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Tunable Erbium-doped Fiber Ring Laser with Signal-Averaging Function for Fiber-Optic Sensing Applications[1]

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Abstract—This work proposes a novel erbium-doped fiber ring laser as a sensing control center (CC) for long-haul fiber Bragg grating (FBG) sensor systems. The tunable erbium-doped fiber laser with signal averaging functionality not only provides intense and stable laser light, but also suppresses the effect of noise on the system performance. A sample 30/60 km FBG sensor array is connected to the fiber ring laser to demonstrate experimentally the feasibility and effectiveness of the laser as a CC. The experimental results indicate that the signal averaging operation inside the proposed setup increases the system signal-to-noise ratio (SNR).

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1. INTRODUCTION

A long-haul or large-scale fiber sensor system generally is composed of a fiber Bragg grating (FBG)-based sensing system and a control center (CC) [1, 2]. The CC is responsible for providing the light source and discriminating among the back-reflected sensing signals from the sensor system. The light source for FBG sensing applications is normally a broadband amplified-spontaneous-emission (ASE) source [3, 4]. However, when the ASE source is used, the optical power reflected from the FBGs is weak. The broadband ASE therefore limits the resolution and the capacity of a fiber sensor system.

Since fiber lasers are easily implemented, have a high output power and can be incorporated into a fiber system [5–16], they are excellent candidate laser sources for fiber-optic sensing applications. This work develops a novel fiber ring laser with signal-averaging functionality as a sensing CC for long-haul FBG sensor systems. A signal-averaging module is introduced into the fiber laser to reduce the impact of noise on the system performance, increasing the SNR of the system. The following section will experimentally demonstrate the operation of the CC based on the proposed fiber ring laser.

2. EXPERIMENTAL SETUP AND RESULTS

As presented in Fig. 1, a sample long-haul FBG sensor array is connected to the proposed fiber ring laser to demonstrate experimentally the feasibility and effectiveness of the latter as a sensing CC. The sample passive fiber sensor array consists of a 30/60 km single-mode fiber (SMF) and three FBG sensing elements. The peak reflectivity of each FBG is around 94%, and the Bragg wavelengths of the FBGs λ_i ($i = 1, 2, 3$) are 1548.26, 1551.22, and 1554.62 nm, respectively. As shown in this figure, moreover, the fiber ring laser is constructed from a 2 × 2 30/70 coupler (C), an erbium-doped fiber amplifier (EDFA), a tunable Fabry–Pérot filter (FPF), a photodetector (PD), a sampler, an analog-to-digital converter (A/D) and a signal processor. Its lasing wavelength is determined by the tunable FPF. Such a fiber laser incorporates signal-averaging functionality inside the CC, markedly improving the SNR performance of the sample long-haul FBG sensor array, as will be verified in the following.

Seventy percent of any lasing light is fed into the sensing FBG chain via the 2 × 2 fiber coupler to interrogate the deployed FBG sensors. Figure 2 displays the output spectra at the 70% lasing port when the FPF is tuned with a voltage controller. To tune the voltage to within the above operating range, a lasing wavelength in the waveband 1523.78–1576.35 nm is chosen. The lasing peak power from this 70% output port is about 10.76 dBm. Figure 3 shows the stability of the laser with a central wavelength of 1552.48 nm, which is measured at the 70% lasing port within 15 min. From the measured power curve, the variation in the output laser power is $(P_{\max} - P_{\min})/\bar{P}_{\text{out}} = 0.58\%$, where $P_{\max}$, $P_{\min}$, and $\bar{P}_{\text{out}}$ represent the maximum, minimum and average output laser powers, respectively.

The average wavelength variation is 0.04 nm. The stability of a long-haul fiber sensor system that is based on the proposed fiber laser scheme as its CC depends on the above two metrics and the adopted electronic signal-processing method.

