

# Optical Engineering

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## **Fiber-handling robot and optical connection mechanisms for automatic cross-connection of multiple optical connectors**

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**Abstract.** Conventionally, in intelligent buildings in a metropolitan area network and in small-scale facilities in the optical access network, optical connectors are joined manually using an optical connection board and a patch panel. In this manual connection approach, mistakes occur due to discrepancies between the actual physical settings of the connections and their management because these processes are independent. Moreover, manual cross-connection is time-consuming and expensive because maintenance personnel must be dispatched to remote places to correct mistakes. We have developed a fiber-handling robot and optical connection mechanisms for automatic cross-connection of multiple optical connectors, which are the key elements of automatic optical fiber cross-connect equipment. We evaluate the performance of the equipment, such as its optical characteristics and environmental specifications. We also devise new optical connection mechanisms that enable the automated optical fiber cross-connect module to handle and connect angled physical contact (APC) optical connector plugs. We evaluate the performance of the equipment, such as its optical characteristics. The evaluation results confirm that the automated optical fiber cross-connect equipment can connect APC connectors with low loss and high return loss, indicating that the automated optical fiber cross-connect equipment is suitable for practical use in intelligent buildings and optical access networks. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.OE.52.7.076116](https://doi.org/10.1117/1.OE.52.7.076116)]

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## 1 Introduction

With the rapid progress of broadband Internet service, optical communications networks have been extended to the office and home. In these networks, many optical fibers must be connected or exchanged at the connection points between floors in buildings and between access and office networks. Conventionally, many optical cross-connections in an optical cabling system are done manually. Manual cross-connection is time-consuming and complicated, and there is a definite possibility of misconnection. Moreover, skilled maintenance personnel have to be dispatched to remote places to correct failures. From now on, especially in Japan, a rapidly aging society with fewer children is expected. In the communications equipment industry, a shortage of skilled labor will pose a problem.

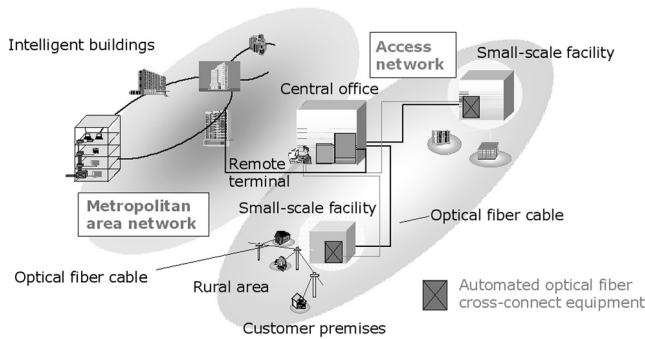
In addition to automatic cross-connection, optical cross-connect equipment requires high optical performance: low insertion loss, high return loss, and transparency at optical wavelengths. Moreover, the optical connection should be self-holding even if the power supply is cut off. For cross-connection work, several optical matrix switches, such as a laser diode optical matrix switch<sup>1</sup> and thermo-optic optical matrix switch,<sup>2</sup> have been proposed. However, these switches do not satisfy the above requirements. On the other hand, cross-connection using optical connectors provides high performance and can meet these requirements;

therefore, automated optical fiber cabling systems have been developed.<sup>3-5</sup> In an optical network, when it is desired to minimize adverse effects of reflected light produced as a result of inserting an optical module, angled physical contact (APC) optical connector plugs are used, which have their connecting end surface polished at a predetermined angle to a plane vertical to a light's axis. For low-loss connection, APC optical connector plugs need to be connected so that their connecting end surfaces contact each other in parallel.

In this paper, we report a fiber-handling robot and optical connection mechanism for automatic cross-connection of multiple optical connectors. We describe the key elements of 200 × 200 automated optical fiber cross-connect equipment that enables remote cross-connection operation. We also present evaluation results for a prototype and show an improved optical cross-connection mechanism, which can handle and connect APC optical connectors.

