Distributed Strain and Temperature Sensor

OZ Optics Limited

June 2018
Company Profile

- Company founded in 1985
- Corporate headquarters located in Ottawa, Canada
- Manufacturing facility in Ottawa/Canada, Izmir/Turkey, and Jiaxing/China
- Seven Product Groups: Laser-to-Fiber Delivery Systems, High Power Fiber Optic Components, Polarization Maintaining Products, Attenuators, Opto-Electronic Packaging, Test Equipment, Fiber Optic Sensor Systems
- Sales offices in Canada, USA, Europe, Turkey, and China
Product Innovation

Fiber Optic Fault Finder for Optical Network Safeguard™
- Monitors and reports network health status in real time, 24 hours/day, 365 days/year
- Reduces revenue loss due to fiber plant outages
- Reports fault location, giving GPS coordinates with time stamp
- Lowers network operating and maintenance expenses
- User friendly interface via various wireless interfaces (Wi-Fi, GPRS1, GSM, or RS-232)
- Early alert and outage reports via cellular phone, email, IM, SMS, or text messaging

OZ Guard™ Automated Test Solution
Remote Monitoring a WDM Network
Remotely Accessible Wireless Fault Finders
GPS Locator
Company Profile

Over 420 employees worldwide

- 240 in Ottawa and US
- 70 in Turkey
- 110 in China

OZ Canada

OZ China

OZ Turkey
Company Profile

OZ Optics is lead by an experienced team:

- Ömür Sezerman, Chairman, President & CEO
  - Founder and CEO since inception (33 years)
- Zahide Sezerman, VP of Human Resources
  - With OZ Optics since inception (33 years)
- Garland Best, VP of Components Division
  - 26 years at OZ Optics
- Gordon Youle, VP of Test Equipment Division
  - 19 years at OZ Optics
- Martin Powell, Operation Manager
  - 14 years at OZ Optics
- Sarah Miller, Controller
  - 8 years at OZ Optics
- Metin Sezerman, General Manager of OZ Turkey
  - 17 years at OZ Optics
- Bing Li, General Manager of OZ Optics China
  - 14 years at OZ Optics
Company Profile

- Using our strong direct sales and distributors, we address the following markets:
In-House Production Capabilities

➢ Experienced and well-trained staff in following fields:
  - optical, mechanical, electronics & software

CNC Machine Shop

AR Coating

Femtosecond Laser Lab

Clean Room

Laser Conditioning/Cleaving
Facility – Ottawa Headquarters

- 60,000 sq ft. – Manufacturing and R&D Facilities
- 15,000 sq ft. – Admin, Sales and Marketing
- 15,000 sq ft. – Training and Fitness Facility
- R&D, Product Design, Engineering, Final Assembly & QA
Facility – Ottawa Headquarters

- Production Area
- Training Centre Building
- Meeting Room
- Swimming Pool
OZ Optics – Turkey Factory

- Operational since 2000
- 33,000 sq ft. Manufacturing Facility
- Located in Free Trade Zone
- Low Tax Rates
- Sub Component Parts Manufacturing
- Cost Effective Manufacturing
- High Quality Labor
OZ Optics China

- Operational since 2009
- Wholly Foreign Owned Enterprise
- Subcomponent Parts Manufacturing
- Cost Effective Manufacturing
- High Quality Labor
- Extensive Training
  (3-6 months in OZ Canada)
OZ China Facility

Jiaxing, China

- Located in Economic Development Zone
- 500 sq meters – Admin, Sales and Marketing
- 1500 sq meters – Manufacturing Area
  - 100 sq meters – Class 10,000 Clean Room
  - 100 sq meters – ESD Working Area
Manufacturing Strategy

OZ Canada

R&D Design Engineering

Sub-Components

World-Wide Sourcing

Made-in China

Made-in Turkey

Sub-Components

Customer

OZ CND Qualification

Customer Qualification

Final Assembly Quality Assurance

Customer

OZ CND Qualification

Customer Qualification

Customer Qualification

OZ CND Qualification
Industry Standards

All products manufactured are in strict accordance with international industry standards:

- Qualified for F35 JSF Program
- Telecordia Compliance
- CE Compliance
- RoHS Compliance
- ISO 9001:2015 Certified (Canada, China and Turkey)
- Controlled Goods Directorate Registered
Conventional Temperature & Strain Sensors

- **Temperature sensor:** thermocouple
- **Strain sensor:** electrical strain gauge
  - Temperature influence
  - Electromagnetic interference (EMI)
  - Humidity influence
  - Point sensor
Fiber Optic Sensors

