History of fiber optic physical contact connector for low insertion and high return losses

Ryo Nagase*1, Yoshiteru Abe*2, and Mitsuru Kihara*2
*1 Chiba Institute of Technology, Tsudanuma, Japan
*2 NTT Access Network Service Systems Laboratories, Tsukuba, Japan

***Abstract*—SC and MPO connectors using physical contact technology developed by NTT are in use as the de facto standard by carrier networks and data center networks throughout the world. In this paper, we review the SC and MPO connectors that laid the foundation for the fiber connection technologies that support today's optical communication systems.**

Keywords—fiber optic connector, physical contact connection, SC connector, MPO connector

I. INTRODUCTION

Research on optical transmission system was triggered by the successful emission of the ruby laser [1]. Research on the practical use of optical transmission systems was accelerated when the continuous emission of semiconductor laser light was achieved at room temperature [2], and glass optical fiber with a transmission loss of 20 dB/km was realized [3]. In around 1974, NTT started full-fledged research on optical transmission systems. In 1985, NTT completed an optical fiber network over a distance of 2000 km from Hokkaido to Kyushu in Japan. A fiber optic connector that makes it possible to connect/disconnect optical fiber is an indispensable device when constructing such network systems. A fiber optic connector connects optical fibers by butt-jointing ferrules that have a high precision hole in which an optical fiber is fixed in place with adhesive. NTT developed an FC connector [4] with which to construct the above-mentioned optical fiber network, and then went on to develop various fiber optic connectors to meet the requirements of optical fiber network systems. In this way, NTT has contributed to the development of optical communication network technologies. In the history of the development of the fiber optic connector, the physical contact (PC) connection technology developed by NTT has been fundamental in supporting the performance and reliability of the current commercially available fiber optic connectors. Fiber optic connectors can be divided into two types: simplex and multiplex. NTT used PC connection technology to develop an SC connector [5] and an MPO connector [6] as representative simplex and multiplex connectors. In this paper, we review the development history of fiber optic PC connector including the SC and MPO connectors.

II. SIMPLEX FIBER OPTIC CONNECTOR

During the early stages of connector development in the 1970's, the most important issue was finding a way to reduce insertion loss. The connectors needed an alignment mechanism with a repeatable accuracy of around 1 μm for an insertion loss of less than 0.5 dB at mated single-mode fibers. To meet this insertion loss target, the early connectors employed an active alignment method the fiber position was adjusted by monitoring the output power from the fiber end. The FC connector developed by NTT confirmed that low-insertion-loss connection is possible without active alignment simply by inserting the ferrules into a split sleeve. Figure 1 shows the FC connector configuration. The optical fiber is fixed to a precise alumina capillary embedded in the stainless steel ferrule with adhesive. When FC connector plugs are inserted into the adapter, two ferrules in each plug are butt-jointed within a split sleeve housing in the adaptor. The passive alignment mechanism enables us to connect the optical fibers with a repeatable accuracy of better than 1 μm. The butt-jointed ferrules and the split sleeve are floated from the connector housings during connection. The floating mechanism enables us to maintain the optical performance even if an external force acts on the optical cable during operation. In the FC connector, the plug is coupled with the adapter by rotating a coupling nut with the fingers.

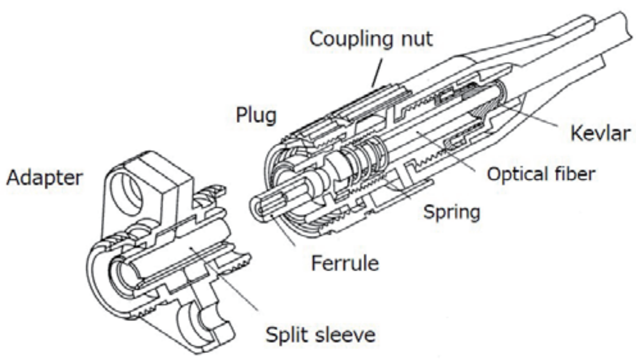
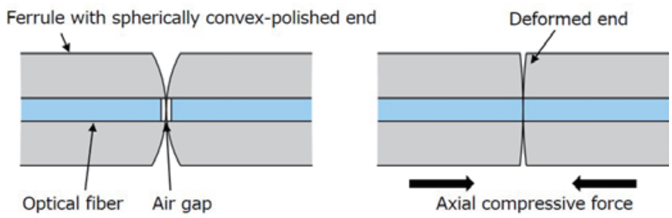


