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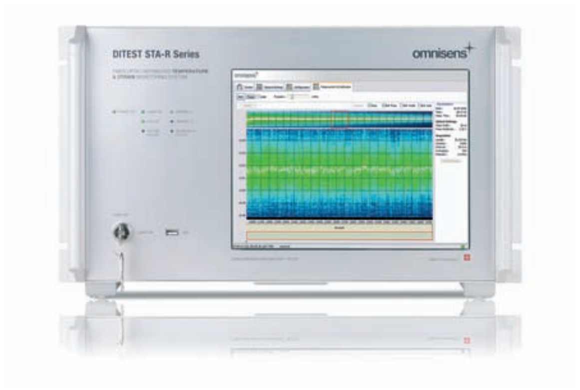
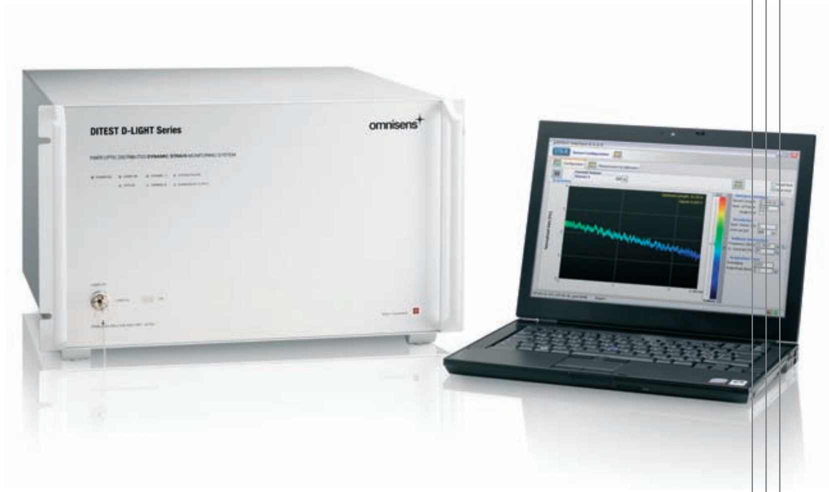
Technical Note





Omnisens DITEST ™

FIBER OPTIC DISTRIBUTED TEMPERATURE & STRAIN SENSING TECHNIQUE

Introduction

Omnisens DITEST™ (Distributed Temperature and Strain sensing) is a distributed temperature and/or strain monitoring system capable of accurately measuring every point over long and very long distances (range of more than 50 km) from a single interrogator.

Using standard telecommunication-grade single mode optical fiber as the sensor, the DITEST™ owes its high signal-to-noise ratio and long term stability to Stimulated Brillouin Scattering (SBS) measurement. This technique gives fast and reliable measurements, making it ideal for long range, continuous monitoring of high consequence assets, such as transmission cables, oil & gas subsea infrastructures and pipelines.

Performance benefits of Omnisens DITEST™ for securing high consequence assets:

> **Distance: offers long range measurement of up to 50 km per channel from a single interrogator. Based on the use of low loss single mode optical fiber which maintains performance over long distances.**

> **Accuracy: spatial resolution from 0.5 m for temperature and strain, detects temperature and/or strain events as they develop.**

> **Precision: measurement resolution from 0.1°C (temperature) or 2 microstrain (strain), detecting small changes before they become catastrophic**

> **Speed: fast acquisition time - one second for dynamic monitoring to one or two minutes for high resolution measurements so changes which might affect the operation of the asset can be quickly diagnosed and appropriate action taken.**

> **Power: large optical budget available, ensuring the asset is monitored despite challenging application conditions.**

> **Durability: performance even where hydrogen penetration or radioactivity can cause fiber darkening.**

> **Flexibility: user definable configurations to optimize measurement for each application.**

What is Distributed Sensing?

The term 'distributed sensing' refers to the use of an optical fiber as a linear sensor which provides valuable measurement information from all along the fiber itself. The measurement is based on the analysis of back-scattered light when a laser pulse travels down the optical fiber.

The sensing fiber is integrated into the asset (pipeline, cable or structure) using a dedicated fiber cable. A single optical fiber replaces thousands of single-point sensors, providing a significant reduction in installation, calibration, and maintenance costs. In addition, assets can be monitored in real-time where previously this was impractical due to their distance, location or environment. Optical fiber is cheap, lightweight, pliable, immune to electromagnetic interference (EMI), and has a life expectancy of more than 40 years, which makes it a cost-effective, flexible, durable and inert sensor medium.