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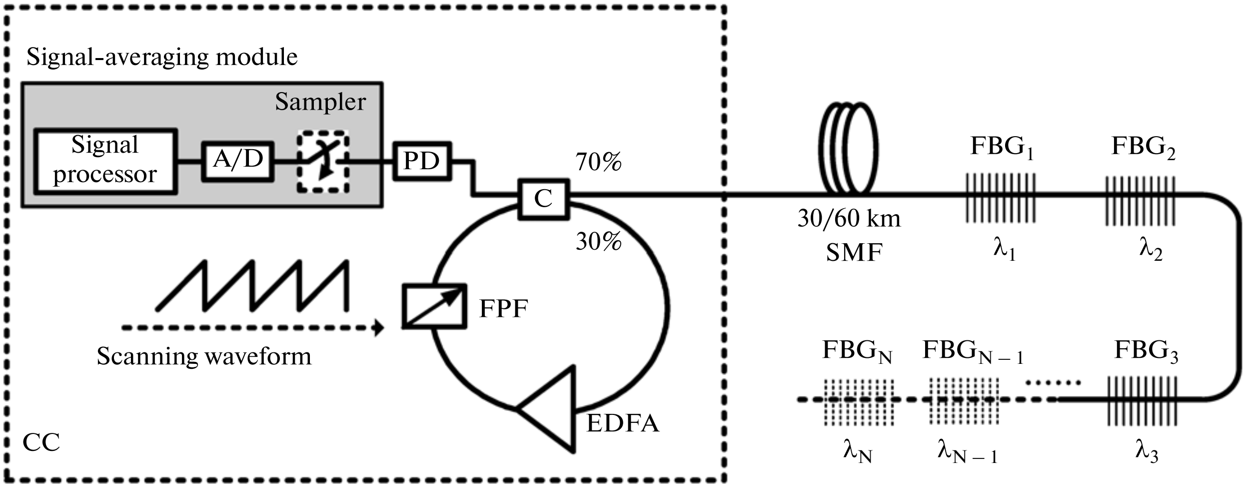

Fig. 1. Experimental setup for demonstrating feasibility of proposed fiber ring laser as a sensing CC. (C: 2 × 2 fiber coupler, EDFA: erbium-doped fiber amplifier, FPF: Fabry–Pérot filter, PD: photodetector, A/D: analog-to-digital converter, SMF: single-mode fiber, FBG: fiber Bragg grating).

The interrogation of the deployed FBG sensors depends on the scanning FPF operation. The back-reflected sensing signals from FBGs λ_i ($i = 1, 2, 3$) are successively fed into the PD and converted to electrical signals. Next, they are sampled, digitized and buffered in that order. After the above process has been carried out 256 times, signal-averaging is performed by the signal processor and the average SNR for each FBG sensor is thus calculated. Figures 4a and 5a plot the output signals obtained without signal-averaging processing when 30 and 60 km FBG sensor arrays, respectively, are attached to the proposed fiber ring laser. The SNR of the system declines as the distance between the fiber laser scheme and the FBG sensors increases. The signals that have undergone signal-averaging processing, displayed in Figs. 4b and 5b, are not as rough as the output signals in Figs. 4a and 5a. Accordingly, the signal-averaging operation increases the SNR of each remote FBG sensor.

3. CONCLUSIONS

This work presents a tunable erbium-doped fiber ring laser with signal-averaging functionality for long-haul fiber-optic sensing applications. It significantly reduces the influence of noise on system performance. The operation and effectiveness of the proposed fiber laser as a sensing CC were experimentally demon-

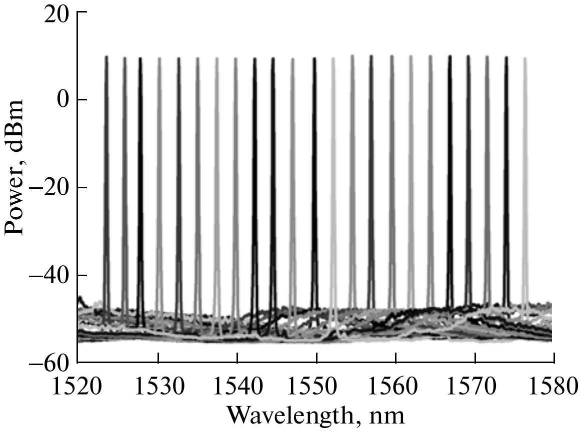

Fig. 2. Output spectra from 70% lasing port within range from 1523.78 to 1576.35 nm.

