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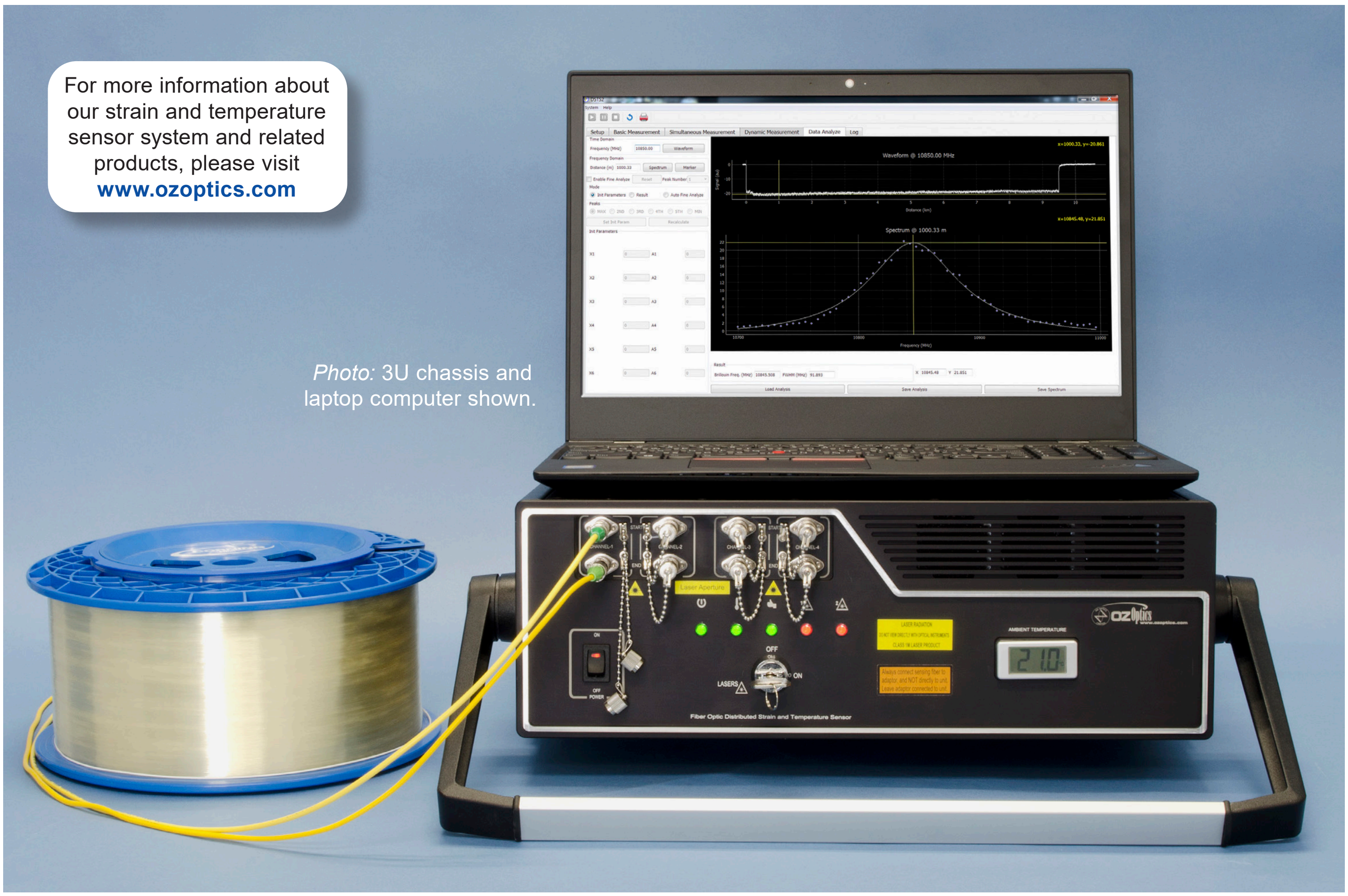
# Fiber Optic Distributed Strain and Temperature Sensors (DSTS)

## BOTDA Module




For more information about our strain and temperature sensor system and related products, please visit **www.ozoptics.com**

*Photo:* 3U chassis and laptop computer shown.

### Features

- Uses standard telecom single mode fibers for
- strain and / or temperature measurement
- Real-time measurement of strain and temperature
- High spatial resolution, strain, and temperature resolution and accuracy
- DLL available for system integrator

### Performance at a glance

- As low as 0.1 m spatial resolution
- Max. 100 km sensing range with max. 160 km fiber length

### Product Description

OZ Optics' Foresight™ series of fiber optic Distributed Strain and Temperature Sensors (DSTS) BOTDA modules are sophisticated sensor systems using stimulated Brillouin scattering in optical fibers to measure changes in both strain and temperature along the length of an optical fiber. By deploying a sensing cable that includes standard telecom single mode fiber, users can detect when and where the strain or the temperature of the object has changed and correct potential problems before failure occurs.

