Distributed Temperature Sensing Based on φ-OTDR Using Back-reflection-enhanced Fiber

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Abstract: Distributed temperature sensing with 10 dB back-reflection-enhanced fiber is performed based on φ-OTDR. While the temperature sensitivity of such fibers is similar to that of standard single-mode fibers, a 3-times higher temperature resolution is observed.

1. Introduction

Distributed optical fiber sensors (DOFS) based on coherent Rayleigh scattering have been intensively studied and further developed in recent years [1]. Rayleigh-based sensing shows relatively high sensitivity to strain and temperature measurements, but it suffers from a major drawback, which is the significantly low back-scattered signal. The conversion efficiency from the isotropic scattered light to that captured by a standard single-mode fiber is $\eta = 0.13\%$, corresponding to -29 dB [2], which results in low back-scattered power reaching the fiber input. Several techniques have been investigated in literature to enhance this back-scattered signal. Fiber Bragg gratings have proven their high sensitivity as point sensors, thus received much attention as promising candidates for quasi distributed sensing. Fiber Bragg Gratings (FBGs) written inside the fiber would allow a directional reflected signal, which may be larger than the isotropic Rayleigh recaptured signal even for grating reflective depletions lower than the total scattering loss [3]. Accordingly, a higher signal-to-noise ratio (SNR) can be obtained, resulting in a higher measurement resolution when compared to a standard single-mode fiber.

In this paper, distributed temperature measurement based on Phase-sensitive Optical Time-Domain Reflectometry (φ-OTDR) is carried out comparing the performance of two fibers, namely a standard single mode fiber (SMF) and a special back-reflection-enhanced fiber (REF) (from OFS Optics Company). REF provides around 10 dB enhancement over the naturally occurring Rayleigh backscatter in G.652.D fiber and the loss is less than 0.7 dB/km at a wavelength of 1550 nm [4]. The 10 dB enhancement of the back-reflected signal is achieved by inscribing ~15 mm long individual chirped gratings along the fiber, which are spatially overlapped over ~5 mm [4]. The chirping of the gratings results in a 10 nm wide spectral bandwidth (1545 nm to 1555nm) allowing the freedom to have any probe laser in this specified spectral range. Experimental results showed nearly three times enhancement of the temperature resolution when compared to standard SMF.

2. Experimental Setup

In the experimental setup shown in Fig. 1, a distributed feedback (DFB) CW laser having a 1 MHz line width is used as the coherent light source in direct-modulation φ-OTDR interrogation. An SOA is used as an external modulator to generate optical pulses of 10 ns pulse width with a high extinction ratio thereby providing 1 m spatial

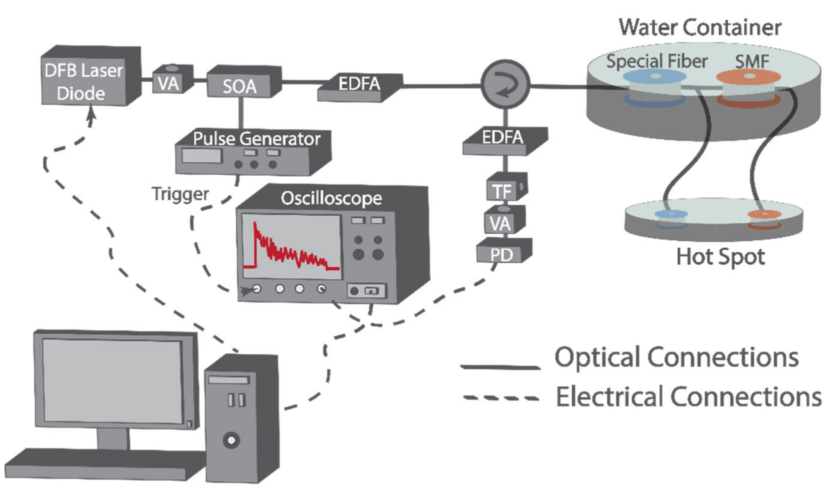

Figure 1: Experimental setup to implement a φ-OTDR over ~240 m-long sensing fiber; (SOA: Semiconductor Optical Amplifier, EDFA: Erbium-doped Fiber Amplifier, VA: Variable Attenuator, TF: Tunable Filter, PD: Photodetector).