DITEST™ Sensing

Omnisens DITEST™ is a major development in distributed sensing since it measures not only temperature but also strain using optical fiber as the sensor. Thanks to SBS, it sets new standards of accuracy and reliability, over longer distances than ever before, extending the benefits of monitoring to an ever-increasing range of applications and industries.

Distributed fiber optic sensing overcomes the inherent limitations of traditional measurement technologies (thermocouples, strain gauges), and enables monitoring solutions for the protection of people and critical assets, especially in inaccessible or inhospitable environments.

Omnisens has developed a series of turnkey asset integrity monitoring solutions targeting the specific needs of the energy, oil and gas industries to protect critical assets and secure the supply of energy. Examples are condition monitoring of oil and gas transmission pipelines, buried and submarine power cables, and subsea infrastructures such as umbilicals, risers and flowlines.

The use of the Omnisens DITEST™ systems enables the operators to make decisions based on actual data and not on assumptions by providing condition monitoring information of their assets in real-time.

The Physics of Distributed Sensing Techniques

Distributed sensing is based on the analysis of backscattered light emitted when a laser pulse is transmitted down an optical fiber. The backscattering is due to interaction of laser light with density fluctuations and molecular vibrations of the medium.

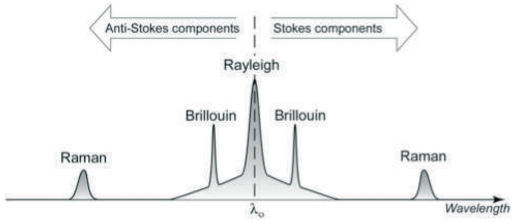


Fig. 1: Typical spectrum of the backscattered light from a monochromatic laser source (single wavelength lo) propagating in an optical fiber.

Spontaneous backscatter occurs at every point in optical fibers and comprises three significant forms relevant to distributed sensing (Fig. 1):

- **Rayleigh scattering** – produces the largest magnitude of backscatter at the same frequency as the incident light. It is widely used for the evaluation of optical fiber link attenuation and losses by Optical Time Domain Reflectometers (OTDRs).
- **Brillouin scattering** – produces backscatter of lower intensity than Rayleigh, due to thermally excited acoustic waves (acoustic phonons), but exhibits a frequency shift of around 10 GHz (0.1 nm at 1.5 micron wavelength). This frequency shift, the so-called Brillouin shift is directly related to both local temperature and strain conditions of the fiber.
- **Raman scattering** – produces backscatter of the lowest intensity, due to thermally excited molecular vibrations (optical phonons), and exhibits a frequency shift of up to 13 THz (100 nm at 1.5 micron wavelength). The intensity of Raman scattered light is dependent on the local temperature of the fiber.

The scattering of the light occurs at low energy levels and increases with the optical energy present in the fiber.

Unlike other backscattering phenomena, Brillouin Scattering can be stimulated by special optical processing, dramatically increasing the magnitude of the Brillouin interaction and making it significantly more efficient for sensing purposes. The Omnisens DITEST™ technique takes advantage of this unique feature and stimulates the scattering process by launching a counter-propagating lightwave in the fiber, giving a uniquely enhanced measurement performance in terms of measurement quality and distance range.

Omnisens SA
Riond Bosson 3, 1110 Morges – Switzerland
T: +41 21 510 21 21 - F: +41 44 274 20 31
sales@omnisens.com
www.omnisens.com

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Advantages of Brillouin based Sensing Technique

> The Omnisens DITEST™ exploits the sensitivity of the Brillouin frequency shift for temperature and strain sensing applications.

> The technique uses standard low-loss single-mode optical fiber offering several tens of kilometers of distance range from a single interrogator and compatibility with standard telecommunication components.

> Since there is no dipersion effect in single-mode optical fibers, the optical signal characteristics are not affected, with the result that spatial resolution is maintained all along the sensing length. In contrast, the dispersion effects of multi-mode fiber based Raman sensing systems cumulate along the sensing length degrading the spatial resolution.

> Brillouin scattering can be optically stimulated resulting in the greatest intensity of the scattering mechanism and consequently an improved signal-to-noise ratio providing large optical budget and long distance capabilities.

“ The Omnisens DITEST™ is designed for applications requiring speed, long distance range, accuracy or a high optical budget. ”

> Brillouin, being a frequency-based technique is inherently more accurate and more stable in the long term than intensity-based techniques such as Raman, since intensity-based techniques suffer from a tendency to drift.

