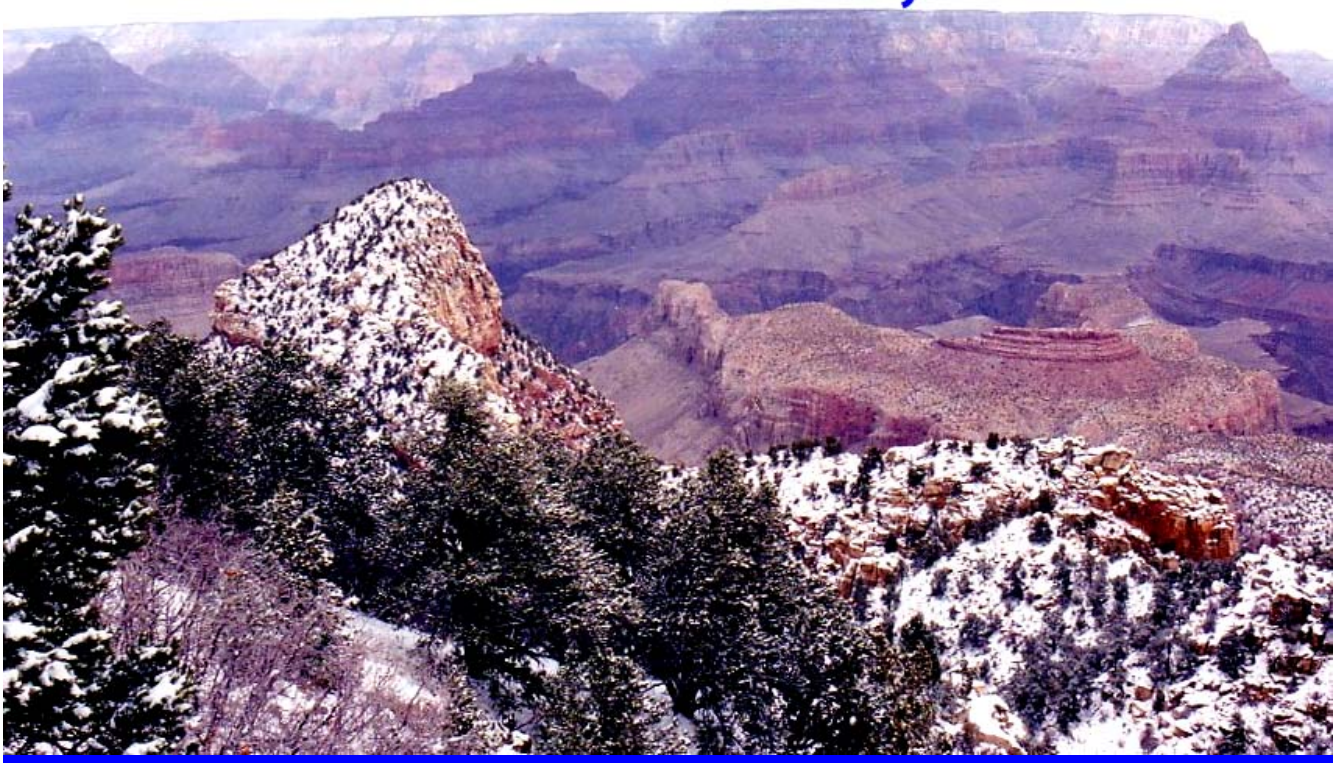
NOVAKINETICS, LLC



SMALL WIND TURBINE BLADE MANUFACTURING PROCESS DEVELOPMENTS 2008

PRESENTER:
MICHELLE CORNING,
GENERAL MANAGER/ SENIOR ENGINEER

Composites Manufacturing Products, Continued:

Novakinetics produces engine nose cowlings, fairings, wingtips, cockpit canopies, internal ductwork and empennage parts for the Air Tractor AT-802F fire fighting airplane shown here.

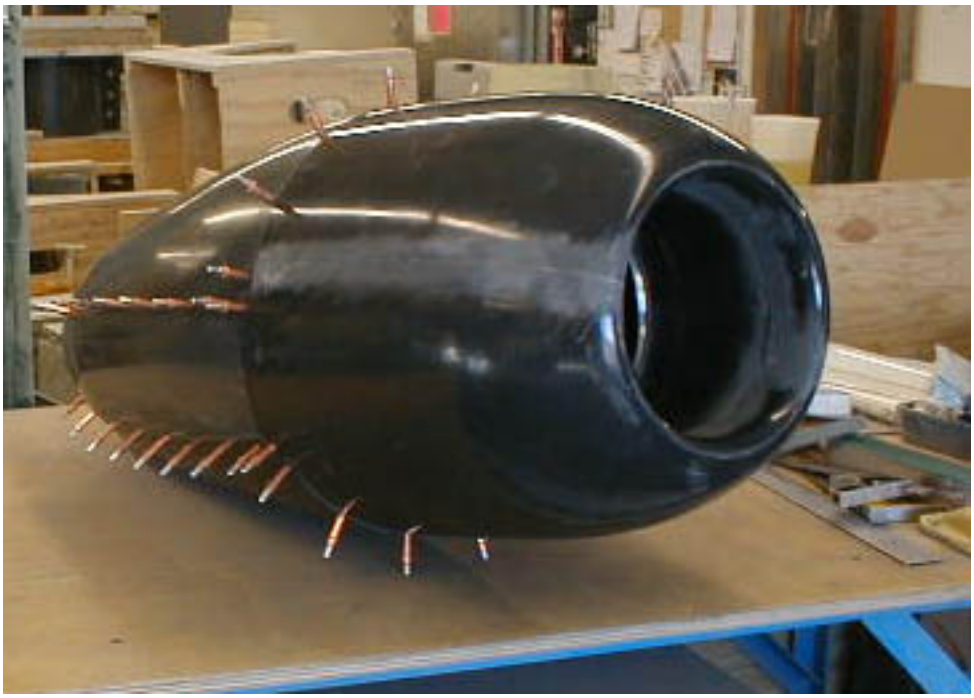
Novakinetics engineering designed and produced tooling for the Hoerner wingtips now flying on Air Tractor AT-802 airplanes. Shown is a structural load test on a prototype wingtip using bags of lead shot.

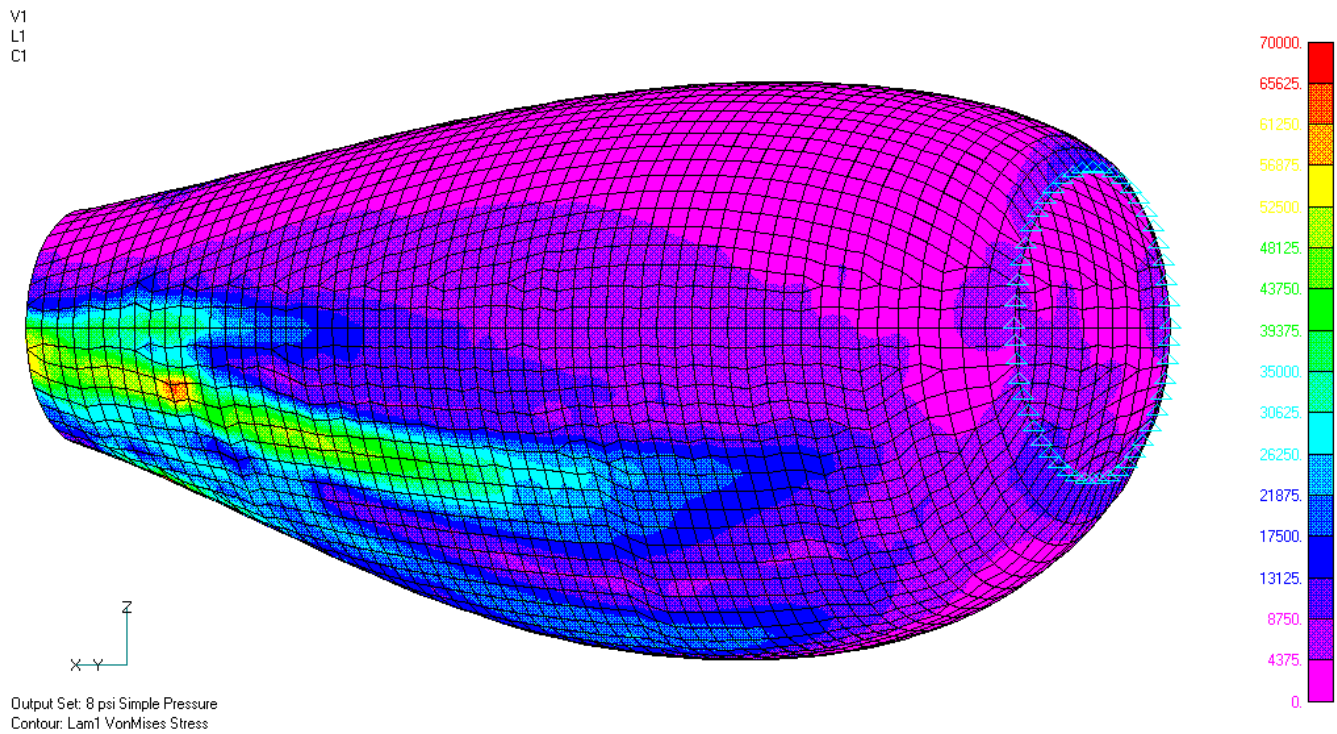
We often work closely with our customers, at their facilities, to create new parts and ensure that they fit perfectly and repeatably.

Engineering and Design Services:

Novakinetics engineering and tooling specialists produced this series of models to help a client explore engine cowl design concepts for a new cargo plane.

These scale models were produced as a quick and cost effective way to evaluate different engine intake and exhaust system layouts.




V1
L1
C1
70000.
65625.
61250.
56875.
52500.
48125.
43750.
39375.
35000.
30625.
26250.
21875.
17500.
13125.
8750.
4375.
0.
Z
X Y
Output Set: 8 psi Simple Pressure
Contour: Lam1 VonMises Stress

We still get into our work

NOVAKINETICS, LLC

CMS
Chandler Monitoring Systems Inc.

CEL Official Integrator

Fiber Optic Sensing & Monitoring of Wind Turbines

Cleveland Electric Laboratories

361 South 52nd Street

Tempe Arizona 85281

Phone: 480-967-2501

Rich Schwab

CLEVELAND ELECTRIC LABORATORIES
Thermocouple Products & Services

THE RIGHT TECHNOLOGY makes a world of difference.

Contents

- *Motivation & Background*
- *FlexPatch: A novel FBG strain Sensor*
- *Sensor Design & Fabrication*
- *Sensor Testing*
- *Conclusions*

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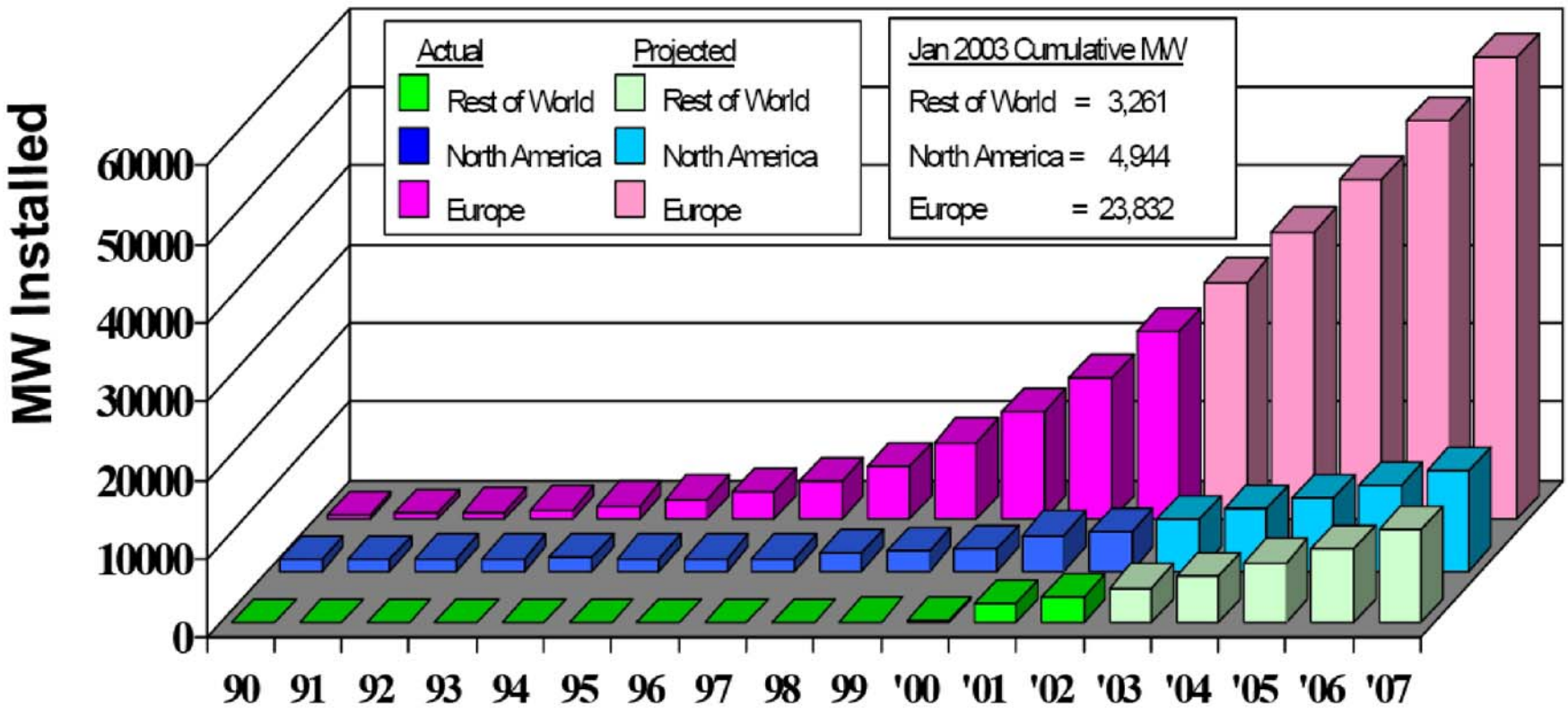
Worldwide Wind Energy:
Capacity Growth



