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LONG RANGE TEMPERATURE SENSOR BASED ON BRILLOUIN FREQUENCY SHIFT

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Key words to describe the work: Temperature Sensor, Distributed Optical Fibre Sensors, Brillouin Scattering.

Key Results: The temperature change measurement at 60km of sensing fibre is reported for the first time.

How does the work advance the state-of-the-art?: Measuring temperature change at this long range will help the development of long range high performance temperature distributed optical sensors.
Motivation (problems addressed): Long range temperature sensors above 57km have not been previously realised. Existing applications demand greater range.

Introduction

Long range distributed fibre sensors attract a lot of interest due to their potential usage for monitoring temperature/strain of underground power cable, live optical links and large scale structures. Brillouin frequency shift and change in its intensity may be used to obtain simultaneously temperature and strain change along a link of fibre [1][2]. However the accuracy of intensity measurement limits the performance in long sensing range [3]. Brillouin frequency shift measurement may be used alone to measure temperature or strain change provided one parameter is well defined [4] [5]. In this work we introduce experimental results of measuring temperature change at a range of 60km of standard single mode sensing fibre which to our knowledge, is the longest sensing range reported to date.
Brillouin scattering has been researched extensively for use in long range distributed optical sensors, where both stimulated and spontaneous Brillouin scattering techniques have been reported [6] [7]. The stimulated technique requires access to both ends, whereas access to only one end of the sensing fibre is required for spontaneous measurement and is generally more practical for long range sensors. Direct detection and coherent detection have both been used. Direct detection requires optical filtering of the Brillouin component from the Raleigh signal, whereas electrical filtering is employed in coherent detection, which improves SNR and provides greater dynamic range [5]. In coherent detection, the Brillouin backscattered signal is mixed optically with a strong Optical Local Oscillator (OLO) allowing indirect amplification of the much weaker Brillouin signal which becomes proportional to the square root of the mixed signals. The technique of - coherent detection has been achieved by arranging for the Intermediate Frequency (IF) after optical-mixing to be approximately equal the Brillouin shift (~11GHz). The beat frequency lies within the BW of a fast detector.

Experimental Se t up and Measurements

The experimental arrangement for coherent detection of Anti-Stoke spontaneous Brillouin backscatter is shown in Figure 1.

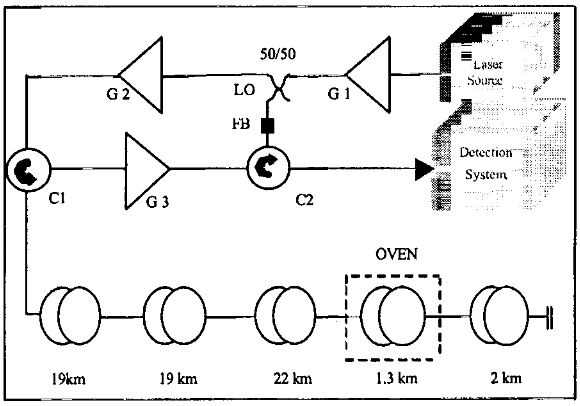

Fig.1 Set-up for measuring Brillouin frequency shift.

The principle of Brillouin Optical Time-Domain Reflectometry (BOTDR) and coherent detection is used; the source is a tuneable laser @ 1533.2 nm, with 1MHz line width, and 100μW CW output. Two *EDFAs* generate a probe pulse of 60mW, 200ns which is launched into the 63km sensing fibre. A preamplifier is used to amplify the weak backscattered signal (a few nano-watts) generated in the sensing fibre prior to mixing with 1.8mW OLO. A 20GHz lightwave detector and RF spectrum analyzer allow the collection of time domain traces centred at the desired RF frequencies. The sensing fibre is standard telecommunications single mode silica fibre which has the following characteristics: loss of ~0.199dB/km, effective area of $60\mu m^2$, and dispersion of 17 *ps/nm.km* @ 1550nm. The sensing fibres are in 5 sections, fusion spliced and arranged as shown in Figure 1. The first 19km, 19km and 22km remain on the original spools at room temperature; the subsequent 1.3km was subject to low-level tension and placed in an oven at 60°C. The subsequent 2km was subject to room temperature and low-level tension as a reference. The temperature change along the sensing fibre can be utilized by analysing the frequency shift of Brillouin backscatter. Brillouin spectra were built from 25 separate backscatter traces, each averaged 2^{12} times, taken every 10MHz, starting at 11GHz. A Lorentzian curve was fitted to each spectrum and the peak frequency was evaluated at each point along the sensing fibre Figure 2.

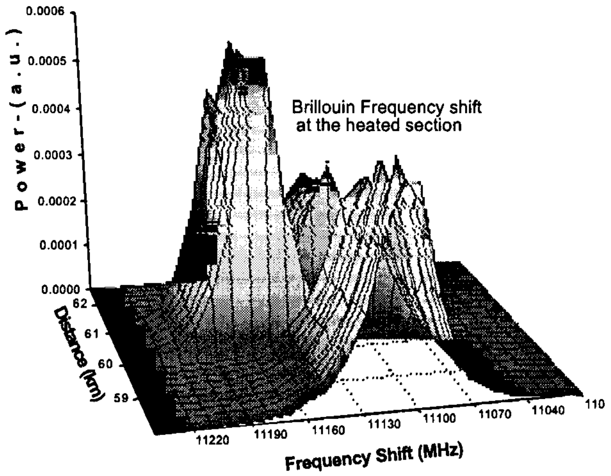

Fig. 2 3D plot of Brillouin frequency shift at the heated section.

Results and Discussion

In order to validate sensor performance and accuracy, results were taken for the final 4km (between 58 and 62km) at oven temperatures of 60°C. Figure 3 shows Brillouin frequency shift as a result of this temperature change of 1.07±0.07 MHz/°C, which is in agreement with previously reported results [8].

The sensor is able to record temperature changes of less than 0.5°C up to 50km. The error is increased with distance to less than 4.5°C at the end of the sensing fibre. The best result was obtained with 60mW-launched power. Above this power ASE and nonlinearity effects degraded the sensor sensitivity. The time taken for the experiment including trace averaging and data analysis was less than 25 minutes, which may be further reduced by using faster data acquisition equipment.

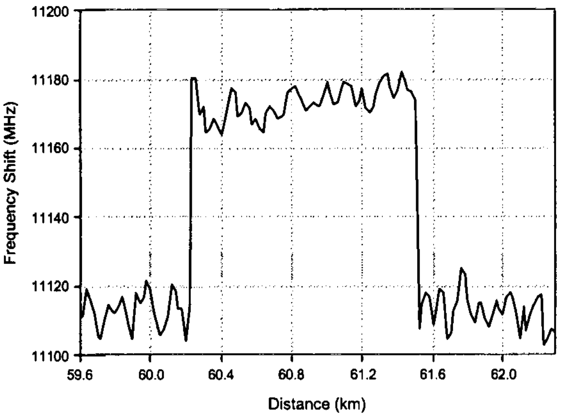

Fig.3 Brillouin frequency shift at the heated section at 60km down the sensing fibre.

Conclusion

In conclusion, experimental work on long range temperature change measurement has been performed. The technique of spontaneous Brillouin scattering and microwave heterodyne detection, achieved a 4.5°C temperature resolution, and a spatial resolution of 20m with 60mW of launched power over 60km of single mode fibre. The result is promising for practical long range Brillouin-based distributed optical sensing systems.

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