プラスチック光ファイバを用いたブリルアン光相関領域反射計のノイズ低減法

Noise suppression technique for distributed Brillouin sensing using plastic optical fibers

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1. Introduction

Brillouin optical correlation-domain reflectometry (BOCDR) [1] is a promising structural health-monitoring system for measuring strain and temperature distributions along a fiber under test (FUT). Recently, to enhance the strain dynamic range of the system, plastic optical fibers (POFs) have been intensively used as the FUT.

In conventional systems with a silica single-mode fiber (SMF), the noise was suppressed by acquiring the spectral difference between with and without pump light, which enables correct distributed measurements by mitigating the electrical noise [2]. However, when the FUT was a POF, the Fresnel reflection at the SMF-POF boundary was so strong that distributed sensing was not performed appropriately with the aforementioned noise suppression technique.

In this study, we develop a new noise suppression technique for correct distributed sensing based on BOCDR even when the FUT is a POF. In this technique, we acquire the spectral difference between with and without reference light (not pump light). We experimentally show the effectiveness of this technique and demonstrate POF-based distributed temperature sensing and dynamic strain sensing.

2. Principle

Conventionally, to suppress the noise floor, we acquired the spectral difference between with and without the pump light. When the pump light is injected into the FUT, the heterodyned signal is composed of three factors: (i) the beat signal of the Brillouin-scattered light and reference light, which is effective for distributed measurement, (ii) the beat signal of the Brillouin-scattered light and Fresnel-reflected light, which serves as noise in distributed measurement, and (iii) the electrical noise mainly caused by the output-power fluctuations of the microwave frequency sweeper. In the meantime, when the pump light is not injected in the FUT, only (iii) is included in the observed spectrum. Therefore, by calculating the spectral difference, the final spectrum includes (i) and (ii). When the FUT is a silica SMF, the Fresnel-reflected light is extremely weak, and thus (ii) is negligibly small.

However, when the FUT is a POF, the Fresnel reflection at the boundary of a silica SMF and the POF is so strong that (ii) is not negligible. Therefore, the final spectrum includes both (i), which is effective, and (ii), which is not effective, leading to difficulty in performing POF-based distributed measurements.

Thus, as a new noise suppression technique for POF-based distributed measurement, we acquire the spectral difference with and without the reference light. When the reference light is present, the final spectrum includes (i), (ii), and (iii); while the reference light is not present, it includes (ii) and (iii). Therefore, their difference gives only (i), which directly contributes to distributed sensing.

3. Experiments

Figure 1 shows the experimental setup of POF-based BOCDR for verifying the new noise suppression technique. A 3.0-m-long POF was employed as the FUT. Variable optical attenuators were used in the pump and the reference path, so that we can switch on/off the pump light and the reference light for the noise suppression.

First, we evaluated the conventional noise suppression technique by acquiring the spectral difference between with and without the pump light. The correlation peak was located at the midpoint of the FUT (f_m = 13.552 MHz), and the nominal spatial resolution was set to approximately 65 cm (Δf = 0.4 GHz) [3]. The spectra measured with and without the pump light are shown in **Figs. 2(a)** and **(b)**, respectively. **Figure 2(a)** exhibited a clear BGS peak, but the spectrum was distorted by the electrical noise. **Figure 2(b)** shows the electrical noise spectrum. The spectral difference of these two, obtained using a calculating function of the ESA, is shown as a solid curve in **Fig. 2(c)**. And a dotted curve in **Fig. 2(c)** shows the spectrum when a 0.6% strain was applied to a 1.0-m-long section around the midpoint of the FUT. As the electrical noise was suppressed, the spectral shape seemed to be ideal, but the downshift of the peak frequency was ~33 MHz, which was lower than half the theoretical value (~73 MHz). This is because, as strain was applied, part of the spectrum (corresponding to (i)) shifted to lower frequency, but the remaining part of the spectrum (corresponding to (ii)) did not shift. Thus, it is difficult to use the conventional noise suppression technique to derive the correct value of the BFS change caused by applied strain.

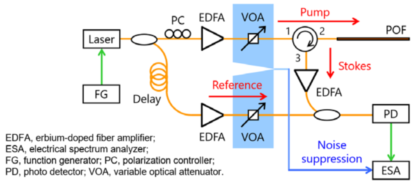

Fig. 1. Experimental setup.

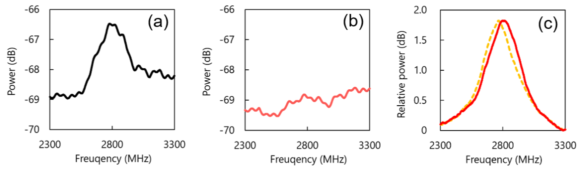

Fig. 2. Spectra measured with the conventional noise suppression technique. **(a)** Raw BGS. **(b)** Noise floor. **(c)** Noise-suppressed BGS. The dotted curve is the spectrum when a 0.6% strain was applied.

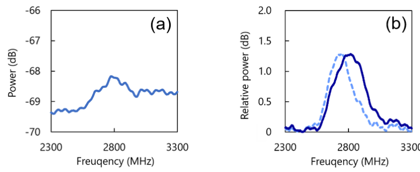

Fig. 3. Spectra measured with the new noise suppression technique. **(a)** Noise floor. **(b)** Noise-suppressed BGS. The dotted curve is the spectrum when a 0.6% strain was applied.

Subsequently, we evaluated the new noise suppression technique by acquiring the spectral difference between with and without the reference light. The spectrum measured with the reference light is basically the same as **Fig. 2(a)**. The spectrum measured without the reference light is shown in **Fig. 3(a)**, which included not only the electrical noise spectrum but also a clear BGS peak. This peak corresponds to (ii) and does not contribute to distributed measurement. The spectral difference of these two is shown as a solid curve in **Fig. 3(b)**. A 0.6% strain was applied in the same manner, and the shifted spectrum is shown as a dotted curve in **Fig. 3(b)**. The whole spectrum shifted to lower frequency, and the shift of the peak frequency was ~73 MHz, which well agreed with the theoretical value. Thus, the new noise suppression technique was proven to give a correct value of the BFS change caused by applied strain and to be effective for distributed sensing.

Finally, we performed two demonstrations of POF-based BOCDR using the new noise suppression technique. The results will be presented at the meeting.

References

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