Sources: BTM Consult Aps, March 2003
AWEA/EWEA Press Release 3/3/03

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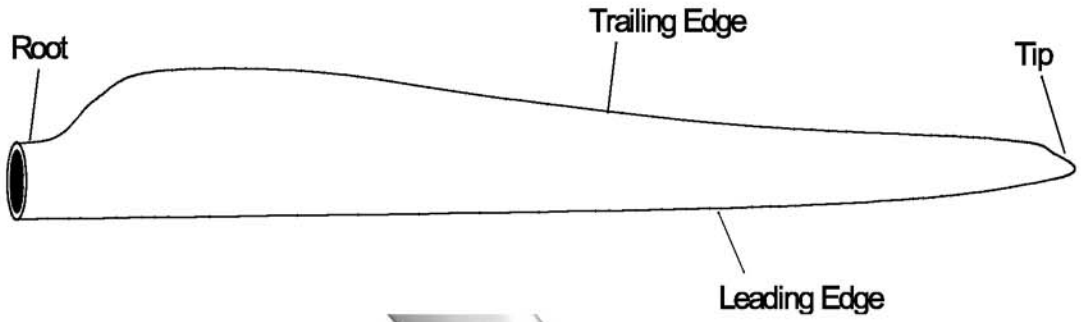
Wind Turbine & Blade Components



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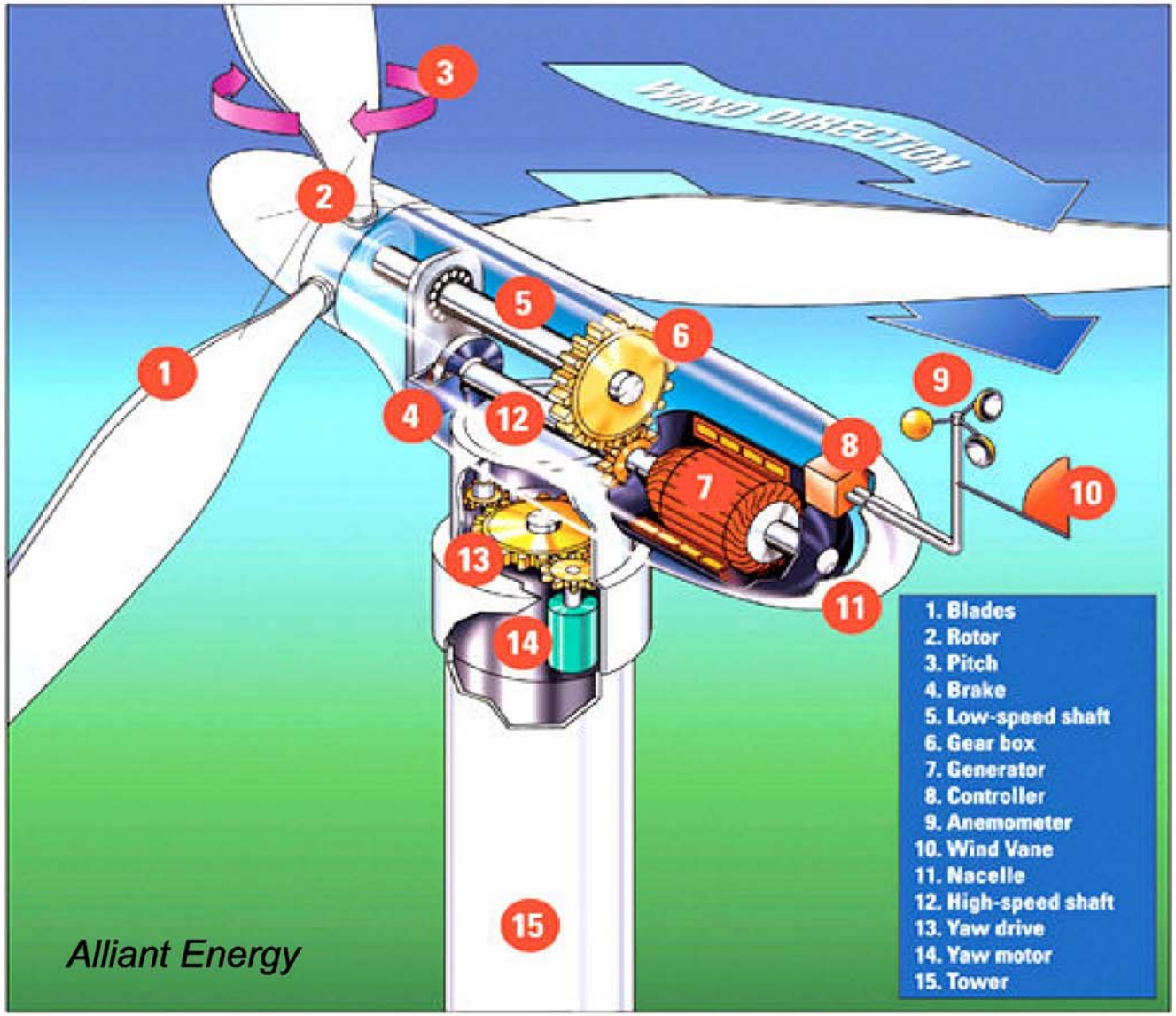
Wind Turbine:
Components & Operation



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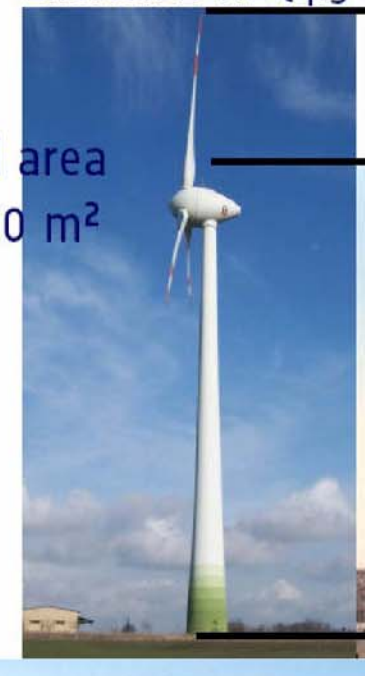
Wind Turbines:
Massive Scale Structures

Enercon E-112 (4.5 MW), E-126 (6 MW) – 198 m

Cologne Cathedral – 150 m

Wind area
12,000 m²



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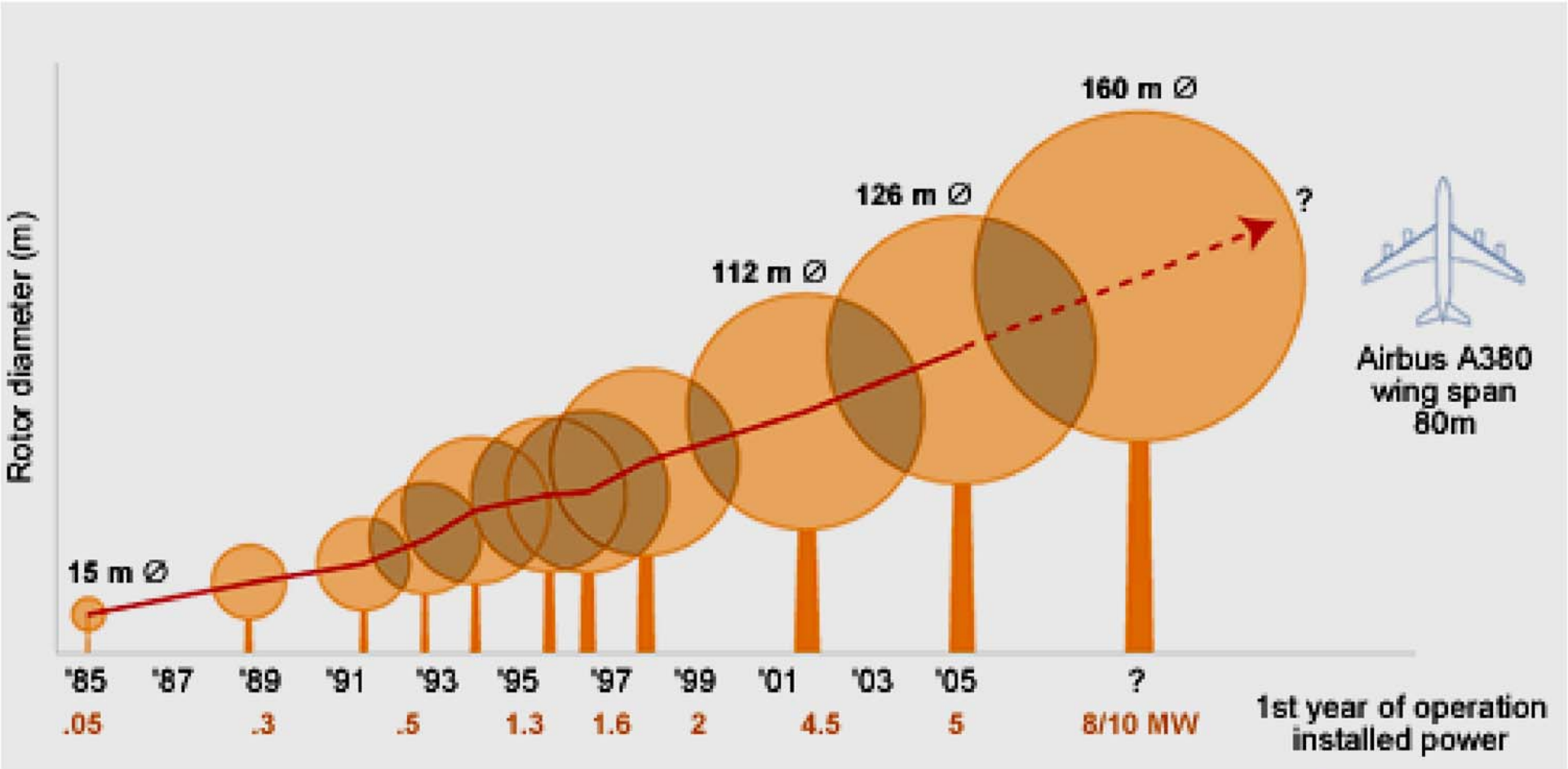
Wind Turbines:
Blade Size trend



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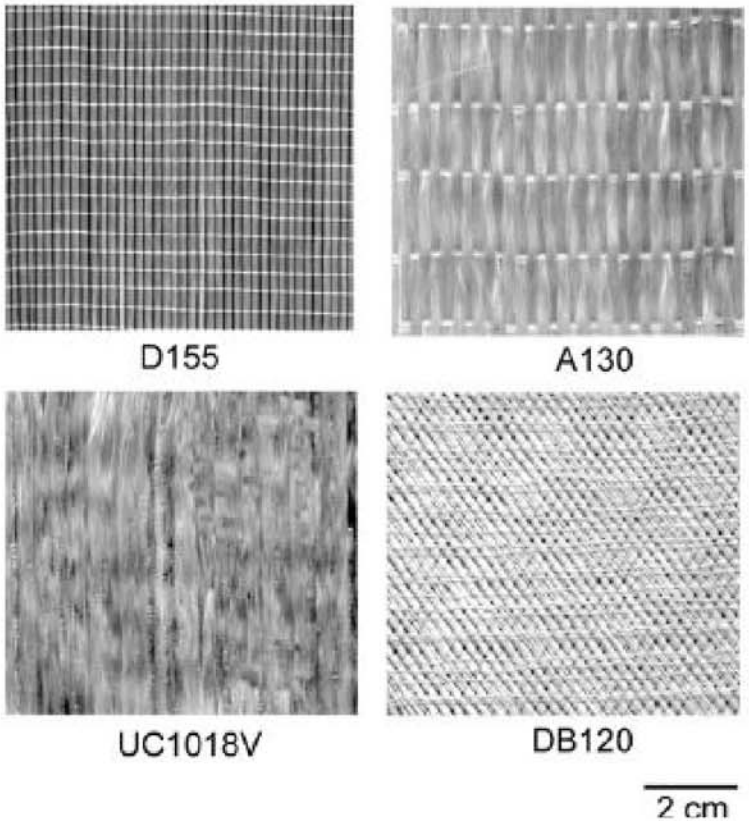
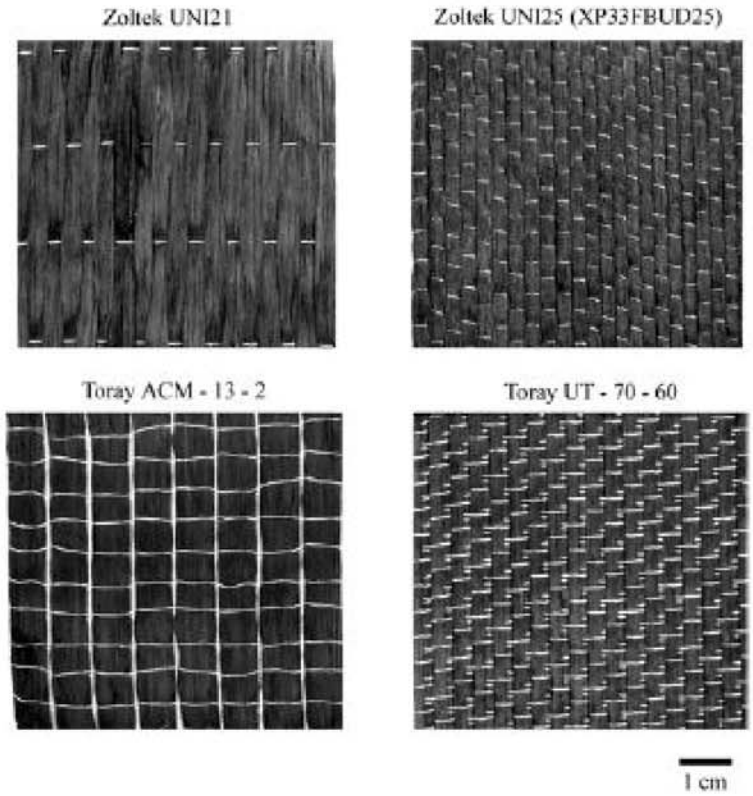
Wind Turbines:
Blade Materials



