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FIBER OPTIC DISTRIBUTED STRAIN AND TEMPERATURE SENSORS (DSTS)

BOTDA MODULE (USA Patent #: 7499151 and 7599047)

Features:

- Uses standard singlemode telecom fibers for simultaneous measurement of strain and temperature
- Real-time measurement of strain and temperature
- BOTDA with optional BOTDR and OTDR built in
- High spatial, strain, and temperature resolution and accuracy
- Measurements can be made over the entire length of fiber, up to 100 km in length
- Multiple channel monitoring
- Real-time fault point detection
- Optional DLL available

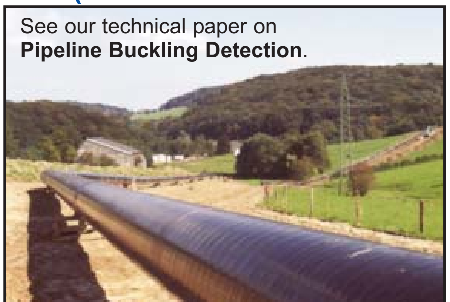
Applications:

- Oil and gas pipeline monitoring
- Bridge, dam, embankment and levee monitoring
- Corrosion/Erosion monitoring of pressurized pipe
- Power line monitoring
- Fire detection
- Crack detection
- Smart structures and structural health monitoring (SHM)
- Security monitoring

Product Description:

OZ Optics' Foresight™ series of fiber optic distributed strain and temperature sensors (DSTS) are sophisticated sensor systems using Brillouin scattering in optical fibers to measure changes in both temperature and strain along the length of an optical fiber. By wrapping or embedding a fiber inside a structure, such as an oil pipeline or dam, one can detect when the structure is being strained or heated/cooled, and correct the problem before failure occurs. Such monitoring capability is invaluable in critical structures where failure could cost loss of lives or millions of dollars.

While accurate measurements of small strain and temperature variations may require several minutes, the OZ Optics system can detect and report larger signals within one second, with only a slight loss of accuracy. This sort of response speed is required for security applications, or strains caused by earthquakes, where an immediate measurement and response may be required. Detecting cracks in structures is a major challenge: only a specialized tool can find the target, and the highest resolution is required to take its measurement. OZ Optics' Foresight™ series of sensors offers our customers a powerful tool to detect cracks on ceramics, concrete beams, dams, and so on.



Oil and Gas Pipeline Monitoring

Dam Monitoring

Oil and Gas Well Monitoring

Bridge and Building Monitoring

Power Line Monitoring

Border Security Monitoring

Highway Safety Monitoring

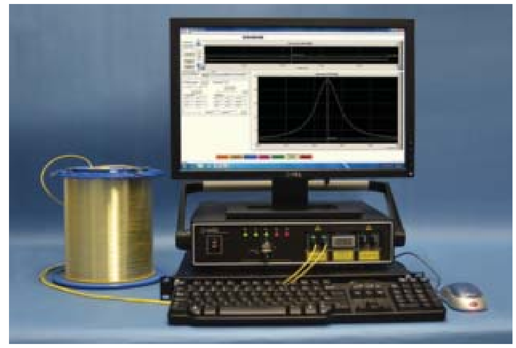
Building Fire Detection

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

The sensing technology gives both strain and temperature readings along the length of the fiber, with spatial resolution as short as 10 cm. Unlike competing products which cannot tell the difference between externally applied strain and temperature induced strain, the OZ system is capable of measuring both parameters simultaneously and independently, allowing regions of temperature induced strain to be identified.

Depending on the configuration selected, measurements can be made over the entire length of fiber, up to 100 km in length. One can use such a setup to monitor a very long length device, like a pipeline or highway, or lay the fiber to form a 2D or 3D grid in a structure, like a dam wall or submarine hull.