• Advantages of Fiber Optic Sensors
  – Electrically insulating materials (no electrical cables are required)
    — high voltage environments
  – Chemically passive, not subject e.g. to corrosion
  – Immune to electromagnetic interference (EMI)
  – Wide operating temperature range

• Fiber Bragg Grating Sensor
  – Strain resolution and accuracy: < 2 με
  – Cannot distinguish strain and temperature
  – Point sensor

• Distributed Fiber Optic Sensors
  – Raman scattering based — only temperature
  – Brillouin scattering based — both temperature and strain
Fiber Optic Sensors

- **Fiber Bragg Grating Sensor**
  - Sensor medium: Fiber Bragg grating
  - Laser source and data acquisition system: Spectrum analyzer

- **Distributed Fiber Optic Sensors (Brillouin Sensors)**
  - Sensor medium: Conventional communication fiber (such as SMF, LEAF, etc.)
  - Laser source and data acquisition system: Brillouin sensor system
    - OZ Optics [Foresight™ DSTS (Distributed Strain and Temperature Sensors)]
    - Omnisens (STA)
    - Yokogawa (AQ8603) (Discontinued)
    - Sensornet (DTSS)
    - Neubrex (Neubrescope)
    - fibrisTerre (fTB 2505)
    - febus
**Working Principle — BOTDA**

$T$ and $\varepsilon$ are variables. In order to differentiate these two variables, Brillouin peak in the spectrum is required.
Working Principle — BOTDA

When the beat frequency $\nu$ matches intrinsic Brillouin frequency of the fiber $\nu_B$, we will get maximum of Brillouin spectrum.

$\nu_B$ changes linearly with the strain and temperature exerted.

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

Sensor medium: standard telecom optical fiber
Comparison of BOTDR and BOTDA

BOTDR (Brillouin Optical Time Domain Reflector)

- Probe Laser: \( \nu_0 \)
- Pulse Modulator: \( \nu_0 \rightarrow \) \( \nu_0 \) \( \oplus \)
- Reference: \( \nu_0 \)
- Heterodyne Receiver: \( \nu_B(\nu'_B) \)
- Digital Processor

- 10^3 photons: \( \nu_B \), \( \nu'_B \), \( \nu_B \)
- at most 1 photon: Brillouin scattered light \( \nu_0 \pm \nu_B(\nu'_B) \)

- Weak signal

BOTDA (Brillouin Optical Time Domain Analyzer)

- Probe Laser: \( \nu_0 \) \( \text{CW} \)
- Pulse Modulator: \( \nu_0 \rightarrow \) \( \nu_0 \) \( \oplus \)
- Pump Laser: \( \nu_0 + \nu_B(\nu'_B) \) \( \text{CW} \)
- Heterodyne Receiver: \( \nu_B(\nu'_B) \)
- Digital Processor

- 10^3 photons: \( \nu_B \), \( \nu'_B \), \( \nu_B \)
- Coherent amplification: Brillouin scattered light \( \nu_0 + \nu_B(\nu'_B) \)

- High dynamic range
3U + Laptop, 4 Channel Model
Foresight™ DSTS

Silver Level Winner

US Patents #: 7499151, 7599047 and 9568307
Merits of DSTS BOTDA

- Coherent amplification of Brillouin scattering signal
  ⇒ longest measured range (160 km fiber length)
- Narrowest Brillouin spectrum (\(\sim 45 \text{ MHz} \))
  ⇒ highest resolution of strain and temperature
- Special low loss fiber components and electronic processing
  ⇒ high stability of system
- With proprietary techniques, Brillouin frequency is extracted accurately
  ⇒ highest accuracy in measuring strain and temperature separately or simultaneously
- New technology
  ⇒ quick measurement of strain and temperature (as low as 1 second: 1 Hz)
Merits of DSTS BOTDR

- Low noise detection for weak spontaneous Brillouin scattering signal
  ⇒ long measured range (70 km in one direction)
- Special low loss fiber components and electronic processing
  ⇒ high stability of system
- Sophisticated design
  ⇒ Small size and light weight
## Double End (A) Competitive Analysis

