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Remote Amplification in Long Range Distributed Brillouin-based Temperature Sensors

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ABSTRACT

A remotely pumped EDFA combined with Raman amplification was used to enhance the performance of spontaneous Brillouin intensity-based temperature sensor. A temperature resolution of 5.7°C, spatial resolution of 20m was achieved at 88km.

Keywords: Distributed sensing, distributed temperature sensor, Brillouin scattering, distributed Raman amplification, remote amplification

INTRODUCTION

The measurement range of single-ended Brillouin intensity based distributed fibre sensors is limited by the attenuation of the probe signal. Both the probe pulse and the backscattered signal are attenuated and result in a reduction in signal power of 0.4dB/km. To overcome this problem, we investigate the use of a remotely pumped EDFA combined with Raman amplification to extend the range and improve the temperature resolution of distributed Brillouin-based temperature sensors.

In this configuration, a cw 1480 nm Raman fibre laser was used to remotely pump an EDFA located at approximately 50km down the sensing fibre. The 1480nm pump travels in the sensing fibre and it provides Raman amplification of both the probe pulse and backscatter signal over the first 50km. The remaining pump power was then used to pump a remotely located EDFA and so provides further amplification of the probe and backscatter signal.

EXPERIMENTAL SETUP

The experimental setup is shown in figure 1. A cw Raman fibre laser, operated at 1480nm, ~700mW, with a linewidth of 0.5nm, co-propagates with a probe pulse, operated at 1533nm with a linewidth of 10MHz and a pulsewidth of 200ns, in the sensing fibre.

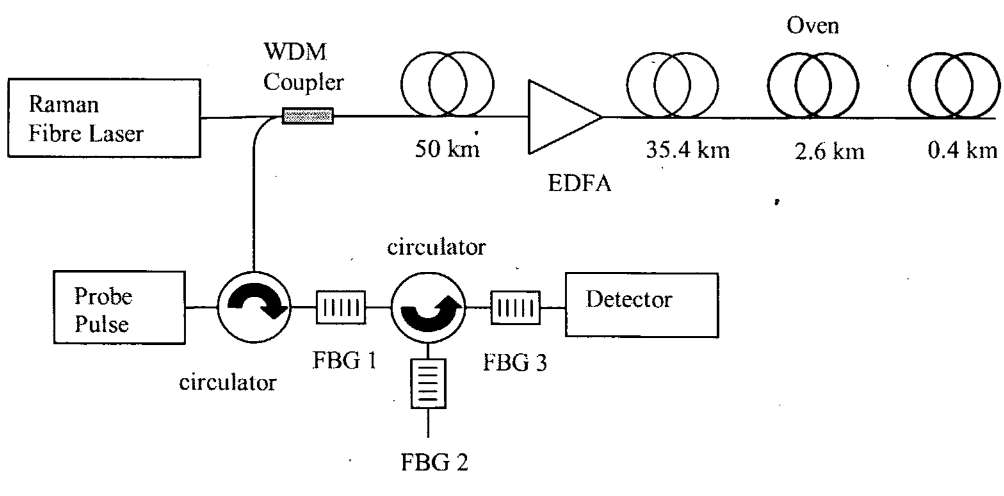

Fig. 1: Experimental setup.

The peak power of the probe pulse power was reduced to 20mW when the 700mW, 1480 nm Raman pump was used, in order to avoid the onset of non-linear effect. The non-linear effect is manifested by a broadening of the probe pulse spectrum of the backscattered Rayleigh and Brillouin signals, leading to the overlapping of the spectrum of the two signals. This phenomenon leads to an apparent reduction in the coefficient for the temperature dependence on the intensity of the Brillouin signal. It has been investigated and has recently been shown to be the result of modulation instability (MI)[1]. The remaining pump power at 50km was then used to remotely pump a 2m length of EDFA with an Erbium concentration of 100ppm. The maximum Raman pump power was limited by the need to avoid saturation of the detector by the backward traveling Raman amplified spontaneous noise (ASE).

