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A method of increasing the range of 1.65μm long range OTDR system based on Raman amplification

H. H. Kee, G. P. Lees and T. P. Newson

Electronics and Computer Science, University of Southampton
Southampton, SO17 1BJ. United Kingdom
Tel. +44 1703 593954 Fax. +44 1703 593149
Email: hhk@orc.soton.ac.uk

1. Introduction

Optical Time Domain Reflectometry (OTDR) is an efficient and reliable technique for locating fibre faults and determining the loss distribution along the fibre. An OTDR system operating at a wavelength of 1.65μm is more sensitive to fibre macro-bending and micro-bending losses than those at the region of 1.3/1.55μm, thus providing an early detection of system faults and reducing the risk of total system failure. The current limitation in the maximum dynamic range of OTDR systems is due to the low power of 1.65μm laser diodes. Raman amplification has been employed to amplify a 1.66μm laser diode pulse by 24.8dB before launching it down the end of a sensing fibre [1].

We propose a novel method of increasing the dynamic range of a 1.65μm OTDR system through the use of delayed Raman amplification within the sensing fibre. By delaying the pump pulse with respect to the OTDR pulse, amplification of the latter may be delayed by tens of kilometres.

2. Theoretical Analysis

In the OTDR system we described above, a 1.65μm probe pulse is amplified by the 1.53μm pump pulse within the single mode sensing fibre. The pump pulse was depleted by fibre attenuation and amplification of the probe pulse. The pump and probe pulses, whilst overlapping, are governed by the following pair of coupled equations:

$$dP_s / dz = (g_R / A_s) P_s P_p - \alpha_s P_s \quad (1)$$

$$dP_p / dz = -(g_R / A_p)(\omega_p / \omega_s) P_s P_p - \alpha_p P_p \quad (2)$$

where the subscripts p and s refer to the pump and Stokes shifted 1.65μm probe pulses respectively; α is the absorption constant of the fibre; A is the effective cross-section area and g is the nonlinear Raman gain constant.

The Raman gain constant is inversely proportional to the pump wavelength [2]. At a wavelength of 1.064μm, the gain constant is given by 9.2×10^{-14} m/W. Using the relationship below, we can calculate the Raman gain constant at a pump wavelength of 1.53μm. This is calculated as:

$$g_R = (1.064/\lambda_p).(9.2 \times 10^{-14}) \qquad (3)$$

3. Experimental Details

The proposed method of increasing the dynamic range is based on the ability to maintain both the Raman pump pulse and the OTDR pulse just below the stimulated Raman threshold at the front end of the fibre under test. Subsequent amplification of the signal pulse allows a greater pulse energy to be achieved some distance down the fibre, thus increasing the dynamic range. The amount of energy available for the process of amplification is dependent on the peak intensity and pulse width of the pump pulse. Furthermore, amplification is achieved without significant noise penalty due to the directionality of the Raman gain.

As the operating wavelengths concerned are in the anomalous-dispersion regime for standard silica fibres, the 1.53μm pulses were timed such that it was propagating behind the 1.65μm pulses and would overlap at a distance along the sensing fibre due to the dispersion process. The 1.53μm pulse will pass through the 1.65μm pulse, amplifying it through a process of Raman amplification.

The set-up for the experiment is as shown in Figure 1. The Q-switched pulses from the Erbium doped fibre laser were passed through a 90/10 coupler. The pulses from both arms were then spliced to 300 metres of standard telecommunications grade fibre. In the 90% arm, 1.65μm pulses were generated through stimulated Raman process. The generated 1.65μm pulses were then separated from the residual 1.53μm pump pulses using a narrow band pass filter centred at 1.65μm. The resulting 1.65μm pulse had a peak power of 1.0 Watt, pulse width of 18ns and 3dB optical bandwidth of 25nm. This pulse was then recombined with the pump pulse in the 10% arm through a 66/34 wavelength division multiplexer coupler (WDM) biased to receive the maximum backscattered signal.

