Multi-Fiber Connectors for Data Center Applications

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The need for optical interconnection has been increasing at data centers (DCs) to process information for cloud computing and mobile internet services. To accommodate the need, multi-mode fiber systems will be replaced with single-mode fiber (SMF) systems. We have developed multi-fiber connectors (such as multi-fiber push-on and dust-proof connectors) as SMF optical connection solution based on high-precision molding technologies. This paper outlines our latest multi-fiber connectors for DC applications.

Keywords: data center, MT ferrule, MPO connector, dust-proof connector, single-mode fiber

1. Introduction

Communication traffic volume has recently been increasing dramatically with the popularization of cloud computing, mobile Internet, and other information services. In data centers (DCs), which process such information, conventional metallic interconnections have been replaced with optical interconnections to send/receive large quantities of data at high speeds over long distances.

For optical interconnection between communication equipment in a DC, single-fiber LC connectors*1 and multi-fiber push-on (MPO) connectors*2 are mainly used (Fig.1). Multi-mode optical fibers (MMFs) with a core diameter of 50 µm are widely used for conventional optical communication. Although MMFs are easy to connect, they are unsuitable for long-distance data transmission.

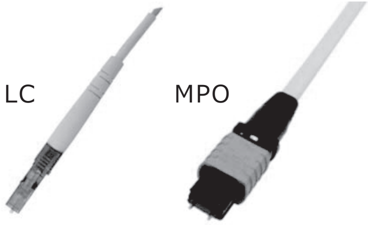

Fig. 1. Optical connectors used for optical communication system in DC

To meet the need of DCs for larger-capacity, larger-scale optical networks, it is expected that communication systems using long-distance, large-capacity single-mode optical fibers (SMFs) with a core diameter of 10 µm will be constructed at a rapid rate in the future. In response to the need for longer-distance, larger-capacity communication, DCs are upgrading their systems from 10 Gigabit Ethernet (GbE)*3 to 40/100 GbE. The IEEE 802.3*4 is working to standardize a next-generation 400 GbE with the target year set at 2017.(1) The above IEEE working group recommends the use of 24 MPO connectors and newly standardized 32 MPO connectors in addition to currently basic 12 MPO connectors for the next-generation 400 GbE. Thus, the need for multi-fiber optical connectors is increasing.(2)

Meanwhile, various problems specific to optical interconnection have been posed as a result of widespread use of optical connectors in DCs and various approaches to these problems have been made. Differing from electrical connectors, optical connectors require their connecting end faces to be cleaned before use in order to deliver the intended performance. An extremely large number of optical connectors are used to connect optical fibers when an optical communication system is installed in a DC.

Therefore, the end face cleaning workload cannot be overlooked. Optical connectors are required to be so easy to handle as electrical connectors. To satisfy the above requirement, various types of dust-proof optical connectors and those that do not require cleaning have been devised and reported.(3)-(6)

This paper describes the new multi-fiber SMF connectors that we have developed and have been developing to satisfy future requirements in DC applications.

2. MPO Connector and Precision-Molding Technology

2-1 MPO connector

An overview of an MPO connector using mechanical transferable (MT) ferrules as its key components is shown in Fig. 2. Fiber-mounted ferrules with and without guide pins are stored in the MPO housing, and are connected via an adaptor. A compression spring (9.8 or 20N) is also built in the housing to ensure mechanical connection (physical contact) of the fiber cores. The end face of an MPO connector for SMFs is polished at 8° to minimize the return loss.

The end face of an MT ferrule that exerts a decisive influence on the MPO connector is illustrated in Fig. 3. Optical fibers 0.125 mm in diameter are arranged at 0.25 mm intervals between two guide holes with a diameter of 0.7 mm. These guide holes are used as the references for positioning the connector. In the coordinate system that uses the center of each guide hole as the origin, the difference of the actual fiber position from the design position is called eccentricity. The connection loss of the MPO connector depends mostly on the axis misalignment of the

