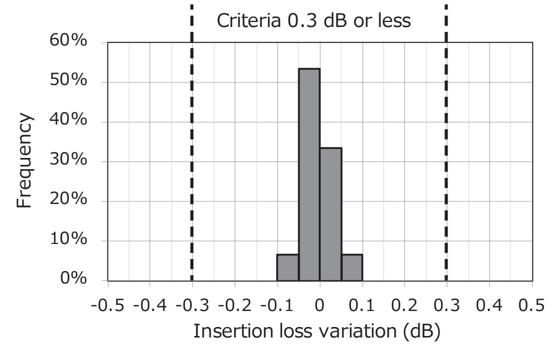
Table 1. Service life tests

Test	Condition
Thermal Aging	85°C, 168 hr
Humidity Aging	95%RH at 75°C, 168 hr
Thermal Cycle	-40 to 75°C, 168 hr (21cycles)
Humidity Cycle	-10 to 65°C 95%RH, 168 hr (14 cycles)
Vibration	10 to 55 Hz, 2 hr / Axis for 3 axis
Flex	2.2 N, ±90°, 100 times
Twist	2.2 N, ±360°, 10 times
Transmission Under The Load	2.2 N, 0°
Impact	1.5 m, 8 cycles
Durability	50 cycles

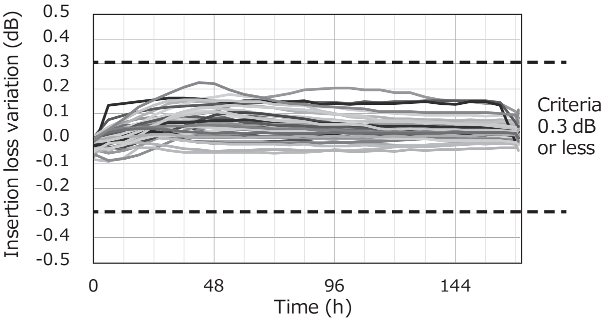
These tests used 15 sets of samples with 360 fibers. The insertion loss was measured before and after each of the tests to reveal any variation. During the tests, the variation in insertion loss was monitored for three fibers per sample set, 45 fibers in total.

Figure 8 represents the insertion loss variation for the first four tests (environmental tests). The insertion loss variation measured before and after the thermal aging test showed a maximum of 0.09 dB. The insertion loss variation was measured before, after, and at 6 h intervals during the humidity aging test. The results showed a maximum variation of 0.22 dB. The insertion loss variation was measured before and after the thermal cycling test and under stable high temperature (75°C), room temperature (23°C), and low temperature (−40°C) conditions. The results showed a maximum variation of 0.19 dB. The insertion loss variation was measured before and after the

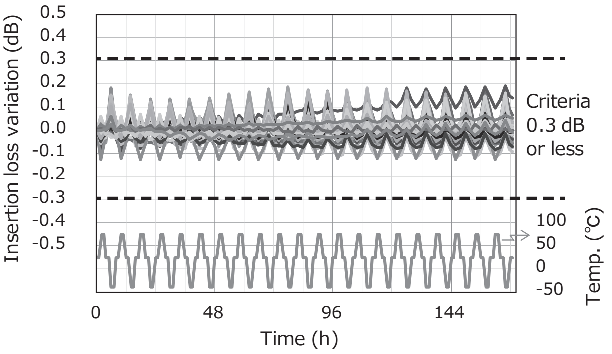
(a) Thermal aging test



(b) Humidity aging test



(c) Thermal cycling test



(d) Humidity cycling test

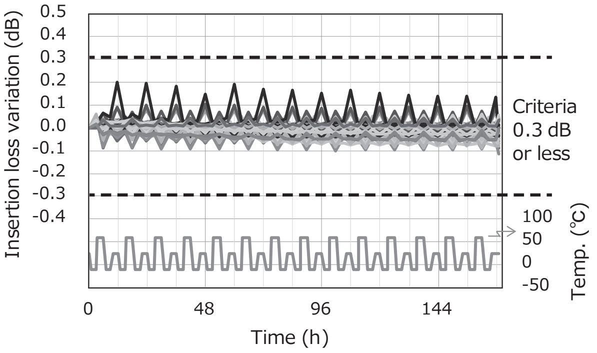


Fig. 8. Service life tests: environmental test results

humidity cycling test and under stable high temperature (65°C), room temperature (23°C), and low temperature (−10°C) conditions, with the maximum variation reaching 0.20 dB. The results of these environmental tests verified that the insertion loss variation of the prototype air gap connector remained below 0.3 dB and thus remained within the limit.

The results of the remaining tests (mechanical tests) are summarized in Table 2. Insertion loss variation was measured before and after each test. The maximum variation of insertion loss was 0.14 dB. The results of these mechanical tests verified that the insertion loss variation was 0.3 dB or less and thus remained within the limit.

Table 2. Service life tests: mechanical test results

Test	Max. loss variation
Vibration	0.02 dB
Flex	0.02 dB
Twist	0.02 dB
Tranmission Under The Load	0.05 dB
Impact	0.14 dB
Durability	0.01 dB

Lastly, insertion losses were measured for all channels. Figure 9 shows a graph of the distribution of insertion loss variations before and after testing. The insertion loss variation was 0.3 dB or less and thus remained within the limit.

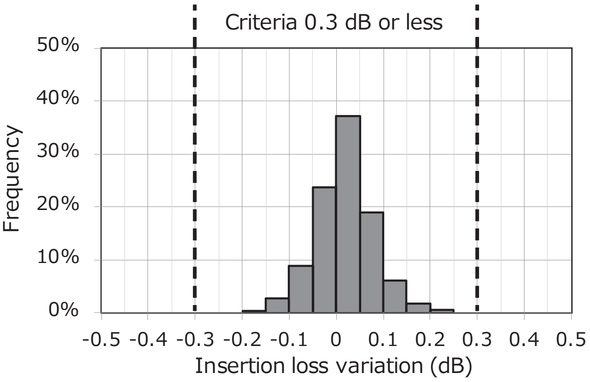


Fig. 9. Service life tests: distribution of insertion loss variation before and after testing

6. Conclusion

Sumitomo Electric has developed a multi-fiber connector that forms a small air gap at the connector interface. Conventional multi-fiber connectors require a strong mating force corresponding to the fiber count to ensure a PC connection, which is not required by the newly-developed connector, FlexAirConnecT. To provide an air gap, FlexAirConnecT uses a film made of the same material as the ferrule, ensuring high reliability. By selecting a suitable film thickness, it is possible to control optical interference and reduce insertion losses without the use of an AR coating.

- FlexAirConnecT is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

Technical Terms

*1 Multi-fiber push-on (MPO) connector: Multi-fiber connector incorporating a PC connection.

*2 International Electrotechnical Commission (IEC): An international organization for standardization specializing in electrical and electronic engineering.

*3 Fresnel reflection: Reflection occurring at the interface between different media. The refractive indexes of the media determine the reflectivity. The use of an antireflective coating reduces the reflectivity.

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