How can the Brillouin effect be used as distributed temperature sensor?

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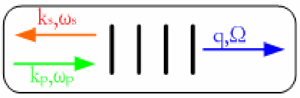
The Brillouin effect can be used for the realization of temperature sensor thanks to the dependence of the Brillouin frequency shift observed in glass on the environment. Because of the scattering properties of optical fibers together with reflectometry techniques, measurement of temperature along the fibre is possible leading to the realization of distributed sensors.

Brillouin scattering refers to backscattering of lightwave by an acoustic wave with a frequency shift

In the optical fiber, there are always spontaneous thermal vibrations which can be visualized as a series of axially propagating acoustic waves. These acoustic waves induce a periodic temporal/spatial modulation of the density (and hence the refractive index) of the medium and by the way of Doppler effect gives rise to **Brillouin scattering** [1].

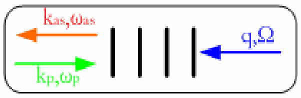
When the pump signal ω_p interacts with acoustic wave through Doppler effect, it will partly backscattered.



The scattered signal (Stokes component) has the frequency which is **smaller** than ω_p

$$(\omega_s = \omega_p - \Omega)$$

if the pump and acoustic waves are travelling in the **same** direction



The scattered signal (anti-Stokes component) has the frequency which is **bigger** than ω_p

$$(\omega_{as} = \omega_p + \Omega)$$

if the pump and acoustic waves are travelling in the **opposite** direction

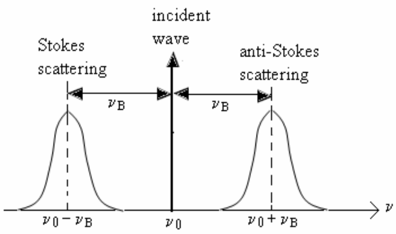


Fig. 1 – Spectrum of Brillouin scattering

Brillouin frequency shift is dependent on the temperature

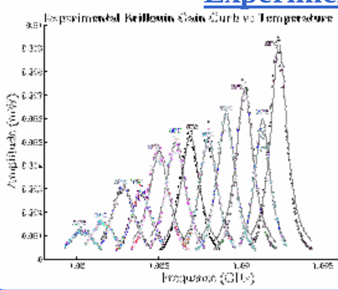
Theory

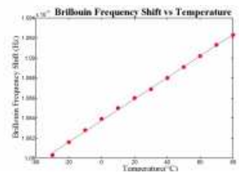
The sensing capability of Brillouin scattering comes from the fact that local acoustic velocity in glass which is proportional to Brillouin frequency shift (ν_B) has dependence on temperature [2] as specified in the following equation [3]:

$$\upsilon_B(T) = \upsilon_B(T_{ref}) + C_{Ftemp}(T - T_{ref})$$

T: temperature
T_{ref}: reference temperature
C_{Ftemp}: coefficient depending on the medium properties

Experimental results





The Brillouin frequency shift is linearly increasing with the temperature

(fiber length, laser source linewidth, and laser input power are **25km**, **100pm**, **40mW** respectively)

The original experimental set-up makes use of a standard OTDR for detection and signal process

Principle of the set-up: a pulsed light and a counter-propagating continuous-wave (CW) light are launched into a fiber. When the frequency difference between the pulsed and CW lights is tuned to the Brillouin frequency shift of the fiber, the CW light intensity experiences gain (or loss) through the stimulated Brillouin scattering process. The increase (or decrease) in the CW light power is measured as a function of time [4].

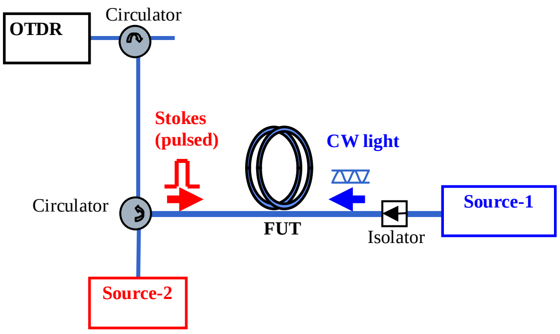


Fig. 2 – Measurement set-up

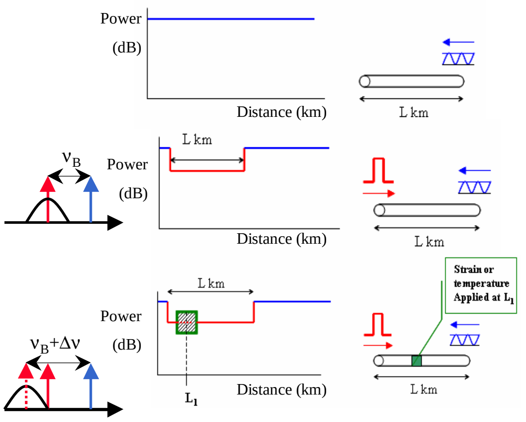


Fig. 3 – Operating principle of the distributed sensor

OTDR trace (reference trace) when there is only CW pump wave

Depletion of CW pump signal resulting from Brillouin interaction

A new physical condition is applied at point L_1. Brillouin gain characteristics of this particular point is different from the rest of the fiber

Conclusions and Perspectives

The linear dependence of the Brillouin frequency shift on temperature was measured. A new measurement set-up was realised. An important challenge of the set-up related to the detecting the CW light by a commercial OTDR has been overcome. Future steps include:

=> Conception of sensing mechanism: formulation of the temperature effect on the observed OTDR trace,
=> Dimensioning of the system: all the system parameters will be determined such as fiber length, pulse width, optical power …
=> Writing specifications of the system (resolution, accuracy …)

- [1] : R. W. Boyd, «Nonlinear Optics», Academic Press, San Diego, California, 1992
- [2]: T. Kurashima, et al.,« Thermal effects on Brillouin frequency shift in jacketed optical silica fibers », Appl. Opt., vol.1, No.15, pp. 2219-2222, 1990.
- [3]: T.Horiguchi, « Development of a Distributed Sensing Technique Using Brillouin Scattering », J. Lightwave Technol., vol.13, no.7, pp. 1296-1302, 1995.
- [4]: M. Niklès, «La Diffusion Brillouin Dans les Fibres Optiques: Etude et Application aux Capteurs Distribues », PhD Thesis No. 1674, Lausanne, 1997.

p, a, s refer to pump, anti-stokes and Stokes components
Ω: acoustic wave angular frequency
ω: optical wave angular frequency   k :wave vector

Matinées des chercheurs

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