



Cord identification technique for ultra-low bending loss fibers using higher order modes of visible light

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ABSTRACT

We propose a cord identification technique for ultra-low bending loss fiber using higher order modes of visible light. With this kind of fiber, bending losses are greatly reduced and it is difficult to obtain sufficient leaked light with a conventional macro-bending technique. The bending loss of higher order modes is several orders larger than that of fundamental modes. Higher order modes can exist at shorter wavelengths and their guiding loss is small when the fiber is not tightly bent. As a result, higher order modes are suitable for cord identification purposes with ultra-low bending loss fiber. We determined that the LP₂₁ and LP₀₂ modes at 650 nm (red) and the LP₃₁ mode at 532 nm (green) are the most effective for cord identification purposes. We employed an offset launch technique to excite higher order modes, and achieved a sensitivity improvement of more than 14 dB. By using our method, a cord can be identified by red or green light even with the naked eye.

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1. Introduction

Fiber to the home (FTTH) is becoming one of the most important methods used for high-speed access networks [1]. A large number of optical fiber cords and cables are installed in both customer buildings and central offices. Bend-insensitive fibers (BIFs) are now under intensive investigation since they can be tightly bent without a noticeable loss increase [2–5]. This property helps facilitate network maintenance by reducing the risk of a temporary communication failure. Moreover, the use of this kind of fiber can reduce the required accommodation space and greatly reduce running costs. For example, hole-assisted optical fiber (HAF), which is a kind of ultra-low bending loss BIF, has already become a popular choice for home network wiring in Japan [6]. One barrier to extending its application range is that there is no identification method for this type of fiber.

Cord identification is a required on-site procedure that is used to prevent the incorrect connection of fibers installed in central offices [7]. Currently, the standard method is a non-destructive macro-bending technique using 1650 nm light. However, bending losses at this wavelength are greatly reduced together with that of the communication wavelengths in ultra-low bending loss fibers. As a result, it is difficult to use the macro-bending technique to obtain sufficient leaked power at a wavelength of 1650 nm. An identification method using a mechanically induced long-period grating has been proposed. This is an effective method for realizing mode conversion between the fundamental LP₀₁ mode and the LP₁₁

mode [8]. However, it is difficult to implement this technique for cord identification purposes because fiber cords have exterior protective structures, which effectively protect the fiber from the shape deformation caused by periodically exerted pressure. Therefore, if we can develop an identification method, ultra-low bending loss HAF cord may become an attractive transmission medium for central offices and other applications because of its inherited advantages as regards maintenance and reliability. We have proposed a cord identification technique for ultra-low bending loss fiber that uses the higher order modes of visible light [9]. Higher order modes have bending losses that are several orders larger than those of fundamental modes while maintaining a low guiding loss in ultra-low bending loss fibers. As a result, they are suitable for cord identification purposes with ultra-low bending loss fiber.

In this study, we employed a simple offset launch technique to excite higher order modes and a macro-bending technique with an optimized bending diameter to leak the light for cord identification. We optimized the wavelengths and the modes for cord identification by undertaking a theoretical and experimental study. We achieved a sensitivity improvement of more than 14 dB by using a wavelength of 532 nm, which is 4 dB greater than that reported in a previous study [9]. We also clarify that the higher order modes in red and green lights can be employed for cord identification with the naked eye.

2. Outline of cord identification using offset launch technique

A schematic of our proposed cord identification method is shown in Fig. 1. Laser diodes emitting at visible light wavelengths

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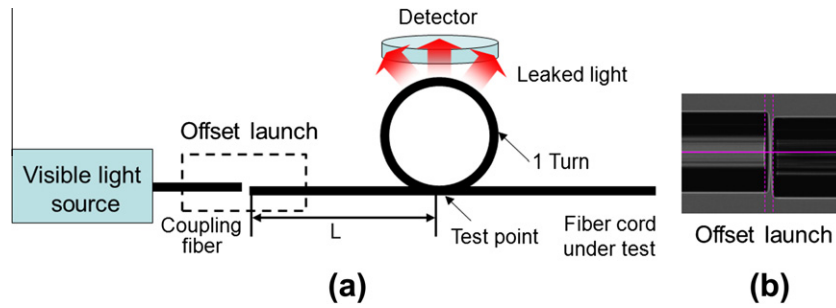


Fig. 1. (a) Schematic of proposed cord identification method and (b) offset launch position.

