A novel 1.65μm Raman based Distributed Temperature Sensor

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Abstract: This paper demonstrates a novel Raman-based distributed temperature sensing (DTS) system using a laser source at a wavelength of 1.65μm, which permits monitoring of temperature in active transmission lines. This Raman based DTS system has been demonstrated utilising conventional telecommunications single-mode silica fibres over a range exceeding 10km, spatial resolution of 10m and temperature resolution of 4°C was achieved.

Introduction: Optical fibre temperature sensors based on spontaneous Raman scattering have been the subject of research for a number of years [1-3]. Optical fibre distributed temperature sensors enable the temperature profile along a length of fibre to be continuously monitored. The sensors operate on the powerful optical time domain reflectometry (OTDR) principle whereby a pulse of light is transmitted down the fibre and the light which is backscattered within the numerical aperture of the fibre is measured. The time between sending the pulse of light and detecting the backscattered signal provides a measure of the distance along the fibre whilst the intensity of the Raman backscattered light provides the information on temperature. Previous Raman-based systems typically operate with a pump light in the wavelength region of 1.5μm and cannot be used in the maintenance of optical transmission systems. By allocating a co-propagating wavelength different from communication wavelengths within the Erbium gain spectrum, a potentially useful DTS system can be developed. Although Brillouin-based systems have been successfully developed for DTS applications with high dynamic range and spatial resolution in the wavelength region of 1.5μm [4], its use at wavelengths different from communications wavelengths is presently limited by the lack of commercially practical narrow linewidth sources. A narrow linewidth source is needed to resolve the narrow separation of pump and Stokes/Anti-stokes Brillouin signals (~11GHz). This difficulty is not experienced by broadband width Raman-based DTS systems. This letter demonstrates a novel Raman based DTS system for conventional telecommunications single-mode silica fibres which utilises a pump source operating at a wavelength of 1.65μm.

Experiment: A high power pulsed laser source at the wavelength of 1.65μm wavelength has been previously reported [5]. A similar laser was utilised in this experiment. It consists of a Q-switched Erbium-doped fibre laser coupled with a 390m length of conventional silica fibre (NA=0.12, cutoff=1.2μm). A schematic of the experimental set-up is shown in Figure 1. The Q-switched Erbium-doped fibre laser produces pulses of up to 100W of peak power and a duration of 33.5ns for repetition rates of less than 1kHz. By the process of stimulated Raman scattering, pulses at a wavelength of 1.65μm are generated along the 390m of fibre. The generated 1.65μm pulses are separated from the residual 1.53μm pump pulses by a band-pass filter (FWHM 25nm) centred at 1.65μm, to produce pulses with 1.5W of peak power and 40ns pulse width. The broadband nature (25nm) of these pulses are ideal for OTDR as coherent effects are reduced to a minimum. The pulses are then launched into the sensing fibre through a 1.6μm/1.5μm wavelength division multiplexer (WDM). The sensing fibre was 10.1km in total, consisting of four sections of standard single-mode telecommunications fibre spliced together with lengths of 8.6km, 500m, 500m and 500m respectively. The Raman backscattered signal was then measured using an InGaAs PIN detector in conjunction with a transimpedance amplifier with a bandwidth of 3MHz and sensitivity of 11mV/nW. The detected signal was then electrically amplified with a 30dB gain amplifier. The backscatter signal was averaged 2^{19} times. A narrow bandpass filter (FWHM 25nm) centred at 1.53μm was placed before the detector to filter the anti-Stokes signal from the backscattered Rayleigh.

Results: The Raman backscatter measurement which was obtained for the whole range of sensing fibre is shown in Figure 2. The plot also shows three sections of fibres (500m each) at a distance of 8.6km from the front end of the sensing fibre. The middle section of fibre is heated to 59°C from the room temperature of 23°C. The plot shows a clear rise in the Raman signal indicating the heated section. It can be seen that a measurement with the signal being well above the noise floor can be made for the range exceeding 10km. Figure 3 shows in detail the three sections of 500m test fibres indicating the splice positions. This signal cannot be used to provide an absolute temperature value due to its dependence on fibre attenuation and splice/bend losses. To accurately predict temperature changes the Raman signal has to be referenced to the temperature-independent Rayleigh signal which must therefore be measured with the same spatial resolution. The ratio of the Rayleigh and Raman signals provides a temperature dependent signal which is independent of splice/bend losses and corrected for fibre attenuation. Figure 4 shows this ratio for the same three sections of test fibres. The RMS noise on the ratio was measured to be 2.2×10^{-3}, which corresponds to a temperature resolution of 4°C. The spatial resolution was measured to be 10m, which was limited by the detector bandwidth of 3MHz. Using the Raman anti-Stokes temperature sensitivity of $0.8\%K^{-1}$ [2], the temperature change was calculated to be 36K, and this was in agreement with the measured fibre temperature change.