A unique feature of our Foresight™ DSTS system is its ability to measure temperature and strain, simultaneously and independently, allowing regions of temperature induced strain to be identified.

## Oil and Gas applications

**Oil and Gas Pipeline Monitoring**

- Pipeline leakage monitoring
- Up to 100 km sensing range per channel
- High spatial resolution supports localized measurement with long sensing range
- Short acquisition / response time

**Oil and Gas Well Monitoring**

- Well integrity management
- Temperature, strain and pressure monitoring with proper sensing cable and installation
- Not sensitive to hydrogen which may change the attenuation of the fiber

**Refinery Efficiency Sensing**

- Improve the efficiency of the refinery per distributed temperature profile
- Reduce downtime while ensuring safety levels
- Uses low cost telecom single mode fiber cable

## Civil Engineering applications

**Dam Monitoring**

- Dam internal temperature monitoring
- Crack / sediment / deformation / seepage monitoring
- Up to 100 km sensing range per channel

**Structural Health Monitoring (SHM)**

- Sediment monitoring
- Strain and crack monitoring
- Up to 100 km sensing range per channel
- High spatial resolution supports localized measurement with long range object

## Civil Engineering applications *continued*

**Geohazard Monitoring**

- Landslide, subsidence and deformation of levee / ground / highway monitoring
- Can monitor trends in ground movement
- Up to 100 km sensing range per channel

**Highway Safety Monitoring**

- Internal temperature / strain monitoring with proper sensing cable and installation
- Highway subsidence monitoring
- Up to 100 km sensing range per channel

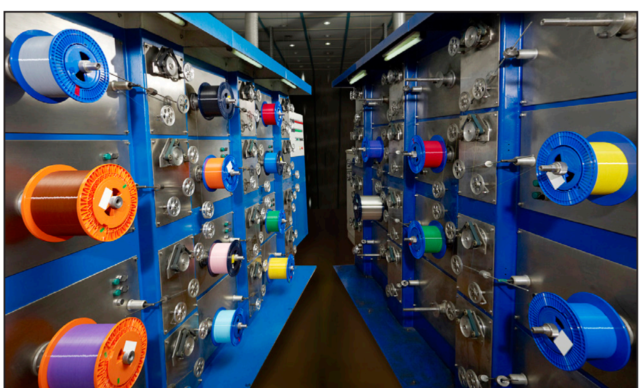
## Utility and cable applications

**Overhead Power Line Monitoring**

- Lightning strikes, icing and broken wires can be detected
- Up to 100 km sensing range per channel
- No additional components required along power line route
- Easy deployment

**Submarine Cable Monitoring**

- Ongoing quality / status monitoring throughout the life of the cable
- May only require one fiber
- No additional components required along the route



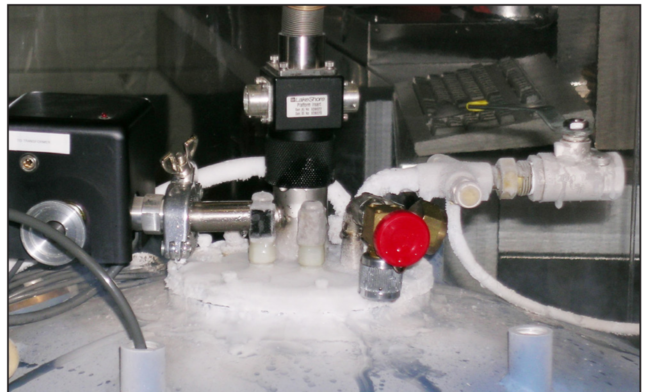
**Quality Inspection of Fiber Optic Cable**

- More sensitive to strain than OTDR
- High level quality control based on high level technology
- Can monitor the quality of power cable / OPGW with optical fiber unit

**Security, Cryostat, and Fire applications**

**Border Security Monitoring**

- Fast, dynamic measurement
- High precision of event location
- Can work in conjunction with a video surveillance system



**Cryostat Temperature Sensing**

- Able to measure temperatures as low as 25 K
- May use low cost telecom single mode fiber
- Up to 100 km sensing range per channel
- High spatial resolution with good temperature resolution / precision

**Building Fire Detection**

- Fast, dynamic, and accurate temperature measurement
- Up to 100 km sensing range per channel
- May use low cost telecom single mode fiber cable