Field-ready version



Compact version

Specifications:

	Model		Foresight™ Series			
			DSTS-F-10	DSTS-F-0.1	DSTS-C-10	DSTS-C-0.1
Performance	Number of Channels		2–25 (contact OZ Optics if more than 2 channels are required)			
	Sensor Configuration		Standard is BOTDA loop but optional built-in single ended BOTDR is also available upon request.			
	Maximum Fiber Length		160 km			
	Sensing Range		100 km			
	Spatial Resolution		1 m to 50 m	0.1 m to 50 m	1 m to 50 m	0.1 m to 50 m
	Spatial Accuracy		as low as 5 cm			
	Dynamic Range		30 dB	25 dB	30 dB	25 dB
	Sampling Interval		20 per meter			
	Temperature Range		-270 °C to +1000 °C (depending on cable material)			
	Strain Range		-3% (compression) to +4% (elongation) (depending on cable material)			
	Temperature Resolution		0.005 °C*			
	Temperature Accuracy (2σ)		± 0.1 °C (Whole sensing range for BOTDA)			
	Strain Resolution		0.1 $\mu\varepsilon$*			
	Strain Accuracy (2σ)		± 2 $\mu\varepsilon$ (Whole sensing range for BOTDA)			
	Acquisition Time (full scan)		as low as 1 second			
	Averaging		1 to 30,000 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 °C*			
		Temperature Accuracy (2σ)	± 0.1 °C (Whole sensing range for BOTDA)			
		Strain Resolution	0.1 $\mu\varepsilon$*			
		Strain Accuracy (2σ)	± 2 $\mu\varepsilon$ (Whole sensing range for BOTDA)			
		Sensing Range	50 km			
	Measured Variables		Strain and/or temperature, Brillouin spectrum			
General	Graphical Interface		SVGA 17" color screen		SVGA 17" color screen (optional)	
	Communication & Connections		Ethernet port, USB			
	Output Signals		Software alarms via TCP/IP, SPST, SSR relays (optional)			
	Data Storage		Internal hard disc (80GB or more)			
	Data Format		Database, text files, MS Excel, bitmap plot			
	Optical Connections		FC-APC**			
	Laser Wavelength		1550 nm band (Class 3B type)			
	Operating Temperature		1 °C to 40 °C, non-condensing humidity			
	Power Supply		115 or 230 VAC; 50-60Hz; max 300W			
	Dimensions (L x W x H)		560 x 690 x 560 mm (field-ready package)		DSTS-C 430 x 420 x 90 mm (Not including computer)	
	Weight		< 60 kg (including a rugged field housing)		<18KG	
Features	Measurement Modes		Local, automated local repeating, remote, automated remote.			
	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, deformation, 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			

* This value is estimated/calculated from the uncertainty of laser beat frequency, 5 kHz, and temperature and strain coefficients of fibers.

** Adaptors and patch cords are available for mating with other types of optical connectors.

Related Products

OZ-Guard™ Fault Finder

The OZ-Guard™ Fault Finder is an OTDR-based product that detects and locates breaks or major bends in fiber optic cables. OTDR-based monitoring is an excellent low-cost complementary technology and gives pipeline operators even more reason to consider fiber optic monitoring. The OZ-Guard™ Fault Finder offers the best value of any product in this segment. Although the OZ-Guard™ Fault Finder is primarily intended for optical telecommunications network health monitoring, it can also be used to detect and locate major pipeline incursions or other major structural failures. For applications that do not currently justify the cost of a state-of-the-art Brillouin system, the OZ-Guard™ Fault Finder enables low-cost detection and location of major pipeline accidents or other structural failure incidents that cause breaks or severe bends in a fiber optic sensor probe. Our Fault Finder can locate events up to 20 km. For distances up to 100 km, please contact OZ Optics with your requirements.

Because OZ Optics' Foresight™ series of DSTS uses standard optical telecommunications fiber as the sensor element, the OZ-Guard™ Fault Finder is interchangeable with our Brillouin system. This provides users with additional flexibility and a choice to deploy continuous monitoring systems on a wider variety of pipelines and structures. Another deployment option is continuous monitoring with OTDR-based devices and periodic surveys with our full-featured Brillouin system. The combination of Brillouin structural monitoring and OTDR-based major event detection makes fiber optic monitoring the most powerful - **and economical** - choice for your pipeline. Please contact OZ Optics to receive a competitive proposal for your pipeline or structural monitoring project.

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 system and related products, please visit www.ozoptics.com.

Ordering Information

Part Number Description: ***DSTS-CT-SR-MSR-PS***

CT = Chassis Type
F = Field Ready
C = Compact

SR = Spatial Resolution (m)[1]
0.1
0.1/10
0.1/50
10
50

PS = Processing Speed[3]
N = Normal
H = High Speed

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

Notes:

1. Each DSTS 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 DSTS 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 DSTS unit needs to achieve 0.1 meter resolution over a 1 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 0.1/50, and maximum sensing range (MSR) as 1/100.