Conclusion: The results demonstrate the use of a signal source at the wavelength of 1.65μm in a spontaneous Raman based DTS system which allows existing live optical transmission systems to be used to also monitor distributed temperature. The pulsed source produced 1.0W peak power at 1.65μm with a pulse width of 30ns for repetition rates less than 1kHz. A temperature resolution of 4°C with a spatial resolution of 10metres for a range of over 10km was demonstrated using this source. Further improvements in temperature and spatial resolution could be obtained by increasing the available peak power of 1.65μm sources. Since a backscattered trace is required, such a system is presently confined to unrepeated and unamplified communication links.

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Captions:

Figure 1 – Experimental set-up for the 1.65μm pulsed source

Figure 2 – Raman backscatter signal for the whole length of 10.1km sensing fibre, with a heated section at 59°C

Figure 3 – Raman backscatter signal at the end of the 10.1km of sensing fibre with the heated section at 59°C

Figure 4 – Ratio of Raman signal to Rayleigh signal, showing a temperature change of 36°C and temperature resolution of 4°C

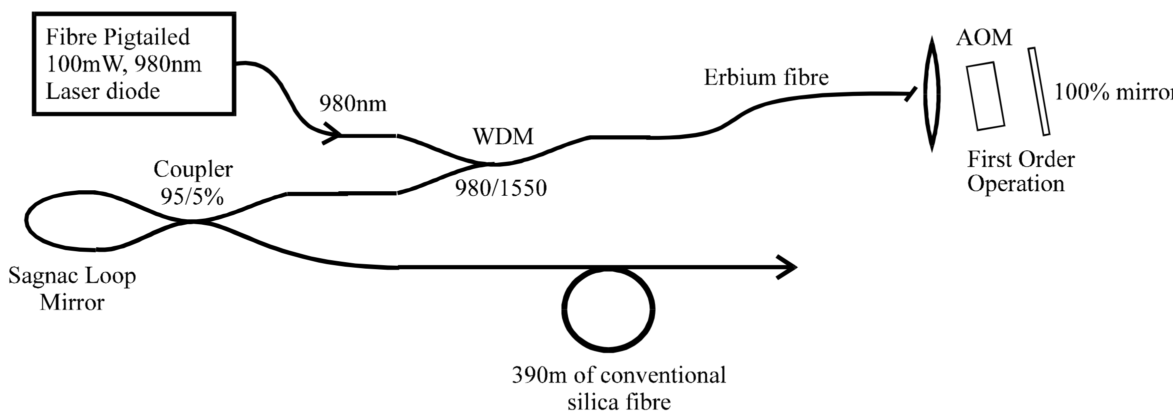
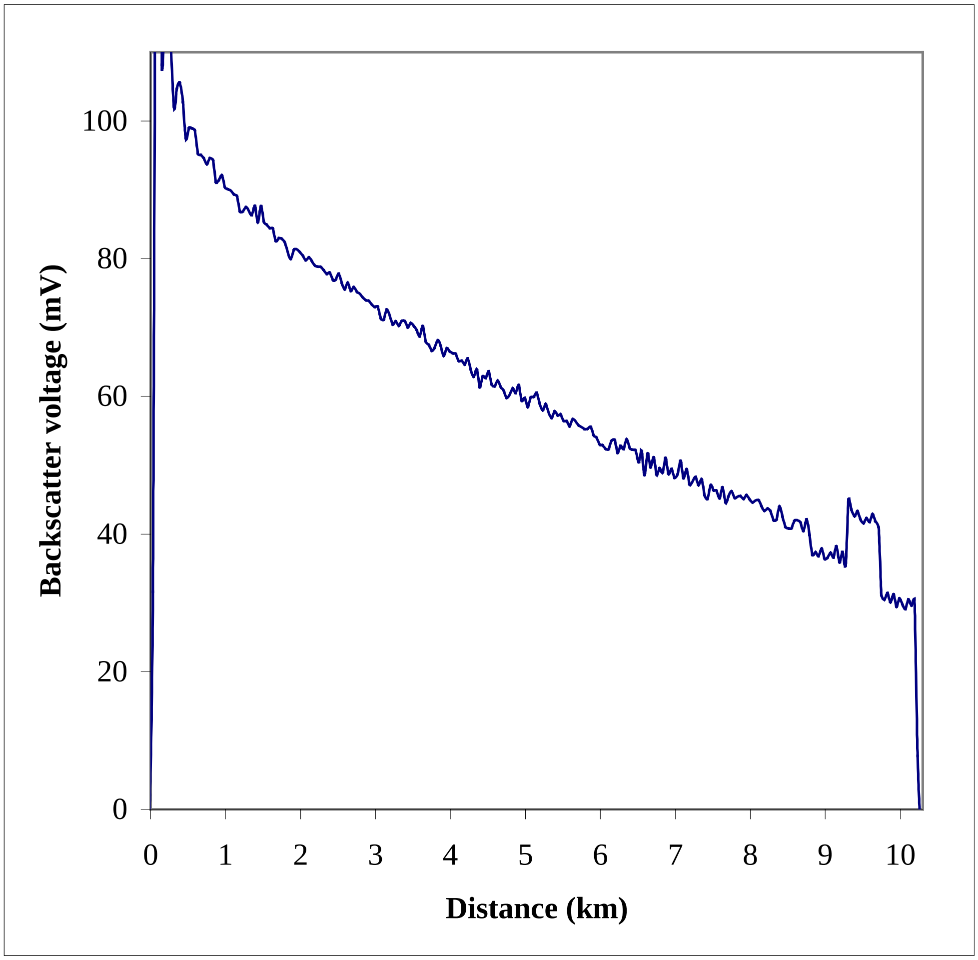


