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Sahar Farahbakhsh, Ludovic Chamoin, Martin Poncelet. High resolution strain measurement using optic fiber sensors. LMPHD'S Day, 2022, Jun 2022, Gif-sur-Yvette, France. . hal-04425605

HAL Id: hal-04425605

<https://hal.science/hal-04425605>

Submitted on 30 Jan 2024

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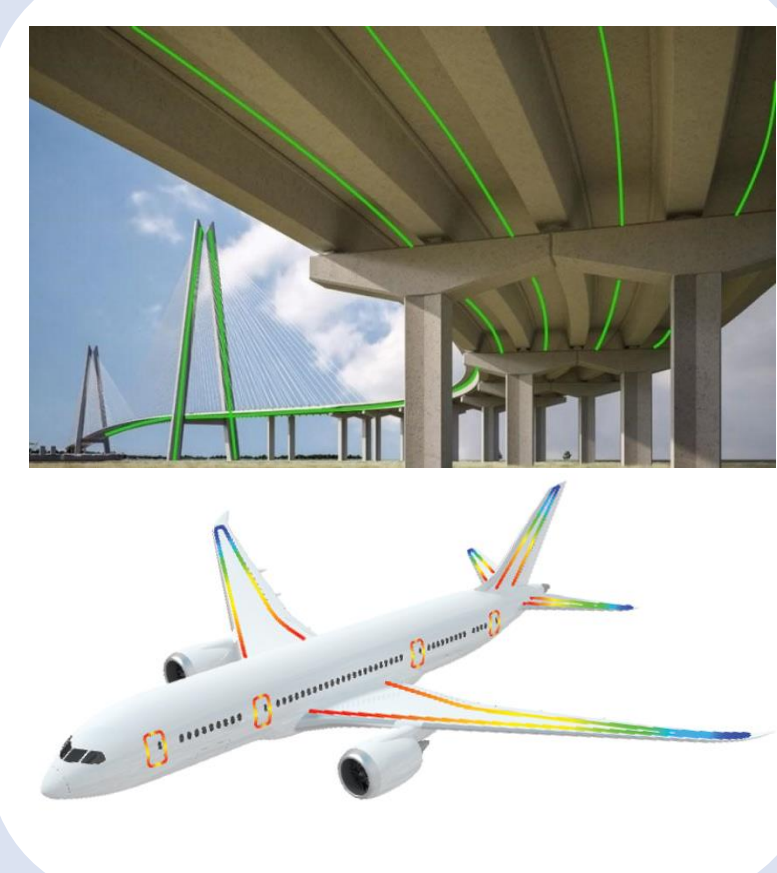
HIGH RESOLUTION STRAIN MEASUREMENT USING OPTIC FIBER SENSORS

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Introduction

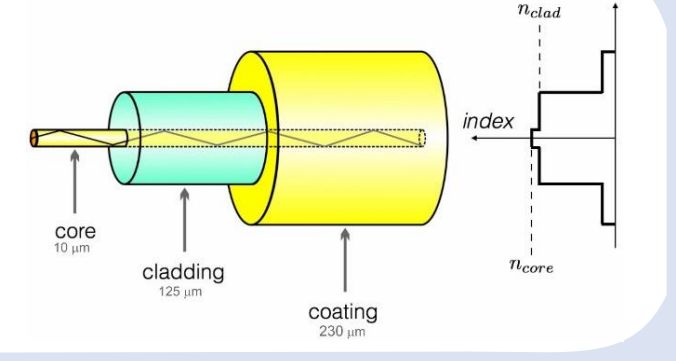
Distributed Optic Fiber Sensors (DOFS) are an efficient tool for structural health monitoring (SHM) and damage detection. This technology now permits real-time temperature and strain sensing with high spatial resolution. Optic fibers are immune to electromagnetic fields and are simple to install on structures or embed in structural material, which brings them a wide variety of use.



