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81 km Temperature Sensor Based on Spontaneous Brillouin Scattering and Coherent Detection

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Abstract: We present the longest reported sensing range of temperature change measurement along single-ended optical sensing fibre. The technique is based on spontaneous Brillouin scattering and microwave heterodyne detection. Brillouin frequency shift was used to obtain temperature change at range of 81km with temperature error less than 5°C, and spatial resolution of 30m, at relatively low input pulse power of 70mW.

Fiber optics sensors ,Brillouin Scattering, Heterodyne, Scattering measurements, , Temperature, Frequency shifting.

1. 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 81km 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 where it is directly measured.

2. Experimental Set-up and Measurements

The experimental arrangement for coherent detection of Anti-Stoke spontaneous Brillouin backscatter is shown in Figure 1. 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 70mW, 300ns which is launched into the 83km 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 60μm^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 11km, 17.2km, 19km and 22.3km 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 2.2km 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 15 separate backscatter traces, each averaged 2^{14} times, taken every 10MHz, starting at 10.93GHz. A Lorentzian curve was fitted to each spectrum and the peak frequency was evaluated at each point along the sensing fibre.

3. Results and Discussion

A peak frequency plot is shown in Figure 2 for the entire 83km sensing fibre length; the 1.3 km heated section at 60°C is clearly visible at 81km. The different fibre sections exhibit different Brillouin frequency shifts at room temperature either to dissimilarity in fibre properties or due to differences in fibre winding tensions; however the last three sections were selected to be from the same fibre for measurement clarity. In order to validate sensor performance and accuracy, results were taken for the final 4km (between 79 and 83km) at oven temperatures of 60°C, 40°C, and at room temperature 21°C. Figure 3 shows Brillouin frequency shift as a result of these 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 about 5°C at the end of the sensing fibre. For whole length monitoring, the scope used in this experiment limits the spatial resolution to 200m due to its sampling capabilities. However, when zooming to the heated section sensor spatial resolution is 30m limited by the pulse width used in this experiment. The best result was obtained with 75mW-launched power. Above this power nonlinearity effects degraded the sensor sensitivity. The time taken for the experiment including trace averaging and data analysis was less than 55 minutes, which may be further reduced by using faster data acquisition equipment.

The accuracy of the sensor is expected to increase with longer averaging time which follows the $(N)^{1/2}$ relation. The Brillouin power measurement was found to be unpractical for simultaneous measurement of temperature and strain at the far end.

4. 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 5°C temperature resolution, and a spatial resolution of 30m with 75mW of launched power over 81km of single mode fibre. The result is promising for practical long range Brillouin-based distributed optical sensing systems.

Acknowledgment

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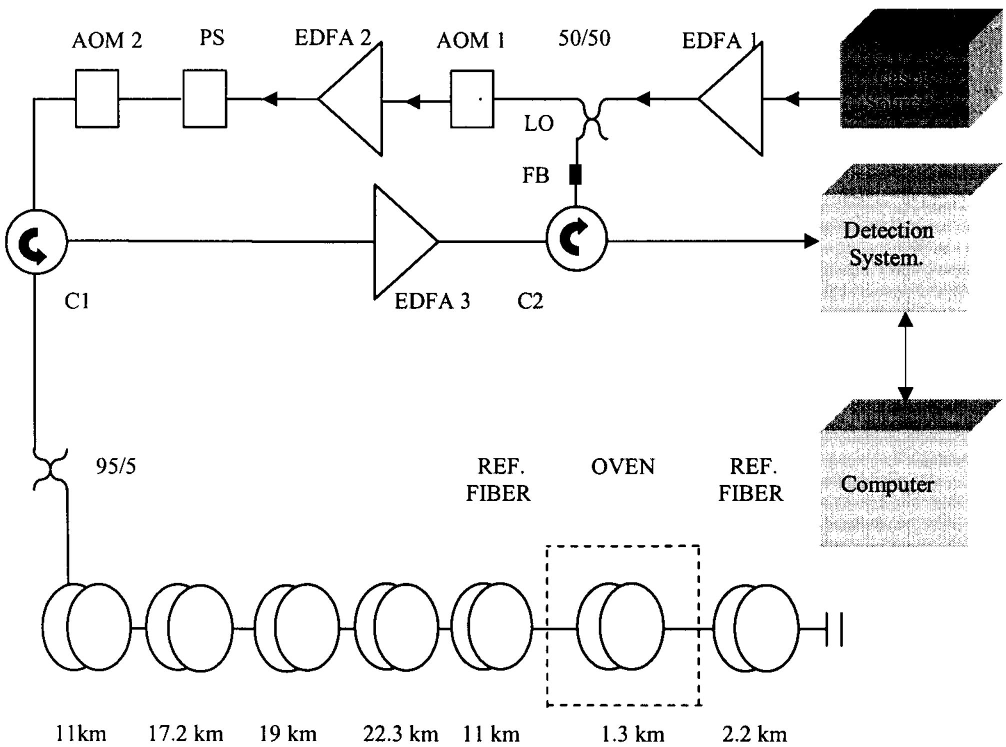