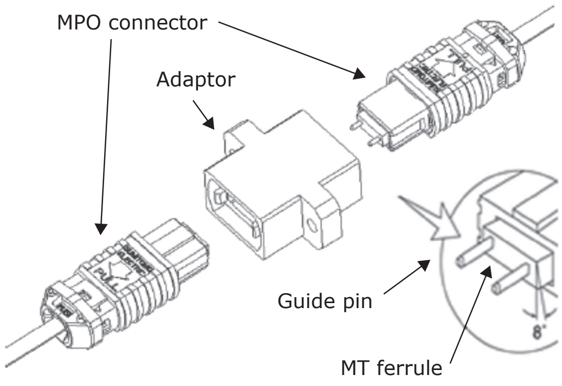

Fig. 2. Overview of MPO connector

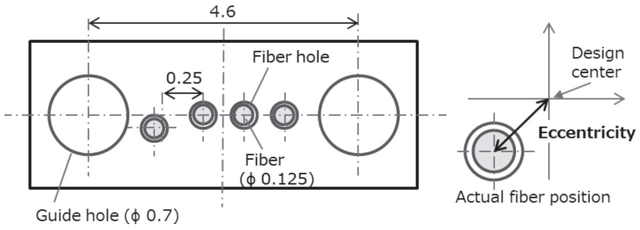

Fig. 3. End face of MT connector and definition of eccentricity

fibers. The technical key to minimizing the connection loss is how to reduce axis misalignment.

The correlation between the axis misalignment and connection loss for an SMF is shown in Fig. 4.(7) In general, the axis misalignment between fibers must be reduced to 1.6 µm or less to achieve the connection loss required for so-called low-loss (LL) grade connectors, which is 0.5 dB or less. On the other hand, the connector must be positioned accurately until its eccentricity reaches one-half of the above misalignment or the submicron level of 0.8 µm. Meanwhile, the yield rate of multi-fiber connectors is affected by a certain power of the increase in the number of fibers. To manufacture stable quality multi-fiber connectors, it is indispensable to employ sophisticated MT ferrule processing technology.

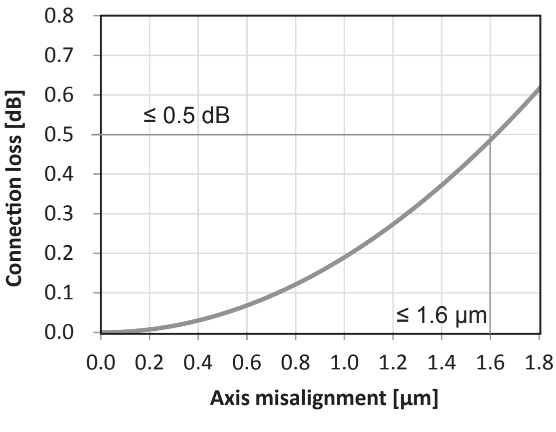

Fig. 4. Correlation between axis misalignment and connection loss

2-2 Ultraprecision molding technology

MT ferrules are resin products manufactured by a processing technology called injection molding. In injection molding, one of the current plastics processing technologies, heat-melted resin is injected into a die and cooled/solidified to a product (molding). Injection molding excels in continuously mass-producing resin products by using an automatic injection machine. For popular injection-molded products having a size similar to that of MT ferrules, molding shrinkage (approximately 0.5%) gives the products a dimension error of several tens of µm. To manufacture MT ferrules by injection molding for which a sub-micron dimensional accuracy is required, it is essential to employ a high-precision molding technology that can reduce the dimension errors to the required levels. Specific element technologies are described below.

As the material for MT ferrules, we use poly phenylene sulfide (PPS),*5 a crystalline thermoplastic engineering plastics. PPS is generally characterized by excellent dimensional accuracy, mechanical strength, and chemical resistance. We add spherical silica to PPS to the upper content rate limit in order to provide this resin with high dimensional accuracy by minimizing the molding shrinkage, thermal expansion coefficient, and anisotropy.

Figure 5 shows an overview of MT ferrule molding die components. The slider holds the core pins that are used to form fiber holes and guide holes, while the slider is fixed by the pin catcher when molding the MT ferrules. Dimensions of the principal components have submicron accuracy. In addition, we use a molding die of a special construction in order to reduce the curvature of fiber holes to the utmost limit. Curved fiber holes have substantial influence on the quality of connectors in the manufacturing process (polishing process). The cavity support (CS) shown in Fig. 5 holds the core pins, which are used to form fiber holes, in the center of the molding die. This structural design restrains the resin pressure from bending the core pins during the molding process. The use of the above molding die can guarantee the curvature of the MT ferrule fiber holes to be 0.2° or less.

