Optical Fiber Breakpoint Detection in Drop Cables Using Lock-in Thermography with Low Optical Input Power

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Abstract

We propose a method to detect optical fiber breakpoints in drop cables using lock-in thermography. Synchronously detecting temperature responses induced by modulated optical input enables a breakpoint to be localized at a maximum optical input power of −2 dBm, more than 5 dB lower than that of conventional methods.

1. Introduction

Aerial optical fiber cables in access networks are susceptible to damage from environmental factors such as strong winds and tree contact. Conventional fault localization relies on optical time-domain reflectometry to identify the approximate fault section [1], followed by injecting visible light to pinpoint the breakpoint by observing light leakage. However, optical fibers can break inside the cable without visible sheath damage due to bending or lateral pressure, making visual localization ineffective. We previously proposed a breakpoint localization method using infrared thermography (IRT), exploiting the heat generated by light leakage [2]. This method enables a breakpoint to be non-destructively localized without damaging the cable sheath. However, it requires optical input power exceeding +3 dBm, posing a risk of damaging communication equipment if light is inadvertently injected into an operational fiber. To address this, we applied lock-in thermography [3], which detects minute temperature changes by synchronously detecting modulated signals. We propose a breakpoint localization method using lock-in thermography and experimentally clarify the required optical input power and detection time for optical drop cables.

2. Experiment and results

Figure 1 shows the experimental setup for fiber breakpoint detection using lock-in thermography. The system consists of an arbitrary waveform generator (AWG), Fabry-Perot laser diode (FP-LD), drop cable, and thermal camera. The AWG outputs a sine wave for modulating laser intensity and a rectangular wave for triggering the camera. The rectangular wave frequency was fixed at 30 Hz, while the sine-wave frequency was set to three values: 0.1, 0.5, and 0.9 Hz. Intensity-modulated laser light with a center wavelength of 1550 nm was injected into the fiber within the drop cable. The maximum optical input power of the modulated light was varied from −8 to 0 dBm in 2-dBm increments. The cross-sectional dimensions of the drop cable used were 2.25 × 1.59 mm. We used samples in which only the internal fiber was intentionally broken while the cable sheath remained intact. The periodic heating of the cable sheath by light leaking from the breakpoint was captured using a thermal camera. The thermal camera had 640 × 480 pixels, operated at 30 fps, and provided a spectral band of 8–14 μm with a noise-equivalent temperature difference of 40 mK. Continuous imaging with the camera began simultaneously with laser-light irradiation and was recorded for a maximum of 120 s. A temporal fast Fourier transform (FFT) was applied to each pixel of the acquired thermal image series to extract the laser-modulation-frequency component, thus improving the signal-to-noise ratio (SNR).

Figure 2 shows the amplitude and phase images obtained through lock-in detection. Figure 2(a)–(c) show results at modulation frequencies of 0.1, 0.5, and 0.9 Hz with a maximum optical input power of 0 dBm and an imaging time of 120 s. Amplitude increased at the fiber breakpoint at all frequencies. Phase delay also increased with distance from the breakpoint. This phase delay originated from propagation delay due to thermal diffusion. Higher modulation frequencies improved spatial resolution but reduced the detectable range. Conversely, lower frequencies increased amplitude and widened the detection range, making low-frequency measurement more effective for localizing fiber

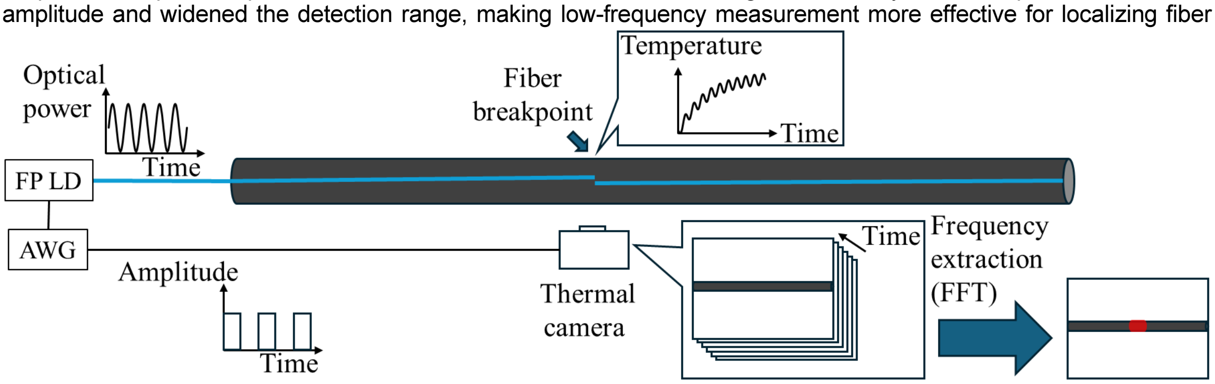

Figure 1. Experimental setup for fiber breakpoint detection using lock-in thermography.

