A new optical fiber line testing function for service construction work that checks for optical filters below an optical splitter in a PON

Noriyuki Araki, Toshikazu Yamane and Hisashi Fujimoto

NTT Access Network Service Systems Laboratories, NTT Corporation, 1-7-1 Hanabatake, Tsukuba-city, Ibaraki 305-0805, Japan
Phone: +81-29-868-6365, Fax: +81-29-868-6360 E-mail: noriyuki@ansl.ntt.co.jp

Abstract: We propose a new function for construction-work undertaken to install optical cables for services in PONs. We demonstrated to determine whether an optical fiber is "live" or "unused" in branched fiber-region below optical splitter exactly.
©2010 Optical Society of America
OCIS codes: (060.2300) Fiber measurements; (060.3735) Fiber Bragg gratings

1. Introduction

In recent years, the demand for broadband access services has increased throughout the world. A large number of optical fiber cables are being installed daily to meet the current demand. Therefore, the smooth construction, operation, and maintenance of these network plants have become considerably more important [1]. During the installation and maintenance of optical fiber communications networks, field engineers must first correctly identify a specific fiber from a bundle of fibers to prevent the incorrect cutting and/or connection of an optical fiber at a worksite. In particular, they must prevent cutting "live" (signal carrying) fibers in order to maintain service reliability. Therefore, it is necessary to distinguish between "live" and "unused" (no signal) fibers in branched optical fiber regions. In this paper, we propose a new function for construction work undertaken to install optical fiber lines for services in a PON, and describe a novel measurement technique for checking optical filters located in front of an optical network unit (ONU) in branched optical fiber regions for PONs with outside optical splitters. The purpose is to determine whether an optical fiber is "live" or "unused." This technique facilitates cable construction and removal during maintenance work on optical access networks.

2. Basic concept of proposed method

Figure 1 shows the configuration of the PON access network model with an optical fiber line testing system. Optical fiber line testing systems are installed to reduce construction and maintenance costs and improve service reliability in PON systems [2]. The fiber Bragg grating (FBG) filter, which is installed in front of ONU, has wavelength dependent characteristics for in-line monitoring. A test light at a wavelength of 1650 ± 5 nm, which is in accordance with ITU-T Recommendation L.66, is reflected strongly, but test lights at other wavelengths (e.g. 1625 nm) are hardly reflected at all. The wavelength dependence of test lights at the above two wavelengths reflected from the filter can be utilized when determining whether or not a filter is present. Since a live fiber must have an optical filter to enable in-line monitoring with an optical fiber line testing system, field engineers working at a branched region below an optical splitter can distinguish between live and unused fibers by knowing whether or not there is an optical filter at the end of the branched fiber.

When installing or removing a customer's optical fiber cable, field engineers must first correctly identify a specific fiber from a bundle of fibers in a closure to avoid the incorrect cutting and/or connection of an optical fiber at a worksite. Figure 2 illustrates the scene at the worksite. It is very important for field workers to find the fiber that they must cut and connect for service provision. They must at least know whether fibers are "live" or "unused" to avoid damaging "live" fibers. Therefore, a new function that can provide this information is urgently required.
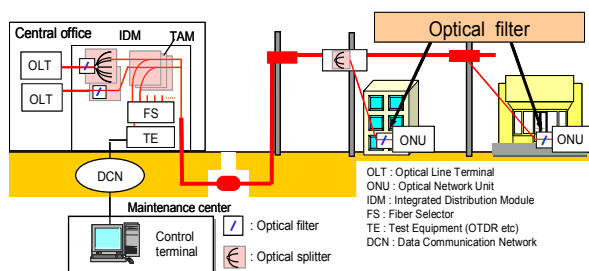

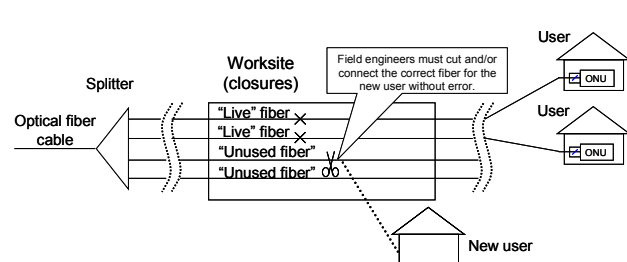**Fig.1.** Configuration of optical access network

Fig.2. Service installation work at the worksite.

3. Design and experimental result of estimation method

Figure 3 shows the theory behind our proposed method, the test light wavelength allocation and the filter characteristics. We first determined that the primary wavelength (λ_p) should be 1650 nm. The secondary wavelength (λ_s) should be 1625 nm, close to the primary wavelength. This is because the difference between the wavelength dependent fiber losses and bending losses for the primary and secondary wavelengths must be negligible. This method consists of test light sources at the above two wavelengths and monitoring equipment, which is based on the non-destructive macrobending that the optical fiber identifier employs [3]. The equipment consists of a photo-detector (PD) and a bender to allow us to monitor the leaked optical power caused by macrobending. The PD installed in the monitoring equipment has an asymmetric design as seen in Fig. 3 (near the splitter and the direction of the PD along the bender design), because the PD must effectively detect test lights that are reflected at the far end of the fiber line but not detect test lights transmitted directly from a CO. The optical powers are detected by the PD at two wavelengths (λ_p and λ_s). By comparing the difference between the powers for the two wavelengths, we can determine whether or not there is a filter at the end of the fiber line.