E-Glass Fiber



Carbon Fiber

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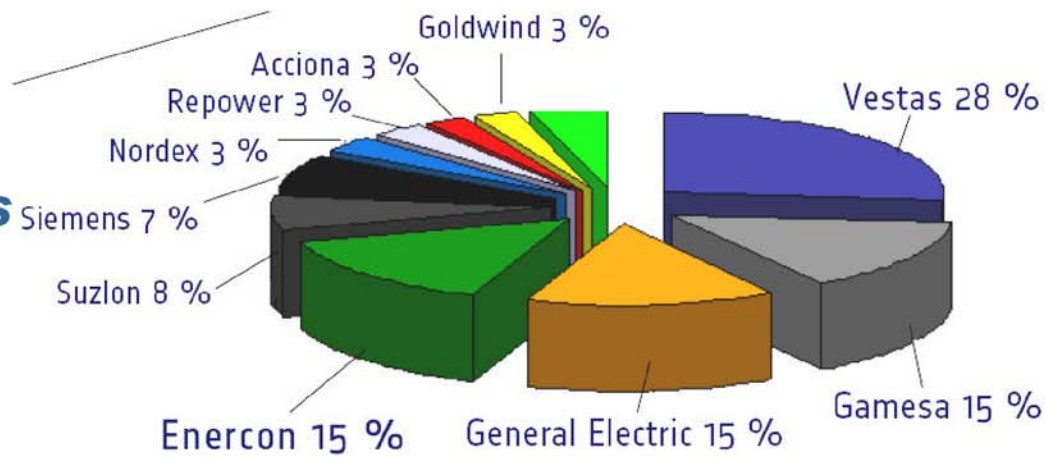
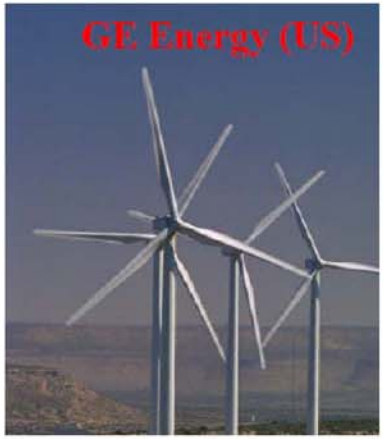
Wind Turbines:
Manufacturers

- *Acciona*
- *Aeroblade*
- *Ecotecnia*
- *Enercon*
- *Gamesa*
- *Eolica*
- *GE Wind*
- *Goldwind*
- *Mitsubishi*
- *Nordex*
- *Novakinetics*
- *REpower*
- *Siemens*
- *Suzlon*
- *Vestas*

Worlwide market share
90MW Turbines





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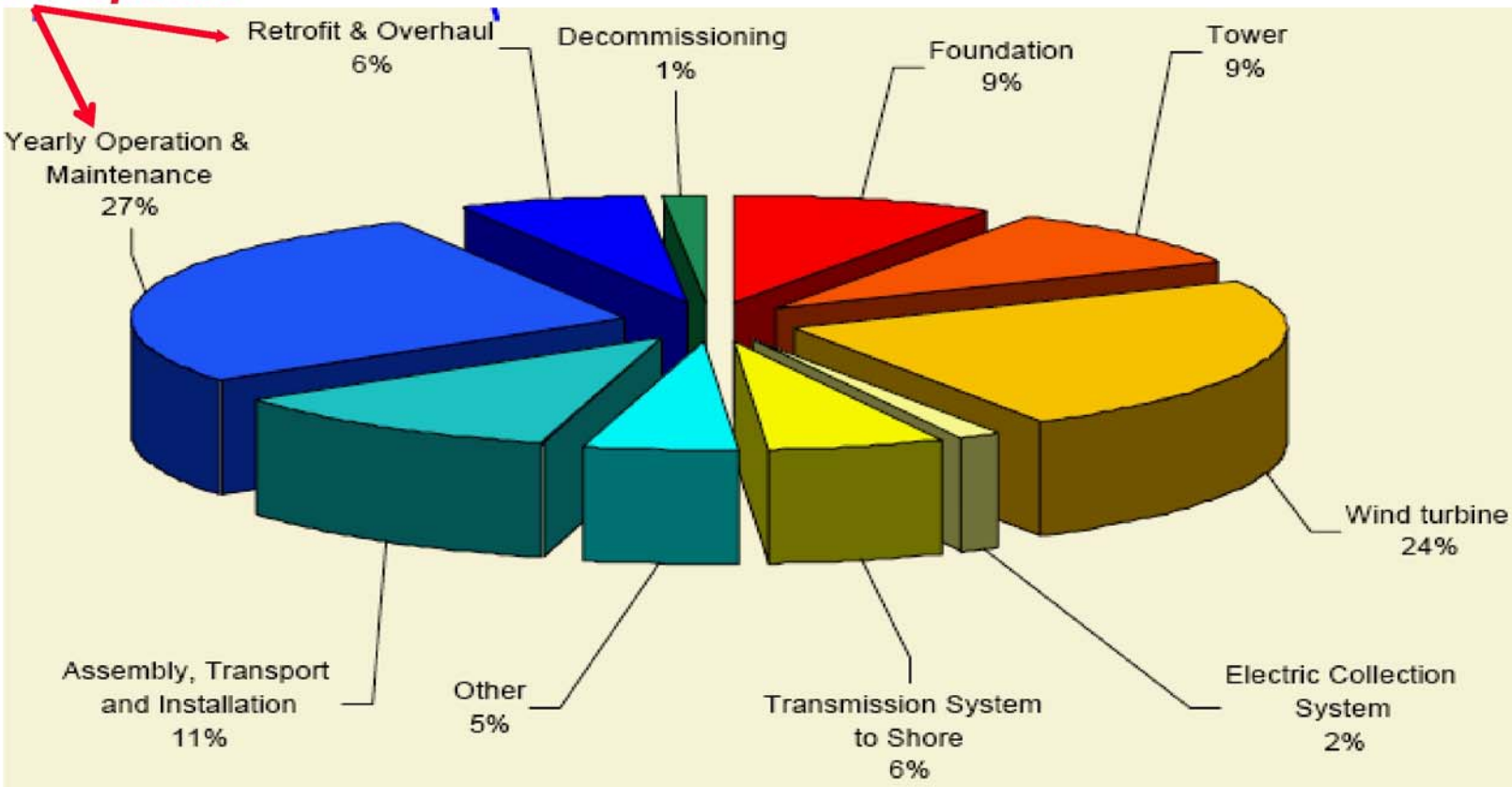
Wind Turbine Monitoring:
Motivation—Operating Expenses

~33% spent on maintenance & repairs!



Source: DOWEC study (Netherlands)
Offshore wind turbine operating expenses

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Wind Turbine Monitoring:
Motivation—Safety & Reliability

- **Increased safety.**
- **Improve turbine reliability.**
- **Prolong service lifetime.**
- **Reduce downtime.**
- **Detect and locate early blade damage.**
- **Monitor service loads and vibrations.**
- **Turbine cost reduction—design improvement.**
- **Reduce insurance costs.**

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Why Fiber Optic Sensors?

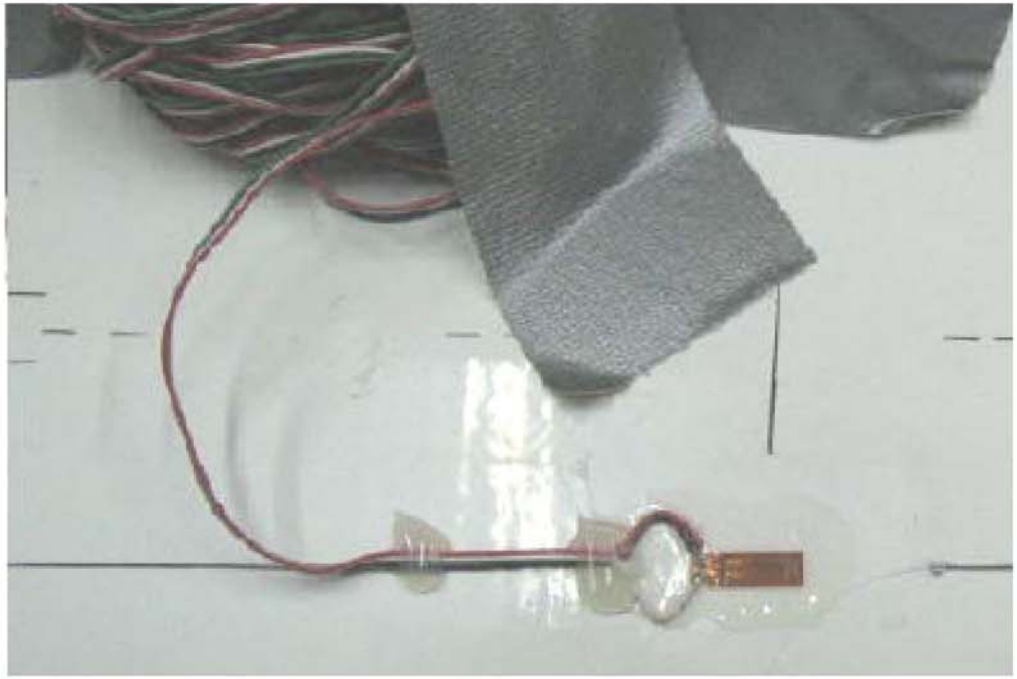
Source: NASA Langley
Composite wing IVHM testing

400 conventional strain gage sensors

3000 fiber optic FBG strain sensors

Why Fiber Optic Sensors?

- Immunity to lightning and electric shorts
- Ease of installation
- Better reliability & longevity than foil gages
- Multi-point sensing



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Applications:
Blade Testing & On-Line Monitoring

- **Design Verification & Testing**
  - Ultimate strength & fatigue
  - Design verification & improvement
  - Qualification & compliance testing
- **Blade Monitoring**
  - Static & dynamic loads (blade root & full lenght, wind speed, turbulence, etc.)
  - Surface stresses
  - Blade deflection (determine shape profile and avoid tower strikes)
  - Pitch control
  - Vibrations (frequencies & modal response)
  - Surface condition (ice, dust, fouling)
- **Tower & Foundation**
  - Loads, bending & torque
  - Vibration modes

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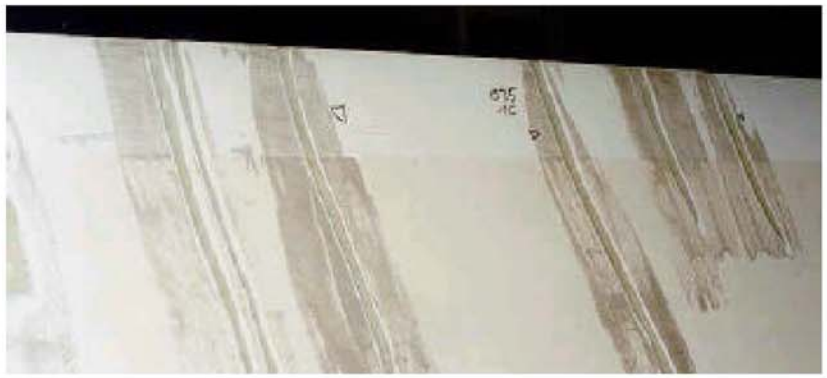
Applications:
Blade Edge Erosion

- ***Leading edge erosion***
- ***Soiling → dirt, oil***
- ***Dings & gouges***
- ***Collisions → birds & debris***



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Applications:
Blade Fatigue Testing & Qualification