2. Maximum sensing range is 60 km or 100 km for long haul operation. Alternately, if the 0.1 m spatial resolution is chosen, a maximum sensing range of 1 km is displayed for that resolution (for short haul operation). Maximum sensing range is described as 1, 1/60, 1/100, 60, or 100.

3. Processing 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.

Rack Mounting a DSTS

The Compact version of the DSTS comes with a removable carrying handle that can be replaced by the user with tabs (included) that allow the unit to be installed in a standard 19-inch rack.

Optional Accessories

Bar Code	Part Number	Description
48298	DSTS-TRAVEL-CASE-1U/3U	Optional aluminum carrying case for DSTS. Includes wheels and handle. 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}.
48979	CI-1100-A2	Handheld Video Microscope kit for Fiber Optic Connector Inspection. The kit includes a 3.5" TFT LCD display with video probe. An ac power adapter with battery charger and a rechargeable battery pack. It also includes one SC/FC PC female connector, one LC/PC female connector, one Universal 2.5 mm FC/PC male connector and one Universal 1.25 mm FC/PC male connector.
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.
48981	CI-1100-A2-PT2-E2K/APC/F	E2000 APC female (in receptacle) connector for C1-1100-A2 Handheld Microscope.
36939	HUXCLEANER-2.5	Receptacle fiber cleaner for FC, SC and ST type.
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 μ Corning SMF 28e fiber patchcord, terminated with angled FC/APC connectors on both ends.
40536	SMJ-3AEA-1300/1550-9/125-3-1	1 meter long, 3 mm OD PVC cabled, 9/125 um 1300/1550 nm SM fiber patch cord, terminated with an angled FC/APC connector on one end and an angled E2000 connector on the other end.
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.
38130	AA-200-EAEA	Panel mount universal E2000/APC to E2000/APC receptacles (rectangular green housing).

User-Developed Software

For users who want to develop their own software application for monitoring strain and temperature, OZ Optics can provide a dynamic link library (DLL) of routines for controlling the DSTS. Contact OZ Optics for additional information.

Optical Connections

The biggest problem that customers encounter is when they fail to properly clean the optical connectors before mating them to a sensor system. As a result of this, fiber end-faces can be damaged, which degrades performance. This may result in a costly repair. For this reason, a buffer patch cord or adaptor should ALWAYS be used between the DSTS and the sensing fiber. Connections should always be made to this patch cord or adaptor, while the patch cord remains attached to the DSTS at all times. The patch cord should only be removed from the DSTS if it becomes damaged and needs to be replaced. Following this procedure helps to ensure trouble-free operation of the sensor.

In addition, connectors and receptacles must always be properly cleaned prior to mating. **Damage to the end-face of the fiber in the receptacle on the front panel of the DSTS is not covered by the instrument's warranty.** Buffer patch cords or adaptors (with spares) are provided with each DSTS. Extra patch cords or adaptors may be purchased separately. Patch cords are available from OZ Optics to mate with any type of connector. Contact OZ Optics with your specific 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:

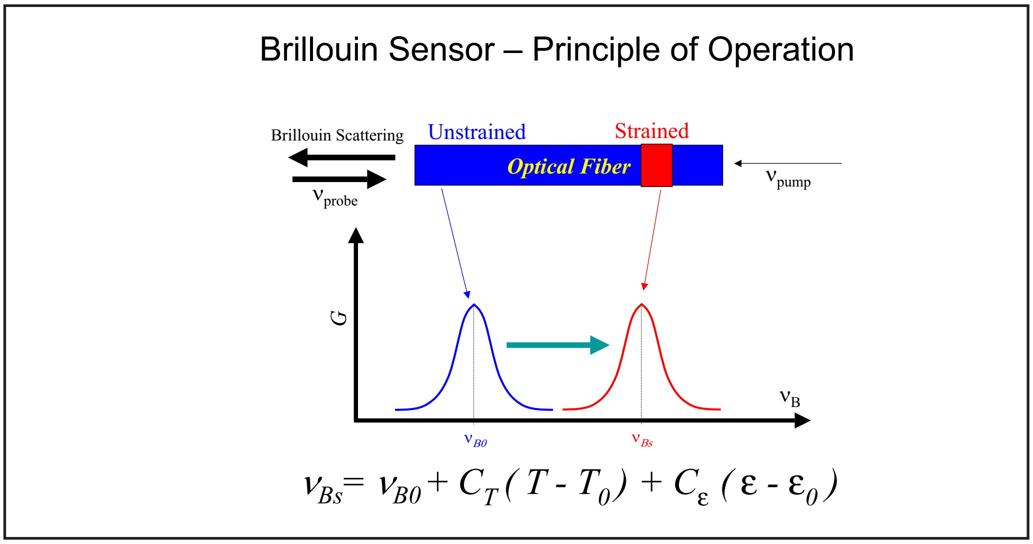


Figure 1: Brillouin spectral peaks from strained and unstrained fibers.