Possible applications of DOFS

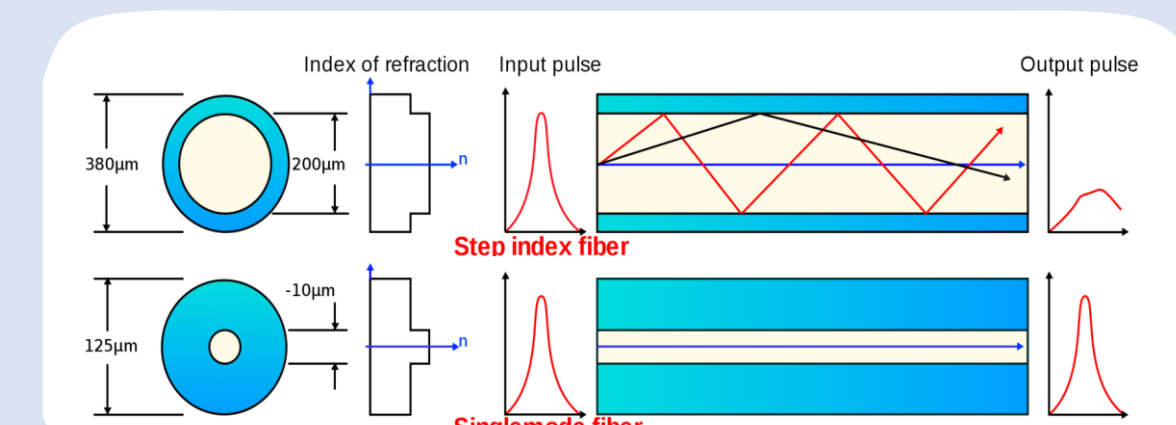
Basic principles

A small difference in the refractive index of core and cladding, leading to total internal reflection



General structure of optic fibers

Fiber type	Beams	Dispersion	distance
Multi mode	Several	Yes : intermodal	short
Single mode	One	Few, only intramodal	long

