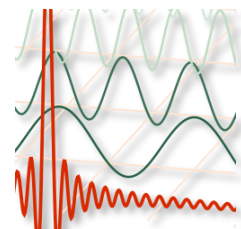
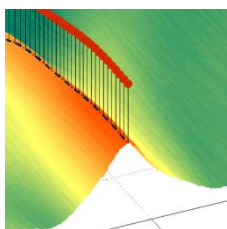




## Distributed fiber-optic Brillouin sensing The fTB 2505 series

### *Technical Note: Understanding BOFDA*



### **Latest innovation. Earliest detection.**

In times where projects for energy, transportation and infrastructure reach unprecedented levels of complexity each year, structural monitoring during construction and operation has become as essential as switching on the light.

Operators and constructors no longer rely on theoretical numbers or pin-point measurements. Structural monitoring means getting the whole picture – in other words: 21<sup>st</sup> century challenges shall be addressed with 21<sup>st</sup> century tools.

fibrisTerre stands for the latest generation of distributed strain and temperature sensing in optical fibers. At industry-leading accuracy, fibrisTerre's all-digital Brillouin technology complies with the demands on reliable monitoring of pipelines, power cables, railway lines and geotechnical infrastructure.

### **The company**



fibrisTerre Systems GmbH is a Berlin-based designer and manufacturer of the pioneering Brillouin Optical Frequency Analysis (BOFDA) based distributed fiber optic sensing.

In 2010, a team of experts in electronics, fiber-optics and software engineering with extensive experience in structural health monitoring joined forces to provide reliable, cutting edge monitoring solutions for the energy industry and geotechnical infrastructure. The technology emerged from research at BAM, Germany's authority for materials research and testing. With a strong focus on research and development, fibrisTerre Systems GmbH permanently improves the capability and quality of its technology.

## A bit of physics: Distributed Brillouin sensing

The fTB 2505 system is designed to record a continuous profile of strain and temperature along an optical fiber. The strain and temperature information is retrieved by exciting an optical effect known as Stimulated Brillouin Scattering within the fiber.

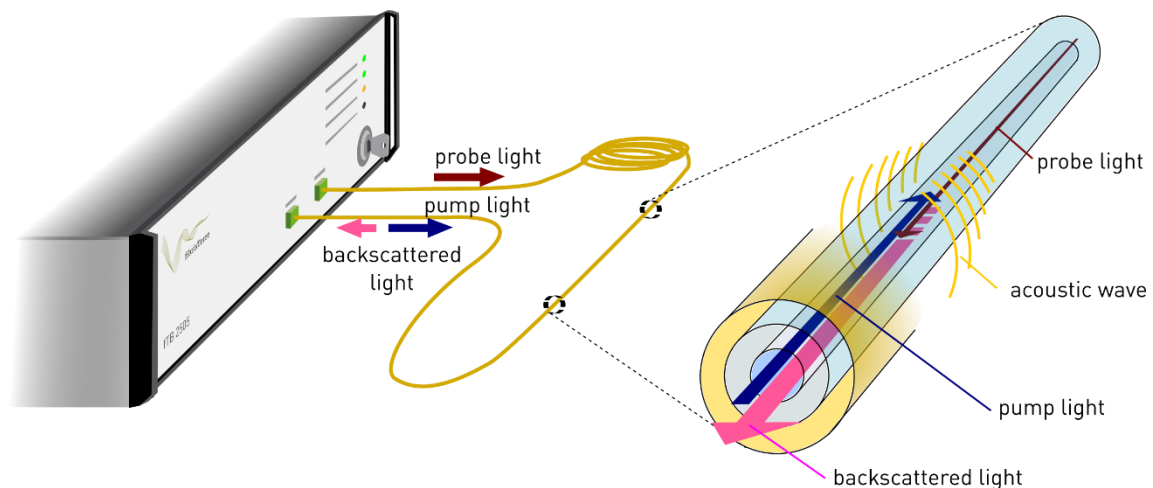
### Stimulated Brillouin scattering in a nutshell

Imagine two light waves that are injected into an optical fiber, one from each end. Where these light waves meet, the intensity of light in the fiber becomes so high that the glass begins to shiver – literally. This shivering of the medium is, in physical terms, a tiny, high-frequency acoustic wave, which, in turn, means a disturbance to the propagation of light.

The disturbance of the light (caused by the acoustic wave that the light waves themselves had excited) leads to backscattering of portions of the original light waves. And this backscattering now will meet again with the incoming light wave, will form an acoustic wave and will cause more light to be backscattered – a self-amplifying effect, which has one condition: The optical frequencies of the two original light waves must not be equal, but have a certain offset, which matches the speed of sound in the optical fiber.