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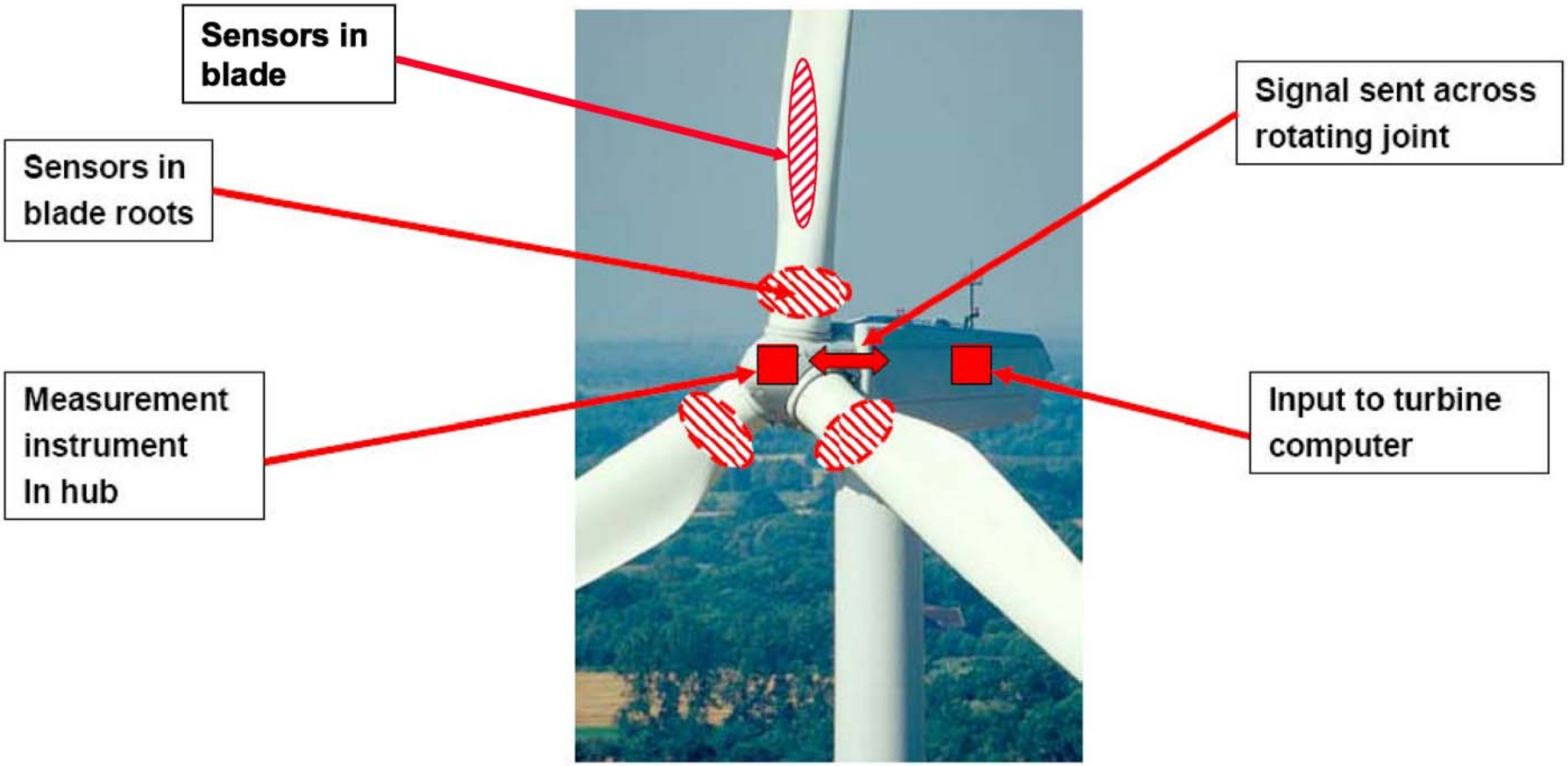
Wind Turbine Monitoring:
System Configuration



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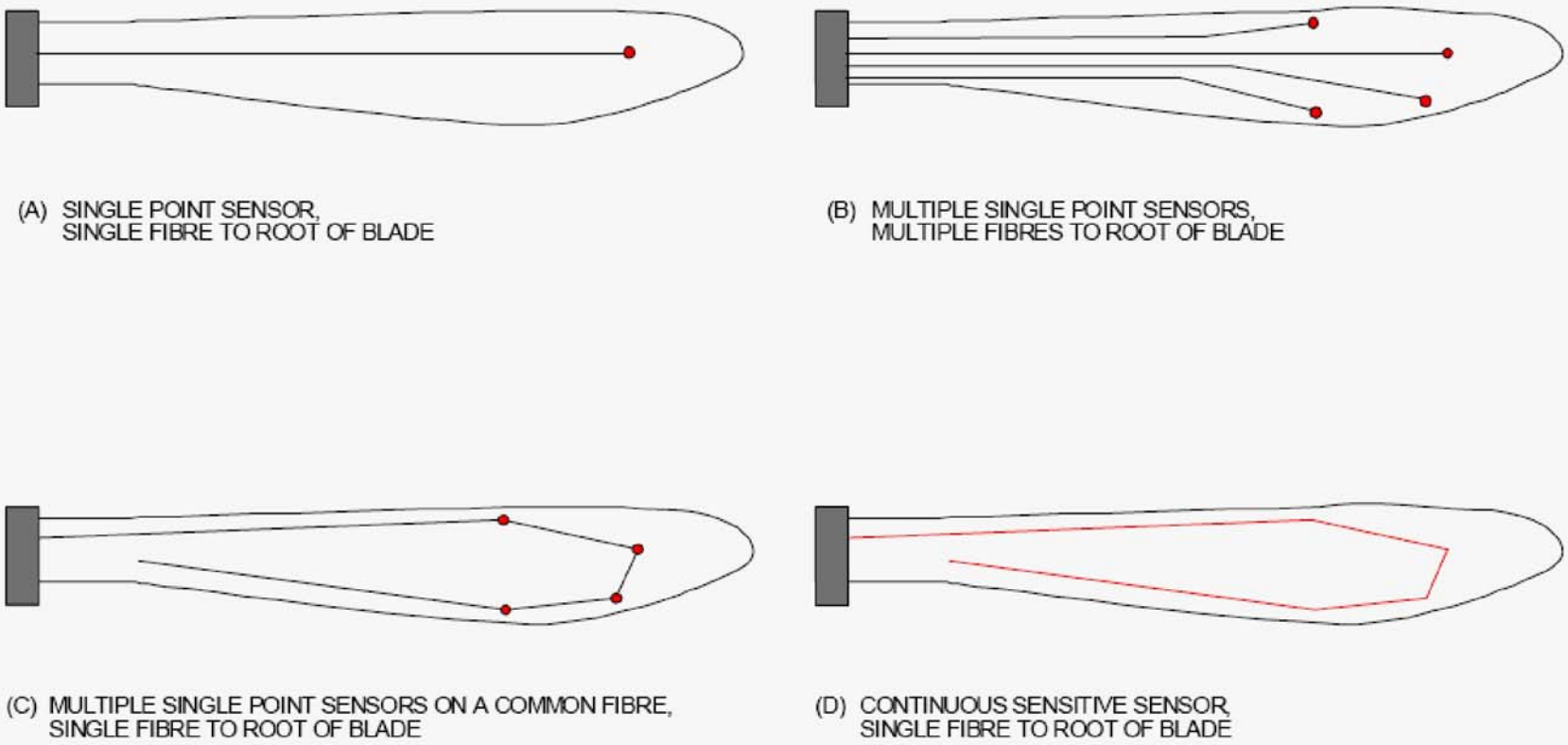
Blade Strain Monitoring:
Sensor Locations



Source: ECN

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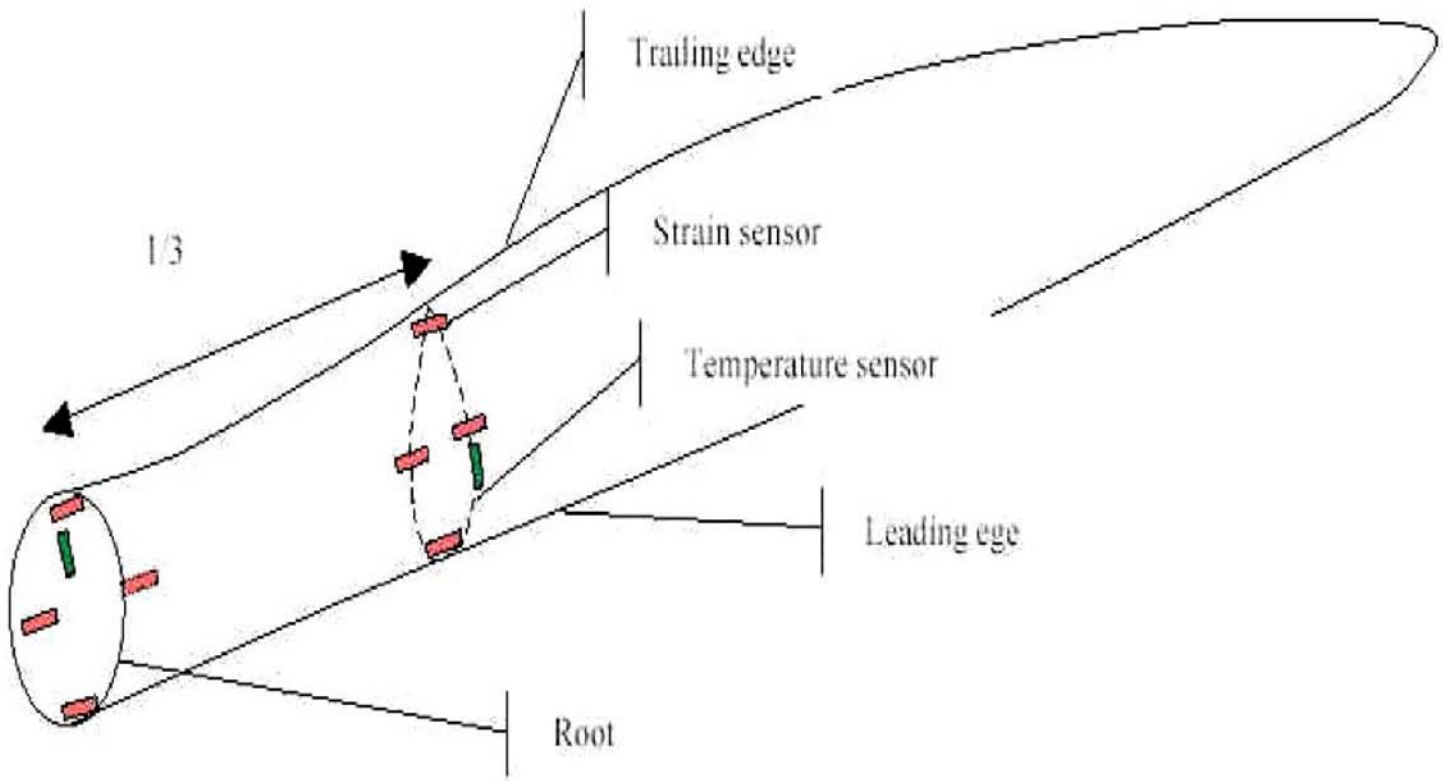
Blade Strain Monitoring:
Sensor Locations