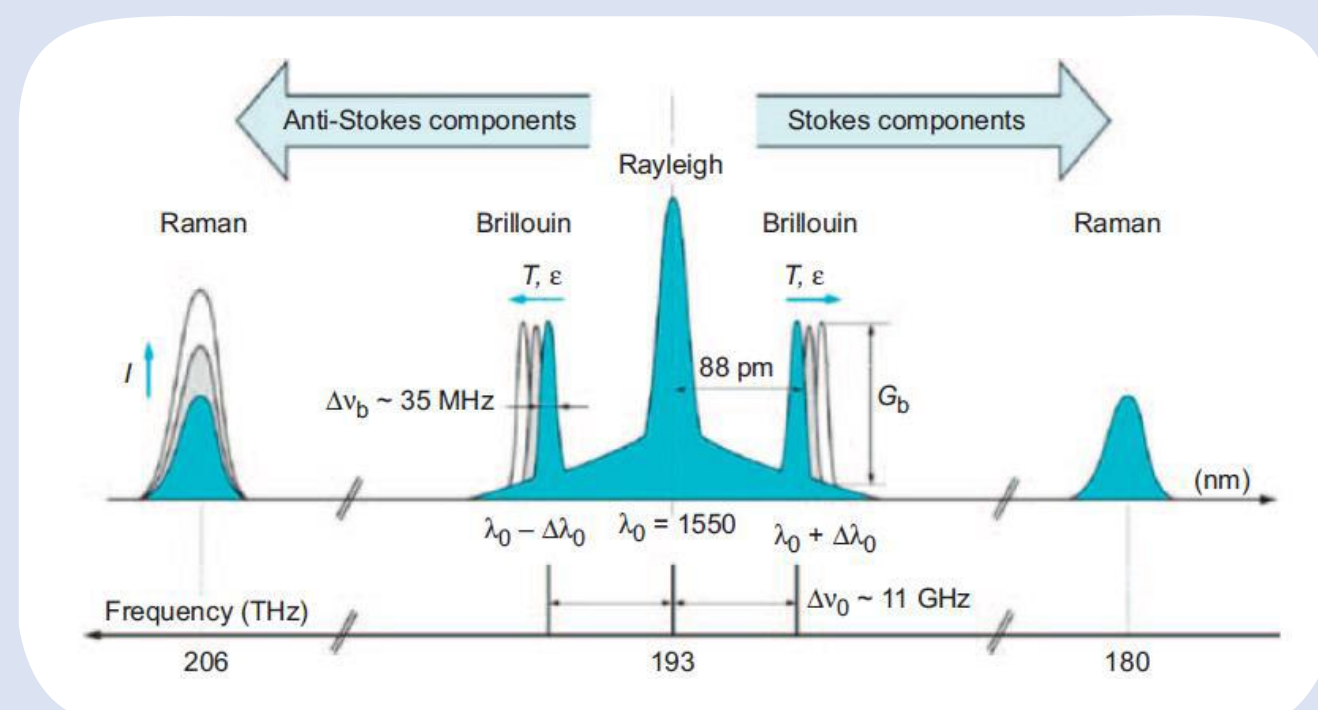


Multimode and Singlemode optic fibers

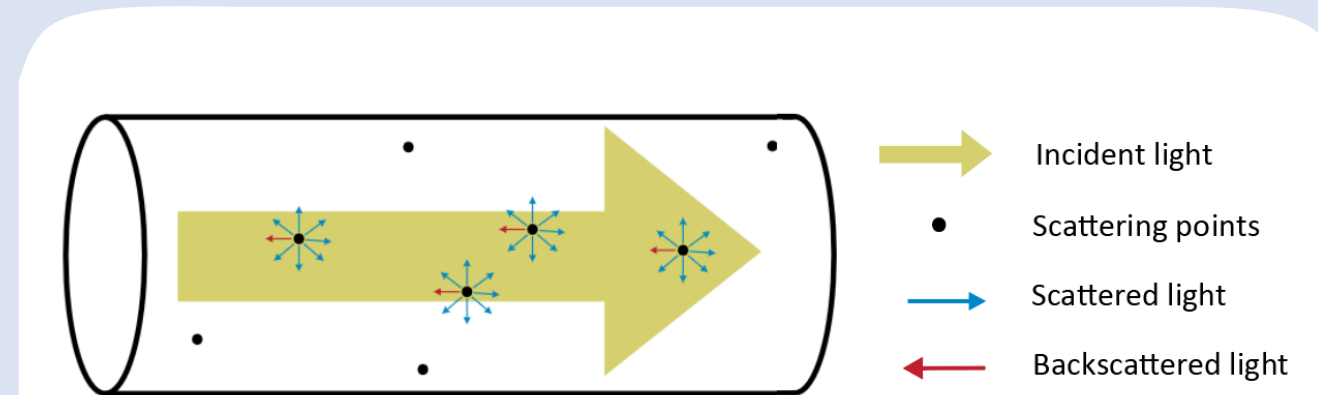
Rayleigh backscattering

Three main scattering phenomena used in fiber optic sensors:

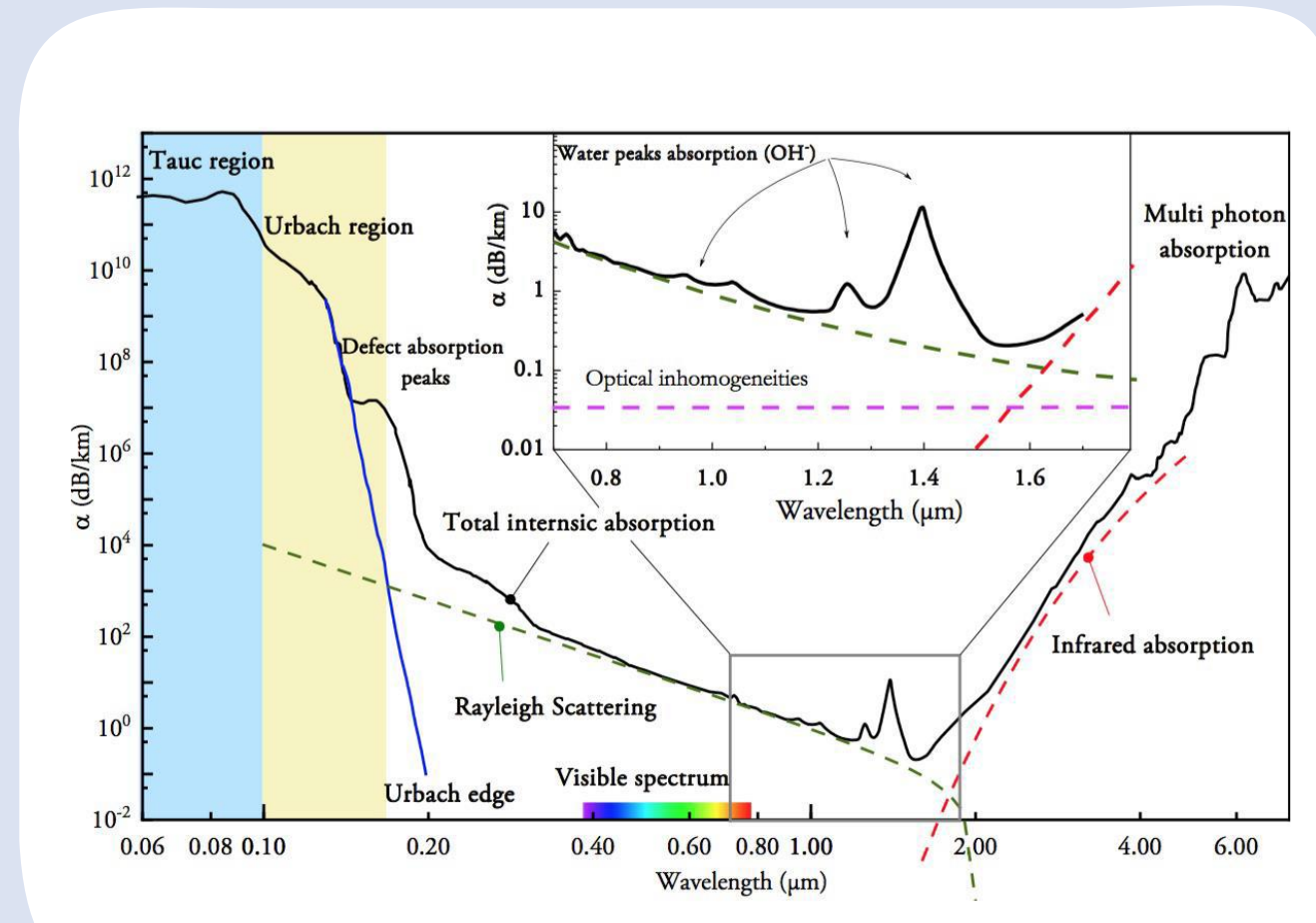
- Raman: highly dependent on temperature, shifts light frequency, used in fibers up to 60 km
- Brillouin: small frequency shift in light, more complex detection, more accurate and stable in long term
- Rayleigh:
 - Most common
 - Source: interference of light with core small inhomogeneities due to manufacturing process
 - Unchanged light frequency
 - Causes the most attenuation in the optic fiber (disadvantage in telecommunications)