Fig. 1. FC connector.

The initial FC connector needed refractive index matching material applied to the fiber endface to suppress the Fresnel reflection induced by the air gap between the connected fibers. However, if the connection must be performed repeatedly, it is better to eliminate the use of refractive index matching material for the optical connector. To meet this requirement, NTT developed a new connection mechanism called a physical contact (PC) connection [7] where the fiber endfaces are brought into direct contact by pressing together ferrules, with a polished convex spherical shape. Figure 2 shows the PC connection mechanism using a cross-sectional view of the ferrule housing the optical fiber. The polished endface has a spherical convex surface. Since it is difficult to maintain the initial shape of the ferrule endface, the fiber end protrudes or withdraws slightly from a virtual sphere on the ferrule endface. Most of the fiber end withdraws from the ferrule endface. This displacement of the fiber ends is the result of environmental factors such as temperature change. The fiber withdrawal from the ferrule endface generates a gap between the mated fibers, which degrades the return loss. To overcome this fiber end separation from the ferrule endface, the ferrule is deformed by the application of axial compressive force, as shown in Fig. 2. However, the optical connectors are connected for a long time, and so this axial compression force causes an increase in the fiber withdrawal because of the creep of the adhesive used to fix the fiber to the ferrule. When the temperature increases, the difference between the expansion ratios of the fiber and the ferrule materials causes an increase in the fiber withdrawal. To overcome these problems and maintain the initial optical performance, it is important to optimize the fiber end dimensions as shown in Fig. 3. NTT optimized the ferrule end dimensions for realizing a stable PC connection [8]. After polishing the ferrule ends the optimized dimensions are a spherical radius of 10 to 25 mm, a fiber withdrawal of less than 0.05 μm and a convex vertex eccentricity from the ferrule center of less than 50 μm. The optimized PC connection enables us to reduce the reflected light power to about 1/1000 of the signal light power at the connection point and achieve a stable loss of less than 0.5 dB.



(a) (b)

Fig. 2. Physical contact connection mechanism.

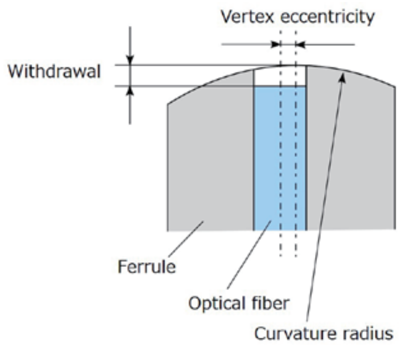


Fig. 3. Ferrule end dimensions.