## 2 Automated Optical Fiber Cross-Connect Module

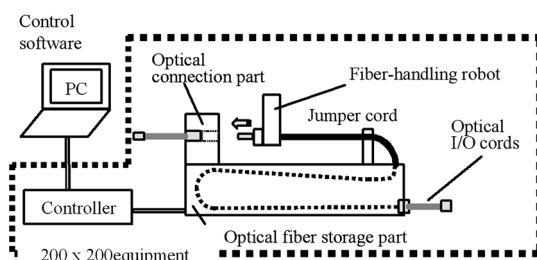
Here, we explain a configuration of the automated optical fiber cross-connect equipment. Figure 1 shows how the automated optical fiber cross-connect equipment is used in an access optical network and a metro network. By introducing this equipment in the optical access network, telecommunication lines can be automatically connected and disconnected in an instant. Therefore, telecommunication



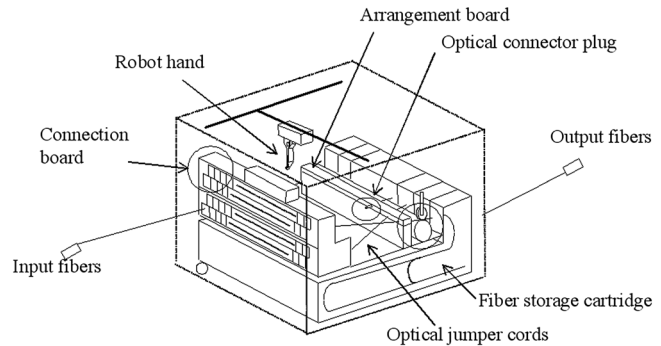
**Fig. 1** Application of automated optical fiber cross-connect equipment.

service can be started and ended promptly; no one has to be dispatched to small-scale facilities in an optical access network. In a metro network, flexible network restructuring becomes possible when floor layouts are remodeled and private networks between floors can be easily constructed in intelligent buildings. A low insertion loss and a high return loss with an optical wavelength independency are desired. Self-holding is also required even if the power supply fails. The switching time should be 1 min on average. To meet all the above requirements, we devised a robotics-based handling method in which a fiber-handling robot connects and disconnects optical connectors to and from optical adaptors to achieve cross-connection of optical fibers. Figure 2 shows the configuration of the 200 × 200 automated optical fiber cross-connect equipment. The equipment comprises a control-terminal physical contact (PC) and the optical fiber cross-connect module. In the terminal PC, operation and maintenance software controls the equipment, issues cross-connection commands, and manages the equipment. The module mainly consists of an optical connection part, robot mechanism part, fiber storage part, and controller.

Figure 3 shows the inside of the automated optical fiber cross-connect module and the fiber-handling robot. The module can connect any 200 input optical fibers to any 200 output fibers by exchanging optical jumper cords. Cross-connections are made by exchanging one plug for another. First, the robot hand disconnects two target plugs, each of which has a jumper cord, and arrange them on the arrangement board. The cord is rewound into the fiber storage cartridge so that it does not become tangled with other cords. Next, the robot hand grasps one of the target plugs and connects it to the target adaptor in the connection



**Fig. 2** Configuration of the automated optical fiber cross-connect equipment.



**Fig. 3** Inside of automated optical fiber cross-connect equipment.

board. It then connects the other plug in the same way. Here, in the operation state of the equipment, each optical connector with an input fiber cord is invariably connected to the optical connection board. This is because it avoids influence on connection loss deterioration due to the sticking dusts on the surface of the optical connectors.

To achieve compactness and high density in this module, we developed the robot mechanism, optical connection part, and optical fiber storage cartridge. To satisfy environmental requirements, the positioning error due to thermal expansion caused by temperature change is corrected by using an *xyz*-positioning sensing method.

