New Optical Splitter Module with High Reliability for FTTH in Outside Environments

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Abstract
This paper describes new optical splitter modules designed and developed for fiber to the home (FTTH). To reduce the time required for optical splitter installation in optical aerial closures, we need optical splitters that are easy to handle and connect. These modules have plug and socket optical connectors and optical fiber cords, and can reduce the time needed for their installation in optical aerial closures. We show that planar lightwave circuit (PLC) type optical splitters used in these modules have sufficient reliability by estimating the number of failures. We confirmed that these modules offer good optical and environmental performance in outside passive optical networks (PONs). To reduce the maintenance cost of the optical fiber network, we need highly reliable optical splitters. We confirm that optical splitter modules installed for PONs in outside environments have sufficient reliability as regards heat and moisture from damp heat test results.

Keywords: optical splitter; splitter module; reliability; FTTH; outside environment; outside plant; PON; aerial closure; failure rate; PLC; insertion loss; temperature and humidity cycle; damp heat.

1. Introduction
The rapidly increasing number of fiber to the home (FTTH) subscribers in Japan had exceeded 7.9 million by the end of December 2006 [1]. The main FTTH service is based on gigabit Ethernet passive optical network (GE-PON) systems. Figure 1 shows the typical optical fiber networks for PONs in Japan. 1x4 optical splitters are installed in central offices and 1x8 optical splitters are widely employed as outside plant, for example in optical aerial closures [2]. Telecommunication operators must construct optical fiber networks quickly in order to meet the huge customer demand. In passive optical networks in particular, we need optical splitters that are easy to handle and connect to reduce the time required for installing optical splitters in optical aerial closures.

Passive optical devices in optical fiber networks must have sufficient optical performance at the wavelengths used for commercial PONs. They must also have good environmental performance when used as outside plant in order to provide stable network services. It is important for telecommunication operators to use optical fiber networks efficiently for long periods in order to reduce their maintenance and operating costs. Therefore passive optical devices, especially those used outside, must be highly reliable.

This work describes new optical splitter modules that are designed and developed for outside plant. We confirm that these modules can contribute to reduce the time for installation and have sufficient levels of optical and environmental performance for optical devices for PONs and high reliability as regards heat and humidity for outside use.

![Figure 1. Optical fiber networks for PON systems](image)

2. Development of optical splitter module

2.1 Existing optical splitter
A number of planar lightwave circuit (PLC) type optical splitters have been installed in optical aerial closures in Japan [3]. It is necessary to use mechanical or fusion splices for optical connection, and to store optical fibers in a tray for installation in an aerial optical closure. This connection and storage work is hard to undertake, especially on a telegraph pole. The processes for connecting and storing optical fibers in an optical aerial closure must be simplified.

2.2 Design of new optical splitter module
We designed a new optical splitter module for aerial closures that can be installed more easily than existing optical splitters. Table 1 compares the technologies of the existing optical splitters and our newly developed optical splitter modules. We improved the optical connections and the margin part of optical fibers of the optical splitters.

Table 2 shows the parameters of the optical splitter modules. This module contains a 1 x 8 PLC type optical splitter, and it can be installed in the tray of the new optical aerial closure [4]. The size of the main body of this module is 94 mm x 122 mm x 5 mm. It has a 1.7 mm diameter optical fiber cord for the input side of the optical splitter, and eight 0.9 mm diameter optical fiber cords for the output side. It also has a plug type optical connector for the input side and eight socket type optical connectors for the output side. These connectors are compatible with the new connector for optical aerial closures [5]. This technology makes it unnecessary to handle optical fibers directly and eliminates the need for fusion and mechanical splices during installation in the optical aerial closure. The working time needed for installing an optical splitter in an aerial closure is reduced from 46 to 17 minutes when we compare storing existing optical splitters and new optical splitter modules [4].

![Figure 2. 1x8 optical splitter module](image)
Therefore it is easier to handle an optical splitter module with optical fiber cords and plug and socket type connectors than to handle the currently used PLC type optical splitter directly. This can assist us to construct optical fiber networks more quickly.

Table 1. Comparison of existing optical splitters and new optical splitter modules

<table>
<thead>
<tr>
<th></th>
<th>Existing Optical Splitter</th>
<th>New Optical Splitter Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Connection</td>
<td>Mechanical Splice / Fusion Splice</td>
<td>Plug and Socket type Optical Connectors</td>
</tr>
<tr>
<td>Optical Fibers</td>
<td>Storing optical fibers directly in tray</td>
<td>Storing optical fiber cords in tray</td>
</tr>
</tbody>
</table>