Fig. 1. Experimental arrangement for measuring Brillouin frequency shift.

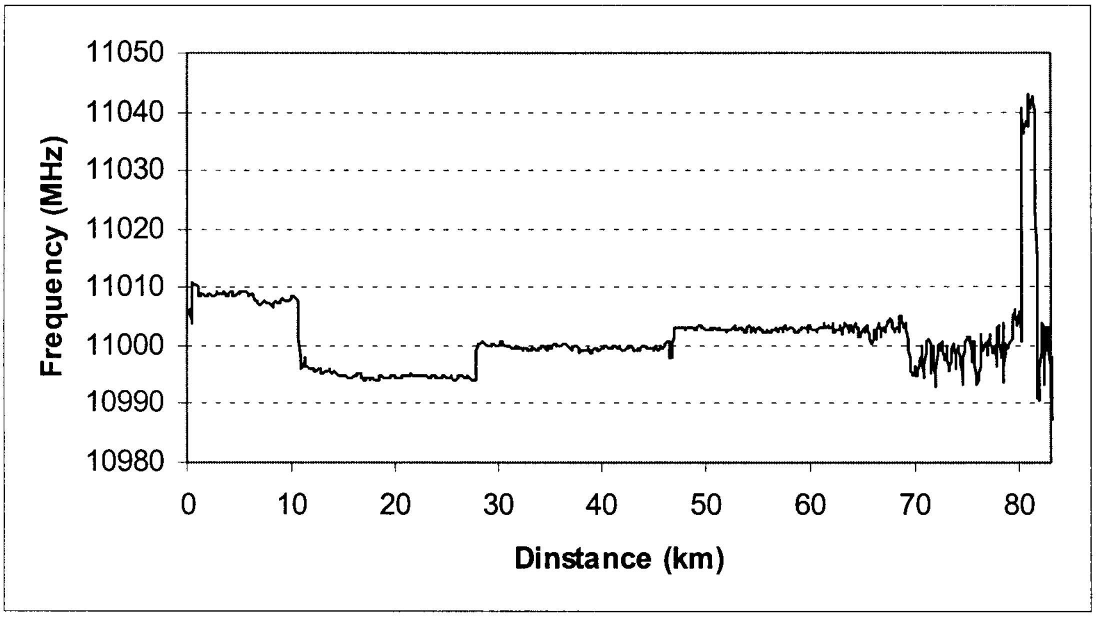

Fig. 2. Brillouin frequency shifts at a heated section down the sensing fibre (left) the corresponding temperature change is shown on the right side scaled to the heated fibre.