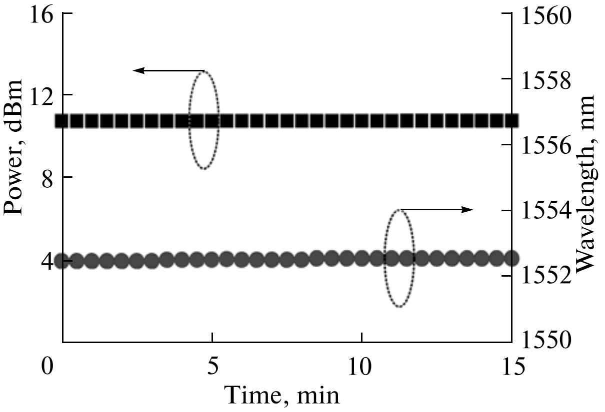

Fig. 3. Laser stability in terms of output power variation and wavelength drift, measured over 15 min.

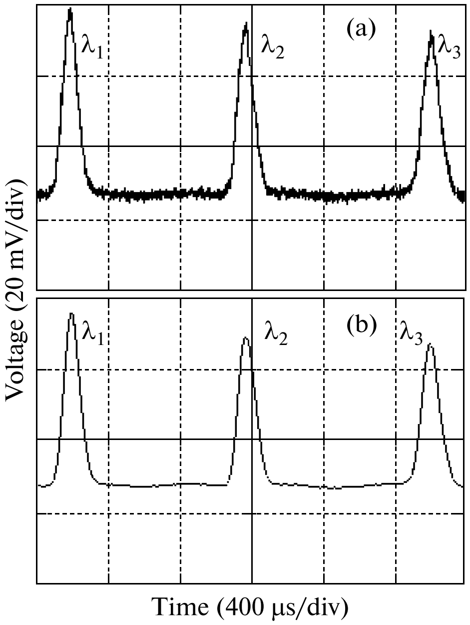

Fig. 4. Output signals (a) without and (b) with signal-averaging processing when a 30 km FBG sensor array is attached to the proposed fiber laser.

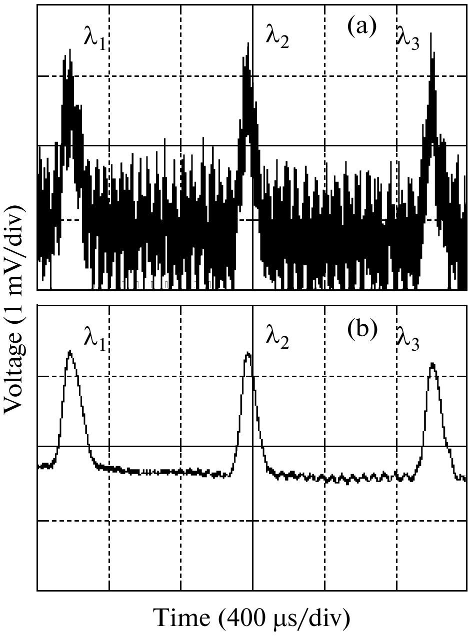

Fig. 5. Output signals (a) without and (b) with signal-averaging processing when a 60 km FBG sensor array is attached to the proposed fiber laser.

strated and characterized. The experimental results reveal that the signal-averaging operation inside the presented scheme increases the SNR of the system.

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