## Specifications

| | Parameter | | Description | | |
|---|---|---|---|---|---|
| Performances | Spatial Resolution | | 1 m to 50 m | 0.5 m to 50 m | 0.1 m to 50 m |
| | Dynamic Range | | 30 dB | 30 dB | 25 dB |
| | Number of Channels | | 2 to 25[1] | | |
| | Sensor Configuration | | Fiber Loop, BOTDA+BOTDR combo unit is optional | | |
| | Maximum Fiber Length | | 160 km | | |
| | Sensing Range | | 100 km | | |
| | Spatial Accuracy | | as low as 5 cm | | |
| | Spatial Step | | as low as 5 cm | | |
| | Temperature Range | | -270 °C to +2100 °C (depending on cable material) | | |
| | Strain Range | | -3% (compression) to +4% (elongation) (depending on cable material) | | |
| | Temperature Resolution | | 0.005 °C[3] | | |
| | Temperature Accuracy (2σ) | | ± 0.1°C (Whole sensing range for BOTDA) | | |
| | Strain Resolution | | 0.1 με2 | | |
| | Strain Accuracy (2σ) | | ± 2 με (Whole sensing range for BOTDA) | | |
| | Acquisition Time (full scan) | | as low as 1 second | | |
| | Averaging | | 1 to 65,000 scans | | |
| | Fault Point Detection | Acquisition Time | 1 second per thousand scans | | |
| | | Sensing Range (round trip) | 100 km | | |
| | Simultaneous Measurement of Strain and Temperature (using patented cable design) | Temperature Resolution | 0.005°C2 | | |
| | | Temperature Accuracy (2σ) | ± 0.1°C (Whole sensing range for BOTDA) | | |
| | | Strain Resolution | 0.1 με2 | | |
| | | Strain Accuracy (2σ) | ± 2 με (Whole sensing range for BOTDA) | | |
| | | Sensing Range | 50 km | | |
| | Measured Variables | | Strain and/or temperature, Brillouin spectrum | | |
| General | Communication & Connections | | Ethernet port, USB | | |
| | Output Signals | | Software alarms via TCP/IP, SPST, SSR relays (optional) | | |
| | Data Storage | | Internal hard disc (128 GB or more) | | |
| | Data Format | | Database, text files, MS Excel, bitmap plot | | |
| | Optical Connections | | FC/APC[4] | | |
| | Laser Wavelength | | 1550 nm band | | |
| | Operating Temperature | | 0 °C to 40 °C, <85% RH, Non-condensing | | |
| | Power Supply | | 115 or 230 VAC; 50-60Hz; max 300W | | |
| | Dimensions (L x W x H) | 3U Chassis | 390 mm x 344 mm x 133 mm (not including computer)[5] | | |
| | Weight | 3U Chassis | <12 kg (not including computer) | | |
| Features | Measurement Modes | | Manual, remote or automatic unattended measurements | | |
| | Data Analysis | | Measurement analysis, multiple trace comparison with respect to selectable baseline, measurement trends, graphical zoom | | |
| | Alarm & Warnings | | Automatic alarm triggering, configurable alarm settings (heat, threshold, etc.) | | |
| | Remote Operation | | Remote control, configuration and maintenance via TCP/IP | | |
| | Watch Dog | | Long term operation 24/7 guaranteed by automatic recovery and continuous self diagnostics | | |

1 2 channels or 4 channels are provided within the sensor unit. Additional channels can be added by using an external optical switch.
2 Better spatial resolution is optional.
3 This value is estimated/calculated from the uncertainty of laser beat frequency (5 kHz), and temperature and strain coefficients of fibers.
4 Adaptors and patch cords are available for mating with other types of optical connectors.
5 Dimensions do not include carrying handle. Air vents on sides of unit must not be obstructed.

## Related Products

### Fiber Optic Sensor Probes, Components, Termination Kits, and Training

OZ Optics offers a full spectrum of fiber optic sensor probes, components, termination kits and training. OZ Optics' standard fiber optic products have been used worldwide in high performance sensor and telecommunications applications since 1985. OZ Optics also offers specialty fiber optic sensor probes and custom cabling for high temperature applications and other hostile and corrosive environments. System integrators with experience in structural and pipeline monitoring will find that OZ Optics offers a complete suite of enabling products and services for installing and maintaining fiber optic systems. If you are planning a pipeline or structural monitoring project, please contact OZ Optics to learn more about our fiber optic solutions.