We performed experiments using this method to confirm the presence of a filter at the far end of an optical fiber line. The experimental setups for testing the proposed method are shown in Fig. 5. We employed a wavelength tunable light source as the test light source using wavelengths of 1650 nm (λ_p) and 1625 nm (λ_s). The test lights were modulated at 270 Hz and 310 Hz, respectively. We used an optical attenuator to maintain the optical power at a value of –20 dBm at wavelengths of 1650 and 1625 nm. We used single-mode fibers (SMF) complying with ITU-T standards as the samples. Three kinds of fiber, which were in accordance with ITU-T Recommendations G.652 and G.657-class A (R30/0.25, R15/0.25 and R15/05), were prepared as samples and employed in the experiments.

We tested this method three times per sample for 36 samples, with and without a filter. The determination of the presence or absence of a filter was excellent, with a probability of 100%. Figures 6 shows histograms of ΔP measured with and without a filter, respectively. Without the filter, the average ΔP value is 0.0 dB, whereas the average ΔP value with the filter is 9.0 dB in Fig. 6. The maximum and minimum ΔP values with and without a filter are 13.2 and 6.3 dB, and 2.6 dB and -2.9 dB, respectively. The ΔP value range is about 5 dB. This is because the values depend on coupling efficiency, and fluctuations tend to occur during the measurement because of the use of the macrobending method and long-wavelength test lights. Therefore, with this method it is important to clamp the fiber so that it cannot move and as far as possible obtain the same coupling efficiency in each experiment. However, the ΔP values with and without the filters are clearly different, and so we can successfully determine the presence of a filter at the far end of a fiber line.
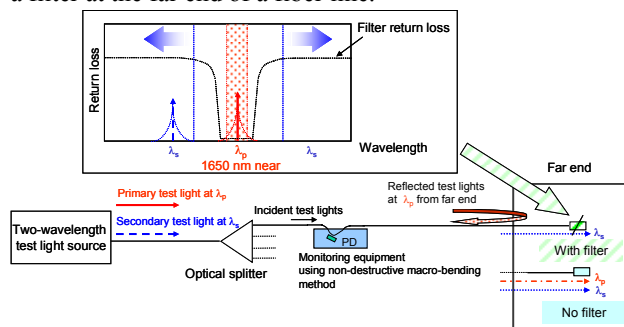
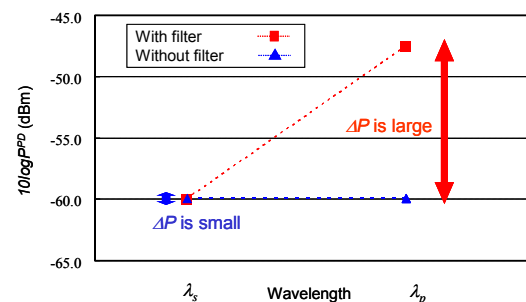**Fig.3** Theory of proposed method and test light wavelength allocation

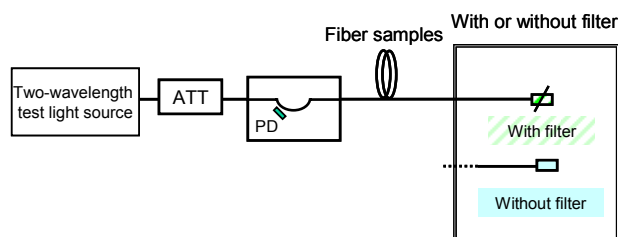**Fig.4** Calculated $P^{PD}(\lambda)$ between two wavelength with or without filter
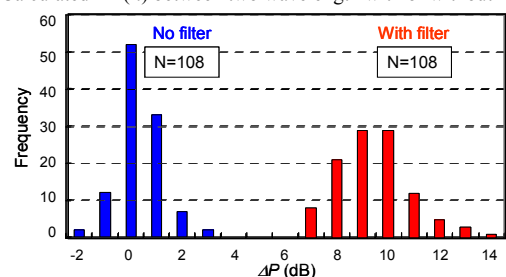
Fig.5. Experimental setup for testing proposed method

Fig.6. Histogram of measured ΔP with and without filter

4. Enhanced estimation method using two photo-detectors

We have discussed the theoretical and experimental performance of this estimation method under the condition that the round-trip loss L_L is very small. When the round-trip loss L_L is large, the ΔP value with this method varies

greatly because the optical power of the reflected test light decreases. Therefore, we propose an enhanced estimation method that uses two PDs that are installed symmetrically as shown in Fig. 7. The feature of the enhanced method is that it only compares the optical powers of the reflected test light received by PD1 at two wavelengths by eliminating the influence of the incident test light launched into PD1. The difference between the optical powers of the reflected test lights at two wavelengths detected by PD1 is given as follows (defined as $\Delta P'$).