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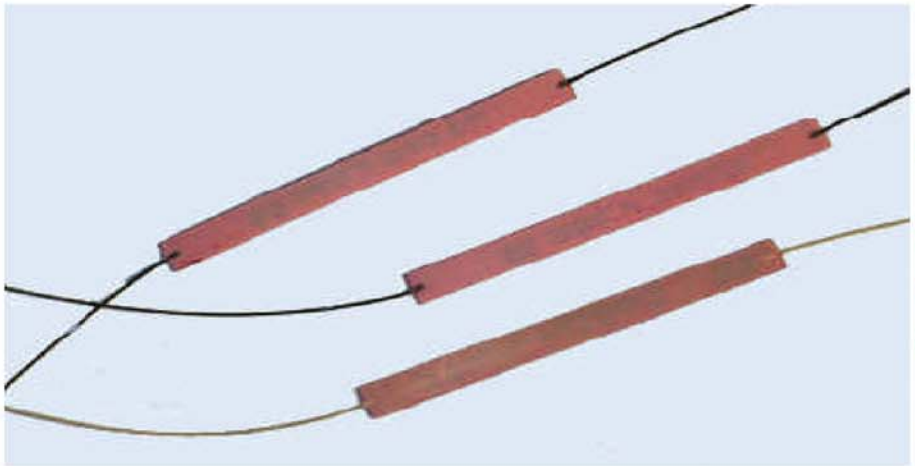
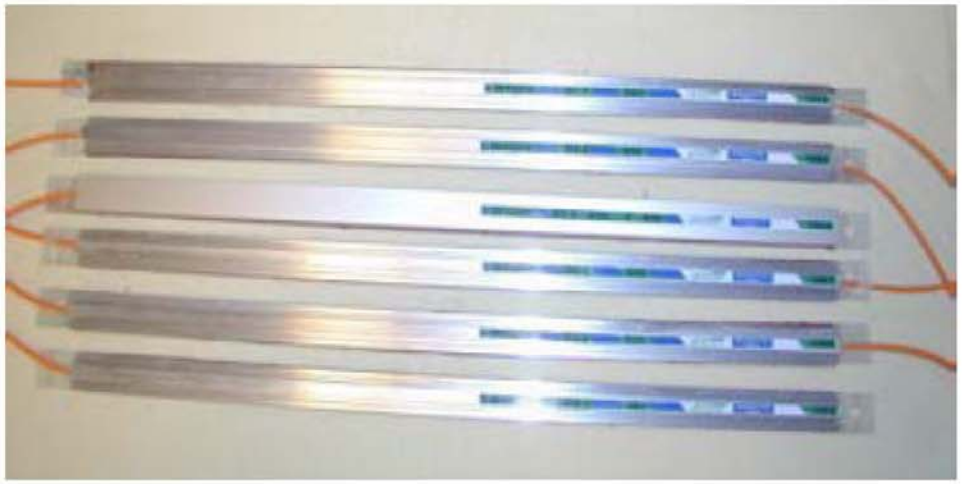
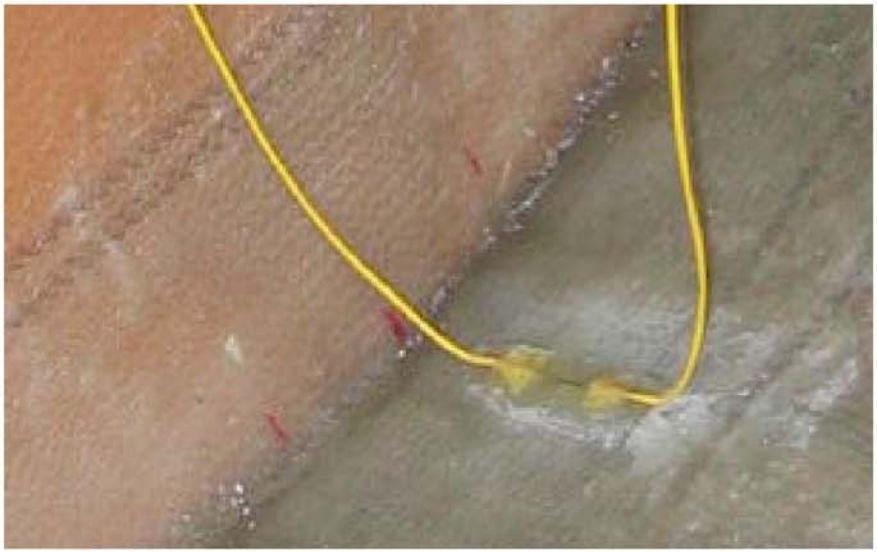
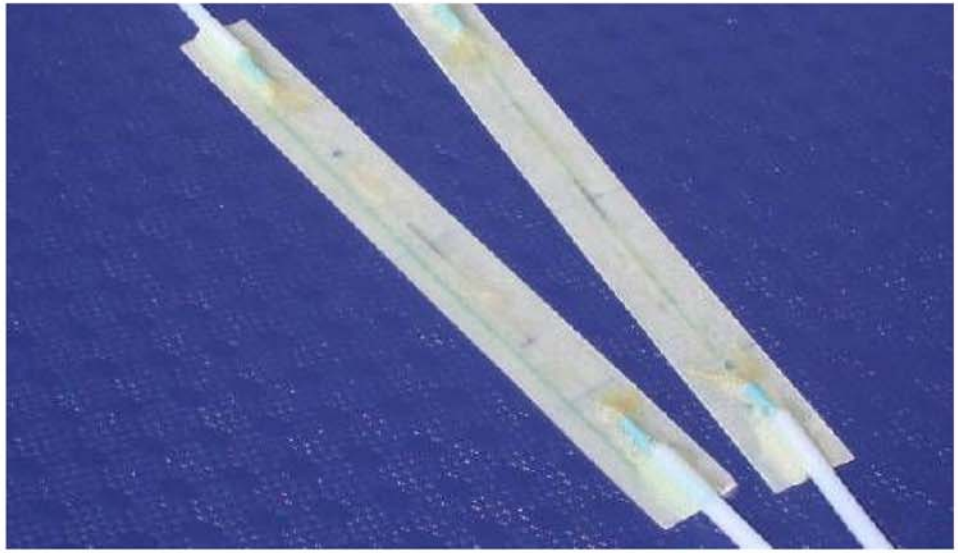
Examples of FBG Strain Sensors









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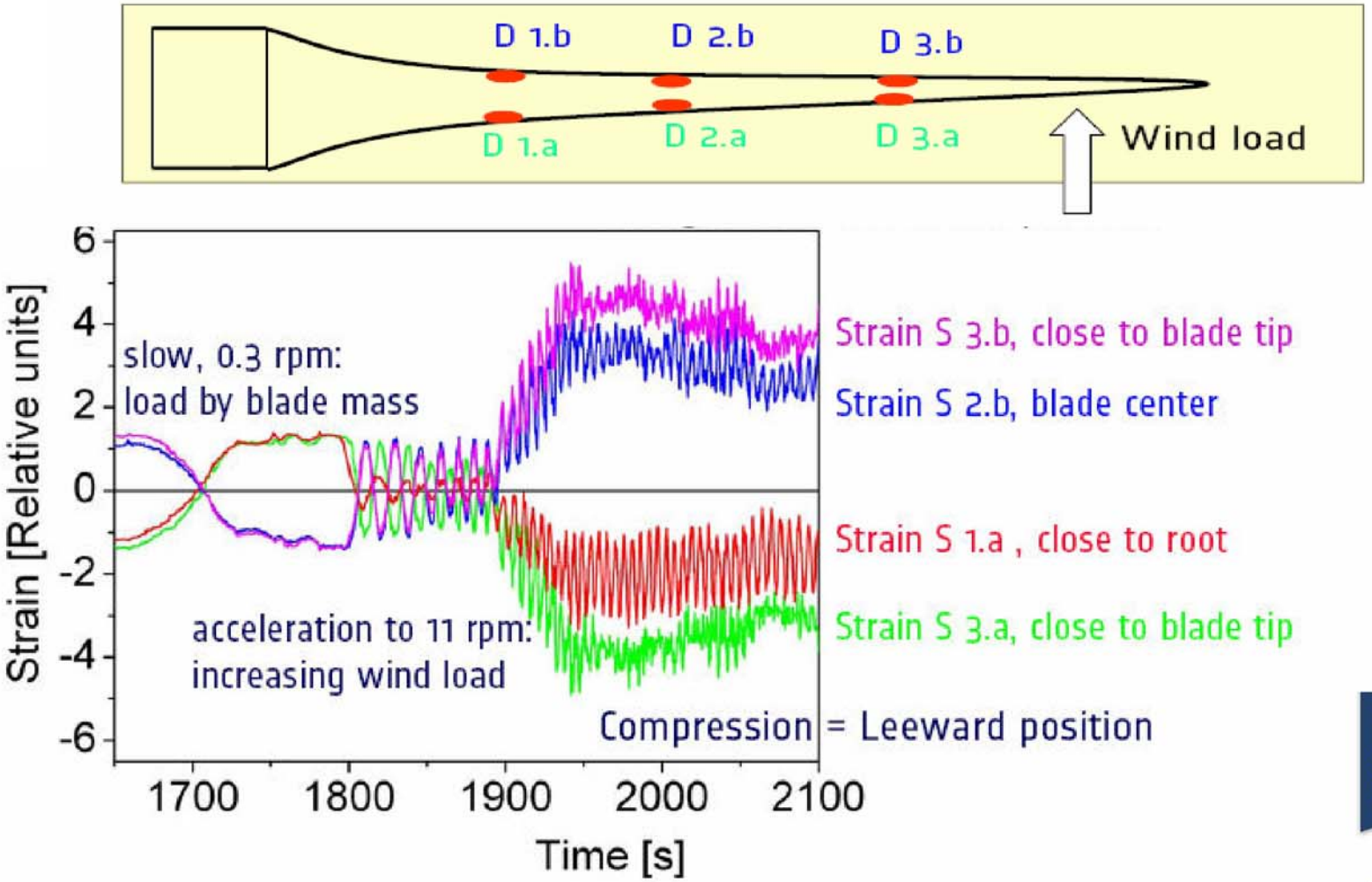
FBG Sensor Outputs:
Blade Strains



Source:

NOVAKINETICS, LLC

CMS
Chandler Monitoring Systems Inc.

CEL Official Integrator

Fiber Bragg Grating (FBG) Basics

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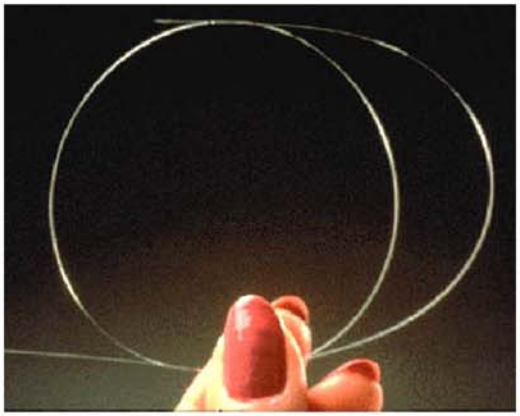
THE RIGHT TECHNOLOGY makes a world of difference.

Advantages of Fiber Optic Sensors



- *Galvanic isolation*
- *EMI immunity → no failure under electric lightning*
- *Intrinsically safe → explosion-proof*
- *Passive: no need for electrical power*
- *Possibility of remote, multiplexed operation*
- *Small size and lightweight*
- *Integrated telemetry: fiber itself is a data link*
- *Wide bandwidth*
- *High sensitivity*

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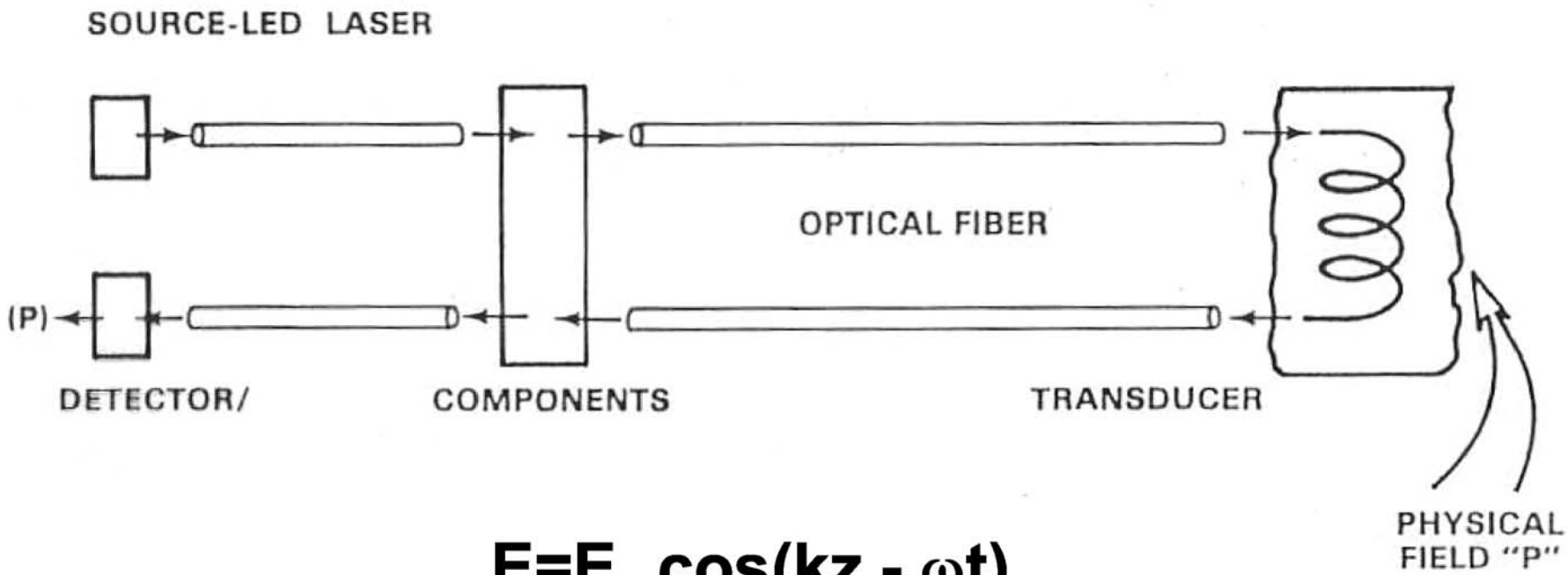
Fiber Optic Sensor:
Basic Configuration



$$E=E_o \cos(kz - \omega t)$$

Sensing is based on detecting a change in one or more of the light wave properties:

intensity ***phase***
polarization ***frequency***

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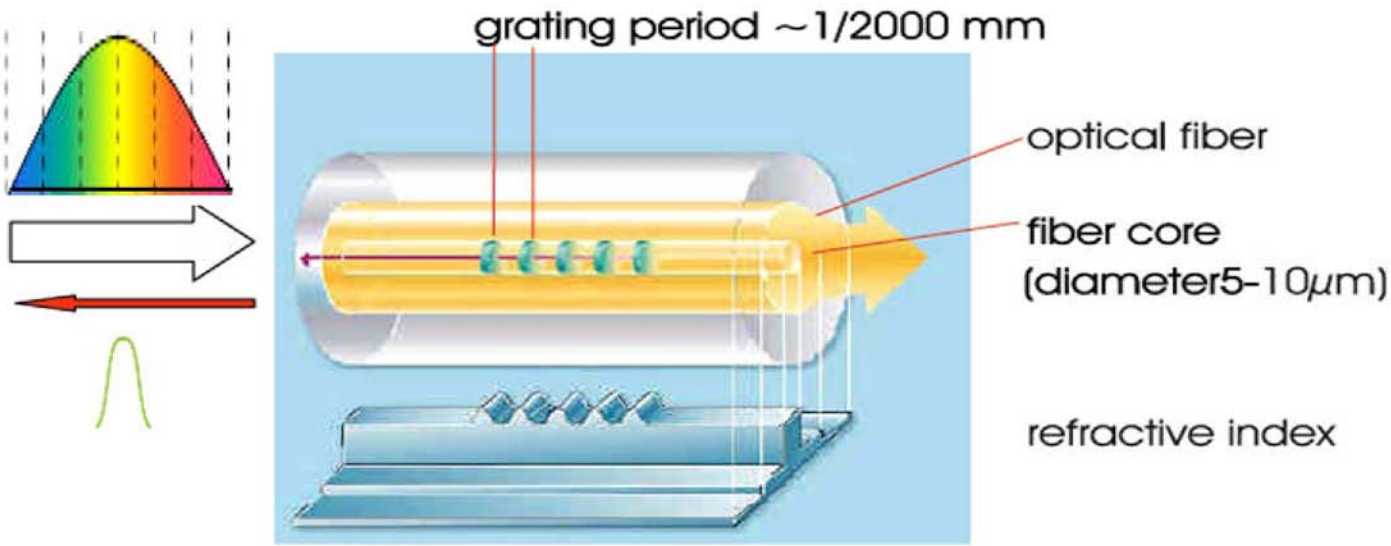
Fiber Bragg Gratings:
Operating Principle