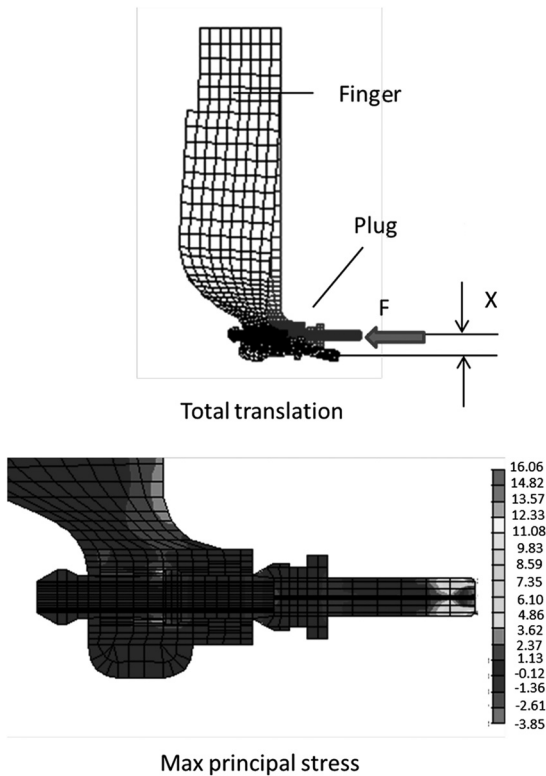
For applying cross-connection between APC connector plugs, we have also developed the finger mechanism of the fiber-handling robot to handle the APC connector plug. We have also developed an optical fiber cord with an APC connector plug and a configuration of an arrangement board in the optical connection part. These mechanisms are also applicable to normal PC optical connectors, which are usually used in an optical fiber cross-connect module.

### 3 Fiber-Handling Robot

#### 3.1 Finger Mechanism

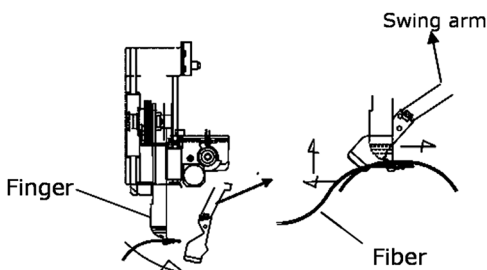
Performing optical cross-connection to a connection board in a high-density mounting requires a finger that can access the whole area of the connection board. A long and thin finger structure is needed so that the finger can maneuver through parts overcrowded with the fiber. We designed such a finger using the finite element method (FEM). The FEM analysis produced a finger shape with enough strength. The analysis model and result are shown in Fig. 4. The stress in the finger part is equal to or less than 1/5 of the yielding point. We confirmed that the finger has enough strength. Moreover, the displacement is 8 μm, which is within the permissible positioning error. Even, when the maximum force is applied to a plug, the displacement is within the designed tolerance.

When the finger connects or disconnects, the connector plugs into or from the adaptors, it must remove the overcrowded fibers without cutting the optical jumper cord and move. Therefore, we developed a mechanism for removing entangled fibers, which is shown in Fig. 5. The arm of the mechanism synchronizes with the vertical motion of the finger. The arm swings rotationally, which enables the fiber to be released from the finger. These approaches contribute to the stability of cross-connecting the optical fibers.

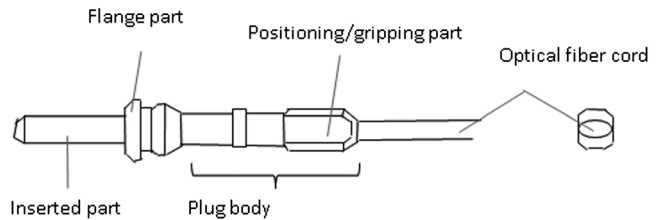


**Fig. 4** FEM analysis model for designing a long and thin finger and result.

Next, we explain the fiber-handling mechanism for treating APC optical connectors. Figure 6 shows the state where the fiber-handling mechanism grips an optical connector plug. As shown in Fig. 6, such a positioning/gripping part can set the posture where optical connection can be done because the optical connector is gripped along with the positioning side using the fiber-handling mechanism. An optical fiber cord is fixed in the body region so that the positioning side becomes parallel to the minor axis of the ellipsoidal section of the optical fiber cord when an optical fiber cord is an ellipsoidal cross section; in other words, the optical fiber cord is at right angles to the major axis of the ellipsoidal section of the optical fiber cord. Further, because the rotational position of the optical connector plug held in the optical connector plug-alignment part can be kept in a predetermined alignment by using the cross sectional shape of the optical fiber cord and the corresponding guide passage in the optical connector plug alignment part, the fiber-handling mechanism can grip the rotational angle reference surface of the optical connector plug easily and reliably.