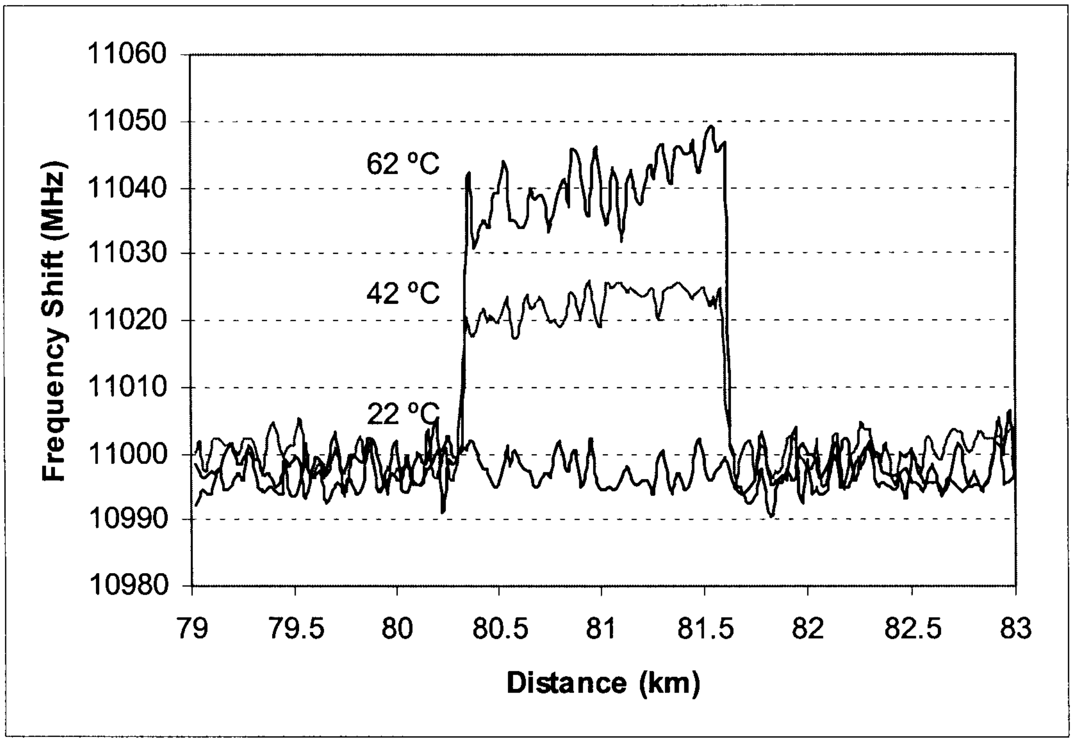

Fig. 3. Brillouin Frequency shift at different applied temperatures at the heated section (left), the corresponding temperature change are shown on the right side.

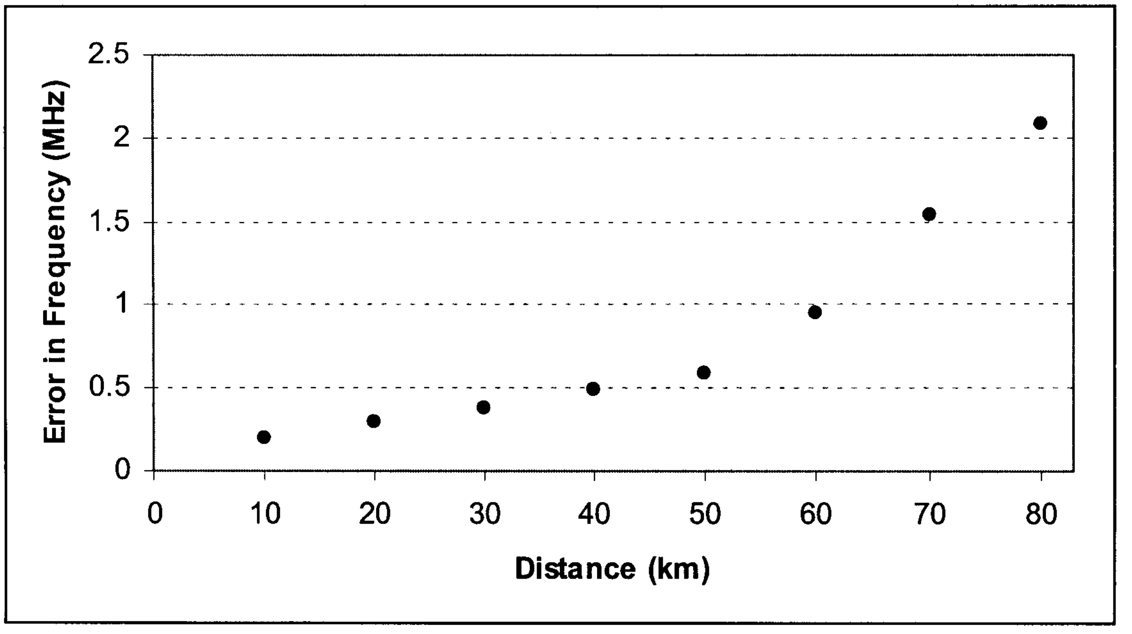

Fig. 4. RMS of Frequency error and corresponding temperature errors along the sensing fibre taking every 10km over a length of 2km.