A Fiber Bragg Grating is a periodic change of the refractive index in the core region of an optical fiber.

$$\lambda_B = 2n_{eff}\Lambda$$



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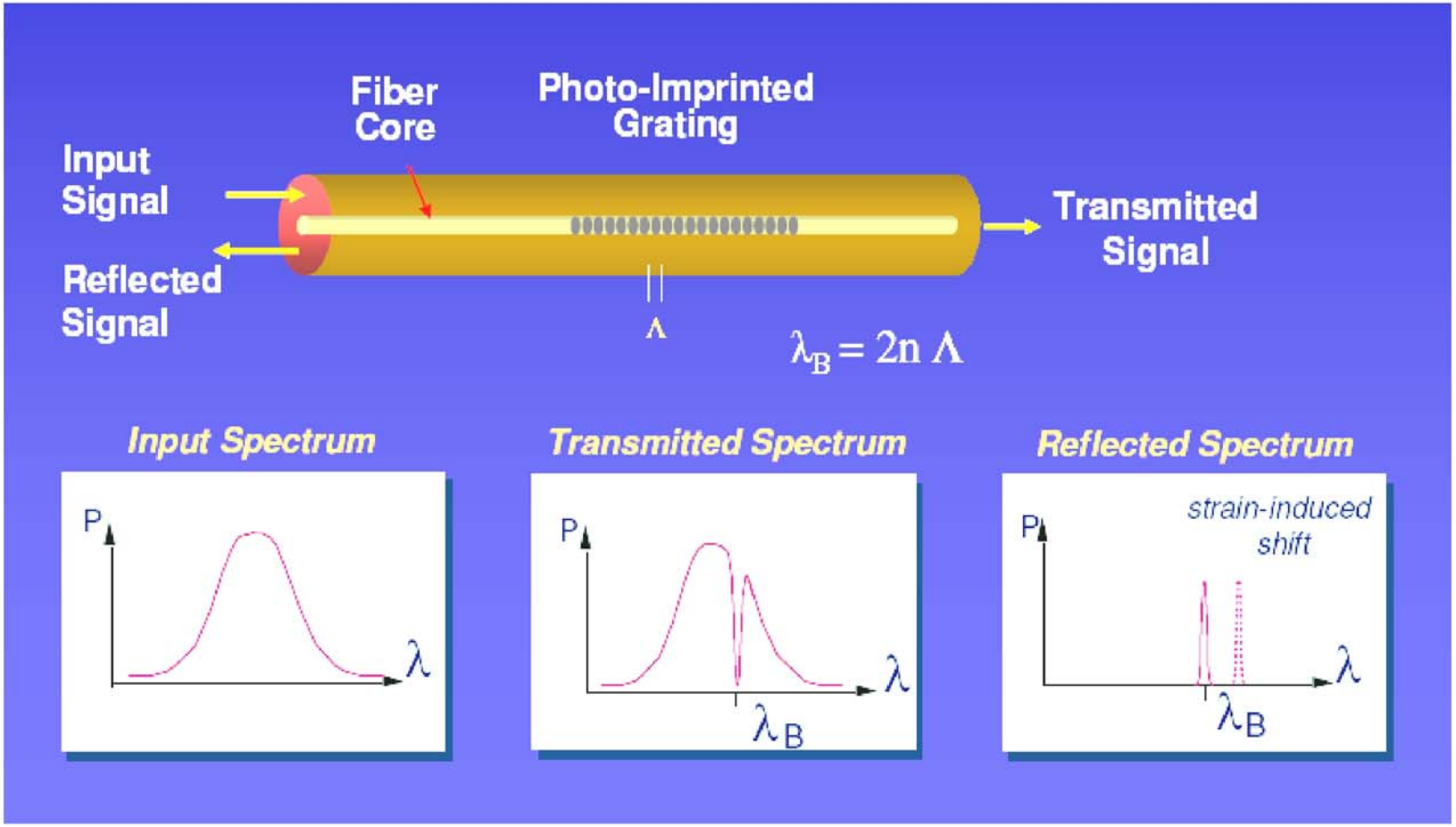
Fiber Bragg Gratings:
Operating Principle



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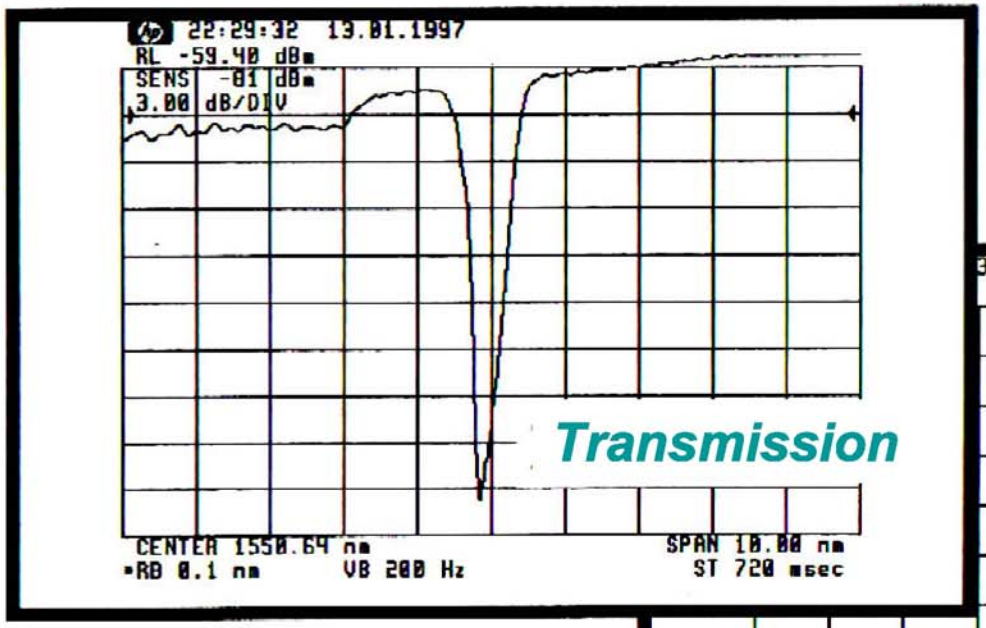
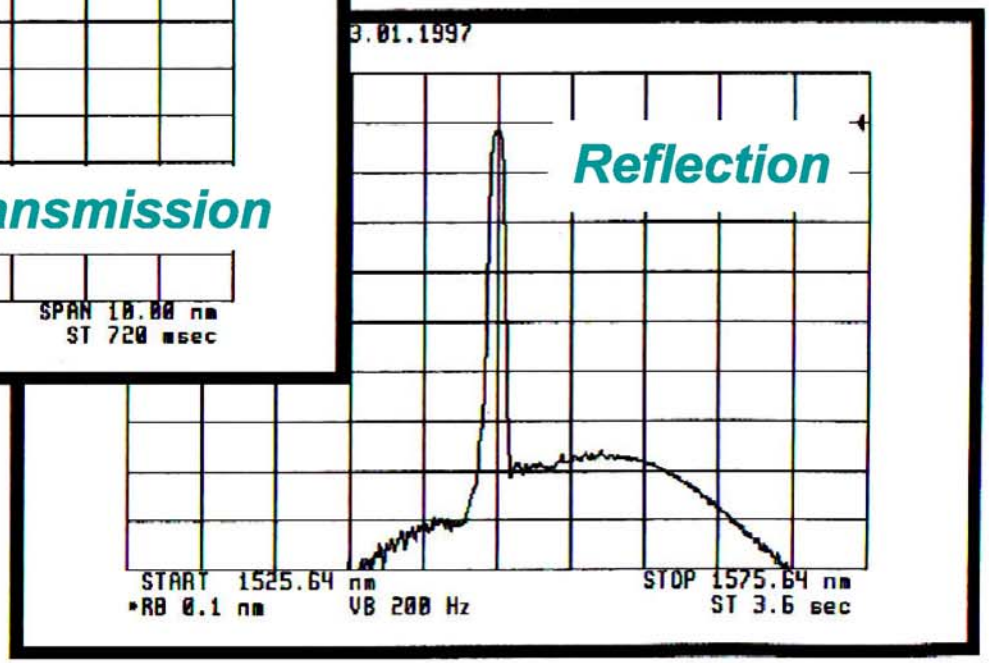
Fiber Bragg Gratings:

Transmission & Reflection Spectra—Single FBG





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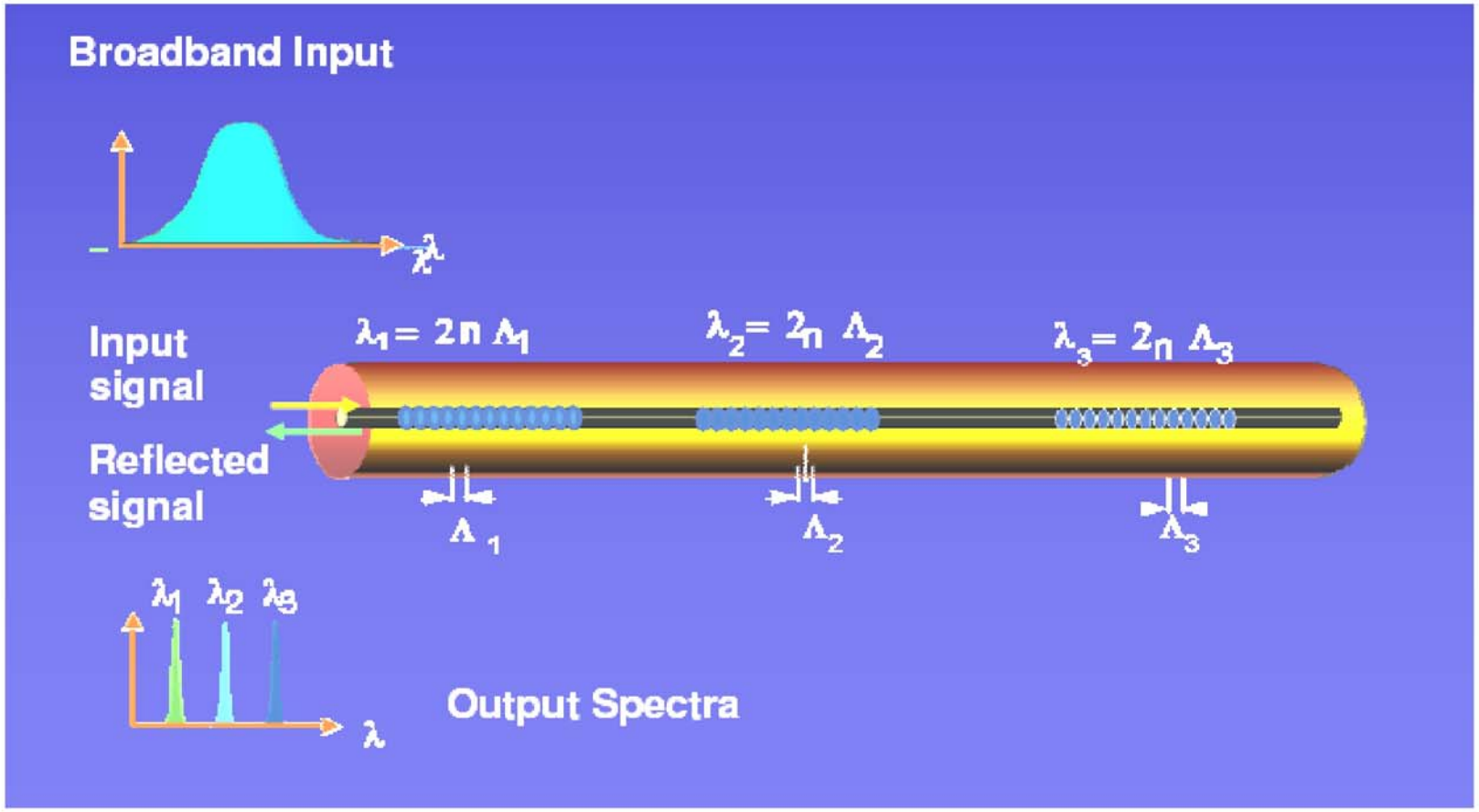
Fiber Bragg Gratings:
Fiber Arrays & WDM Addressing



Each grating sensor is at different fiber location and allocated a separate central wavelength and spectral operating window band.