Table 2. Optical splitter modules parameter

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Function</td>
<td>1 x 8 optical balanced branching devices for PONs</td>
</tr>
<tr>
<td>Size</td>
<td>94 x 122 x 5 (L x W x H: mm)</td>
</tr>
<tr>
<td>Optical Fiber Cords</td>
<td>Input side: Diameter 1.7 mm x 1</td>
</tr>
<tr>
<td></td>
<td>Output side: Diameter 0.9 mm x 8</td>
</tr>
<tr>
<td>Interface</td>
<td>Input side: Plug type optical connector x 1</td>
</tr>
<tr>
<td></td>
<td>Output side: Socket type optical connector x 8</td>
</tr>
<tr>
<td>Use</td>
<td>For optical aerial closures in outside environments</td>
</tr>
</tbody>
</table>

3. Failure rate of PLC type optical splitter

3.1 Failure rate of optical components

It is important for telecommunication operators to confirm that passive optical devices installed in their optical fiber networks have sufficient reliability because the operation failure rate and maintenance costs depend on the optical components of the networks. Therefore, the optical component failure rate must be estimated. First we examined only the PLC type optical splitter in the optical splitter module, since the optical splitter is the main optical component of this module.

The reliability of an optical fiber network depends on the reliability of every optical component in the network. To achieve an optical fiber network with a low failure rate, the failure rate of all the optical components that compose the network must be at the same low level. Therefore, the optical fiber failure rate is the benchmark because the optical fiber is in widespread use and rarely breaks down as a result of long-term deterioration.

3.2 Estimation of cumulative failure rate

We confirmed the effectiveness of the PLC type optical splitters in the optical splitter modules. The reliability of PLC type optical splitters is greatly affected in high temperature and high humidity environments because the adhesives used in them deteriorates with exposure to heat and moisture [6]. Therefore we examined PLC type optical splitter for the optical splitter module to estimate the cumulative failure rate $F(t)$ before developing the optical splitter module.

We compared the estimated cumulative failure rate of the PLC type optical splitter with that of optical fiber to allow a comparison with the other optical components of fiber optical networks.

3.3 Accelerated aging tests

We performed accelerated aging tests on these splitters under several conditions and compared the results with an Arrhenius plot [7]. We measured the loss changes of all the ports of the optical splitters continuously, and determined their time to failure when the loss change of one port was 0.5 dB at a wavelength of 1.31 μm.

Table 3 shows the test conditions, the number of samples, the number of failures, and the aging time duration of accelerated aging tests. The failure rate distributions of the PLC type optical splitters are plotted as Weibull distributions.

3.4 Cumulative failure rate

The median life $\xi$ is the time $t$ derived from $F(t) = 0.5$, and the median life $\xi$ of PLC type optical splitters is expressed as follows,

$$\xi = c \exp \left( \frac{E}{kT} \right) \frac{1}{(RH)^n}$$

(1)

where $c$ is the integration coefficient, $E$ is the temperature acceleration coefficient, $k$ is Boltzmann's constant, $T$ is temperature, $RH$ is relative humidity, and $n$ is the humidity acceleration coefficient [7].

Figure 3 shows the cumulative failure rate of optical fiber derived from 0.01 FIT/km/fiber [8] and the cumulative failure rates of the PLC type optical splitter at a temperature of 45°C and humidity of 100% RH. A typical environmental measurement shows that the most severe environment in an optical aerial closure in Japan is 45°C and 100% RH, and so we estimated the cumulative failure rate at these values.
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We confirmed that the PLC type optical splitter has sufficient reliability for the optical splitter modules because it has a lower rate than optical fiber after ten years as shown in Figure 3. Although the PLC type optical splitter consists of optical fibers, the length of optical fiber used in the splitter is much less than 1 km, it is not pulled strongly and it experiences little stress. As a result the cumulative failure rate of the PLC type optical splitter was lower than that of optical fiber. The performance data in section 4 and the reliability data in section 5 are those for the optical splitter module in which this PLC type optical splitter is installed.

4. Performance of optical splitter module

4.1 Passive optical components for PONs

The conventional communication wavelengths are in the 1.31 and 1.55 μm bands. The transmission wavelengths of GE-PON, which is widely used in Japan, are 1.31 μm for upstream and 1.49 μm for downstream data transmissions, and that of video PON is 1.55 μm for video transmission [2]. Therefore, the optical performance of passive optical components for PONs must be examined at least with respect to wavelengths of 1.31 and 1.55 μm, which are the short and long sides of the wavelengths that are actually used for transmissions.

The insertion loss change of passive optical components should be small in an outside environment to prevent any loss changes induced by changes in temperature and to maintain a stable data transmission. The recommended temperature range in which the performance should be guaranteed is from -40°C up to at least 75°C for branching devices used as outside plant in the application environment [9]. Therefore, the environmental performance of the optical splitter module as outside plant must be examined in terms of temperature changes.