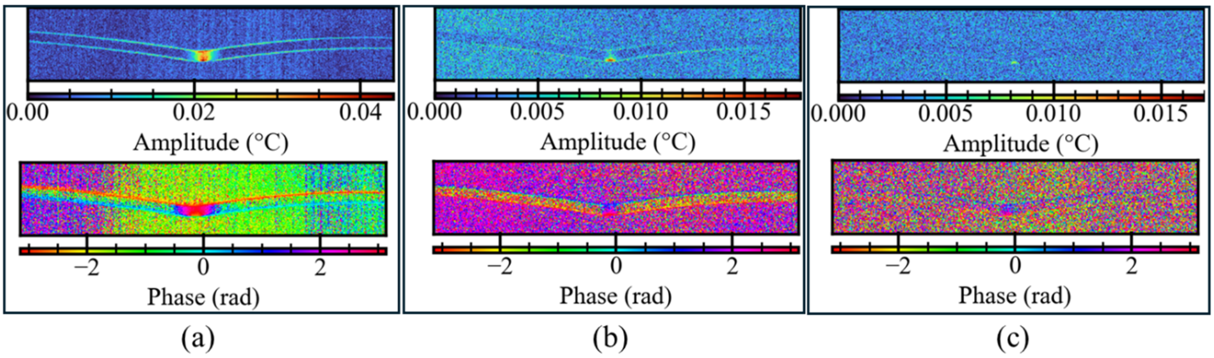

Figure 2. Amplitude and phase images obtained through lock-in detection. (a–c) Frequency dependence at 0.1, 0.5, and 0.9 Hz, respectively (maximum optical input power = 0 dBm, time = 120 s).

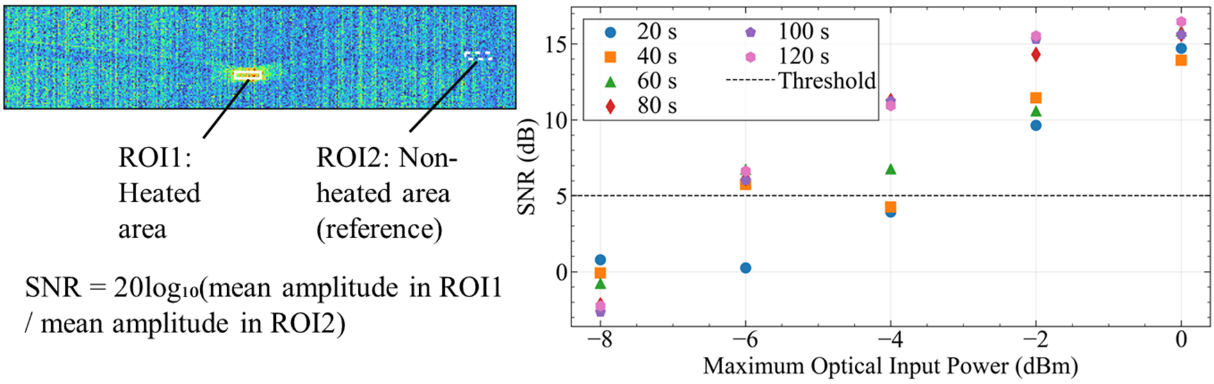

Figure 3. (Left) Amplitude image obtained at a maximum optical input power of −2 dBm, 0.1 Hz modulation frequency, and 20-s imaging time, showing ROI1 (heated region) and ROI2 (reference region). (Right) SNR at 0.1 Hz modulation frequency versus maximum optical input power for each measurement time.

breakpoints. Figure 3 shows the SNR at a modulation frequency of 0.1 Hz as a function of maximum optical input power for different measurement times. The SNR was defined as $20\log_{10}$(mean amplitude in ROI1 / mean amplitude in ROI2), where ROI1 and ROI2 represent the region heated by light leakage and the non-heated reference region, respectively, as indicated in the left half of Fig. 3, which shows an amplitude image obtained with −2 dBm input, 0.1 Hz modulation frequency, and 20-s imaging time. In this study, detection was regarded as successful when the SNR exceeded 5 dB, at which the breakpoint was visually identifiable in the amplitude image. Measurement time was varied from 20 to 120 s at 20-s intervals to evaluate detection characteristics under each condition. The SNR tended to improve as the optical input power and measurement time increased. An SNR exceeding 5 dB was achieved at all measurement times for input powers of −2 dBm and above. While conventional steady-state thermography requires optical input exceeding +3 dBm [2], the proposed method detects the fiber breakpoint at −2 dBm, reducing the required optical input power by more than 5 dB. This power level is comparable to or lower than typical optical power levels used in access-network operation, thereby reducing the risk of damaging communication equipment even if light is accidentally injected into an operational fiber.

3. Conclusion

We proposed a method for non-destructively localizing a breakpoint in an optical fiber cable that overcomes the high optical input power requirements of conventional steady-state thermography by applying lock-in thermography. By combining intensity-modulated optical signals with synchronous detection using a thermal camera, our method enables minute temperature changes to be detected highly sensitively. We experimentally demonstrated that even with a measurement time as short as 20 s, our method can identify the fiber breakpoint in the drop cable at an optical input power of −2 dBm, more than 5 dB lower than the +3 dBm or higher input required by conventional methods.

References

[1] K. Borzycki and P. Gajewski, "Accurate location of fiber cable fault with OTDR," Journal of Telecommunications and Information Technology, no. 4, pp. 42–52, 2021.

[2] T. Oda, K. Makino, T. Hosome, M. Miyazaki, and H. Hashimoto, "Thermal imaging-based localization technique for fiber breakpoints in drop cables," *OFC2025*, paper M1C.2, 2025.

[3] D. Wu and G. Busse, "Lock-in thermography for nondestructive evaluation of materials," *Revue générale de thermique*, vol. 37, no. 8, pp. 693–703, 1998.