To ensure the manufacture of high-precision, high-quality MPO connectors, the precision of the measurement technology used for them must be equal to or higher than that of the molding technology. We have acquired various technologies that can measure connector dimensions to submicron accuracy.

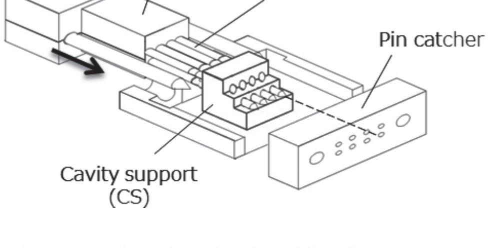

Fig. 5. Overview of MT ferrule molding die components

3. MPO Connector for SMF

The products we have already commercialized or are currently developing by employing the high-precision molding technology discussed above are presented below.

3-1 MPO connector for 40/100 GbE application

Use of 12 MPO and 24 MPO connectors are recommended for 40/100 GbE. The specifications of 40 GbE are based on a 12-fiber cable solution in which four fibers are used to send signals and another four fibers are used to receive signals (10 G × 4 ch). In one of 100 GbE specifications, 10 fibers of totally 24 fibers are used to send signals and another 10 fibers are used to receive signals (10 G × 10 ch).

(1) Q8MPO (MT)

Out of the 12 fibers of a 12 MPO connected to an optical transceiver (QSFP) used for sending and receiving signals, four fibers in the center of the cable are usually left unused (dark fibers). Leaving these fibers unused is an issue that cannot be overlooked for DCs where huge amounts of cabling materials are used. We have already devised an 8 fiber solution that can use cabling materials economically.

An overview of a Q8MPO connector that eliminates the use of dark fibers is shown in Fig. 6. In this connector, four fiber holes in the center of a conventional standard 12 MT ferrule are eliminated and four fibers are arranged on both sides, thereby using all optical fibers effectively. Figure 7 shows the distribution of loss that was measured when a Q8MPO for SMFs was connected randomly. It can be confirmed from this figure that the Q8MPO has satisfactory performance characteristics. In particular, the average and maximum connection losses measured at a wavelength of 1.31 µm were 0.09 and 0.31 dB, respectively.

A Q8MPO may be connected to a standard 12 MPO in some applications. In preparation for such applications, we connected/disconnected a Q8MPO to/from a 12 MPO continuously 500 times, and observed the end face condition (roughness) of the Q8MPO ferrule. The observation result is shown in Fig. 8. The flat area in the center of the end face, where no fiber was placed, was free of dent that might have been formed as a result of physical contact between opposing fibers. It has also confirmed from the performance reliability test results for the above Q8MPO connected to another 12 MPO that the Q8MPO satisfies the requirements of the applicable standard and has sufficient connection interchangeability with standard connectors.