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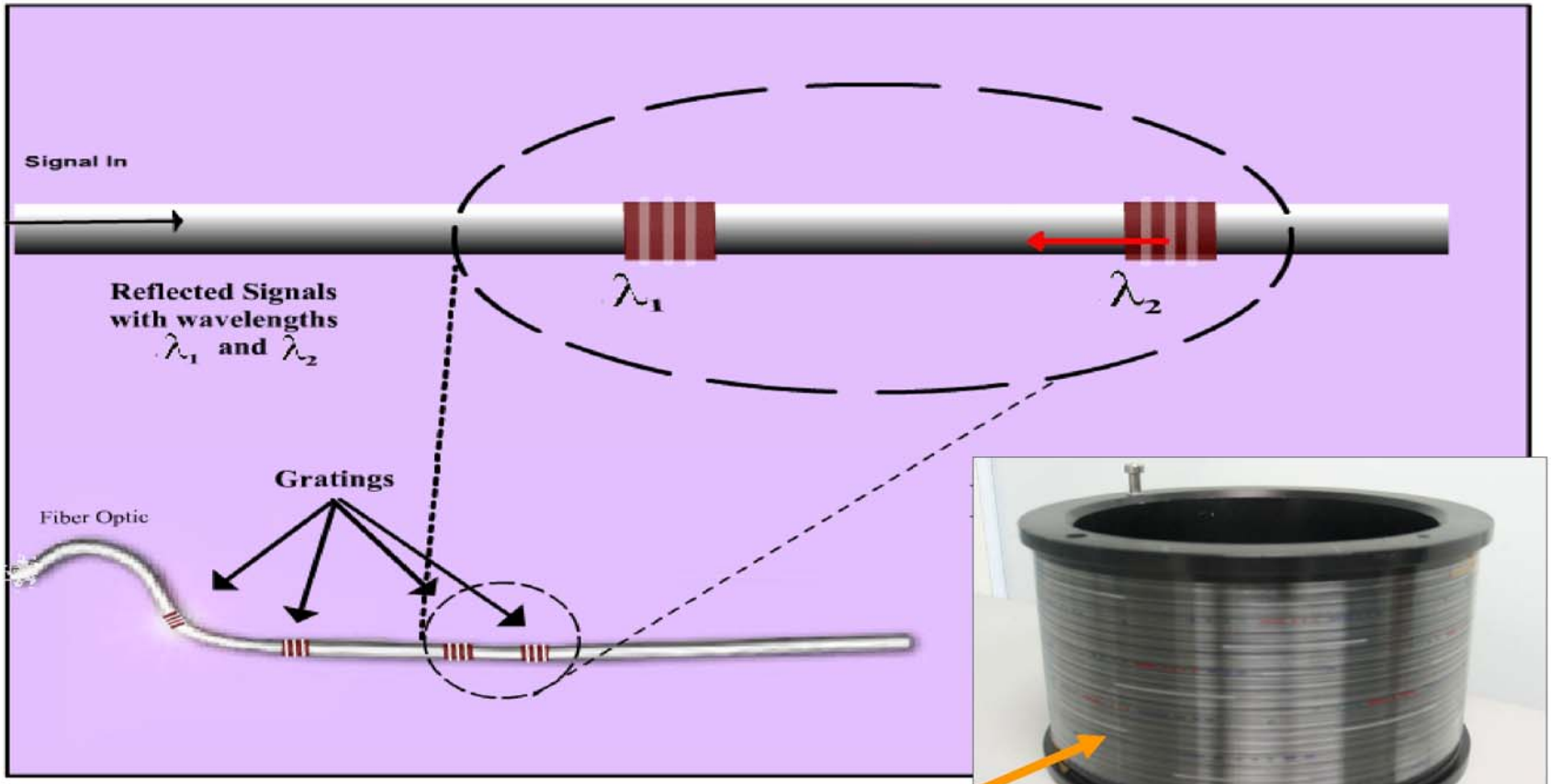
Fiber Bragg Gratings:
FBG Arrays—Multi-Point Sensing



Spool with FBG Sensor Array -- 100s of FBGs positioned at discrete points along a single fiber.

Source: LxSix

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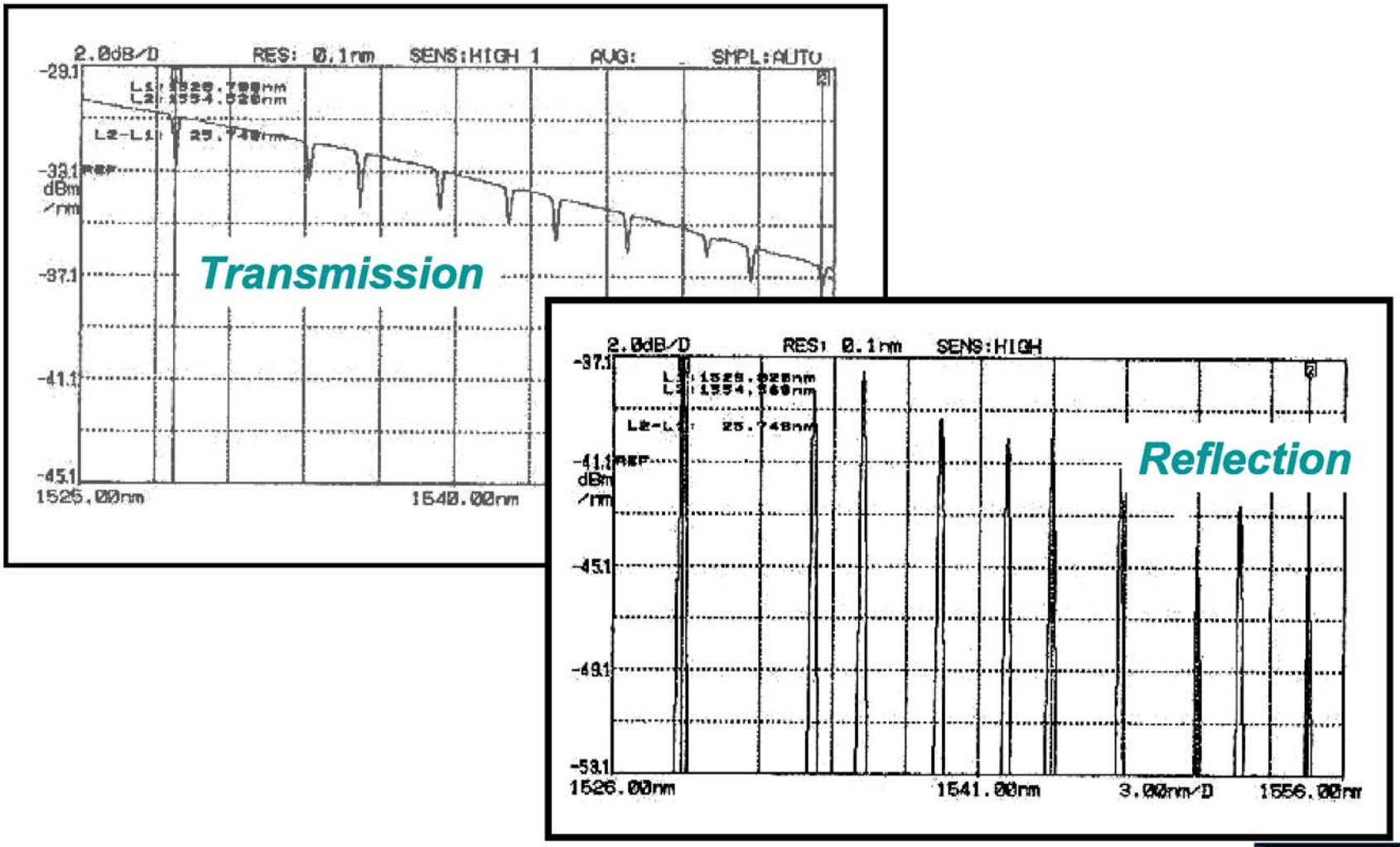
Fiber Bragg Gratings:

Transmission & Reflection Spectra—FBG Array



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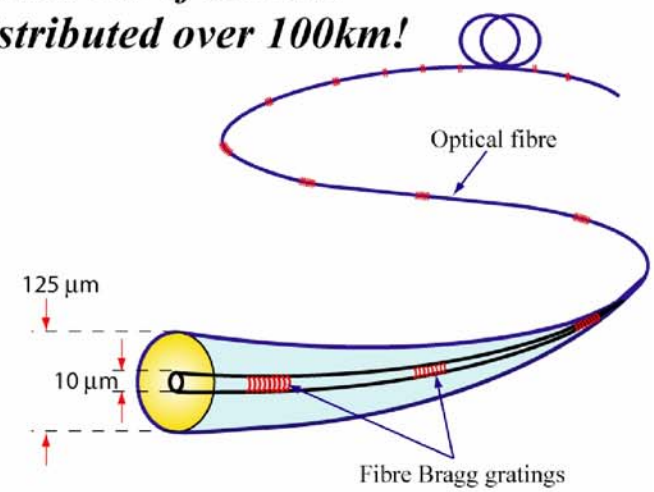
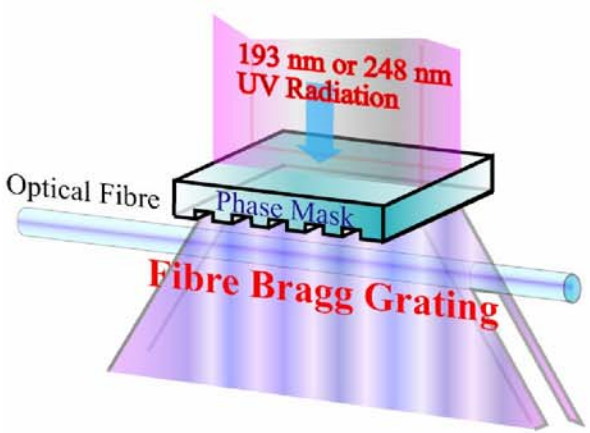
Why FBG Sensors??

Hundreds of sensors distributed over 100km!



…An attractive sensing solution:

- *Wavelength Encoded*
- *Self-Referencing*
- *Linear Output*
- *Small and Lightweight*
- *WDM & TDM Multiplexing*
- *Mass Producible*
- *Reflective & Transmission Operation*
- *Single- & Multi-Point Sensing*
- *Multi-Parameter Sensing*
- *Long Range*
- *Reasonable Cost*
- *Durable*



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CMS
Chandler Monitoring Systems Inc.

CEL Official Integrator

FBG Strain Sensors

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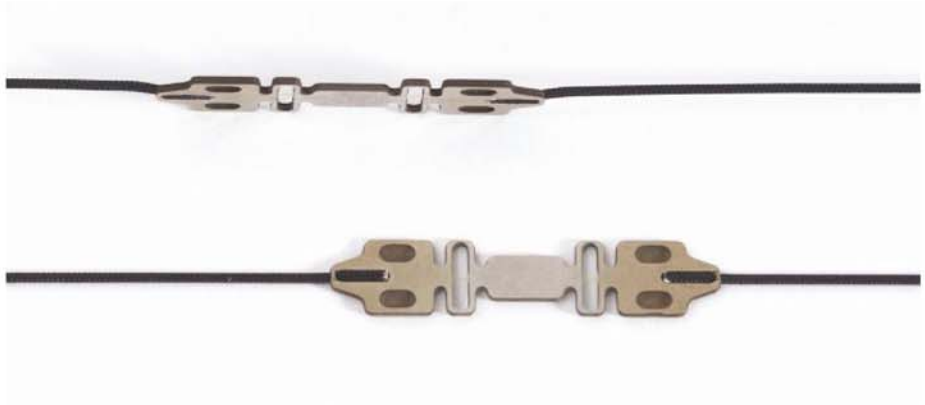
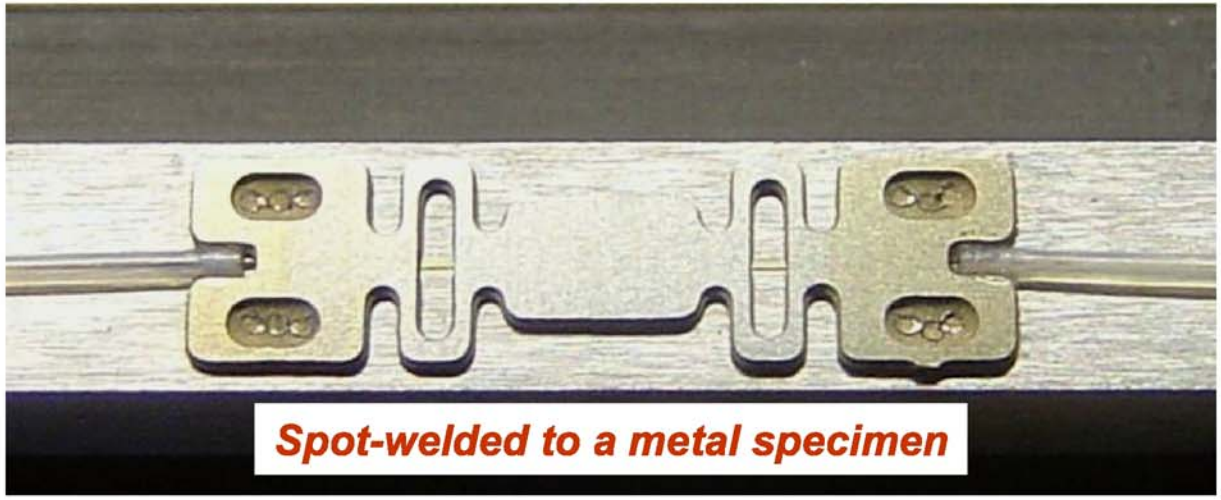
THE RIGHT TECHNOLOGY makes a world of difference.