<table>
<thead>
<tr>
<th></th>
<th>OZ Optics</th>
<th>OmniSens</th>
<th>Neubrex</th>
<th>fibrisTerre</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>BOTDA</td>
<td>BOTDA</td>
<td>BOTDA</td>
<td>BOFDA</td>
</tr>
<tr>
<td><strong>Maximum Sensing Range</strong></td>
<td>(fiber length up to 160km)</td>
<td>60 km (120km max. total fiber loop distance)</td>
<td>27km</td>
<td>25km</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>Internal 4 External 24 More channels optional</td>
<td>Internal 4 up to 20 channels via external SO-N Switch module</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Highest Spatial Resolution / Spatial step (sample interval)</strong></td>
<td>10cm/5cm</td>
<td>50cm/25cm</td>
<td>2cm/1cm</td>
<td>50cm/5cm</td>
</tr>
<tr>
<td><strong>Dynamic Range at highest spatial resolution</strong></td>
<td>7dB</td>
<td>N/A</td>
<td>0.5dB</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Strain / Temperature Accuracy (Repeatability) (σ)</strong></td>
<td>2με/0.1°C (1m spatial resolution / 2km fiber / 1 minute 40 seconds)</td>
<td>2με/0.1°C (1m spatial resolution / 2km fiber / 10 minutes)</td>
<td>7.5με/0.35°C</td>
<td>2με/0.1°C</td>
</tr>
<tr>
<td><strong>Strain / Temperature Resolution</strong></td>
<td>0.1με/0.005°C</td>
<td>2με/0.1°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Specifications of other vendor’s products are based on their public datasheets.

1) Based on scientific definition, the spatial resolution is defined by pulse width. 10ns pulse width is equivalent to 1m spatial resolution while 1ns pulse width is equivalent to 0.1m spatial resolution.
## Single End (R) Competitive Analysis

<table>
<thead>
<tr>
<th>Company</th>
<th>OZ Optics</th>
<th>OmniSens</th>
<th>Neubrex</th>
<th>Febus</th>
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<tr>
<td><strong>Technology</strong></td>
<td>BOTDR</td>
<td>BOTDR</td>
<td>BOTDR</td>
<td>BOTDR</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>Internal 4</td>
<td>Internal 4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>External 24</td>
<td>up to 20 channels via external SO-N Switch module</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>More channels optional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Maximum Sensing Range</strong></td>
<td>70km (max 100km)</td>
<td>45km</td>
<td>27km (max 100km)</td>
<td>30km</td>
</tr>
<tr>
<td><strong>Highest Spatial Resolution / Spatial step (sample interval)</strong></td>
<td>1m$^1$/5cm</td>
<td>1.5m/25cm</td>
<td>0.5m / 5cm</td>
<td>1m</td>
</tr>
<tr>
<td><strong>Dynamic Range at highest spatial resolution</strong></td>
<td>10dB</td>
<td>10dB</td>
<td>2dB</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Strain / Temperature Accuracy (Repeatability) ($\sigma$)</strong></td>
<td>10$\mu$ε/0.5°C</td>
<td>20$\mu$ε/1°C</td>
<td>30$\mu$ε/1.5°C</td>
<td>10$\mu$ε/0.5°C</td>
</tr>
<tr>
<td><strong>Strain / Temperature Resolution</strong></td>
<td>0.1$\mu$ε/0.005°C</td>
<td>2$\mu$ε/0.1°C</td>
<td>N/A</td>
<td>N/A</td>
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1) Based on scientific definition, the spatial resolution is defined by pulse width. 10ns pulse width is equivalent to 1m spatial resolution while 1ns pulse width is equivalent to 0.1m spatial resolution.
## Combo Unit Competitive Analysis

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<th>Neubrex</th>
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<tr>
<td></td>
<td>External 24</td>
<td>up to 20 channels via external SO-N Switch module</td>
<td>N/A</td>
</tr>
<tr>
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<td>10cm/5cm</td>
<td>1m/5cm</td>
<td>50cm/25cm</td>
</tr>
<tr>
<td>Dynamic Range at highest spatial resolution</td>
<td>7dB</td>
<td>10dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Strain / Temperature Accuracy (Repeatability) ($\sigma$)</td>
<td>2µε/0.1°C (1m spatial resolution / 2km fiber / 1 min 40 secs)</td>
<td>10µε/0.5°C (1m spatial resolution / 2km fiber / 10 mins)</td>
<td>2µε/0.1°C</td>
</tr>
<tr>
<td>Strain / Temperature Resolution</td>
<td>0.1µε/0.005°C</td>
<td>0.1µε/0.005°C</td>
<td>2µε/0.1°C</td>
</tr>
</tbody>
</table>

Specifications of other vendor’s products are based on their public datasheets.

1) Based on scientific definition, the spatial resolution is defined by pulse width. 10ns pulse width is equivalent to 1m spatial resolution while 1ns pulse width is equivalent to 0.1m spatial resolution.
Detailed Comparison Facts

Sensing Range -- The Longest Functional Measurement Fiber Length. Results comparison between OZ unit and other vendor’s unit. Fiber under test is 101km long. Results are displayed below. Same test configurations are applied.