**For more information about our strain and temperature sensor systems and related products, please visit www.ozoptics.com.**

## Ordering Information

**Part Number Description:** **DSTS-*CT* *CO* *I*-*SR*-*MSR*-*AS*-BOTDA-*X*-*CH***

***CT*** = Chassis Type of DSTS opto-electronics box
3U = 3U chassis

***CO*** = Computer Type
L = Laptop (requires 3U chassis)
X = Customer supplier computer

***I*** = Internal Interface between DAQ and computer
T = Thunderbolt (requires 3U chassis)
S = Standard

***SR*** = Spatial Resolution (m)[1]
1/10
1/50

***CH*** = Number of channels
2CH = 2 built-in channels
4CH = 4 built-in channels

***X*** = Connector Type
3A = FC/APC

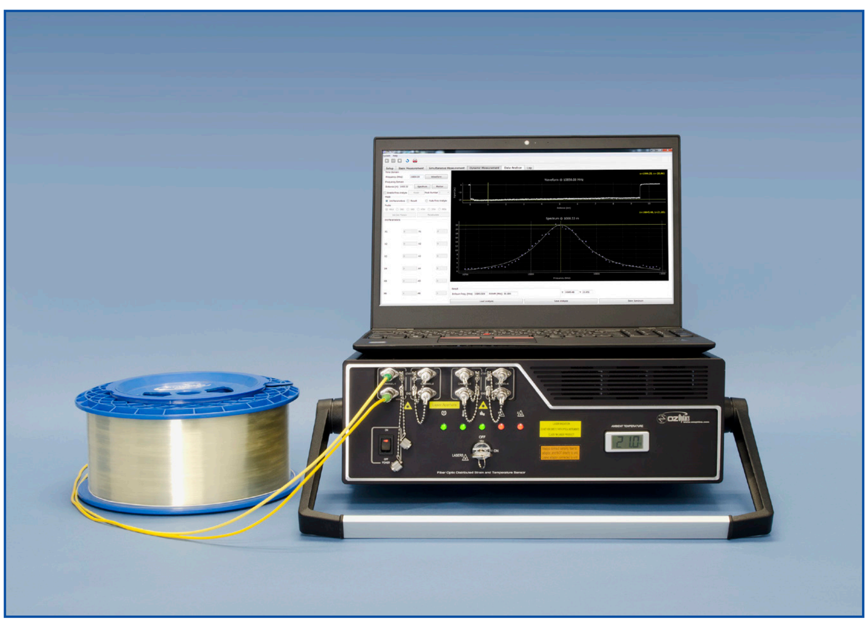
***AS*** = Acquisition Speed[3]
N = Normal
H = High Speed

***MSR*** = Maximum Sensing Range (km)[1,2]
60
100

For a field-ready unit, replace the chassis type, computer type, and computer interface with a single letter “F.” Field ready units include a built-in computer, monitor, keyboard and mouse.

**Notes:**

1. Each BDTS can be configured for short haul operation, long haul operation or both. The configuration must be specified at the time of purchase. The spatial resolution indicates the best resolution at the maximum sensing range. If the BDTS is configured for both short-haul and long-haul measurements then two numbers will be listed indicating the resolutions and maximum sensing range for each operating mode. For example, suppose the BDTS unit needs to achieve 1 meter resolution over a 10 km range for short-haul applications, and 50 meter resolution over a 100 km range for long-haul applications. The part number will specify the spatial resolution (SR) as 1/50, and maximum sensing range (MSR) as 100.
2. Maximum sensing range is 60 km or 100 km for long haul operation.
3. The acquisition speed is described as normal or high speed. N and H are used respectively. The high-speed version is typically at least a factor of two faster than the normal-speed version during the acquisition of data.



**3U model with laptop computer**

The 3U version of the BDTS comes with removable carrying handles. The user can easily replace the handles with tabs (sold separately) that will allow the unit to be installed in a standard 19-inch rack.