The typical 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 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 are BOTDA-based sensor systems. They offer highly accurate and fast measurement of strain and temperature. 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**	**Foresight™ DSTS**
Strain Accuracy	± 1 µstrain	± 30 µstrain	± 2 µstrain
Spatial Resolution	0.1 m	1 m	0.1 m
Length Range	Point sensor	30 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	N/A	± 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 Specifications for 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 (very long, or very 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**
Bridge Monitoring	■	■	■
Pipeline Monitoring	■	■	■
Process Control	■	■	■
Structural Health Monitoring (concrete & composite structures)	■		■
Security Fences	■		
Power Lines	■	■	■
Fire Detection	■	■	■
Crack Detection	■		■

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 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 of the DSTS 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 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.

	10 cm	50 cm	1 m	2 m	3 m	4 m	5 m	10 m	20 m	50 m
<=1 km	0.3 °C/6 με	0.2 °C/4 με								
<=2 km	0.4 °C/8 με	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 Measurement Accuracy as a Function of Fiber Length and Spatial Resolution (Acquisition time ≤ 100 seconds).

Fire Detection Mode:

The DSTS may be used in a fire detection and control system The use of distributed fiber optics 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 Fire Detection 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 Fire Detection Mode is to accurately detect a change in temperature associated with a pending fire or outright fire in a nominal amount of time. Therefore the performance of the DSTS in fire detection mode 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

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 long distance coverage for structural monitoring 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 structural 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 recent pipeline shutdowns 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.

To obtain a spreadsheet version of this cost saving calculator, to request a customized version for your structural health monitoring application, or **for more information about our strain and temperature sensor system and related products, please visit www.ozoptics.com.**

Suppressed Brillouin Response Fibers

In some single mode fibers, the Brillouin effect is suppressed in order to minimize loss. Since Brillouin effects are a type of back reflection and this energy comes at a minimal dB loss per km of fiber, some manufactures have specially designed fibers with absolutely minimal losses. While the vast majority of fibers are not engineered to remove the Brillouin effect, some are not suitable for Brillouin sensing. If you are uncertain whether or not your fiber is suitable for Brillouin measurement, ask OZ Optics.

Alternately, enhanced Brillouin effect fibers are available in the market but these are not commonly used by telecommunications applications

Background Articles

Pipeline Buckling Detection:
L. Zou, X. Bao, F. Ravet, and L. Chen, "*Distributed Brillouin fiber sensor for detecting pipeline buckling in an energy pipe under internal pressure*," Applied Optics 45, 3372-3377 (2006).

Pipeline Corrosion Detection:
L. Zou, G. Ferrier, S. Afshar, Q. Yu, L. Chen, and X. Bao, "*Distributed Brillouin scattering sensor for discrimination of wall-thinning defects in steel pipe under internal pressure*," Applied Optics 43, 1583-1588 (2004).

Power Line Monitoring:
L. Zou, X. Bao, Y. Wan and L. Chen, "*Coherent probe-pump-based Brillouin sensor for centimeter-crack detection*," Optics Letters 30, 370-372 (2005).

Crack Detection:
L. Zou and Maria Q. Feng, "*Detection of micrometer crack by Brillouin-scattering-based distributed strain and temperature sensor,*" 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).

Accuracy of BOTDA Technology:
L. Zou, X. Bao, S. Yang, L. Chen, and F. Ravet, *"Effect of Brillouin slow light on distributed Brillouin fiber sensors",* Optics Letters 31, 2698-2700 (2006)

Simultaneous Measurement of Strain and Temperature:
L. Zou, X. Bao, S. Afshar V., and L. Chen, *"Dependence of the Brillouin frequency shift on strain and temperature in a photonic crystal fiber",* Optics Letters 29, 1485-1487 (2004)