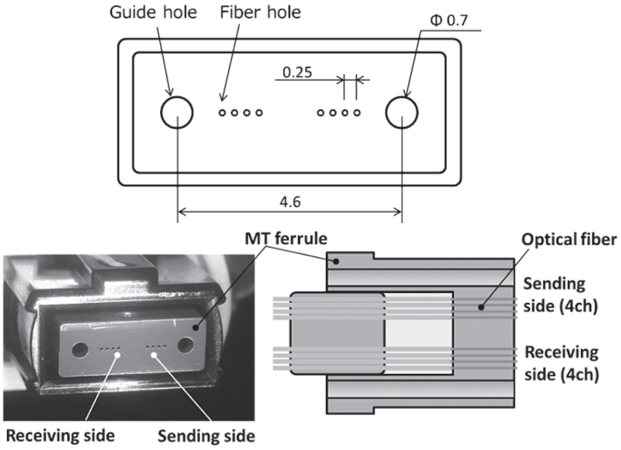

Fig. 6. Overview of Q8MPO connector

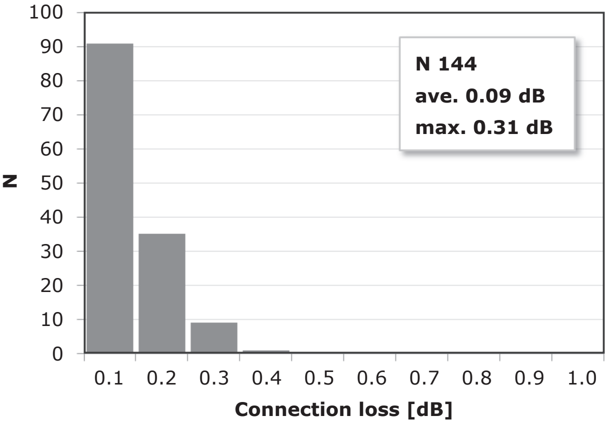

Fig. 7. Connection loss distribution of Q8MPO (SMF) 31/ Fiber

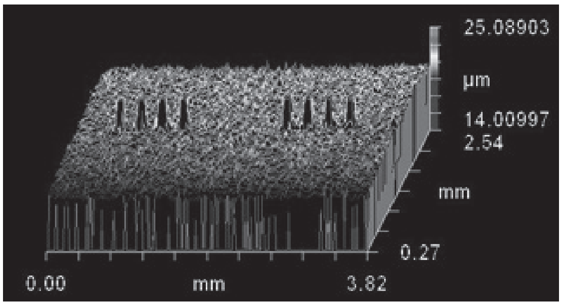

Fig. 8. End face condition of Q8MPO after continuous connection/disconnection 500 times

(2) 24 MPO connector

The end face of a 24 MT ferrule is shown in Fig. 9. The distribution of the random connection loss of the 24 MPO (SMF) connector comprising the above 24 MT ferrule (measurement wavelength: 1.31 µm) is shown in Fig.10. The average and maximum connection losses of 60 facing specimens (1440 channels) were 0.10 dB and 0.38 dB, respectively, verifying that the characteristics of the 24 MPO connector fully meet the requirements for LL grade.

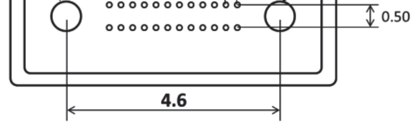

Fig. 9. 24 MT ferrule

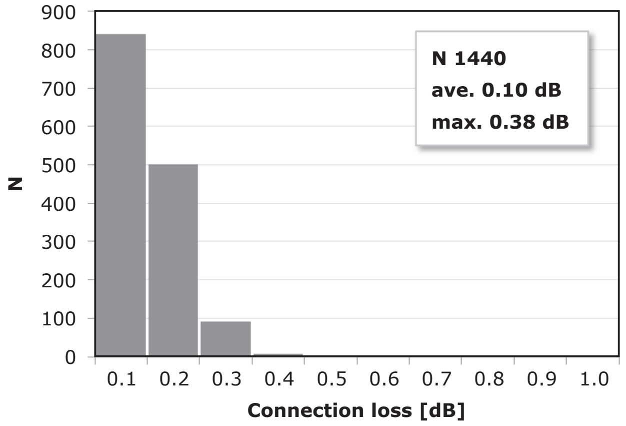

Fig. 10. Connection loss distribution of 24 MPO (SMF)

3-2 MPO connector for 400 GbE

The interface of a 32 MT ferrule for 400 GbE proposed by TIA and IEC*6 is shown in Fig. 11. In the 400 GbE, 16 fibers (25 G × 16 ch) are used on each of both sending and receiving sides. Compared with a conventional 24 MT ferrule, the 32 MT ferrule has the same external dimensions and fiber hole array pitch (0.25 mm in X-direction and 0.5 mm in Y-direction). However, the guide hole array pitch is extended by 0.7 mm from the conventional 4.6 mm to 5.3 mm and the diameter of the guide holes is reduced from the conventional 0.7 mm to 0.55 mm. The purpose of the above dimensional change is to secure an area sufficient for additionally arraying four fibers in the X-direction.