### Optional Accessories

**Fiber fusion splicer - FSP-100-S/M**


**Precision fiber cleaver - FSP-100-CLV**

## Optional Accessories

| Bar Code | Part Number | Description |
|---|---|---|
| 74023 | DSTS-TRAVEL-CASE-3U | Plastic travel case for 2U or 3U DSTS unit, with extendable pull handle and wheels. Designed for checking on airplane. Approximate dimensions: 23.75 (H) x 22.5 (W) x 15 (D). {60.3 cm x 57.2 cm x 38.1 cm}. |
| 65518 | FIBER MICROSCOPE HANDHELD | Handheld Video Microscope kit for Fiber Optic Connector Inspection. The kit includes an LCD display with video probe. An AC power adapter with battery charger and a rechargeable battery pack is included. Several common adaptor types come with the unit, including an SC/FC PC female adaptor and an LC/PC female adaptor. |
| 48980 | CI-1100-A2-PT2-FS/APC/F | Tip for SC and FC APC type female (in receptacle) connector for CI-1100-A2 handheld microscope. |
| 36939 | HUXCLEANER-2.5 | Receptacle fiber cleaner for FC, SC and ST types. |
| 5336 | Fiber-Connector-Cleaner-SA | Disposable Cletop reel type A optical fiber connector cleaner. |
| 8122 | SMJ-3A3A-1300/1550-9/125-3-1 | 1 meter long, 3 mm OD jacketed, 1300/1550 nm 9/125 µm Corning SMF 28e fiber patchcord, terminated with angled FC/APC connectors on both ends. |
| 11 | PMPC-03 | Flanged sleeve thru connector for polarization maintaining FC/PC connectors. Keyway width is 2.03/2.07 mm wide for 2.00 mm wide (Type R) key connectors. |
| 19711 | AA-200-11-9/125-3A3A | Universal connector with a male angle FC/APC connector at the input and a female angle FC/APC receptacle at the output end for SM 9/125 applications. |
| 58975 | DSTS-3U-19IN-RACK-MOUNT-KIT | Brackets with handles & hardware to convert 3U DSTS to 19" rack mountable version. |
| 77982 | FSP-100-S/M | Fiber fusion splicer for singlemode and multimode fiber, featuring fiber core alignment and automatic fiber identification (singlemode vs multimode) for optimum splice loss. Suitable for bare fibers, patch cords, drop cables etc. A fiber cleaver and fiber stripper is included with the unit as a kit. |
| 77984 | FSP-100-CLV | Precision fiber cleaver for fusion splicing, with automatic blade rotation for maximum lifetime. |

## Questionnaire

1. What is your application? Please describe briefly.
2. Are you looking for a BOTDA module (requires both ends of fiber to be connected to DSTS) or a BOTDR module (requires only one end of fiber to be connected to DSTS) or a COMBO unit with both BOTDA and BOTDR functions?
3. What are your resolution and precision requirements for temperature measurements?

   Resolution: ________________________________________

   Precision: __________________________________________
4. What are the highest and lowest temperatures you expect?
5. What are your resolution and precision requirements for strain measurements?

   Resolution: ________________________________________

   Precision: __________________________________________
6. What is the maximum strain to be measured?
7. What is the desired sensing range or fiber length in this application?
8. What spatial resolution do you desire?
9. Do you want to measure temperature, strain or both?
10. What is the desired data acquisition time?
11. Do you need fiber calibration / system design / project engineering service?
12. Where will the unit be housed?
13. Do you need a portable model with a laptop computer or a 19" rack-mounted model with a laptop computer?
14. Any additional information?

Please email **sales@ozoptics.com** for our recommendation about your requirements.

# Applications of Fiber Optic Distributed Strain and Temperature Sensors

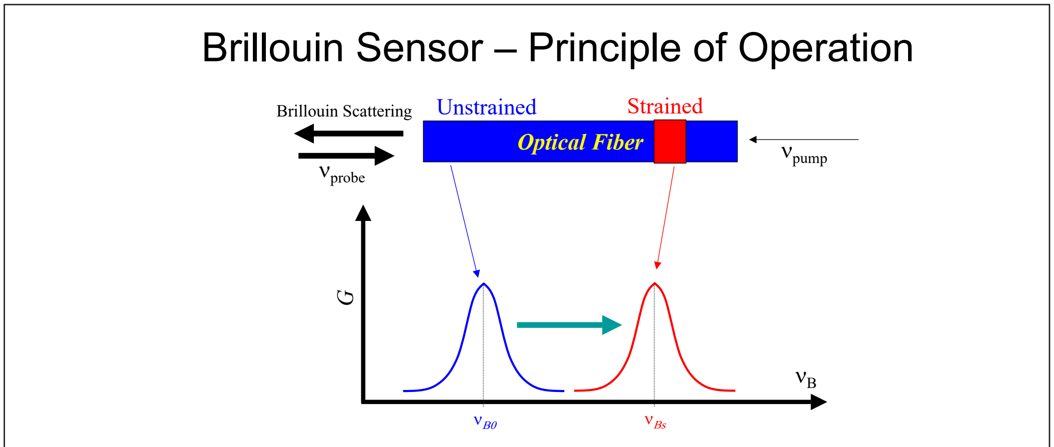
## Executive Summary

Fiber optic distributed strain and temperature sensors measure strain and temperature over very long distances and are an excellent tool for monitoring the health of large structures. These sensors leverage the huge economies of scale in optical telecommunications to provide high-resolution long-range monitoring at a cost per kilometer that cannot be matched with any other technology. Today's distributed strain and temperature sensors offer clear cost and technical advantages in applications such as pipeline monitoring, bridge monitoring, dam monitoring, power line monitoring, and border security / perimeter monitoring. Brillouin sensors are also excellent for the detection of corrosion in large structures.