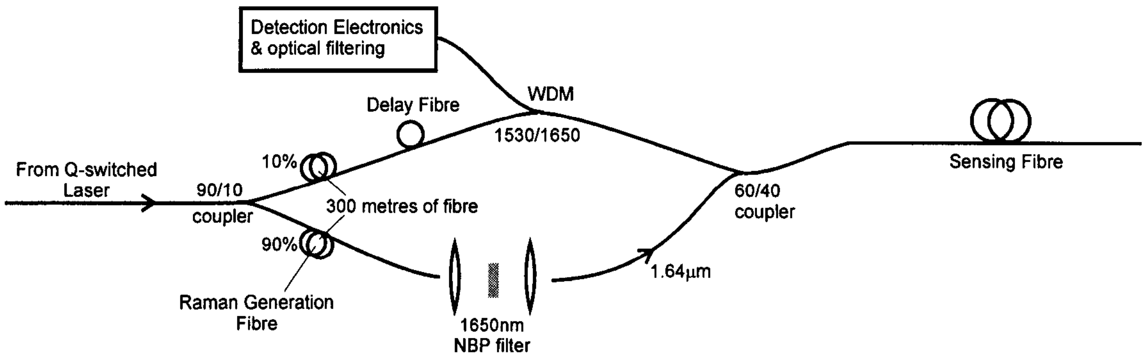

Figure 1: Set-up for Raman amplification experiment

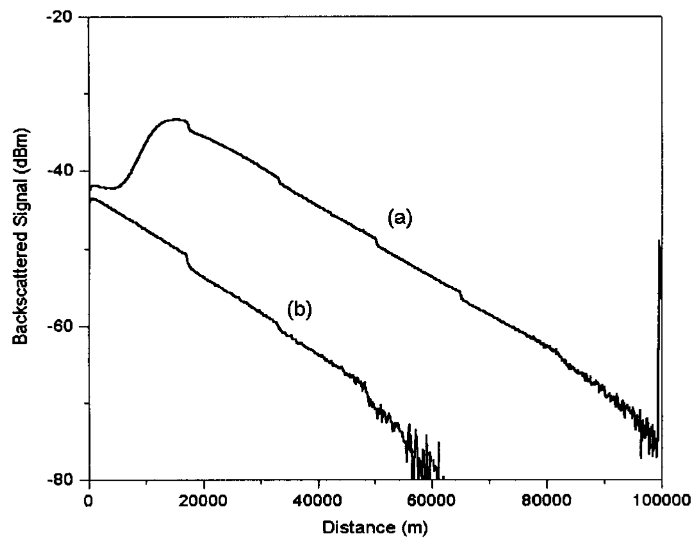

Figure 2:
Raman OTDR backscattered traces of the 1.65μm signal pulses (a) with amplification and (b) without amplification.

The dynamic range was increased by 17.5dB through amplification of the 1.65μm probe pulses, when both the pump and probe pulses overlap down the sensing fibre. The experimental results are shown in Figure 2.

From the relative positions of both the pump and signal pulses at the near and far end of the sensing fibre, the dispersion parameter, D can be calculated. From the experimental data, the dispersion parameter is calculated to be 200ns/(100km·120nm)=16.7ps/(km·nm). This is consistent with the typical dispersion parameter at this wavelength.

A comparison between the experimental results and the numerical analysis governing the differential equations are as shown in Figure 3. The slight discrepancy between the two rates of Raman amplification is due to larger pump depletion from the tail of the experimental Stokes pulse. The deviation between the experimental and theoretical results at the far end of the sensing fibre is due to the accumulation of splice losses which were not accounted for in the model.

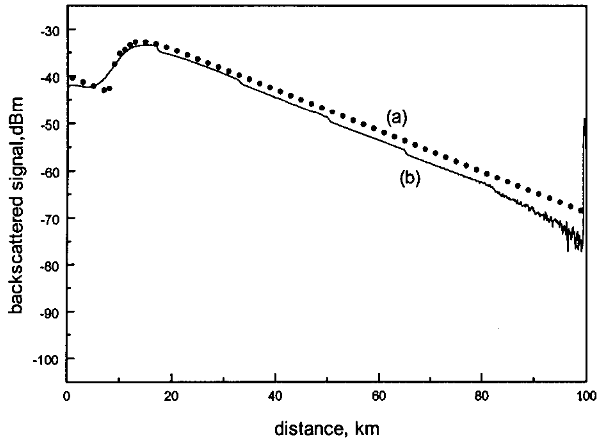

Figure 3:
Results of Raman amplification process. Curve (a) shows the theoretical analysis and curve (b) shows the experimental results.

4. Conclusion

A novel long range 1.65μm wavelength OTDR system has been developed through a process of delayed Raman amplification within the sensing fibre. Using this method, the experimental results demonstrate an increase in dynamic range of 17.5dB. The technique of OTDR system based on Rayleigh scattering measurements can provide a basis for other forms of distributed measurements, such as applications of distributed temperature and strain measurements based on Brillouin and Raman scattering measurements.

5. References

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