Two identical fibre Bragg gratings, FBG1 and FBG3, with a reflectivity of 99.4% an optical bandwidth of 0.1nm and a centre wavelength of 1532.9nm at room temperature were temperature tuned such that the Rayleigh signal from the probe pulse was reflected and the Brillouin signal transmitted to the detector. The cw Rayleigh backscatter and amplified spontaneous Raman noise generated from the Raman pump were attenuated using FBG2. This had a reflectivity of 99%, an optical bandwidth of 1nm and a centre wavelength of 1533.14nm. A 2.6km length of fibre at a distance of 85km from the front end of the sensing fibre was heated to 80°C in an oven and the other fibre was kept at a room temperature of 22°C.

The backscattered Brillouin signal was measured using a detector with an electrical bandwidth of 3MHz and was averaged 2^{20} times. The measurement was repeated without optical amplification, with the Raman pump laser switched off, up to the position of the now un-pumped amplifier, whilst maintaining the same launched probe power of 20mW. The 20mW had been selected to avoid MI from spectrally broadening the pulse in the presence of the Raman gain. Without optical amplification the probe pulse could be increased to 100mW before the onset of MI and so for a meaningful comparison, data was also collected at this probe power. The probe pulsewidth and the number of signal averages were kept constant throughout the experiment.

RESULTS AND DISCUSSIONS

The measured Brillouin backscattered signals with combined EDFA and Raman amplification using a launched probe power of 20mW and 1480nm pump power of 700mw (indicated by a solid line), without any optical amplification and maintaining the launched probe power at 20mW (indicated by a dotted line) and without optical amplification but with an increased launched probe power of 100mW (indicated by a dashed line), are shown in figure 2.

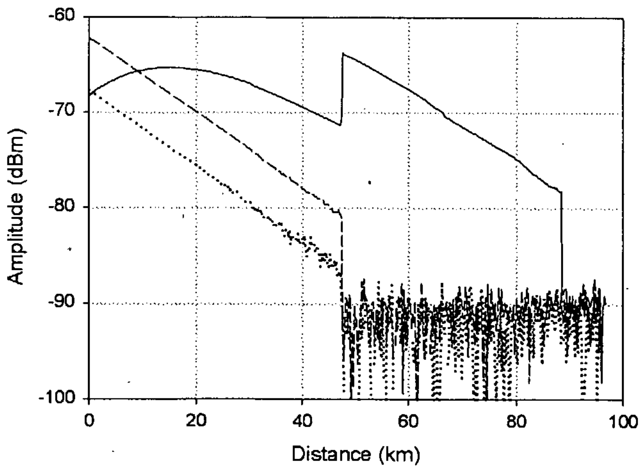

Fig. 2: The measured Brillouin backscattered signals with combined EDFA and Raman amplification using a launched probe power of 20mW and 1480nm pump power of 700mW (indicated by a solid line), without any optical amplification and maintaining the launched probe power at 20mW (indicated by a dotted line) and without optical amplification but with an increased launched probe power of 100mW (indicated by a dashed line).

With optical amplification, the Brillouin backscatter signal can be clearly seen at approximately 88 km. Without optical amplification, the signal may only be observed up to approximately 55 km for the same launched probe power of 20mW. This result was obtained by extrapolating the data from 50km up to 55km. As the probe power was increased to 100mW, the signal remained above the noise floor up to about 70km.

Figure 3 shows an enlarged trace of Brillouin backscattered signal at the far end of the sensing fibre. The step rise in the intensity of the signal at 87km corresponded to the 2.6km of fibre heated to 80±1 °C in the oven. The coefficient for the temperature dependence of the Brillouin intensity was measured to be 0.30%/°C. The standard deviation of the temperature measurement at 87km was measured to be 5.7 °C over the 2.6km of the fibre.