## Working Principle

Although a detailed understanding of Brillouin sensors is not required when using OZ Optics sensor systems in typical structural health monitoring applications, a description of the basic measurement will be useful to users who want a better understanding of the specification tradeoffs when selecting a sensor system solution.

The most common type of Brillouin strain and temperature sensor uses a phenomenon known as stimulated Brillouin scattering. The measurement is illustrated in the figure below:




$$\nu_{Bs} = \nu_{B0} + C_T(T - T_0) + C_\varepsilon(\varepsilon - \varepsilon_0)$$

Figure 1. Brillouin spectral peaks from strained and unstrained fibers.

The typical DSTS BOTDA sensor configuration requires two lasers that are directed in opposite directions through the same loop of fiber (one laser operating continuously, the other pulsed). When the frequency difference between the two lasers is equal to the "Brillouin frequency" of the fiber, there is a strong interaction between the 2 laser beams inside the optical fibers and the enhanced acoustic waves (phonons) generated in the fiber. This interaction causes a strong amplification to the Brillouin signal which can be detected and localized using an OTDR-type sampling apparatus. To make a strain or temperature measurement along the fiber, it is necessary to map out the Brillouin spectrum by scanning the frequency difference (or "beat" frequency) of the two laser sources and fitting the peak of the Brillouin spectrum to get the temperature and strain information.

As the equation at the bottom of Figure 1 shows, the Brillouin frequency at each point in the fiber is linearly related to the temperature and the strain applied to the fiber. In some optical fibers such as dispersion-shifted fiber, there are actually two peaks in the Brillouin spectrum and it is possible to extract both temperature and strain information from a single fiber. If one uses the sensor system with our patent pending sensing fiber, then one can simultaneously measure strain and temperature, while utilizing the same fiber for telecommunications.

## A Comparison of Fiber Optic Sensor Technologies for Structural Monitoring

Brillouin fiber optic sensors excel at long distance and large area coverage; in fact, Brillouin sensors should be considered for any strain or temperature application with total lengths in excess of 10 meters. Another common fiber optic sensor technology appropriate for localized measurements is known as fiber Bragg grating sensors. However, for structural health monitoring, when the potential damage or leakage locations are unknown, it is difficult to pre-determine the places to put fiber Bragg grating sensors or other types of point sensors. Fiber Bragg grating sensors are an excellent localized sensor when the specific area(s) of interest are known. Distributed Brillouin sensors can be used for much broader coverage and can locate fault points not known prior to sensor installation.

There are two types of Brillouin fiber optic sensors. Brillouin Optical Time Domain Reflectometers (BOTDR) resolve the strain or temperature based Brillouin scattering of a single pulse. Brillouin Optical Time Domain Analysis (BOTDA) uses a more complicated phenomenon known as Stimulated Brillouin Scatter (SBS).

For Stokes scattering (including Brillouin scattering and Raman scattering) only a small fraction of light (approximately 1 in $10^3$ photons) is scattered at optical frequencies different from, and usually lower than, the frequency of the incident photons. Based on BOTDR technology, since the intensity of a backscattered Brillouin signal is at least $1/10^3$ less than that of the incident light, the Brillouin scattering signal is very weak. Considering the attenuation of the optical fiber, for example, 0.22 dB/km, the measurement range cannot be very long and the SNR is generally worse than that found with BOTDA technology. The primary advantage of BOTDR technology is that only one end of the fiber needs to be accessible.

The BOTDA technique is significantly more powerful as it uses enhanced Brillouin scattering through two counter-propagating beams. Due to the strong signal strength the strain and temperature measurements are more accurate and the measuring range is longer than that of BOTDR technology. In addition, our patented sensing method allows one to determine simultaneous strain and temperature information.

The BOTDA method requires more optical components and a 2-way optical path so the total system cost is typically higher (the sensor fiber must be looped or mirrored). However, most field units deployed today are BOTDA systems because the additional measurement accuracy more than justifies the moderate increase in system cost.

OZ Optics' Foresight™ series of DSTS has BOTDA, BOTDR and BOTDA/BOTDR combo units. Our customers can enjoy more choices based on their special requirements. Table 1 provides a comparison of common fiber optic strain and temperature sensor techniques, along with typical performance limits for each type:

| | Bragg Grating* | BOTDR | BOTDA |
|---|---|---|---|
| Strain Accuracy | ± 1 µstrain | ± 16 µstrain | ± 2 µstrain |
| Spatial Resolution | 0.1 m | 1 m | 0.1 m |
| Length Range | Point sensor | 70 km | 100 km |
| Acquisition Time | <1 second | 3–20 minutes | As low as 1 second |
| Configuration | Many fibers | Single fiber | Loop or single fibers |
| Temperature Accuracy | ± 0.4°C | ± 0.8°C | ± 0.1°C |
| Strain and Temperature | Multiple fibers | Multiple fibers | Single or multiple fibers |
| Distributed | No | Yes | Yes |
| *quasi-distributed with multiple fibers | | | |

Table 1. Typical Performances of Distributed / Quasi Distributed Fiber Optic Sensors

The simultaneous measurement of strain and temperature is possible by using our patented method. Standard singlemode fiber is used in large quantities for high speed optical telecommunications networks and is inexpensive. It is important to make a decision on the fiber type and cable structure early in any structural monitoring project. Although test equipment can be changed or upgraded in the future, it is essential to install the correct fiber type if the simultaneous measurement of strain and temperature is required.