**Fig. 5** Mechanism for removing entangled fibers.



**Fig. 6** Configuration of the optical fiber cord with the APC connector plug.

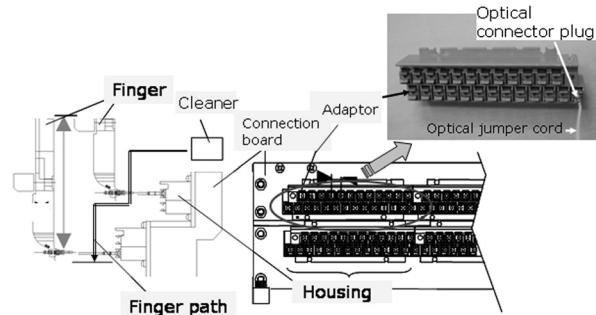
## 4 Optical Connection Mechanism

### 4.1 Optical Connection Board

For high density in the optical connection part, we designed the connection board by using a housing in which 25-port optical adaptors are arranged in two steps. Figure 7 shows the configuration of the optical connection part. The adaptors in the housing are arranged in two lines with the adaptors in one line shifted by a half pitch (3 mm) from those in the other. By stacking the housing, each adaptor is arranged in the vertical direction in four steps. The plug and adaptor are based on the miniature-unit connector so that a low-cost and compact optical connector part can be achieved. The offset sensors for the *xyz*-positioning sensing method are installed on both sides of the optical connection board. The width and height of the optical connection board for 200 ports are 330 and 50 mm, respectively.

### 4.2 Optical Arrangement Board

An arrangement board in the optical connection part is used to arrange the connector plug after an optical fiber cord is rewound into an optical fiber storage unit. The arrangement board aligns optical connector plugs in a horizontal state at an appointed height position and supports it. Figure 8 shows the configuration of the arrangement board. The arrangement board consists of a pair of flat plates. It is made by stacking an upper plate and a base plate. Multiple through-holes allow connection of the optical connection board side and the rewind mechanism side. A guide part is formed at the arrangement board entrance, and a fiber derivation compartment is formed on the exit side. A groove is formed between the guide part and the fiber derivation compartment. For use in the connection of an APC connector, the shape of the entrance of the guide part is similar to the cross sectional shape of the end of the optical connector plug. The section of the vertical direction of the guide part assumes a shape that is the as same as the positioning/gripping part of the optical



**Fig. 7** Configuration of the optical connection part.

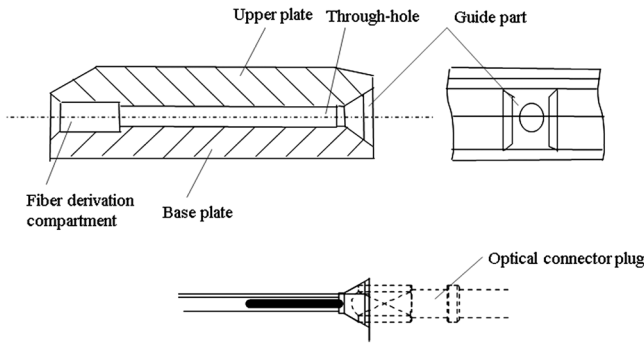


Fig. 8 Configuration of the arrangement board.

connector plug. The cross section of the groove and the cross section of the optical fiber cord assume a similar shape.

### 4.3 Fiber Storage Cartridge

The optical jumper cords are rewound into the fiber storage space to prevent their becoming entangled with other cords during reconnection. The fiber storage cartridge has a function for storing extra lengths of the optical jumper cord. In this optical fiber cross-connection module, it accommodates one of the 200 optical jumper cords, which must be stored into the module. The optical fiber storage cartridge, which is made of plastic molding, was designed so that multiple fibers can be accommodated in one cartridge. This provides compactness and a high packing density and reduces cost. Figure 9 shows the optical fiber storage cartridge. For this cartridge, we developed a structure in which each fiber is aligned and held at four points by the fiber guide parts; therefore, the fibers do not entwine each other. The width and height of the fiber storage cartridges for 200 ports are 310 and 140 mm, respectively.