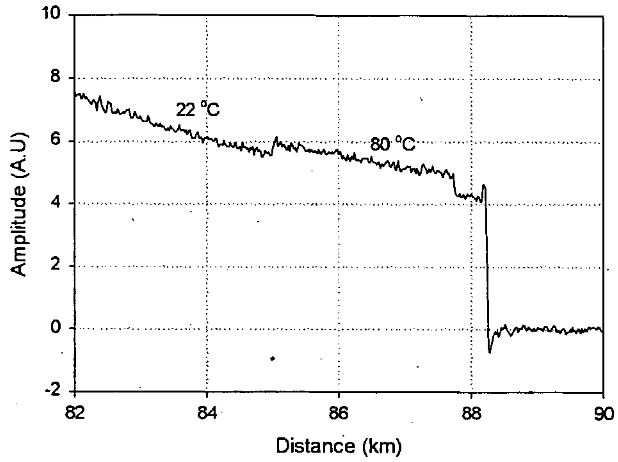

Fig. 3: Measured enlarged Brillouin backscattered signal at 88 km.

The temperature resolutions were calculated over the full sensing range for the various launched conditions by measuring the standard deviation of the Brillouin signal at intervals of 5km and converting to a temperature resolution and are illustrated in figure 4.

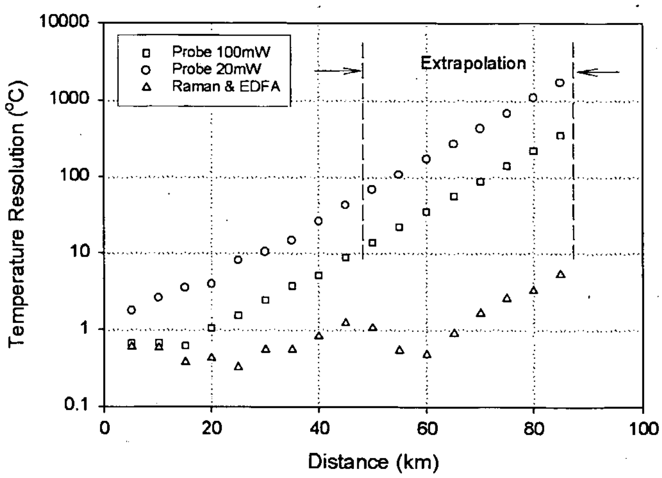

Fig. 4: Temperature resolutions measurement over the full range of the sensing fibre, for the three conditions. Distributed Raman amplifier, remotely pumped EDFA and a launched probe power of 20 mW (indicated by triangles), without optical amplifiers and with a launched probe power of 100 mW (indicated by squares) and without optical amplifiers and with a launched probe power of 20 mW (indicated by circles).

The temperature resolution was measured to be less than 1.5°C (indicated by triangles) with Raman amplification over the first 50km and a launched probe power of 20mW. After the remotely pumped EDFA at 50 km, the temperature resolution improved to 0.6 °C at 55km and then degrades to about 5.0°C at 85km.
With the same launched probe power of 20mW but without remote amplification, the temperature resolution was increased to approximately 68°C at 50km (indicated by circles). The extrapolated temperature resolution at 85km was estimated to be 1715°C assuming a two-way loss coefficient of approximately 0.4dB/km. When the probe power was increased to 100mW (indicated by squares) the temperature resolution at the front end of the sensor was measured to be less than 1.0°C and at 50km was increased to about 14°C. The extrapolated temperature resolution at 85km was 350°C.

CONCLUSIONS

A remotely pumped Erbium doped amplifier situated at 50km was used to improve the performance of a Brillouin intensity based distributed temperature sensor. The amplifier was pumped at 1480nm and this provided useful additional Raman gain. The maximum Raman pump that could be used in this demonstration was limited to 700mW by the present filtering arrangements of the Raman back ASE and the need to avoid saturation of the detector.

A temperature resolution of 5.7 °C with 20m spatial resolution was obtained at a sensing range of 88km using distributed Raman amplification and a remotely pumped EDFA. Without optical amplification, and even after increasing the probe power to 100mW, the temperature resolutions would have degraded to about 350°C at a similar distance. This represents an improvement of approximately 17.9dB using this technique. Further improvement is possible by improving the filtering of back Raman ASE allowing increased Raman pump power to be used.

REFERENCES

1 M.N. Alahbabi, Y.T. Cho, T. P. Newson, P. C. Wait and A.H. Hartog, "Influence of modulation instability on distributed optical fiber sensors based on spontaneous Brillouin scattering", Journal of Optical Society of America B (JOSA B), vol.21, no. 6, pp. 1156-1160, June 2004.