FIGURE 1



100
80
60
40
20
0
Backscatter voltage (mV)
0
1
2
3
4
5
6
7
8
9
10
Distance (km)

FIGURE 2

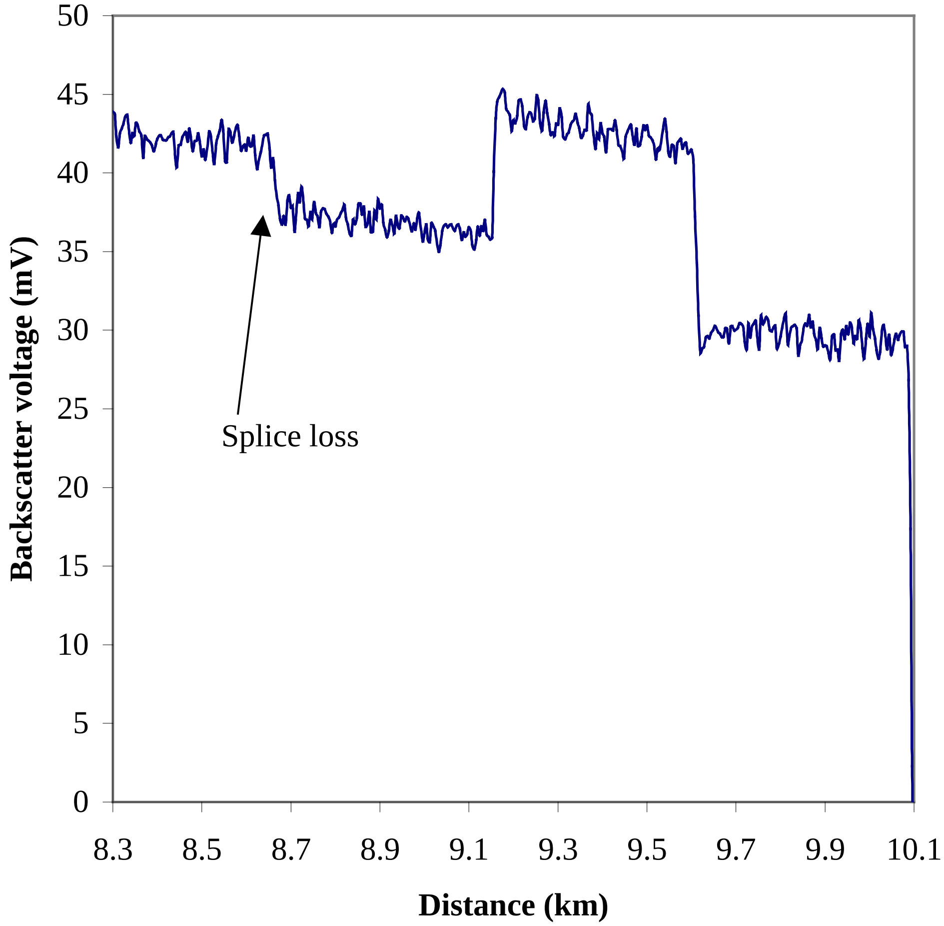

Backscatter voltage (mV)
50
45
40
35
30
25
20
15
10
5
0
Splice loss
8.3
8.5
8.7
8.9
9.1
9.3
9.5
9.7
9.9
10.1