$$\Delta P' = 10\log((P^{PD1}(\lambda_p) - P_{in})/(P^{PD1}(\lambda_S) - P_{in})) \qquad (1)$$

Here, P_{in} is the incident optical power detected by PD1 and the P_{in} value is expressed as follows, $P_{in}=P_F\times\eta_F$. The enhanced method uses the linearity of the coupling efficiency independent of fiber type. When PD1 and PD2 are installed symmetrically around the bender, the coupling efficiencies of the incident and reflected test lights for PD2 equal the coupling efficiencies of the reflected and incident test lights for PD1, respectively. That is, η_F and η_B are the coupling efficiencies of the reflected and incident test lights for PD2. The optical powers received by PD2 are described as follows,

$$P^{PD2}(\lambda) = P_F \times \eta_B + P_F \times (1 - L_E - L_L) \times \gamma \times \eta_F \qquad (2)$$

At a wavelength of λ_s, the test light is hardly reflected at the far end, and the value of the second term in eq. (2) is much smaller than that of the first term, because when using eq. (1) at a wavelength of λ_s with PD1 and PD2, we can estimate the P_{in} value by replacing P_{in} with P^{PD2}, η_B and η_F.

$$P_{in} = P_F \times \eta_F = (P_F \times \eta_B) \times (\eta_F / \eta_B) = P^{PD2} \times (\eta_F / \eta_B) \qquad (3)$$

Therefore, we can eliminate the optical power of the incident test light detected in PD1 by using eqs. (1) and (3). It is difficult to measure the precise optical powers of the incident test lights received by PD1 and PD2 because the optical powers received by each PD have not been separated for the reflected and incident lights of the ref. However, we can improve the measurement dynamic range for determining the presence of an optical filter by using this enhanced method.

We tested the enhanced method in a similar way to that shown in Fig. 5. We used an optical attenuator in front of the far end of the fiber line, and controlled the round-trip loss. Figure 8 shows the experimental result we obtained with a filter when using the enhanced method. The $\Delta P'$ value with the proposed method (normal method) was about 7.6 dB at L_L = 6.0 dB. However, the $\Delta P'$ value with the enhanced method was about 16.8 dB at L_L = 6.0 dB, and could be improved by 9.2 dB compared with that obtained with the normal method. Therefore, we were able to determine the presence of a filter without fail using the enhanced method, and the $\Delta P'$ value range was adequate for detecting the filter. We confirmed experimentally that the dynamic measurement range with the enhanced method was better than that with the normal method.
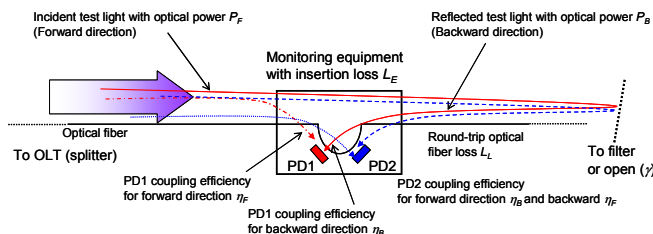

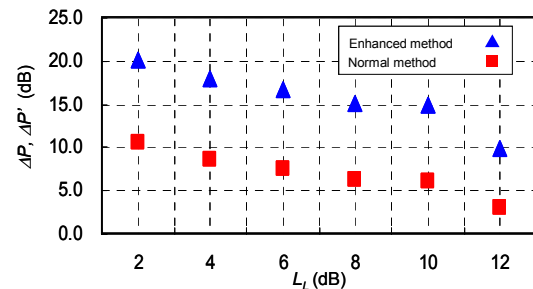**Fig.7.** Configuration of monitoring equipment using two PDs

Fig.8. Measured ΔP and $\Delta P'$ with filter using normal and enhanced methods

5. Conclusion

This paper described a novel measurement technique designed to check for optical filters in branched optical fiber regions in PONs with optical splitters. We proposed a new function for use during construction work when installing new optical fiber lines for service in passive optical networks (PON). We demonstrated that the presence of optical filters can be determined both theoretically and experimentally by using our proposed method. Furthermore, we developed and demonstrated an enhanced estimation method that uses two symmetrically installed PDs to obtain an accurate determination even if the round-trip loss increases. We also confirmed experimentally that the threshold for detecting the presence of a filter could be improved by over 9.2 dB compared with that of the normal method when there is a fiber loss of 6 dB in the branched optical fiber region below an optical splitter.

6. References

[1] H. Izumita, "Recent development in fiber optic monitoring system for access networks," in *Proc OFS-16*, We1-1, pp. 258-261, 2003.
[2] N. Nakao, H. Izumita, T. Inoue, Y. Enomoto, N. Araki, and N. Tomita, "Maintenance method using 1650-nm wavelength band for optical fiber cable networks," *J. Lightwave Technol.*, vol. 19, no. 10, pp. 1513-1520, Oct. 2001.
[3] Y. Aoyagi and K. Shiraki, "Low insertion loss optical fiber identifier realized by using asymmetric bending," *Proc. IWCS*, pp. 484 -488, 2003.