Optical spectrum of scattering in silica



Rayleigh scattering in a fiber core

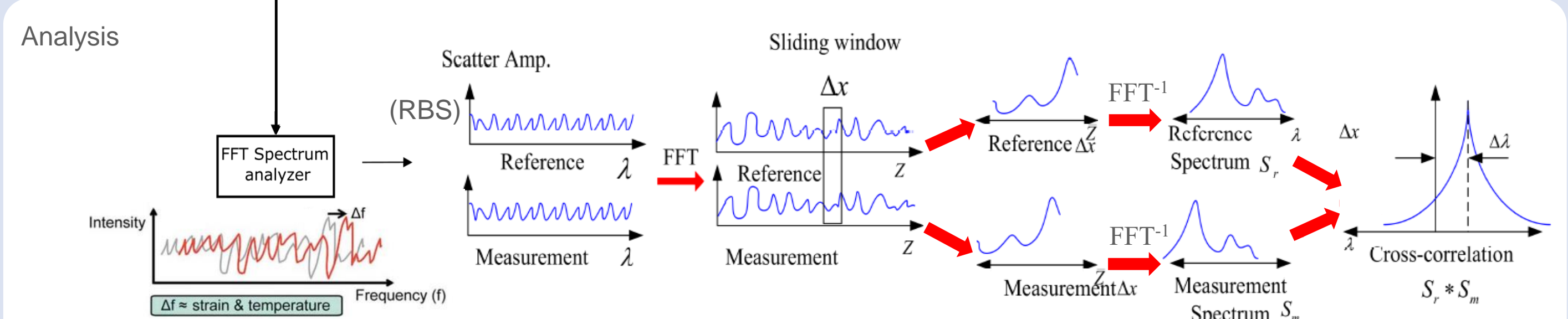
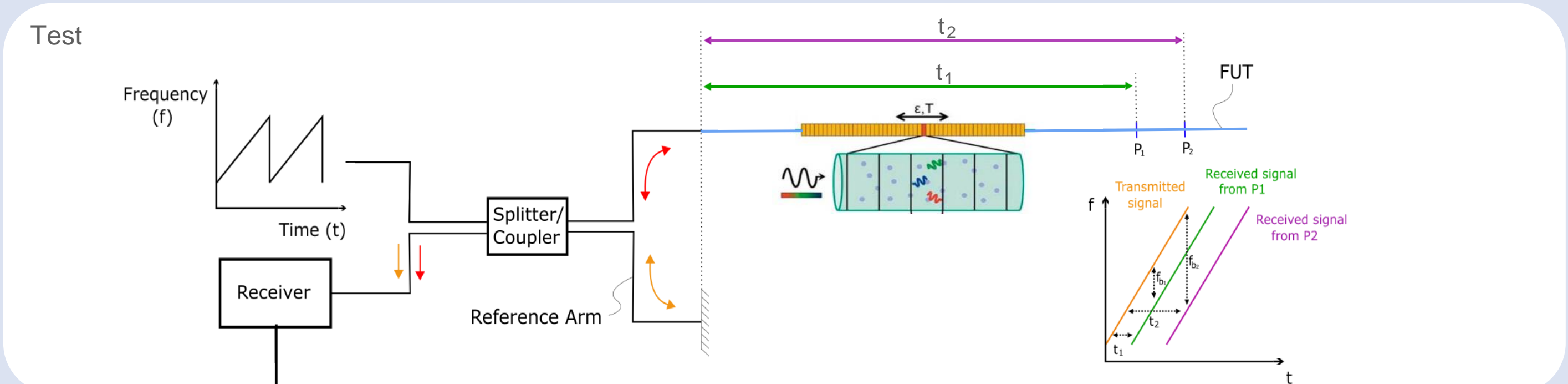