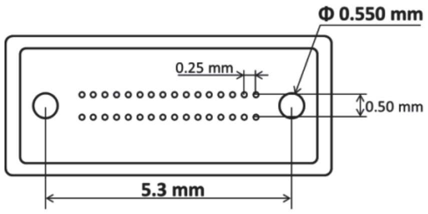

Fig. 11. 32 MT ferrule

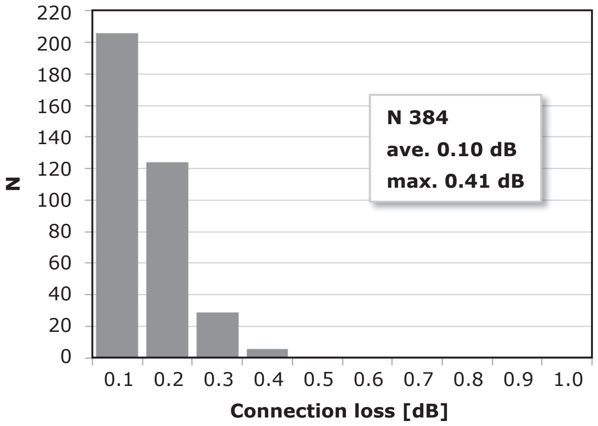

Fig. 12. Connection loss distribution of 32 MPO (SMF)

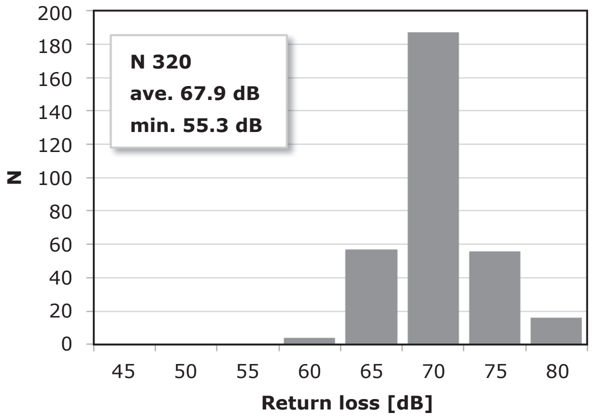

Fig. 13. Return loss distribution of 32 MPO (SMF)

Table 1. Environment test results for 32 MPO (SMF)

Item	Test condition	Max. increase in loss
High temperature	85°C for 7 days	0.06 dB
High temperature/ humidity	75°C/95% for 7 days	0.11 dB
Temperature cycle	-40 to 75°C for 7 days (21 cycles)	0.15 dB
Temperature /humidity cycle	-10 to 65°C/90 to 100% for 7 days (14 cycles)	0.07 dB

Figures 12 and 13 show the distributions of the random connection loss and return loss of the 32 MPO (SMF) we are developing at present, respectively (measurement wavelength: 1.31 μm). The average and maximum connection losses were measured to be 0.1 dB and 0.41 dB, respectively, while the average and minimum return losses were measured to be 67.9 dB and 55.3 dB, respectively. These values verify that the new 32 MPO connector has excellent performance characteristics. To place the 32 MPO connector on the market, we have been carrying out various reliability tests. As an example, the environmental assessment test results for this connector are shown in Table 1. We have confirmed from this table that the increase in the loss of this connector satisfies the requirement of the applicable standard (0.3 dB or less) without raising any problem.

4. Dust-Proof (Non-contact) Multi-Fiber Connector for SMF

The multi-fiber connectors for DC applications are required to further increase the number of connectable fibers and further reduce the connection loss. Various problems must be solved before meeting the above requirement. In particular, the force necessary to insert fibers increases as the number of fibers increases and the connectors must be cleaned carefully to protect the fibers from damage when they are connected. To solve these problems, various non-contact connectors have been devised.

The advantages of non-contact connectors are that they can maintain the insertion force constant irrespective of the number of fibers and that they rarely allow the entry of dust into the contact points. It is difficult to use a plastic lens to guarantee the performance required of an SMF connector in which the fibers must be positioned to an accuracy of 1 µm or less. We are currently working to apply our high-precision MPO molding technology to the development of a silica fiber-based non-contact multi-fiber connector.

A non-contact multi-fiber connector for SMFs is shown in Fig. 14. A graded index (GI)*[7] fiber, which is a silica fiber, works as a lens in this connector. In particular, a GI lens array plate consisting of two or more GI lenses is firmly bonded to the end face of the MT ferrule. Figure 15 illustrates an optical system in which light is expanded by the GI lens, transmitted through space, and optically coupled with each SMF. The size of the light being transmitted through space increases to approximately 10 µm to approximately 50 µm. Therefore, even if dust enters into the contact points, the insertion loss of the connector is expected to be kept almost free from the effect of the dust.