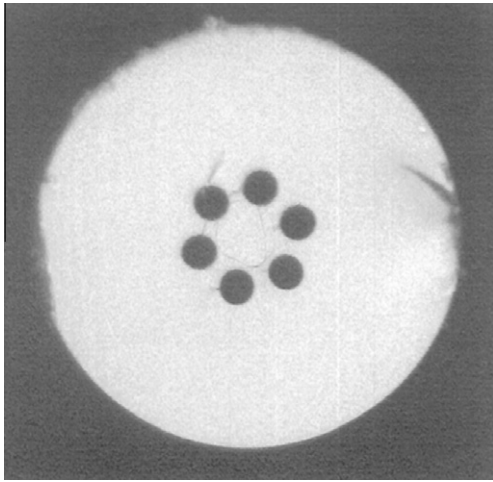


Fig. 2. Image of HAF cross-section.

are used as light sources. Output light from a laser diode is collected using a coupling fiber. To stimulate higher order modes efficiently, the light from the coupling fiber is launched into the fiber cord under test with their cores appropriately offset. At the test point, the cord under test is bent to form a single circle with an optimized diameter to intentionally leak light in higher order modes, and a detector is placed next to the fiber to detect leaked light. The key advantage of this method is that it is applicable to a fiber cord with ultra-low bending loss and a cord can be identified even with the naked eye without interrupting communications. Moreover, the method is simple and does not require expensive equipment.

In this study, we focus on an ultra-low bending loss HAF with six air holes for cord identification application. Fiber cord using this kind of HAF is commercially available and is called free bending optical cord. Its bending loss is less than 0.1 dB with a 2.5 mm bending radius and 10 turns [10]. This kind of HAF is the only ultra-low bending loss fiber in wide commercial use throughout the world [6]. Its cross-sectional image is shown in Fig. 2. Its core diameter and the refractive index difference between the core and cladding at 1310 nm are around 8 μm and 0.35%, respectively. The diameter of air holes and an inscribed circle linking them are around 10 and 20 μm , respectively. In this study, we chose a protective structure exactly the same as that used for the fiber cord in the distribution frame in central offices, which is called an integrated distribution module [11]. The structure is shown in Fig. 3. The yellow¹ cord sheath and the colorless ultra violet curable resin

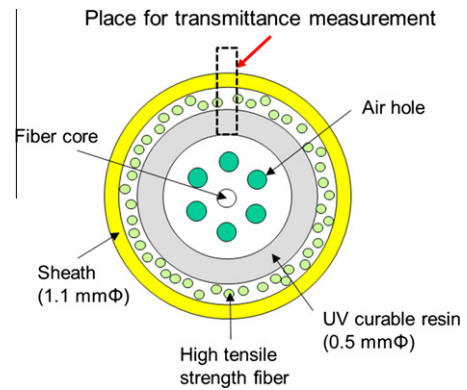


Fig. 3. Protective layer structure of HAF.

have diameters of 1.1 and 0.5 mm, respectively. The space between them is filled with high tensile strength fiber the same color as the cord sheath.

3. Estimation of bending loss properties of HAF cord

The main reason for using higher order modes for cord identification is that the light transmitted in fundamental modes in an ultra-low bending loss fiber is designed to be strongly confined within the fiber core. We measured the bending loss spectra of a 4 m-long HAF cord using a white light source and an optical spectrum analyzer. The output light from the white light source includes higher order modes. We used bending kits to realize one-turn bending circles with different diameters. The results are shown in Fig. 4. The bending losses for wavelengths longer than

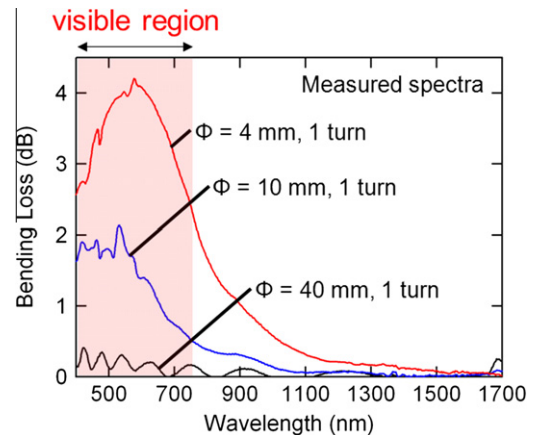


Fig. 4. Measured bending loss spectra.

¹ For interpretation of color in Fig. 3, the reader is referred to the web version of this article.

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