From the 1980s to the 1990s, the connector was required to realize a high-density connection at low cost for access network systems. The FC connector does not satisfy these requirements because it needs a large space in which a coupling nut can be rotated with the fingers, and it uses an expensive ceramic ferrule. In 1988 NTT developed the SC connector using a PC connection to meet the above requirements. Figure 4 shows the SC connector configuration. The basic alignment mechanism is the same as that of the FC connector using a ferrule and a split sleeve. The SC connector has a plastic-molded rectangular housing with a unique push-pull coupling mechanism that makes the connector easy to operate and the quad connection density compared to the FC connector. To realize high-density connection, a new coupling mechanism was required that did not need to be rotated using the fingers when the connectors were connected/disconnected. The coupling mechanism of the SC connector enables us to connect/disconnect the plug and the adapter by pushing/pulling the coupling sleeve toward the insertion/removal directions. The plug cannot be removed from the adapter simply by pulling the optical fiber unless the coupling sleeve is pulled. On the other hand, the plug can be easily removed from the adapter by pulling the coupling sleeve. The appropriate design adopted for the coupling sleeve and the plug frame of the plug and the cantilever of the adapter provide superior operability. The SC connector was the first to employ a zirconia ferrule, which has now become the international standard because it can be mass-produced at low cost. NTT also developed an advanced PC connection technology [9] to obtain a higher return loss. In advanced PC connection technology, a polishing process using ultra-fine silica particles was added to the usual polishing processes for PC connection in order to remove the strain layer with a high refractive index generated by a polishing process using diamond particles. This advanced PC connection technology enables an SC connector to achieve a return loss of over 40 dB.

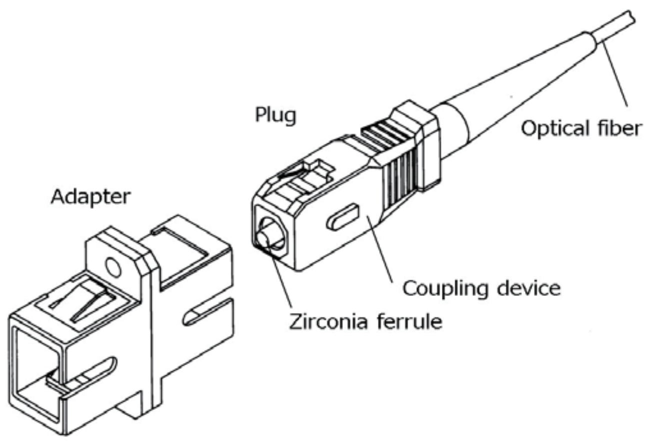


Fig. 4. SC connector .

III. MULTIPLEX FIBER OPTIC CONNECTOR

A compact multifiber connector for optical fiber cable joints was needed to connect two sets of fiber ribbons together in a confined space such as the closure used for access network systems. To meet this requirement, NTT developed the mechanically transferable (MT) connector [10] which makes it possible to connect multiple fibers together. Figure 5 shows the MT connector configuration, which consists of two plastic-molded ferrules with two guide pins, two guide holes and a clamp spring. The fiber ribbon is inserted into a row of fiber holes between two guide holes and fixed in place with adhesive. The ferrules are aligned by inserting the two guide pins into the two guide holes. The coupled ferrules are held together with the clamp spring. Refractive index matching material is used between the ferrule endfaces to reduce the Fresnel reflection caused by the air-gap between the connected fibers. The device is disconnected simply by removing the clamp spring and guide pins. The 4-, 8-, and 16-fiber MT connectors are currently used in fiber-to-the-home (FTTH) services in Japan.

Figure 6 shows the endface of an MT ferrule. In the MT ferrule endface, several fiber holes are positioned between two guide holes. The origin is designated as the middle point of two guide hole centers. Each fiber hole is designed to be arranged with the designated fiber pitch on the basis of the origin. However, the actual fiber hole positions on the fabricated MT ferrule endface are different from the designated ideal positions because the molds are not perfectly accurate and/or plastic might deform during the MT ferrule fabrication. The large fiber hole eccentricity might result in large insertion loss of an MT connector, so it must be minimized for low insertion loss MT connectors. The single-mode up to 12-fiber MT connectors can provide a low insertion loss of less than 1.0 dB.

A physical contact (PC) type multifiber connector that does not need refractive index matching material is also required for multifiber wiring between the equipment used in access network systems. To meet the requirement, NTT developed the multifiber push-on (MPO) connector using a PC connection that achieves a high return loss without refractive index matching material. Figure 7 shows the MPO connector configuration, which consists of two plugs housing the MT ferrule and an adapter. The fiber ribbons fixed in the MT ferrules with the adhesive are coupled by the same alignment structure as the MT connector with two guide pins and two guide holes. The plug and adaptor are engaged by fitting a pair of elastic hooks into the corresponding grooves.