resolution for the measurement. The peak power of the pulse is then amplified by an EDFA and the variable attenuator limits the power to avoid non-linear optical effect in the fibers. Light from port 2 of the circulator traverse through the REF followed by the SMF. The back-reflected light is then directed through port 3 of the circulator to an optical filter with a bandwidth of 1 nm, in order to filter out the amplified spontaneous emission (ASE) noise generated by the EDFA. In order to investigate the signal captured by a 125 MHz PD, a fast oscilloscope is utilized for data acquisition at a sampling rate of 1 GS/s. 100X averages are performed on the trace retrieved on the oscilloscope. Both fibers used are about 120 m long each, and are placed in a water bath to reduce environmental influences. A hot spot of 5 m is made at the end of each fiber for performing temperature measurement. A current scan is performed by remotely controlling the laser driver, in order to sweep the optical frequency over a 13 GHz range with a step of 17 MHz.

3. Result and Discussions

From the φ-OTDR trace of REF in comparison to that of SMF, a 10 dB enhancement of the SNR is observed as mentioned in [4]. To understand the effect of increase in the SNR on the temperature sensitivity and resolution, a distributed temperature measurement is performed with the experimental setup depicted in Fig.1. Fig.2 (a) shows the frequency shift of REF and SMF over a range of 10℃. The linear fit of the plot yielded a correlation coefficient of 0.99, and the sensitivity obtained from the slope, for both REF and SMF, is 1.29 GHz/℃. This implies that, the modifications of the fiber core due to the presence of Bragg gratings in REF, does not alter the thermo-optic coefficient of the silica fiber, thereby providing similar temperature sensitivity. Fig.2 (b) shows the frequency shift response of SMF and REF over a distance interval in each fiber, corresponding to a temperature variation of less than 0.05℃. It can be clearly seen from the figure that the standard deviation of SMF is comparatively higher than that of REF with values 2 MHz and 6 MHz, respectively. This yields a temperature resolution (σ/sensitivity) of around 2 mK and 6 mK, respectively. The decrease in standard deviation, thereby increase in temperature resolution can be attributed to the higher SNR of the REF giving rise to strong local cross-correlation values. As the SNR of the REF is higher than that of SMF, the conventional way of improving the SNR by performing a large number of averaging can be ignored, and accordingly decreasing the measurement time. Besides, the base value of frequency shift (shown in Fig.2 (b)) corresponding to the same temperature variations is different for SMF and REF with SMF showing higher base value than REF (Fig.2 (b)). This can be attributed to the fact that the absorption rate of the different coatings of the fibers to humidity is different as the fibers are kept in a water bath at the commence of the experiment.

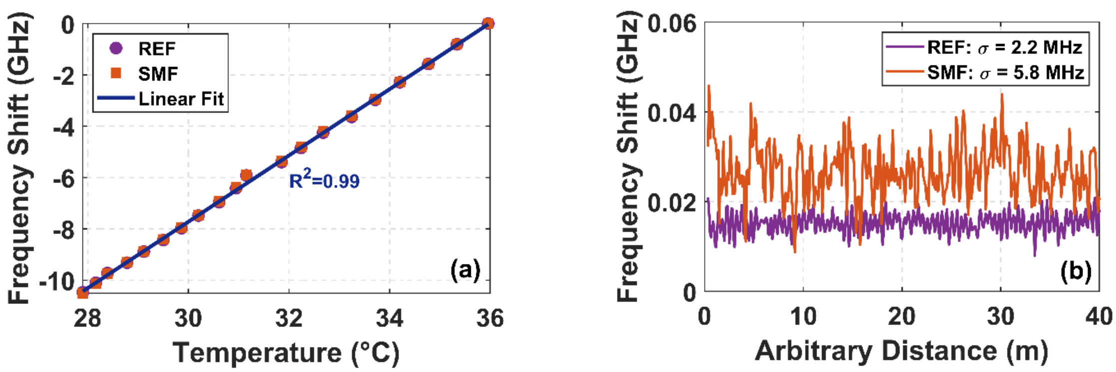

Figure 2: Frequency shift of REF and SMF with respect to (a) temperature and (b) an arbitrary distance of 40 m in each fiber.

3. Conclusions

Distributed temperature measurement based on φ-OTDR is carried out using a 10 dB reflection-enhanced optical fiber, and is compared to a standard single mode fiber. It is shown that the sensitivity of this kind of special fiber to temperature is the same as that of SMF. However, the resolution of such fiber is found to be around 3 times higher than that of SMF in the present scenario as a pure consequence of the enhanced SNR.

3. References

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