## 5 Experiments

### 5.1 Fundamental Optical Characteristics

We first measured the insertion loss of the prototype. Figure 10 shows the initial insertion and return losses of the equipment and the experimental setup for optical characteristics measurement. The initial insertion loss is 1 dB or less, and the return loss is 40 dB or more. Next, we measured the change in insertion and return losses with repeated connection and disconnection. Figure 11 shows the insertion loss and return loss changes. After 500 cross-connections, the insertion loss and return loss satisfies the requirements. We confirmed that the average switching time of an optical

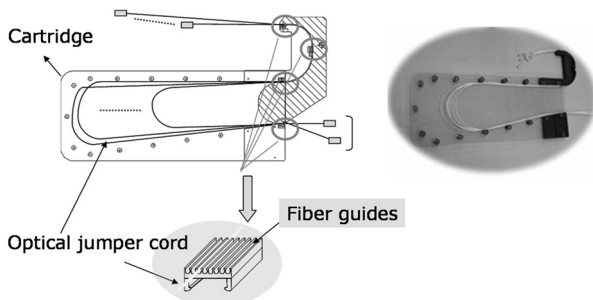


Fig. 9 Optical fiber storage cartridge.

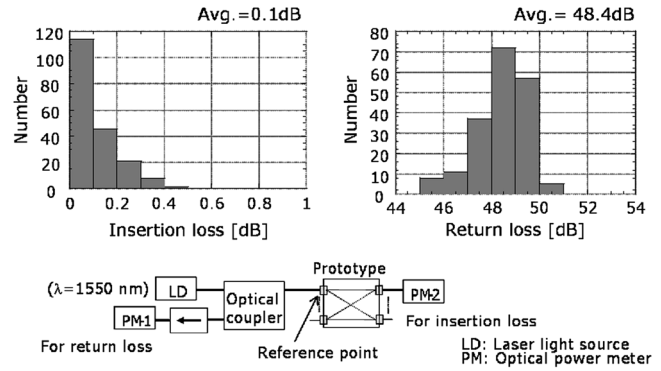


Fig. 10 Initial insertion and return losses.

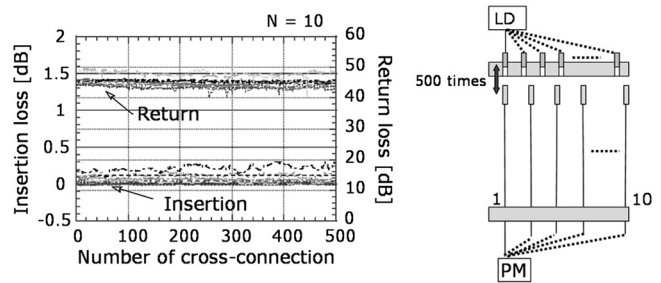


Fig. 11 Change in insertion loss and return loss after 500 cross-connections.

jumper cord pair is <1 min. In the experiments, multiple cross-connection tests were done for random connection patterns. We also confirmed that the jumper cords do not become entangled and can be connected and disconnected normally in random cross-connections. We confirmed the good optical characteristics after connections and disconnections of one thousand times.

Next, we show the results of a cross-connection experiment that was performed to confirm the feasibility of automated optical connection between APC optical connectors. We made prototypes of the optical fiber cords with the APC connector plug, the arrangement boards, and the fingers of fiber-handling robot. These parts are implemented in the 200 × 200 automated optical fiber cross-connect module. We measured the insertion loss of the prototypes. Figure 12 shows the initial insertion and return losses of the equipment and the experimental setup for optical characteristics

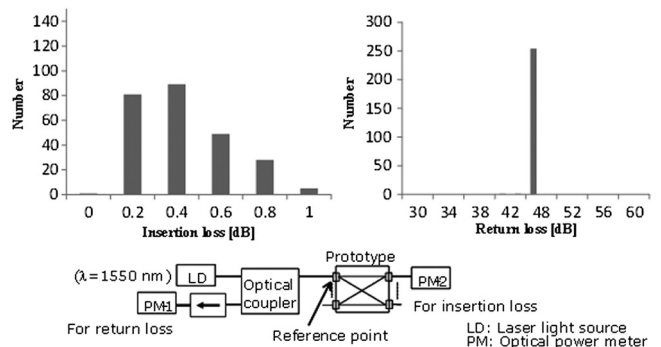
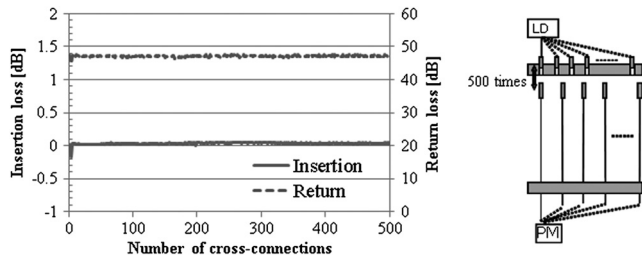


Fig. 12 Initial insertion and return losses (APC).