Attenuation in optic fibers

For all techniques, "time of flight" is used for location along the fiber

OFDR Technology

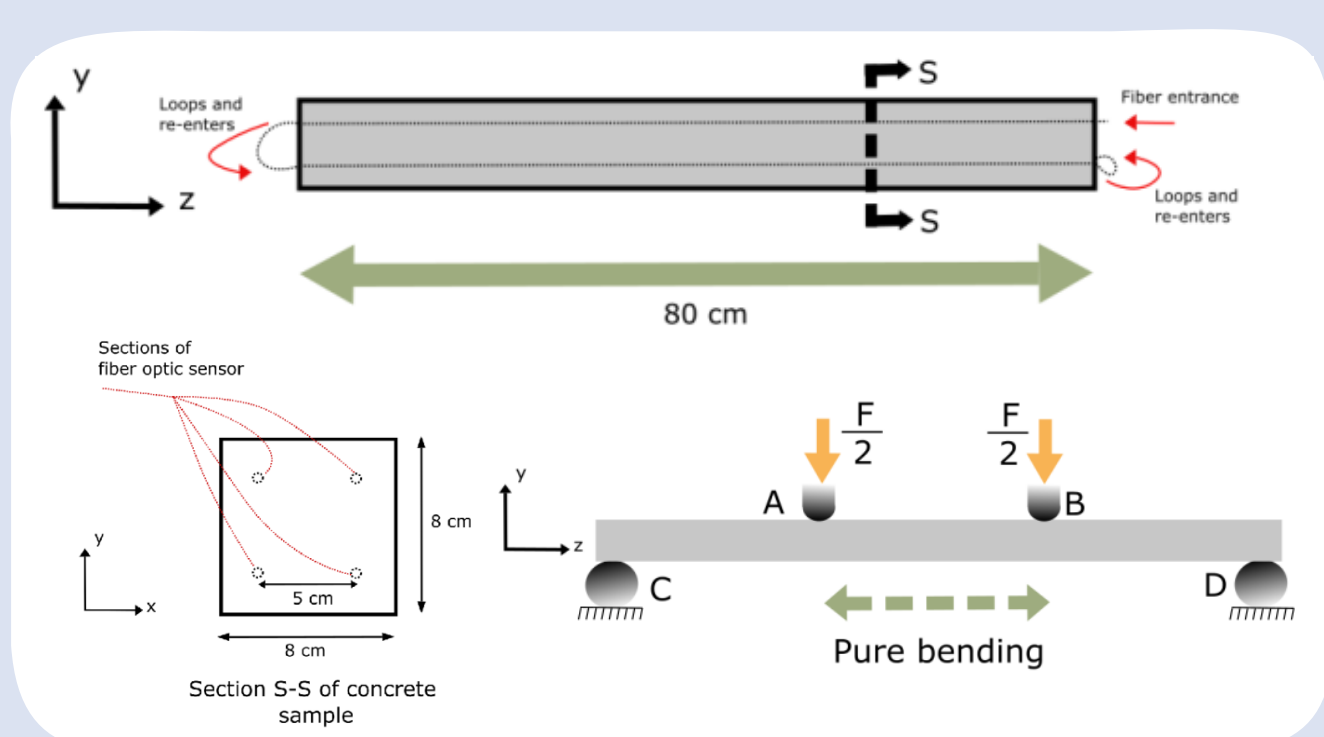
- Uses interferometry and a frequency-modulated optical wave
- Coupled backscattered light from 2 arms => beat frequency revealed by FFT
- Initial state gives Rayleigh backscattering signature (RBS) of fiber
- FFT on RBS and strained fiber => signals in spatial domain
- Inverse FFT applied on a sliding window on both signals
- Cross-correlation in each window => frequency shifts
- Frequency shifts linearly related to temperature and strain changes in fiber