**Other Vender**

Brillouin Spectrum at 80km. Reasonable Spectrum can be only found at 55km.

**OZ Optics DSTS**

Brillouin Spectrum at 100.5km.
### Comparison: DSTS BOTDA and Raman based DTS

<table>
<thead>
<tr>
<th></th>
<th>Raman based DTS</th>
<th>OZ Foresight™ DSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max Fiber Length</strong></td>
<td>20km (MM)</td>
<td>160 km round-trip (physical distance 80 km)</td>
</tr>
<tr>
<td><strong>Fiber Type</strong></td>
<td>Multimode</td>
<td>Standard telecom singlemode</td>
</tr>
<tr>
<td><strong>Response time @ 20km, 2C Resolution</strong></td>
<td>More than 10 minutes</td>
<td>30 seconds to 3 minutes</td>
</tr>
<tr>
<td><strong>Configuration</strong></td>
<td>Single ended or double ended</td>
<td>Single ended or double ended</td>
</tr>
<tr>
<td><strong>Measurement Base and Precision</strong></td>
<td>Intensity based</td>
<td>Frequency based</td>
</tr>
<tr>
<td></td>
<td>Require calibrations</td>
<td>No calibration required after setup</td>
</tr>
<tr>
<td></td>
<td>Sensitive to attenuation changes</td>
<td>Not sensitive to attenuation changes</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>3-4 dB</td>
<td>25-30 dB</td>
</tr>
<tr>
<td></td>
<td>May fail when attenuation increases</td>
<td>Allows better immunity to attenuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wider measurement range and longer use of installed fiber</td>
</tr>
<tr>
<td><strong>Measurand</strong></td>
<td>Temperature</td>
<td>Temperature and Strain</td>
</tr>
<tr>
<td><strong>Measurement Resolutions</strong></td>
<td>Comparable @ over 1 minute</td>
<td>Comparable @ several seconds</td>
</tr>
</tbody>
</table>
Competitive Analysis

- Neubrex
- fibrisTerre
- Sensornet
- OZ Optics
- Omnisens
New Features

• New GUI
• Full DLL support
• Auto-recovery from power outage
• Auto Channel Switch allows continuous scans between channels.
New GUI Login
Measurement Screens
OZ Optics Foresight™ DSTS Benefits

• Reducing risk and influence of failure
  – Fast response
  – Status trend in long term
  – Full range of coverage

• Reducing operating expenses
  – No future re-calibration of unit
  – Expected cable life over 20 years
Applications

- Oil and Gas Pipeline Monitoring
- Dyke and Levee Monitoring
- Power Line Monitoring
- Oil and Gas Well Monitoring
- Bridge and Building Monitoring
- Border Security Monitoring
Oil and Gas

- Pipeline Leakage Monitoring
- Well Integrity Management
- Refinery Temperature Monitoring
Pipeline Leakage Monitoring System

- Policy Requirement
- Economic Requirement

Leakage → Liquid Spill → Ambient Temp Change → Temperature of sensing cable changes → Detected

TCP/IP

SCADA

local control room

Pipeline Leakage Monitoring System

Temperature Sensing Cable
Third Party Evaluation

• Leakages from a 1/8” orifice with an injection pressure as low as 22 psi, and a temperature difference of 20°F between the soil and line temperatures, have been easily detected and accurately located.

• An impressive leakage detection response time of less than 2 minutes has been achieved.

• Evaluation was done under laboratory conditions over a period of one month, by Southwest Research Institute (SwRI) and funded by major oil companies through a joint industry program.
Performance

Large leakage detection from 1/8” orifice with 400 psi injection pressure, soil temperature before test: 85°F, line temperature: 115°F.

Small leakage detection from 1/8” orifice with 50 psi injection pressure, soil temperature before test: 73°F, line temperature: 90°F.
Soil Temperature Monitoring

(a) FOS
(b) TSR
Pipeline Corrosion Monitoring

Pipeline corrosion monitoring in Canmet Materials Technology Laboratory, NRCan, Ottawa, NACE International — Corrosion 2008 Conference and Expo, New Orleans (Louisiana, USA 16-20 March, 2008).
Pipeline Corrosion Monitoring

Pipeline corrosion monitoring in Canmet Materials Technology Laboratory, NRCan, Ottawa, NACE International — Corrosion 2008 Conference and Expo, New Orleans (Louisiana, USA 16-20 March, 2008).
Refinery Temperature Monitoring