4.2 Insertion Loss

We measured the insertion loss of the optical splitter modules at wavelengths of 1.31 and 1.55 μm to confirm that they are suitable as passive optical devices for PONs. Figure 4 shows the insertion loss distribution of the optical splitter module. At wavelengths of 1.31 and 1.55 μm, the mean insertion loss values are both 9.78 dB, and the maximum values are 10.27 and 10.18 dB, respectively. These total insertion loss values include the loss of the PLC type optical splitter inside the main body, the optical fiber cord loss and the optical connection loss.

The insertion loss of the optical splitter module is low because the maximum value is less than the ITU-T standard value of 10.5 dB for the insertion loss of 1 x 8 optical splitters for PONs at wavelengths of 1.31 and 1.55 μm, despite the inclusion of the insertion loss of the one optical connector and optical cords [10]. These modules had sufficient optical performance for passive optical devices for PONs.

4.3 Temperature humidity cycle test

We examined the environmental performance of the optical splitter modules when used outside.

Figure 5 shows the result of a temperature humidity cycle test (-40 to 75°C, 10 to 80 %RH, 8 hours/cycle, 42 cycles) for all the optical components of this module including the plug and socket optical connectors [9]. At wavelengths of 1.31 and 1.55 μm, the average loss changes during this test were 0.18 and 0.15 dB, respectively, and the maximum loss changes were 0.30 and 0.23 dB, respectively. The loss change of the optical splitter modules, including the optical splitter, optical connectors and optical cords, was less than 0.3 dB, which is the criterion established in ITU-T Recommendation L.37 [9]. Other passive optical devices, namely MT connectors, are widely used in outside environments, and their loss change after a temperature change test (-40 to 70°C, 8 hours/cycle, 10 cycles) is also less than 0.3 dB [11]. Therefore, they provide a satisfactory level of environmental performance as outside plant for PONs at the commercially used wavelengths of 1.31 and 1.55 μm.
5. Reliability of optical splitter module

5.1 Reliability of module in outside environments

It is essential to confirm that passive optical components for outside plant offer long-term reliability in outside environments. In section 3 we showed that the PLC type optical splitter has sufficient reliability. With regard to new optical connectors, the loss change in an environmental test consisting of a high temperature test (85°C, 336 hours), a high temperature and humidity test (60°C, 95%RH, and 5300 hours), and a heat cycling test (-40 to 75°C, 8 hours/cycle, 42 cycles) was less than 0.3 dB at wavelengths of 1.31 and 1.55 μm [5].

Therefore, we examined the reliability of the optical splitter module including socket and plug type optical connectors and optical cords, especially with respect to heat and moisture.

5.2 Damp heat test

We performed a damp heat test (85°C, 95%RH, and 5300 hours) on these optical splitter modules including the plug and socket optical connectors to estimate the effects of heat and moisture. Figure 5 shows the loss change distribution after the damp heat test. At wavelengths of 1.31 and 1.55 μm, the average loss changes are less than 0.1 dB, and the maximum loss changes are 0.30 and 0.28 dB, respectively.

The main body, socket and plug type optical connectors and optical fiber cards of the optical splitter modules showed no sign of breaking down after a 5300-hour test. The loss change, including the optical splitter, optical connectors and optical cords, was not more than 0.3 dB, and these modules provide sufficient reliability as regards heat and moisture for use as outside plant because the maximum loss change value is less than the ITU-T standard criterion for a high temperature storage test (85°C, 85%RH, 5000 hours) with 1 x 8 optical splitters for PONs [9].

6. Conclusion

We developed 1x8 optical splitter modules with plug and socket type optical connectors and optical fiber cords for optical aerial closures designed for use as outside plant. These technologies make it easy to install optical splitters in an optical aerial closure, and the working time for installation is reduced to 17 minutes from the current time of 46 minutes. This optical splitter module can contribute to the efficient construction of optical fiber networks for PON systems.

We estimated the number of failures of the PLC type optical splitters in these modules with respect to heat and moisture by using accelerated aging tests, and confirmed that the cumulative failure rate of a PLC type optical splitter for these modules is below that of optical fiber, which is the benchmark rate for optical fiber networks. The optical splitter modules have sufficient optical performance levels for PONs because the insertion loss at the commercially used wavelengths of 1.31 and 1.55 μm is less than the criterion established by ITU-T Recommendation G.671 Amd. for optical splitters. The modules also exhibit good environmental performance as outside plant. The loss change of the module is less than 0.3 dB in a temperature and humidity cycle test, which is the criterion established by ITU-T Recommendation L.37.

We performed a damp heat test to confirm the long-term reliability of these modules. They exhibited sufficient reliability as regards heat and moisture because the maximum loss change was less than the criterion of the high temperature storage test in ITU-T Recommendation L.37 for optical splitters for PONs.

This optical splitter module can help to provide required FTTH services with ease of handling at optical aerial closures, sufficient optical and environment performance levels for PONs, and high reliability in outside environments.

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8. References


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