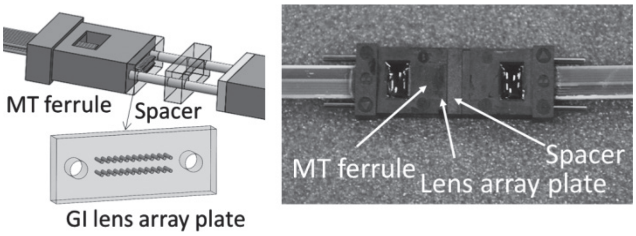

Fig. 14. Internal construction of 24-fiber SMF lens connector

Fig. 15. Illustration of optical system

The distribution of the insertion loss of a prototype 24-fiber SMF lens connector is shown in Fig. 16. The average and maximum insertion losses at a wavelength of 1.31 µm were 0.67 dB and less than 1.6 dB, respectively. Figure 17 shows the temperature-dependence of the insertion loss characteristics in the range of -10 to 60°C. The maximum loss fluctuation after 15 temperature cycles was 0.08 dB, which was sufficiently below the standard value of 0.3 dB. This result was attributed to the fact that the SMF-holding ferrule and GI fiber lens-holding plate were made of the same material, therefore the effect of thermal expansion on the displacement of the fibers was minimized.

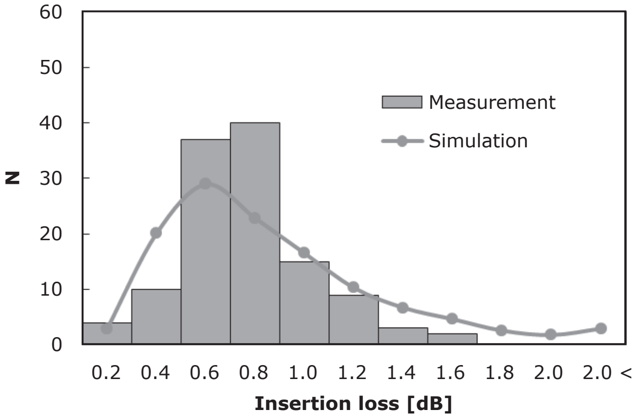

Fig. 16. Connection loss evaluation result

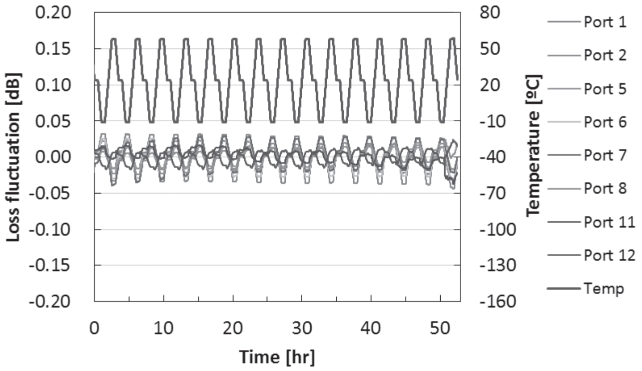

Fig. 17. Temperature-dependence of connection loss characteristics

5. Conclusion

This paper has described our product lineup consisting of various types of MPO connectors and dust-proof connectors, including those under development. These connectors, which are (will be) mass-produced by employing our original high-precision molding technology, can meet the need of next-generation DCs for SMF connection solution.

Technical Terms

∗1 LC connector: An optical connector for single fiber, which uses ϕ1.25 mm zirconia ferrules developed by Lucent Technologies.

∗2 Multi-fiber push-on (MPO) connector: A multi-fiber connector connects optical fibers using physical contact connection technology.

∗3 Gigabit Ethernet (GbE): An Ethernet standard for a communication speed of 1 Gbit/s. 1 Gbit/s represents a data transfer speed of one billion bits per second.

∗4 the Institute of Electrical and Electronics Engineers, Inc. (IEEE): A standards organization in the U.S. IEEE 802.3 is a working group which develops Ethernet standards.

∗5 Poly phenylene sulfide (PPS): A crystalline thermoplastic engineering plastic. PPS is characterized by excellent dimensional accuracy, mechanical strength, and chemical resistance.

∗6 The Telecommunications Industry Association (TIA), the International Electrotechnical Commission (IEC): TIA is a U.S. industry organization devoted to the development of standards for communication equipment. IEC is an international standards organization specialized in the fields of electrical and electronic engineering.

∗7 Graded index fiber: A multi-mode optical fiber whose core has a parabolic refractive index profile.

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