- Refineries use reactors and pressure vessels to transform heavy oil into synthetic crude oil.
- The upgrader reactors are operated at very high temperatures, exceeding 500 °C.
- Due to the thermal stress exerted on the structure of the reactor, a wall-thinning problem might occur, resulting in conductive heat dissipation.
- Without the proper sensing technology, the refinery operator might prematurely shut down operations to perform untimely maintenance, or worse yet, the problem might go unnoticed, resulting in a catastrophic accident.
Pipeline Buckling Detection

- Pipeline buckling detection in TransCanada Pipeline Ltd, Calgary, and C-FER Technology, Edmonton
Metal/Polyimide Coated Hermetic Fibers

Coating materials and maximum sustainable temperatures

- UV-cured acrylate: 100°C
- UV-cured dual acrylate: 150°C
- Polyimide: 400°C
- Copper+polyimide: 400°C
- Aluminum: 450°C
- Copper alloy: 600°C
- Gold: 700+°C
Power Utility

- OPGW Monitoring
- Power Cable (Submarine Cable) Monitoring
- Temperature profile monitoring of an air-cooled gas generator
OPGW Monitoring

- Monitoring the working status of OPGW
- Abnormal event found and located
- Event caused by broken strand, lightning, frost covering, change of strain, etc.
The OPGW is located from Smith Falls to Merivale-Ottawa, Ontario, Canada.
The total fiber length was close to 140 km.
The BOTDA located in Merivale-Ottawa made measurements as often as once every 60 minutes starting in June 2012 and continuing till July 2013.
OPGW Strain Monitoring

- Power line/OPGW monitoring in Hydro-Quebec, Montreal
High Voltage Underground Cable with Fiber
Temperature profile monitoring of an air-cooled gas generator
Concrete Beam/Highway Monitoring

• Concrete beam/Highway monitoring on HW40/University of Sherbrooke, Dr. Brahim Benmokrane
GeoDetect With Embedded Fibers
Christchurch Northern Corridor (CNC) – Measuring settlement with fibre optics

CNC ALLIANCE PROJECT FEATURES

Project engineer Stephen Coleman talks about innovative fibre optics to measure settlement
Crack Detection

Crack detection in University of California, Irvine, Dr. Maria Feng, 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).
Crack Detection

Crack detection in University of California, Irvine, Dr. Maria Feng, 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).
Brillouin Sensor Monitoring of Telecom Fibers

- Detects minor events that are too small to be seen by OTDRs.
- Can replace OTDRs for monitoring fibers.
- Can be used to monitor new or existing fiber installations.
- Permits performance monitoring of fibers above or below ground.
- Avoids unnecessary replacement of old fibers, saving millions of dollars in installation costs.

Yogokawa’s results from AT&T’s old telecom fiber, very broad Brillouin spectrum, which results in poor resolution and accuracy.

OZ’s results from AT&T’s old telecom fiber, very narrow Brillouin spectrum, which results in high resolution and accuracy.
The Cost of Catastrophic Failure

- Example: Druzhba Pipeline July 2006
- Small 50 cubic meter leak results in:
  - Interruption of $100M/day pipeline
  - Global spike in oil prices
  - Report of environmental catastrophe
  - Months of investigation and ecological monitoring
- Single point of failure in 3,000 km pipeline
The Cost of Catastrophic Failure

- Example 2: Nigerian Pipeline July 2006
- Accidental leak
- 180,000 barrels / day shutdown
- \(180,000 \times \$74 = \$13M\) per day
- 10-day shutdown = \$130M
- Brillouin operation \(<\ <$1/m/year
- **Single production shutdown far exceeds lifetime sensor operating costs.**
Acknowledgements

- University of California, Irvine, Dr. Maria Feng
- University of Ottawa, Dr. Xiaoyi Bao
- University of Sherbrooke, Dr. Brahim Benmokrane
- TransCanada Pipelines Limited (TCPL)
- C-FER Technologies
- Canmet Materials Technology Laboratory, NRCan
- Hydro-Quebec
- Southwest Research Institute®
- Tencate Geosynthetics
- NZ Transport Agency
- Christchurch Northern Corridor
- CNC Alliance Project
The OZ Optics Commitment

OZ Optics is committed to providing a complete solution, lab evaluation, and field trial to meet your structural health monitoring requirements.
Your solution provider for existing and next generation fiber optic components and test equipment

Please Contact Our Sales Dept:
Tel: 613-831-0981 ext 3370
Toll Free: 1-800-361-5415
Email: sales@ozoptics.com.
Thank You for Choosing OZ!