Distributed Brillouin fiber sensor featuring 2 meter resolution and 75 km dynamic range

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Abstract: We have used distributed Raman amplification to extend the measurement distance of a Brillouin Optical Time-Domain Analysis (BOTDA) sensor. We successfully demonstrate a dynamic range of 75 km with 2 meter spatial resolution.

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1. Introduction

Distributed optical fiber Brillouin sensors provide innovative solutions for the monitoring of temperature and strain in large structures [1, 2]. The operating range of these sensors is typically in the order of 20-30 km (for 2-3 meter resolution), which limits their use in certain applications in which the distance to monitor is longer. This limitation is basically due to fiber attenuation, which reaches a minimum of about 0.2 dB/km in modern optical fibers at a wavelength of 1.5 µm. To achieve longer measurement ranges, previous works [3, 4] have used distributed Raman amplification in the sensing fiber. However, this has resulted in the past in a relatively low resolution (20-50 meters), which is not desirable in many applications. In this work, we have employed Raman amplification to extend the measurement distance of a distributed Brillouin Optical Time-Domain Analysis (BOTDA) sensor. We successfully demonstrate a dynamic range of 75 km while keeping the spatial resolution of the sensor at 2 meters.

2. Experimental setup

Fig. 1 shows a schematic diagram of the experimental setup used for the tests. The setup includes a conventional BOTDA working at 1550 nm. In this experiment, the Brillouin pump and probe waves are obtained from the same laser diode (LD) through the modulation technique [5]. The LD (1 MHz linewidth) is split in two arms. One is used to shape the Brillouin pump pulse using an electro-optic modulator (EOM) and a pulse generator. The other arm is modulated with another EOM driven by a RF oscillator tuned close to the Brillouin shift of the fiber under test. The lower frequency sideband generated from the modulation is used as the Brillouin probe in the setup. This way the pump-probe frequency difference remains constant and controlled by the RF oscillator, regardless of the absolute frequency changes of the laser.

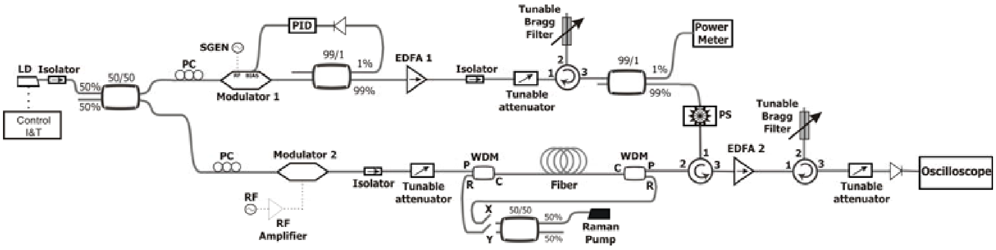


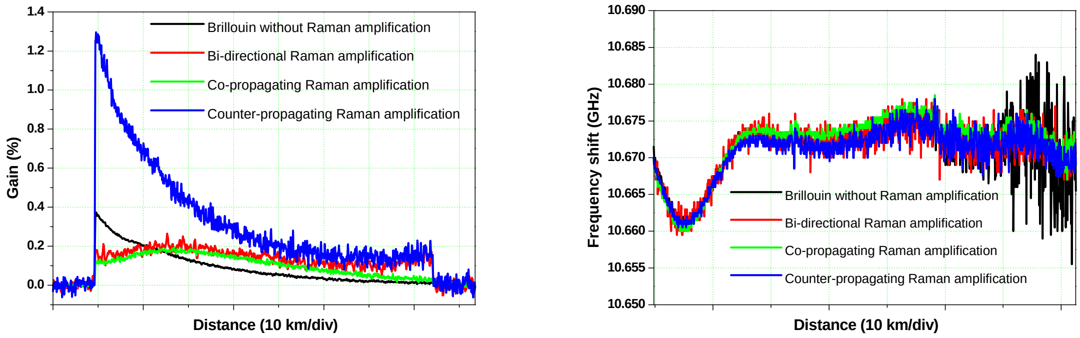
Fig. 1. Experimental setup of the Raman-assisted distributed Brillouin sensor. LD: Laser Dide; PC: Polarization controller; SGEN: Signal generator; PID: Proportional-Integral-Derivative electronic circuit; EDFA: Erbium Doped Fiber Amplifier. RF: Radio-frequency generator; PS: Polarization Scrambler; WDM: Wavelenght Division Multiplexer.

The Brillouin pump and probe waves are coupled to the Raman pumps (by means of suitable WDMs) and introduced in the fiber under test through the opposite ends. Before entering the fiber, the Brillouin pump pulse is boosted with an erbium-doped fiber amplifier (EDFA) and its polarization is scrambled to avoid the polarization sensitivity of the interaction. Before detection, the probe signal is amplified by another EDFA and filtered using a narrow (0.16 nm bandwidth) fiber Bragg grating (FBG) working in reflection. This grating selects only the probe wave amplified by SBS. The Raman pump is a Raman Fiber Laser (RFL) emitting at 1455 nm. The power of this laser can be tuned up to 2.4 W. The RFL beam is divided by a calibrated 50/50 coupler in two beams. Each of them will be coupled to the points X and/or Y represented in Fig. 1, depending on the tested experimental configuration for Raman pumping (co-propagating, counter-propagating or bi-directional propagation with respect to the Brillouin pump pulse).

3. Results

In this section we present experimental results obtained with a standard single mode fiber of 75 km. The width of the Brillouin pump pulses is 20 ns in all cases, thus leading to a 2 meter spatial resolution. In order to achieve this goal, all the configurations have been thoroughly optimised. To correctly determine the Brillouin frequency shift, depletion of the Brillouin pump must be made negligible. Therefore, relatively low Brillouin pump powers and gain values (normally 1-2%) must be preferably chosen. Also, the amount of Raman amplification needed is relatively low, just as much as needed to achieve propagation close to transparency. This optimum value of Raman pumping is around 300 mW on each side (total power around 600 mW in the case of bi-directional amplification) in all studied cases. Additionally, for each configuration we have to search for the optimum Brillouin pump and probe powers so as to avoid pump depletion and maximize the measurement range. The probe power is set high enough to ensure that the signal can be correctly measured in detection. The Brillouin pump is set as high as possible but still trying to avoid depletion. Thus, we show the optimum measurement conditions found with these criteria for all the configurations.

Fig. 2 (a) represents the optimum Brillouin gain traces obtained for a frequency of 10.675 GHz. On average, the contrast of the traces is improved in all the Raman configurations. As we can see, the counter-propagating configuration shows the best improvement in contrast with respect to all the other configurations. The loss in contrast at the input end in the co-propagating and bi-directional configurations is due to the reduction in Brillouin pump power that has been introduced to avoid pump depletion. One remarkable feature of the bi-directional Raman amplification scheme is that the trace obtained is quite flat (the dynamic range in detection does not need to be very large). It is important now to observe the improvements obtained in the determination of the Brillouin shift. Fig. 2 (b) shows the Brillouin shift determined with the gain traces shown before. As we can see, in the conventional BOTDA configuration, the uncertainty in the Brillouin shift grows towards the end of the fiber (up to ±15 MHz), while it remains bounded in all the Raman configurations. In the case of counter-propagating Raman pump, the deviation between measurements is below ±3 MHz. This means that the gain enhancement provided by Raman amplification not only results in an increase of the measurement range, but is also particularly useful in reducing the uncertainty of the measurement.



(a) (b)

Fig. 2. (a) Brillouin gain for the optimum settings in all the configurations. (b) Brillouin frequency shift of the fiber obtained with the different configurations.

4. References

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