### From Brillouin scattering to strain and temperature sensing

So here is what the fTB 2505 does: It sends two light waves into either end of the fiber, and tunes the frequency offset between them, until maximum backscattering is caught back at the instrument. By this, the sonic speed of the fiber is found. Because the sonic speed is directly proportional to strain and temperature of the fiber, both quantities are accurately measured.

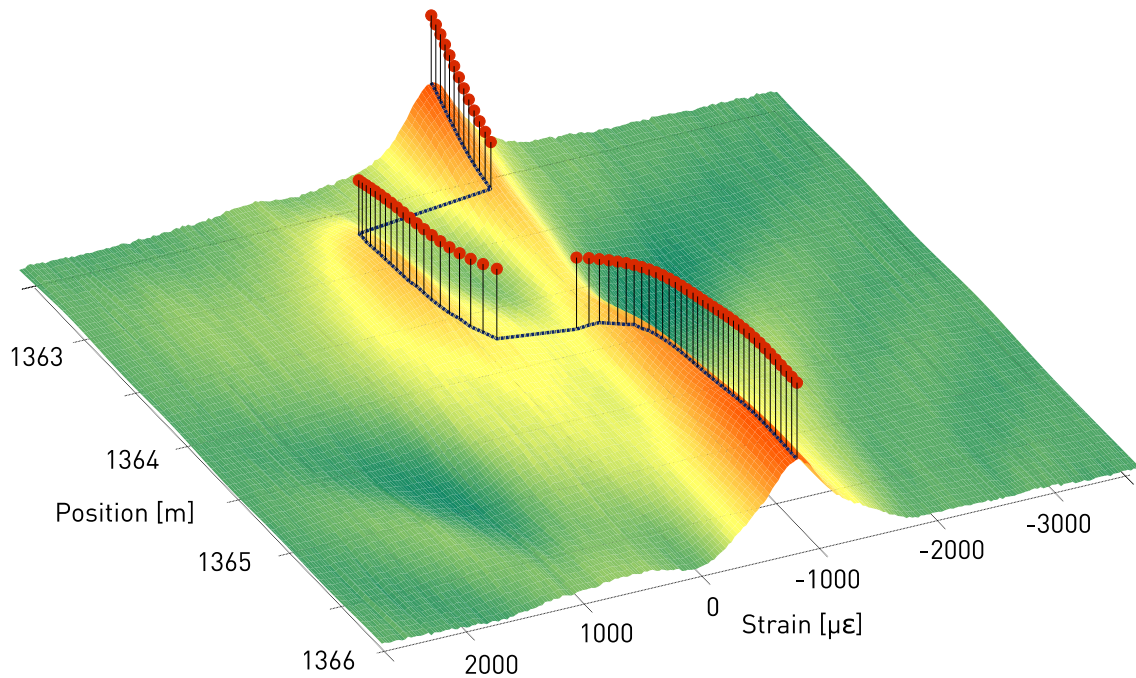


*Two light waves and an acoustic wave: Brillouin interaction in an optical fiber*

## Getting the spatial information

But how does the system know where exactly along the fiber a strain or temperature event takes place? In classic Brillouin sensing systems, one of the two light waves is sent into the fiber in the shape of short pulses, which travel along at the speed of light; everywhere the pulse passes by, they meet the oncoming light wave from the other end, and Brillouin interaction occurs.

Back inside the instrument, the incoming backscattered light is recorded over time. From the time of flight, the exact origin of each backscattered portion can be derived; with this, a spatially resolved profile Brillouin interaction is recorded.



*The 3-dimensional Brillouin data and the resulting 2-dimensional strain profile*

For every point along the fiber, the Brillouin interaction for different frequency offsets between the two light waves is recorded. This gives a 3-dimensional picture: Strong interaction is recorded where the frequency offset matches the sonic speed, low interaction where it doesn't. And for every point, the peak of the interaction curve is presented to the user as the strain or temperature value for this location.