Feedback from applications

Fiber in Concrete

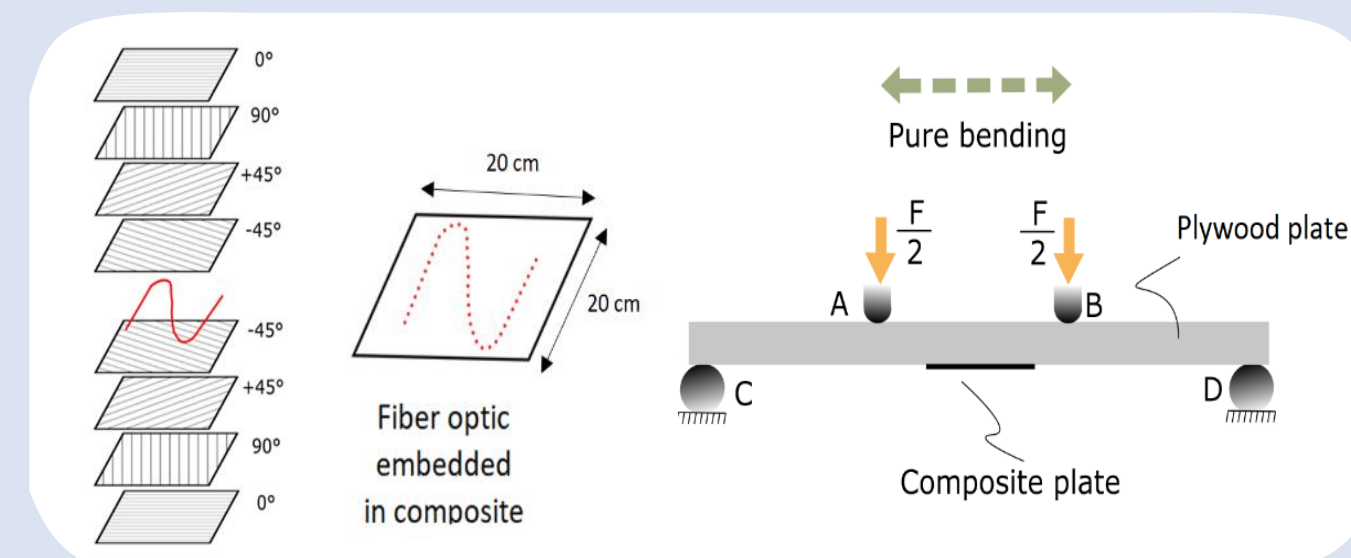
- Beam sample using cement-based fiber-reinforced mortar
- Sample for 4-point bending test
- Optic fiber passed through parts on tension and compression