## Major Applications of Fiber Optic Distributed Strain and Temperature Sensors

Fiber optic distributed strain and temperature sensors have been applied in numerous applications. As mentioned previously, Brillouin-based systems are generally unmatched in applications that require high-resolution monitoring of large structures (long, or large surface areas). Unlike competing sensor technologies, Brillouin systems directly leverage the economies of scale from the millions of kilometers of fiber optic telecommunications fiber installed worldwide. As Table 2 shows below, the most common applications for distributed strain and temperature sensors involves very large linear or spatial dimensions.

| Application | Strain | Temperature | References available upon request by OZ Optics collaborators |
|---|---|---|---|
| Pipeline Leakage Monitoring | ■ | ■ | ■ |
| Power Lines Monitoring | ■ | ■ | ■ |
| Process Control | ■ | ■ | ■ |
| Structural Health Monitoring (concrete & composite structures) | ■ | | ■ |
| Bridge Monitoring | ■ | ■ | ■ |
| Fire Detection | ■ | ■ | ■ |
| Crack Detection | ■ | | ■ |
| Security Fences | ■ | | |

Table 2. Applications of Brillouin Fiber Optic Sensors

OZ Optics is committed to delivering solutions in each of the markets listed above. If your critical monitoring application is not listed in the table, please contact us with your requirements. To get more detailed information related to your application or request a reference article, please contact OZ Optics.

The fiber optic strand provides excellent flexibility and placement over large areas and great distances. For example: a mining conveyor belt may be tens of kilometres long in order to remove excess debris. The material is of little value and detecting a seizing bearing along the length would be difficult via conventional fire detection means. As a bearing starts to seize, it will overheat prior to causing a fire. The DSTS and sensing fiber is easily installed and will readily detect this change in heat at a bearing. While the direct cost of the damage caused by the fire is minimal, the loss of revenue from shutdown of the mining operations while the conveyer belt is repaired will be extensive.

## Sample Performance Table

Distributed Brillouin measurements are quantified by four variables: precision of measurement, variation of strain and temperature to be measured, spatial resolution, and length of fiber being measured. These four interact to determine the time the measurement will take. Conversely, if time is restricted, the other qualities of measurement can be determined.

The ForeSight™ Brillouin based DSTS BOTDA module design enables focus on the variable of most concern. For instance, concrete fracture detection may require tight spatial resolution and high precision. The result will be a known measurement time and the maximum fiber length that can be utilized.

The measurement time can vary from 1 second to 10 minutes based up the requirements dictated by the application. The sample table below reflects some common requirements: better than ± 0.5°C and ± 10 µε precision. All table measurements were completed in less than 1 minute and 40 seconds.

The table is not a restriction of what can be achieved. Variations in the four areas of concern can be accommodated. For instance, the measurement of temperature/strain for 50 km sensing fiber, 2 m spatial resolution, with an accuracy of 0.2°C/4 µε is attainable, but will increase measuring time to 3 minutes and 45 seconds. Another comparison of the interaction of fiber length, spatial resolution, accuracy of temperature/strain, and measurement time: 100 km sensing fiber, 6 m spatial resolution can be 0.4°C/8 µε when measuring time is 4 minutes and 38 seconds, however the same 100 km can have a precision of 0.1°C/2 µε when spatial resolution is increased to 50 m with a measuring time of 3 minutes and 48 seconds.

| | | Spatial Resolution | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 cm | 50 cm | 1 m | 2 m | 3 m | 4 m | 5 m | 10 m | 20 m | 50 m |
| Fiber Length | 1 km | 0.3°C/6 µε | 0.2°C/4 µε | | | | | | | | |
| | 2 km | | 0.3°C/6 µε | 0.1°C/2 µε | | | | | | | |
| | 4 km | | 0.4°C/8 µε | 0.3°C/6 µε | | | | | | | |
| | 10 km | | | 0.3°C/6 µε | | | | | | | |
| | 20 km | | | 0.4°C/8 µε | 0.06°C/1.2 µε | | | | | | |
| | 30 km | | | | 0.2°C/4 µε | | | | | | |
| | 40 km | | | | 0.3°C/6 µε | 0.1°C/2 µε | 0.2°C/4 µε | | | | |
| | 50 km | | | | | 0.2°C/4 µε | 0.3°C/6 µε | 0.2°C/4 µε | 0.1°C/2 µε | | |
| | 60 km | | | | | | | | 0.2°C/4 µε | | |
| | 70 km | | | | | | | | 0.3°C/6 µε | | |
| | 80 km | | | | | | | | | 0.2°C/4 µε | |
| | 90 km | | | | | | | | | 0.4°C/8 µε | |
| | 100 km | | | | | | | | | 0.4°C/8 µε | 0.2°C/4 µε |