### Literature:

- M. Nikles, L. Thevenaz and P. A. Robert, "Simple distributed fiber sensor based on Brillouin gain spectrum analysis", Opt. Lett., vol. 21, p. 758, 1996.
- N. Nöther, "Distributed Fiber Sensors in River Embankments: Advancing and Implementing the Brillouin Optical Frequency Domain Analysis", BAM-Dissertationsreihe, Volume 64, 2010 <http://www.bam.de/de/service/publikationen/dissertationen.htm>

## **fibrisTerre's unique BOFDA technology**

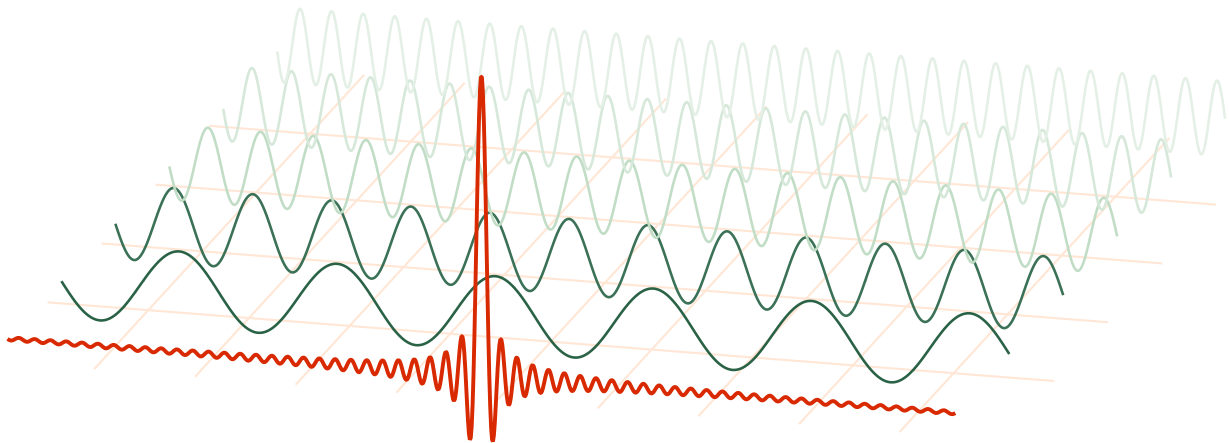
fibrisTerre's distributed Brillouin sensing systems offer industry-leading accuracy for structural health monitoring due to the unique digital frequency domain technology of the readout units. Here, we give deeper insight into the innovations and benefits of this leading-edge approach.

### **Time domain measurements**

The classic BOTDA/BOTDR approach uses short optical pulses that travel along the sensing fiber, generating Brillouin backscattering at every location the pulses pass by. The signal that is captured back at the readout unit contains the desired backscattered light with the local strain and temperature information, but also comprises undesired noise coming from the light sources or from other optical effects occurring along the fiber.

### **fibrisTerre's frequency domain technology**

In contrast to this broadband signal reception, the BOFDA approach takes advantage of the fact that in signal theory, a pulse can be reconstructed from a finite number of sinusoidal waves. In BOFDA sensing, these sinusoidal waves are sent into the fiber one after another, representing the spectral components of the pulse. Now back at the receiver, the electronics do not have to do ultra-fast sampling of the noisy time domain signal, but can focus on the current waveform. Once the returned waveform from the fiber has been captured in amplitude and phase, the next waveform is sent into the fiber, experiencing Brillouin interaction along the way and being sent back to the unit to be captured.



*How to create a virtual pulse from a series of sinusoidal waves*

## Noise filtering in the frequency domain

For each of these steps, the receiver can adjust its narrow-band filters to the current waveform's frequency: Within all the noise coming from kilometers of sensing fiber, the receiver knows exactly where to look for the signal. In effect, for each waveform, more than 99.99 % of the signal is canceled out by the filter. The remaining 0.01% that passed through the filter is the desired information, in sharp and clean form.

## Processing

After all waveforms have been sent out and captured again, from this information the exact same signal that a pulse reflectometry would have provided is reconstructed by means of a Fourier transform, yielding the desired information on Brillouin interaction along the sensing fiber.

## Benefits of the frequency domain analysis

The processing of sinusoidal waves (frequency domain) instead of short pulses (time domain) brings two great advantages:

- Superior signal quality: The signal contrast is significantly increased by the narrow-band reception, which makes it feasible to measure even very weak signals - which provides a very high attenuation budget for the sensing fibers.
- Efficient system design: For the electronics, sinusoidal waveforms are far easier to generate and to process than pulses, which makes it possible to allocate most of the work to digital signal processing components instead of analog circuitry. This has a large positive effect on system cost, weight, size, power consumption and long-term reliability.

## Literature

- D. Garus, T. Gogolla, K. Krebber, and F. Schliep, "Brillouin optical-fiber frequency-domain analysis for distributed temperature and strain measurements," *Journal of Lightwave Technology*, vol. 15, no. 4, pp. 654–662, Apr 1997.
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