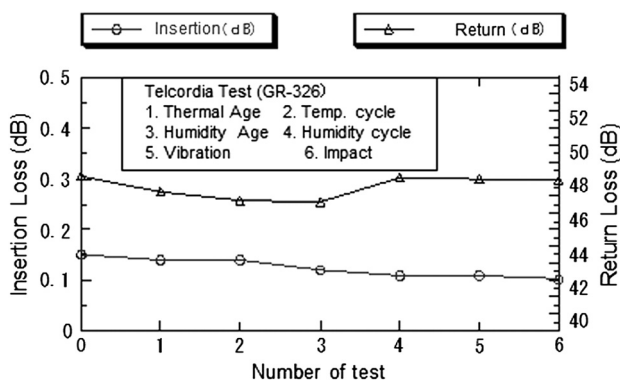


**Fig. 13** Change in insertion loss and return loss after 500 cross-connections (APC).

measurement. The initial insertion loss is 1 dB or less, and the return loss is 40 dB or more. Next, we measured the change in insertion and return losses with repeated connection and disconnection. Figure 13 shows the insertion loss and return loss changes after 500 cross-connections. After 500 cross-connections, the insertion loss and return loss satisfy the requirements. We also confirmed that the jumper cords do not become entangled and can be connected and disconnected normally in random cross-connections in the same way as the connection of the normal optical connector.

## 5.2 Reliability Test

We examined the reliability of the optical connector plug and housing. Our reliability metric is the Telcordia standard GR-326. As shown in Fig. 14, we confirmed that the maximum value of insertion loss was 0.5 dB or less, and the return loss was 40 dB or more during the reliability test and after it. In addition, the loss change did not exceed 0.3 dB during a period of 10 ns in vibration and impact tests. The performance of the optical parts composed of the optical connector plug and the housing is comparable to that of an MU connector and satisfies the Telcordia standard GR-326. Regarding environmental characteristics of the equipment, we confirmed that the equipment operates flawlessly when the temperature in the installation room changes from 5 to 45°C. In telecommunication devices, electromagnetic compatibility (EMC) is demanded. Therefore, we performed an EMC evaluation based on CISPR 22 class A. We confirmed that the equipment satisfies CISPR 22 class A for EMC. The equipment was also found to operate normally after a simulated earthquake of seven in seismic intensity on the first and lower floors (acceleration input: 10 m/s<sup>2</sup>). Table 1 summarizes the environmental and other



**Fig. 14** Insertion and return loss after GR-326 test.

**Table 1** Environmental and other characteristics.

Optical device	
Optical characteristics	Insertion loss: less than 0.5 dB Return loss: more than 45 dB
Reliability	Satisfies Telcordia GR-326 standard
Equipment	
Optical characteristics	Insertion loss: less than 1 dB Return loss: more than 40 dB
Switching time	Less than 1 min (average)
Earthquake-proof	Fully operable after a category 7 earthquake Acceleration input: 10 m/s <sup>2</sup>
EMC	CISPR22 class A
Operating temperature and humidity	Temperature: 5 to 45°C, Humidity: 20 to 85%

characteristics. The evaluation results clarify that the automated optical fiber cross-connect equipment is suitable for practical use.

## 6 Conclusions

We developed the automated optical fiber cross-connect equipment that can cross-connect 200 input and 200 output fibers. The average cross-connection time is <1 min. The insertion loss of the equipment is <1 dB and the return loss of the equipment is >40 dB. The equipment can be installed in a 19-in. rack. We also evaluated the performance of the module with APC connectors, such as its optical characteristics. The average cross-connection time is <1 min. The insertion loss of the equipment is <1 dB and the return loss of the equipment is >40 dB. The evaluation results confirm that the automated optical fiber cross-connect equipment can connect APC connectors with a low loss and a high return loss, indicating that the automated optical fiber cross-connect equipment is suitable for practical use in intelligent buildings and outdoor optical access network systems.

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