> Brillouin scattering is an intrinsic phenomenon in optical fibers (the Brillouin Shift corresponds to a Doppler frequency shift which is directly proportional to the material density) and temperature and strain fluctuations impact the silica density. In this aspect, Brillouin based measurements are independent of the measuring device as it is an intrinsic property of the silica fiber which is analyzed. This absence of calibration drift guarantees accurate and reliable measurement over the long term.

> The Omnisens DITEST™ uses a single laser source for the generation of all optical signals required for the measurement, which self compensates for laser drift.

The Omnisens DITEST is based on the use of a single laser source for the generation of all optical signals required for the measurement in a way that inherently compensates all drifts.

Principle of operation

> Data from the Stimulated Brillouin Scattering (SBS) signal is processed using both time and frequency domain analysis. The analysis is performed by collecting the SBS information from every location along the sensing optical fiber yielding an uninterrupted and fully distributed temperature and/or strain profile.

> The DITEST™ uses a single laser to generate the two signals used to stimulated backscattering (SBS): an optical pulse (or ‘pump’) and a continuous wave (CW) optical signal, known as the ‘probe’ signal. Using a single laser gives stability, since it self-compensates for drift.

> When the frequency difference of the two signals reaches the Brillouin frequency shift, a resonance condition is established, leading to the efficient stimulation of Brillouin scattering. This stimulation induces an energy transfer from the pulse to the probe signal and an amplification of the probe signal. The technique enables the rapid and accurate identification of the local resonance condition at every location along the sensing fiber and computes the local temperature and strain conditions. The SBS stimulation occurs only if pump and probe signals are counter-propagating inside the optical fibers. For this reason two fibers are used in applications: the first one “brings” the probe signal to the far end of the second optical fiber which acts as the sensing fiber. These two fibers form a loop and are, most of the time, integrated in the same cable, i.e. the sensing cable. In some cases the measurement can be performed over the entire loop distance.

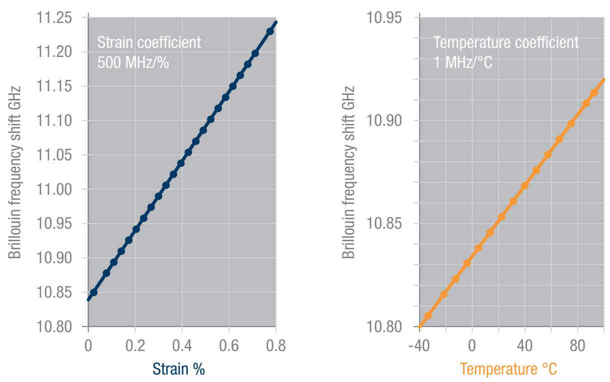

Fig. 2: Brillouin distributed sensing - Brillouin frequency shift temperature and strain dependence

Omnisens SA
Riond Bosson 3, 1110 Morges – Switzerland
T: +41 21 510 21 21 - F: +41 44 274 20 31
sales@omnisens.com
www.omnisens.com

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1. The Stimulation

A' pump' laser lightwave enters one end of a single mode fiber. The counter wave (cw) 'probe' enters from the other end. Pump and probe signals interact through SBS when the resonance frequency condition is met. Temperature and strain along the fiber affect the characteristics of Brillouin scattering. The interaction between pump and probe signals is at its maximum (resonance) when the pump and probe frequency difference matches the local Brillouin Frequency shift. The probe signal is being amplified by this interaction and carries the local temperature and stain information available from the SBS phenomenon.

2. The Measurement

The probe signal carries the information about the event, i.e. local temperature and strain, and its location for processing. Since the pump lightwave is a pulse, the probe signal carries time domain information which is converted into distance knowing the speed of light in the fiber. Repeated scanning using the CW tunable probe signal allows the identification of the Brillouin frequency shift containing the event information. Scanning the pump and probe frequency difference using the tunable probe signal identifies the Brillouin frequency shift at every location along the sensing fiber.

3. The Result

Measurement scans are recorded along the length of the fiber (as shown in the 3D graph providing the full frequency response of the fiber) and the maximum pump and probe interaction (maximum Brillouin gain) is determined. The frequency position of the peaks correspond to Brillouin shift and translate into temperature and/or strain information using fiber calibration data. The measurement does not differentiate between strain and temperature. This is done simply by using a sensor appropriate for the application.