Table 3. Typical BOTDA module measurement precision table (Acquisition time ≤ 100 seconds)

## Fast Measurement Mode

The DSTS BOTDA can be used in a fire detection and control system. The distributed fiber optics technology provides for excellent flexibility to detect fires. The fiber optic strand does not pose a spark risk or explosion risk, and if properly designed, it may be placed in an area subject to ionizing radiation. The spatial resolution is dependent on the fiber length. With a 20 km fiber length, a spatial resolution of 1 m is provided. Shorter lengths can be monitored with better spatial resolution, compared to longer fibers. Similarly, longer lengths can be monitored at the expense of resolution. Refer to Table 3 for more details.

Temperature measurement performance while in Fast Measurement Mode will vary from a nominal Brillouin measurement in that the goals of the measurement are based upon fast detection of a change in temperature. The overall goal of the Fast Measurement Mode is to accurately detect a change in temperature associated with a pending fire or outright temperature changes in a nominal amount of time. Therefore the performance of the DSTS BOTDA will meet or be better than the following table:

| Start Temperature | Required Measuring Temperature By System | Oven Setting Temperature | Specified Measurement Time | Measurement Accuracy |
|---|---|---|---|---|
| 24°C | 30°C | 30°C | 9 sec | 28 - 32°C |
| 24°C | 40°C | 40°C | 11 sec | 38 - 42°C |
| 24°C | 50°C | 50°C | 13 sec | 48 - 52°C |
| 24°C | 60°C | 60°C | 14 sec | 58 - 62°C |
| 24°C | 70°C | 70°C | 16 sec | 68 - 72°C |
| 24°C | 80°C | 80°C | 18 sec | 78 - 82°C |

Table 4. Typical Accuracy for Fire Detection Applications (Fast Measurement Mode)

The following conditions apply for the reference table to be accurate:

- Total fiber length: 60 km
- Spatial resolution: 6 m
- Baseline must be obtained at 24°C before temperature measurements.
- Measurement time does not include sensing cable response time.
- All sensing fiber must be same type of fiber without strain effect.

## Calculating the Cost Savings for Brillouin Fiber Optic Sensors

As stated previously, Brillouin fiber sensors offer high-resolution with long distance coverage at a cost per kilometer unmatched by any other measurement technique. This creates the opportunity to generate a rapid return on investment for Brillouin sensor-based monitoring systems used in critical monitoring applications. The figure below shows a simple cost savings example:

Fiber Optic Monitoring
OZ Optics Ltd. Cost Savings Calculator

| System Parameters | |
|---|---|
| Pipeline Length | 50 km |
| Cost of Failure | $750,000 cost of leak |
| Downtime Cost | $20,000 per hour |

| Comparison | | Monitoring | No Monitoring | Comments |
|---|---|---|---|---|
| Probability of Failure | % / year | 0.25% | 1% | Reduced risk of failure |
| Downtime | hours/year | 4.8 | 24 | Automated preventive maintenance |
| Maintenance Cost | dollars/year | $25,000 | $50,000 | Automation of routine maintenance |
| Total Annual Savings | $414,625 | | | Total Annual Savings |

Table 5. Cost Savings example

Several pipeline shutdown accidents demonstrate the need for continuous online monitoring. While the calculation in Table 5 is for a mid-sized regional distribution pipeline, the economics for major pipelines are even more compelling. The shutdown cost per day can easily exceed $10 million. With long-haul Brillouin monitoring system costs of only $1 - $2 per meter, the prevention of a single shutdown greatly exceeds the installation and operating costs of a monitoring system. Other large structures such as power lines, dams, and bridges also have very high costs associated with catastrophic failure and shutdowns.

The most important factors in a typical cost savings estimate are the reduction in maintenance/inspection cost (due to automated monitoring), the reduction in downtime, and the reduction in the potential for catastrophic failure. In many instances, the downtime and failure costs are much higher than that shown in the example.

For more information about our strain and temperature sensor system and related products, please visit www.ozoptics.com.

## Background Articles

Pipeline Buckling Detection:
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