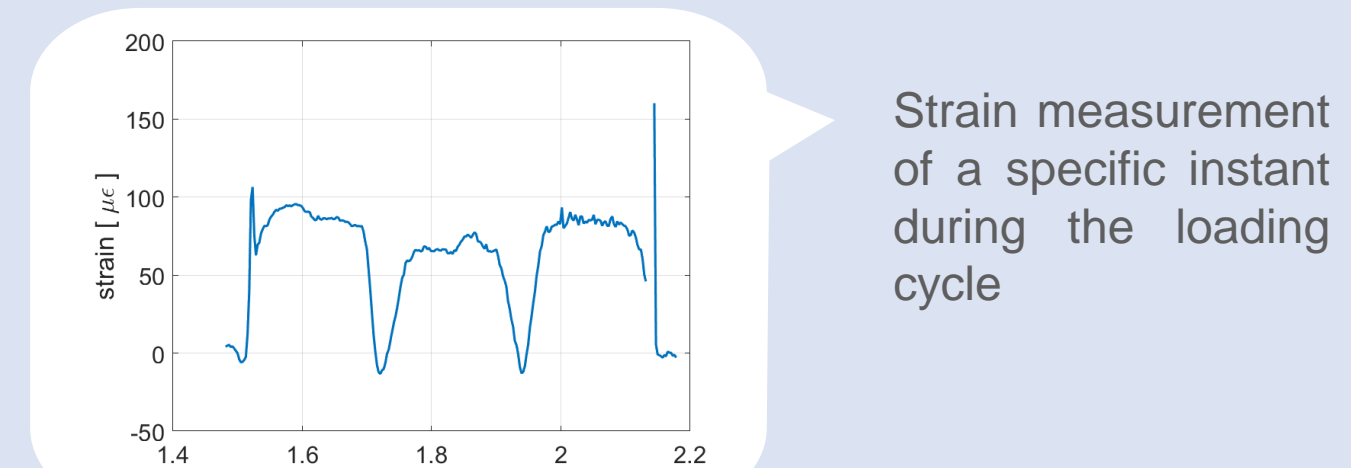
Geometry detail of concrete sample

Fiber in Composite

- Composite plate with carbon fiber reinforcements pre-impregnated by epoxy



Geometry detail of composite sample



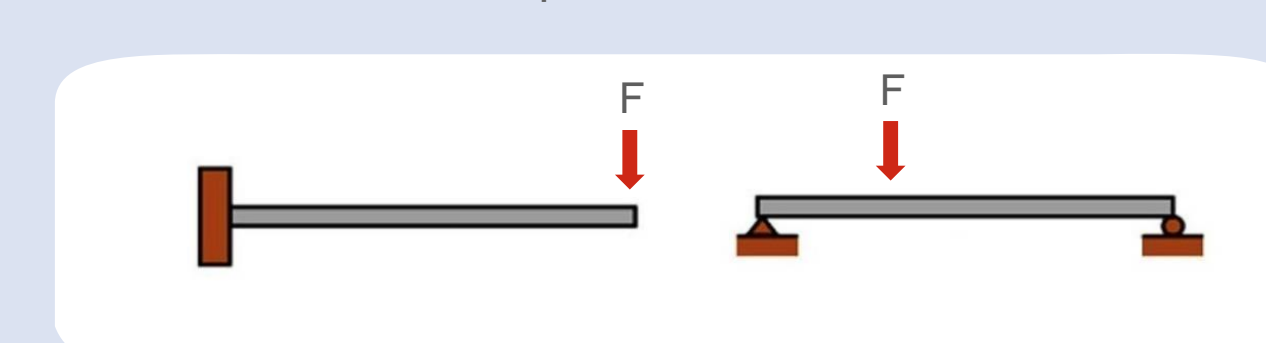
Strain measurement of a specific instant during the loading cycle

Fiber on Aluminium

- Two-part aluminium beam
- Fiber glued
 - perfectly on one arm
 - Intentionally imperfect on the other



Overview of the fiber position on the beam

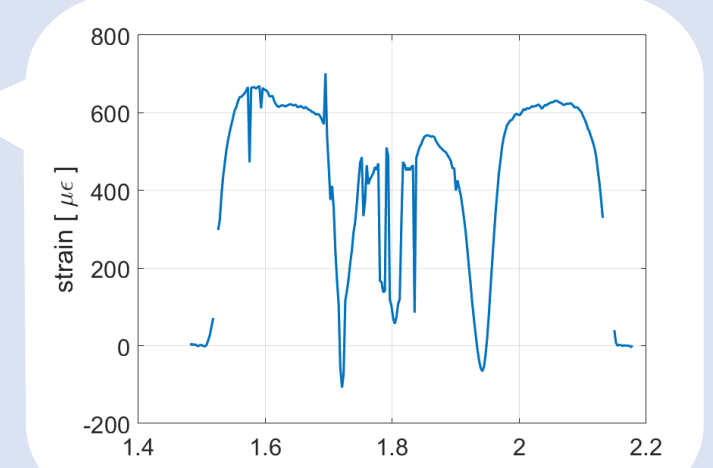


Demonstration test setups

Challenges

- Risk of damaging the fiber during process
- Very sensitive to dirt or scratch on the extremities during connection
- Potential debonding issues
- Difficult to uncouple temperature and strain
- Fiber broken => the remaining length is not usable

Collected strain data of a specific instant on a 4-point bending test on the composite sample



References

- [1] X. Bao and Y. Wang, "Recent advancements in Rayleigh scattering-based distributed fiber sensors," *Advanced Devices & Instrumentation*, vol. 2021, 2021.
- [2] Z. Ding, C. Wang, K. Liu, J. Jiang, D. Yang, G. Pan, Z. Pu, and T. Liu, "Distributed optical fiber sensors based on optical frequency domain reflectometry : A review," *Sensors*, vol. 18, no. 4, p. 1072, 2018.
- [3] X. Bao and L. Chen, "Recent progress in distributed fiber optic sensors," *Sensors*, vol. 12, no. 7, pp. 8601–8639, 2012.