To attain low insertion loss and high return loss with PC connection, the configuration of the ferrule end was improved. Figure 8 shows the structure of two ferrule ends aligned using two guide pins. The MT ferrule and fiber ends are obliquely polished at 8 degrees, and the fiber ends protrudes slightly from the ferrule endface. This configuration is obtained using a simple oblique polishing method. The fiber end protrusion is automatically formed during polishing due to the difference in hardness of the plastic ferrule and the fiber. The shape of the MT ferrule and fiber end enables us to achieve PC connection between multifiber arrays and the single-mode up to 24-fiber MPO connectors to obtain a low insertion loss of less than 1.3 dB and a high return loss of more than 60 dB. The MPO connector with its push-pull mechanism also provides ease of operation when connecting or disconnecting multifibers.

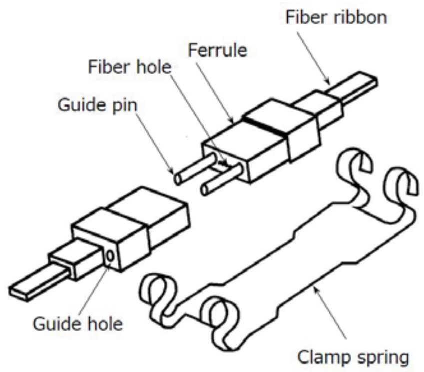


Fig. 5. MT connector.

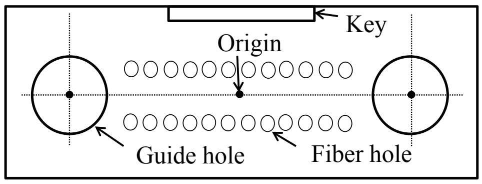


Fig. 6. Endface of MTferrule.

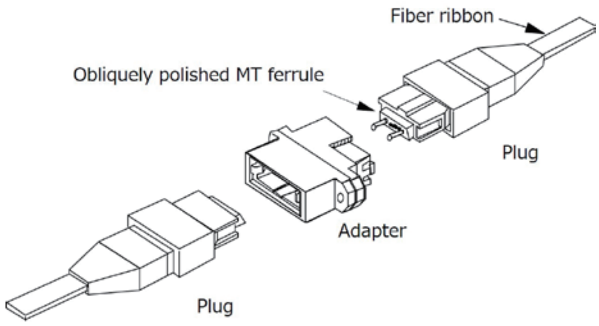


Fig. 7. MPO connector.

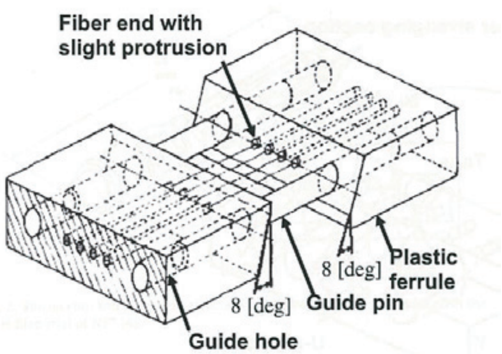


Fig. 8. Structure of two ferrule ends with an oblique endface aligned using two guide pins.

IV. CONCLUSION

The SC and MPO connectors using PC connection technology are superior as regards optical performance, environmental durability, and operability. These excellent features mean that the SC and MPO connectors are still in use as the de facto standard by carrier networks and data center networks throughout the world. Most of the major connectors that have been put to practical use and standardized [11] employ PC connection technology. NTT's development of the SC and MPO connectors laid the foundation for the fiber connection technologies that support today's optical communication systems.

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[11] For examples, see IEC 61754 series (Fiber optic connector interfaces).