Distance (km)

FIGURE 3

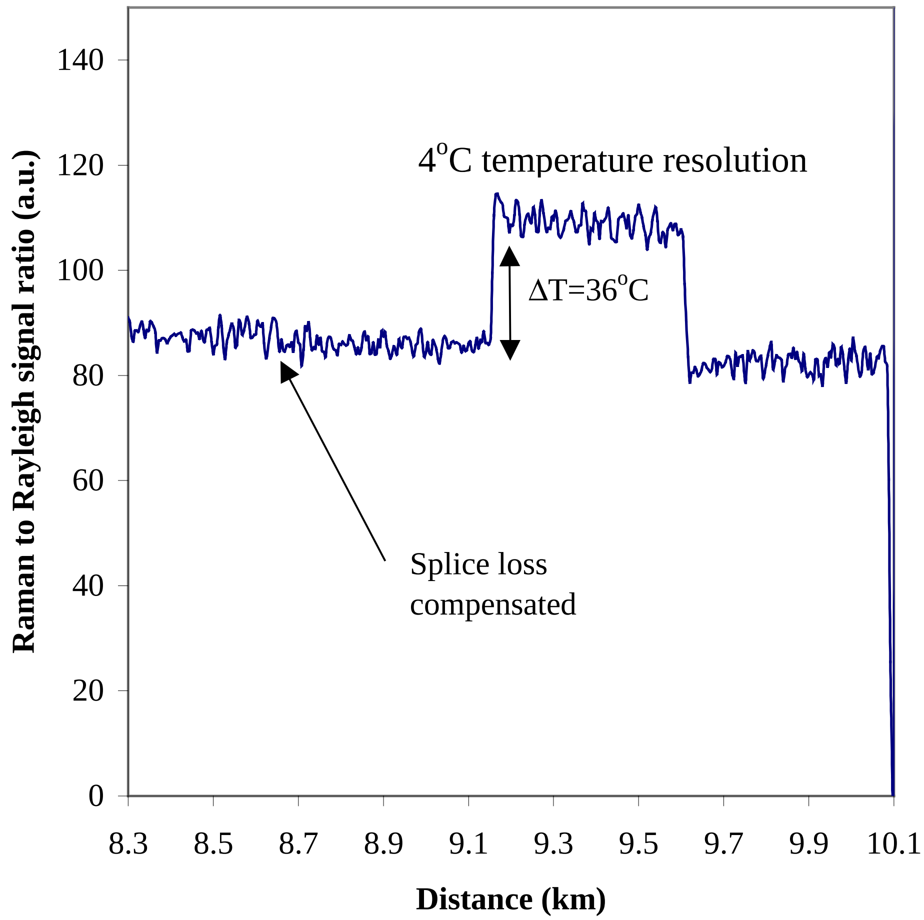

140
120
100
80
60
40
20
0
8.3
8.5
8.7
8.9
9.1
9.3
9.5
9.7
9.9
10.1
Raman to Rayleigh signal ratio (a.u.)
Distance (km)
4^{o}C temperature resolution
ΔT=36^{o}C
Splice loss
compensated

FIGURE 4