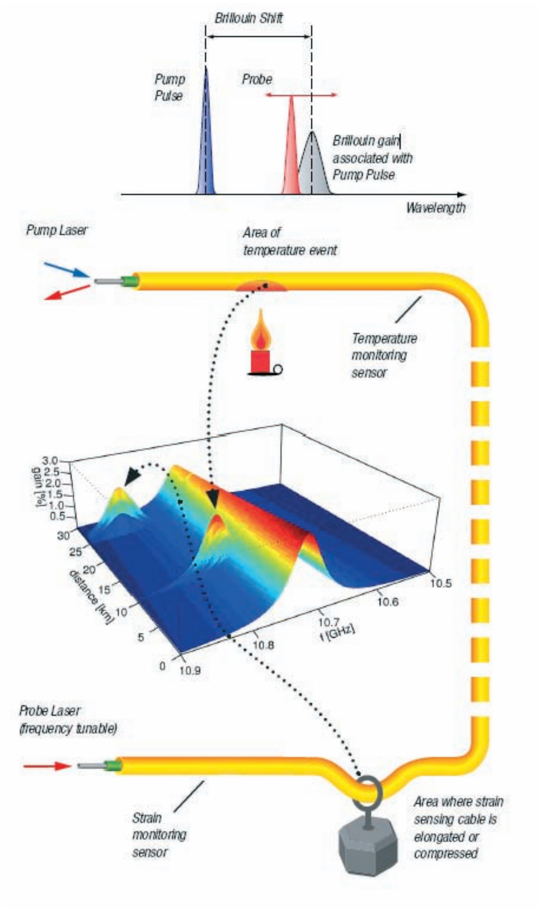

Fig. 3: Effect on the Brillouin spectrum of one temperature event at 10 km and a strain event at 25 km along 2 sections of sensing fibers connected together in series.

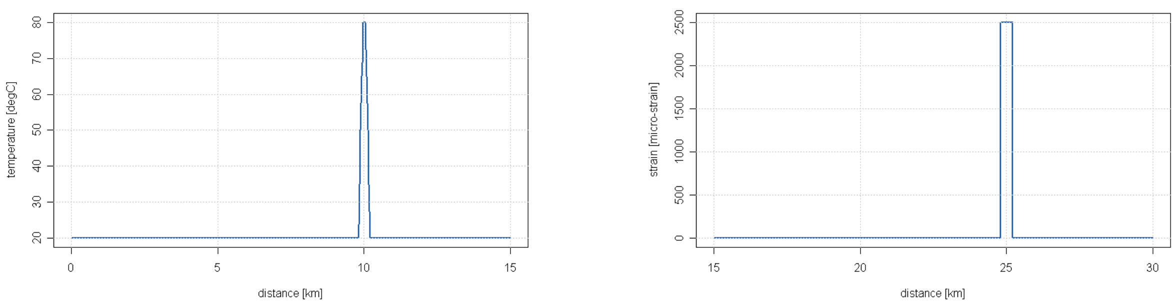

Fig. 4: Using an example of a 30 km cable, a temperature event is measured at 10 km and a strain event at 25 km. Different types of sensor are required for temperature and strain, as strain sensing requires that the structural strain is accurately transferred to the sensing optical fiber.

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Defining measurement performance for Distributed Sensing

The definition of performance specifications for distributed sensors is more difficult than for traditional point sensors as the measurement performance depends on a combination of inter-related measurement parameters. For example, measurement certainty depends on the configured spatial resolution, acquisition time, distance range and/or cumulative loss.

The graph in Figure 5 shows how DITEST™ performance parameters may be evaluated for different measurement times and spatial resolution settings.

Distance range corresponds to the maximum fiber sensor length over which the instrument's stated performances are met. It corresponds to the furthest measured point along the sensing fiber for which the measurement is performed, for a given set of performance criteria.

Spatial resolution is the instrument's ability to measure accurately two adjacent locations subjected to different temperature/strain conditions. The spatial resolution is directly related to the optical pulse width or the distance illuminated by the pulse at a given point in time (10 ns pulse width corresponds to 1 m in the fiber).

Based on this definition, a given temperature/strain that spreads over a distance greater than the spatial resolution is measured with 100% accuracy. If a local temperature/strain change occurs in a distance smaller than the spatial resolution set on the interrogator, the change will not be measured with the full accuracy.

The DITEST™ spatial resolution is configurable from 0.5 m to 10 m. In most practical applications, the spatial resolution is set to between 1 m to 3 m.

Sampling interval is the distance between two measurement points along the sensing fiber and is determined by the number of points along the sensor length. It is given in meters. Sampling intervals as small as 0.1 m can be set on DITEST interrogators.

Distance precision corresponds to the precision of the spatial location of a measured point. In practical applications, it depends on how accurately the cable distance mapping and cable-lay loss of the fiber are known. It can be as small as 1 meter or less over distance range of as DITEST interrogator.

Measurement uncertainty is a measure of agreement between measurements of the same property with a known value under identical, or substantially similar, conditions. It depends on the combination of the calibration error and measurement resolution or repeatability.

Measurement resolution or repeatability is associated to a measure of the short term repeatability and is evaluated as a function of distance for a given spatial resolution and acquisition time, as well as specified fiber attenuation. It is determined by repeating the measurement in identical conditions several times (20 times or more) and by computing twice the standard deviation of the measurements at every location and is reported as a function of distance.

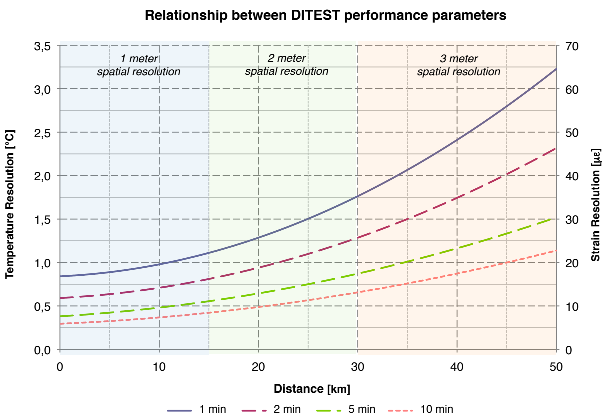

Fig 5: Measurement performance : this figure shows typical achievable performances in terms of temperature and strain resolution (2 sigma repeatability) obtained with a spatial resolution of 1 m to 3 m relative to the distance range. The performance is speficified according to interrelated parameters, such as distance, spatial resolution, acquisition time and fiber attenuation. A graph showing the measurands as specified is the best wasy to display the performance.

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The advantage of the Omnisens DITEST ™

The Omnisens DITEST™ offers significant advantages over other distributed sensing methods:

Reliable temperature/strain measurement - the DITEST™ is able to measure either temperature or strain, or both, using the same optical fiber. Alternatively, when installation conditions dictate, temperature and strain can be measured using separate fibers operating on different channels of the same instrument. For temperature monitoring, the optical fiber is installed within protective loose tubing thereby preventing strain conditions from having a significant effect on temperature measurements. For strain monitoring, a dedicated strain sensor is required, in order to accurately transfer strain to the fiber. Omnisens has developed a series of sensing cables to meet the requirements of specific applications.

Excellent performance high resolution or fast acquisition applications - adjustable probe signal intensity solves the problem of lossy fibers or attenuation associated with spontaneous scattering techniques. For challenging applications, this guarantees the highest possible optical budget.

Superior reliability, accuracy and repeatability - automatic settings of optical intensities are user-configurable to optimize the performance in various operating conditions.

Faster measurement times - thanks to the high signal-to-noise ratio of the SBS technique, measurements using the Omnisens DITEST require less averaging than other techniques for maintained performance (50 km of fiber can be measured at highest performance in just a few minutes).

Dynamic strain monitoring: Stimulated Brillouin scattering gives dynamic strain measurements with an updating time of <1 second.

High optical budget - measurement performance can be maintained with up to 20 dB of attenuation.

Longer range measurements - up to 50 km range per channel, with a spatial resolution of better than 3 m. Optional switch modules can be used to expand the number of channels.

Proven measurement technology - Omnisens systems are built using proven components and have been developed with the emphasis on measurement reliability and accuracy.

Flexible solutions - the unique optical signal processing technique incorporated in DITEST™ brings a high level of flexibility to suit a wide range of applications and environments.

Cost-effective fiber optic sensor - the physical attributes and cost-effectiveness of optical fiber make it particularly suited for long distance monitoring applications such as transmission pipelines, power cables and remote sensing of subsea infrastructures.

Suitable for demanding environments - different types of optical fiber sensor for both temperature and strain monitoring are available to meet the most challenging installations.

For example, sensors with enhanced crush resistance and rodent damage protection are available for subterranean, submarine and tunnel environments

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