Aspect of Micron Optics os3100
Fiber Optic Strain Sensor





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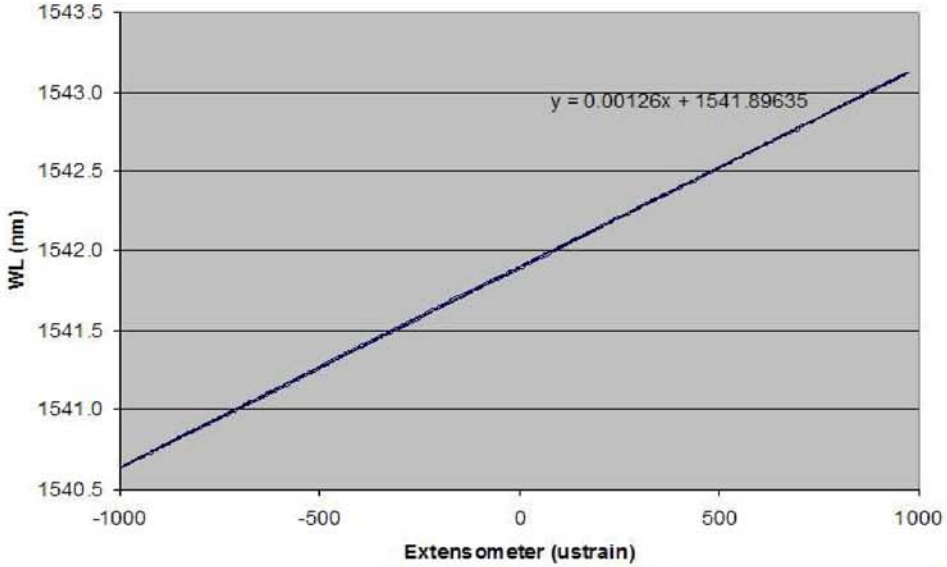
os3100:
Specifications

General Specifications:

Lot Number: FP1-0607001
Gage Type: Weldable Strain Gage Patch
Gage Factor(F_G): See Table
Gage Factor Tolerance: ± 1.0% at 21°C
Gage Length: 24 mm
Operating Temperature Range: -40 to 120°C
(150°C Short Term
Strain Limits: +/- 2500 μm/m
Fatigue Life: > 20×10^6 cycles, ± 1000 μm/m
Dimensions: 36 mm x 8 mm x 1 mm
Pigtail Length: 1 m ± 10 cm
Connectors: (Optional) FC/APC
Weight: 1.1 g

Optical Specifications:

Fiber Type: SMF-28 Equivalent
FWHM Bandwidth: .25 nm ± .08 nm
Side Mode Suppression: >12 dB



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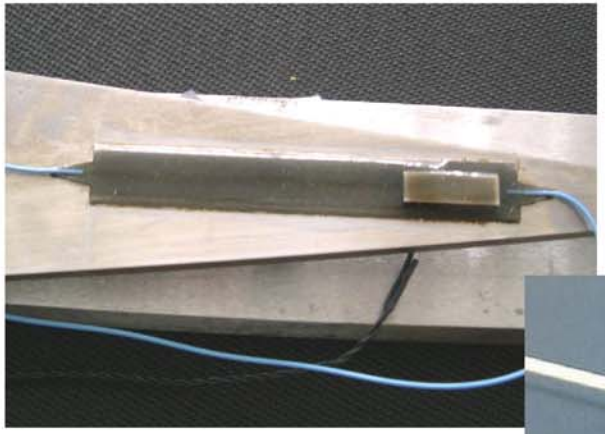
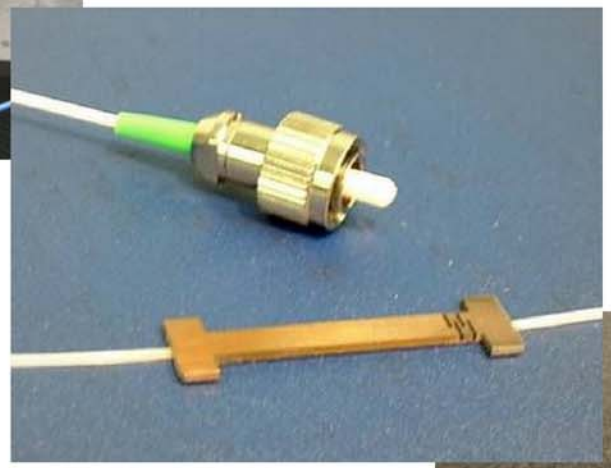
os3100:
Sensor Design Evolution



Encapsulation

Flexure



Advanced Flexure

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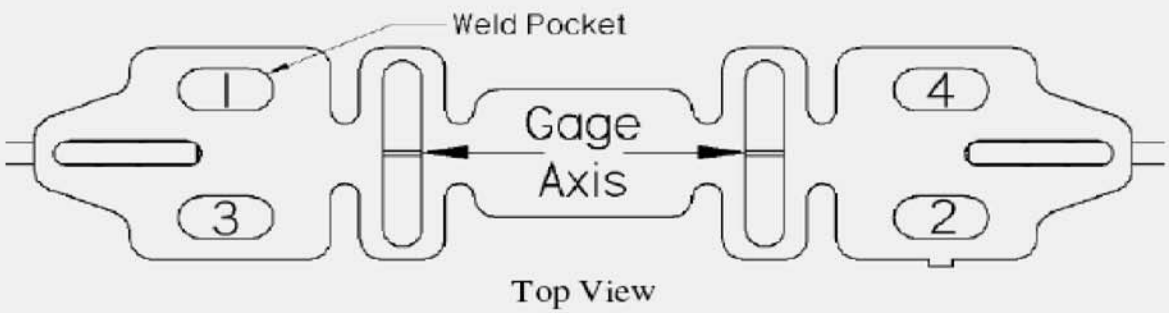
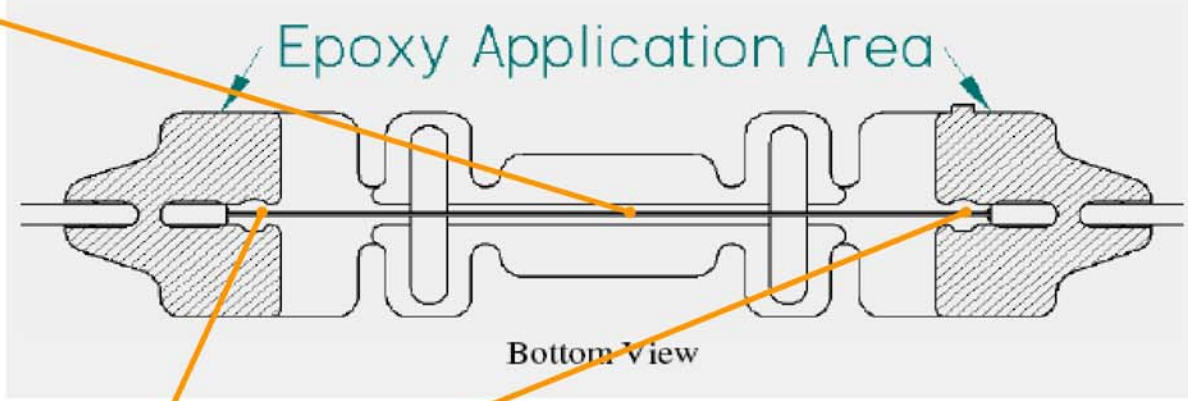
os3100:
Sensor Design & Construction





Flexure springs

Metal carrier flexure

FBG

Fiber bonding points

36x8x1mm

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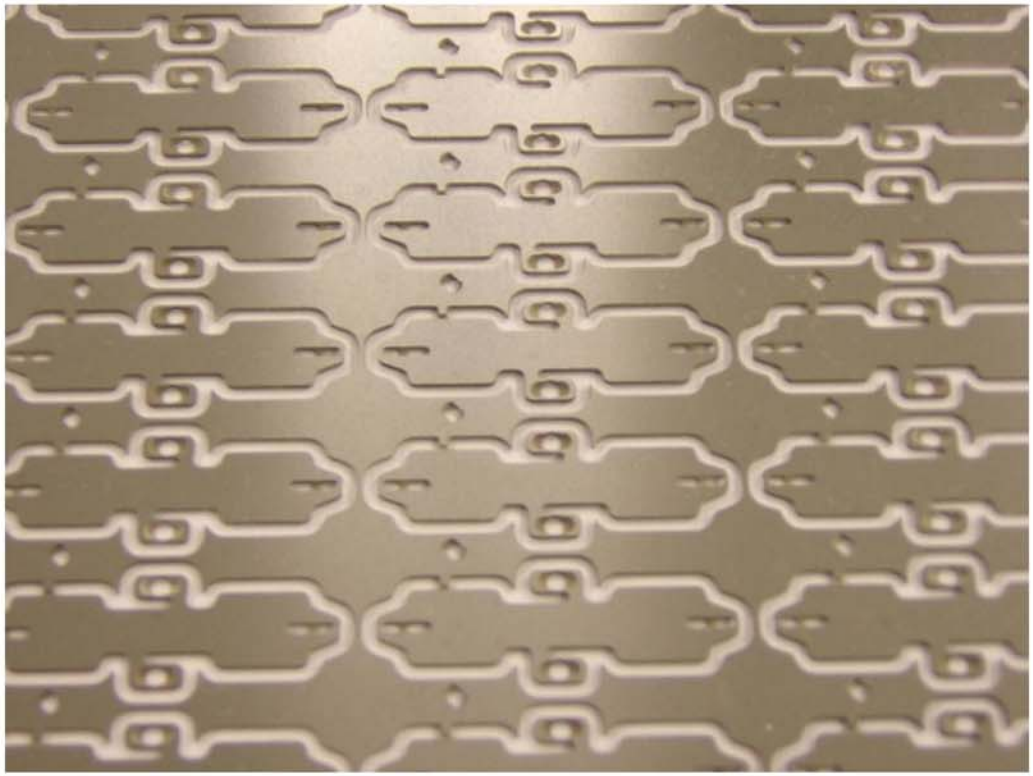
os3100:
Fabrication Process



Carrier flexures batch fabricated using EDM or water jet cutting techniques.

Carrier profile and features are cut out from a precision metal shim plate.

Fibers pre-stretched and mounted using proprietary bonding technique.

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os3100:
First Commercial FBG Strain Gage

- **Repeatable manufacturing processes**
- **Qualification by design**
  - Gage factor
  - Temperature compensation
  - Humidity resistance
  - Fatigue resistance
- **Easy installation**
  - Weld
  - Adhesive
- **Rugged packaging for ease of handling**
- **Customizable (different gage factors)**
- **Low cost**

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Testing Program

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Sensor Qualification:
Environmental & Mechanical Testing Program

- **FBG Reflection Spectrum Quality** → axial effects, side lobes, bi-refringence, etc.
- **Strain Response** → +/- 3000με using a constant stress beam or a dynamic pull using a universal testing machine.
- **Temperature Response** → temperature cycling from - 20° to + 120°C, 500 cycles
- **High Temperature Soak** → 150°C for 45 days
- **75/75 Environmental Soak** → exposure, under constant strain, at 75°C & 75 RH for 1,000 hours.
- **Cyclic Fatigue** → 100Million cycles, 20Hz, +/-3,000με

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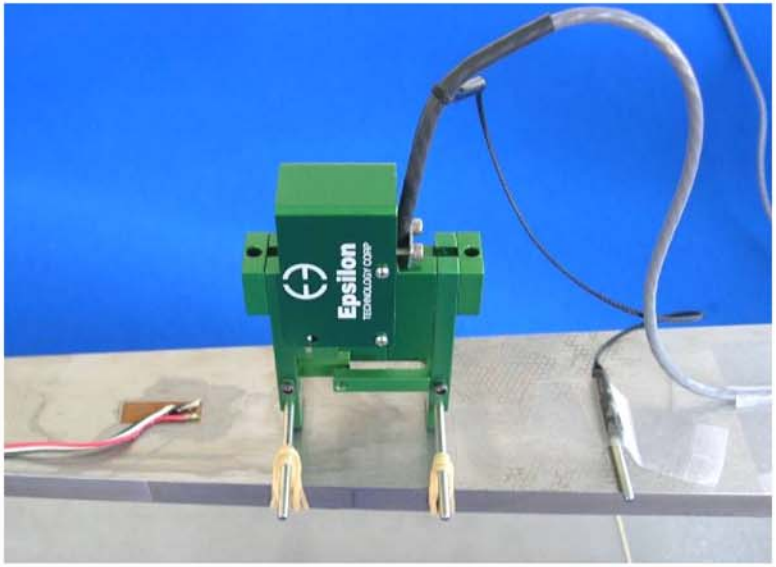
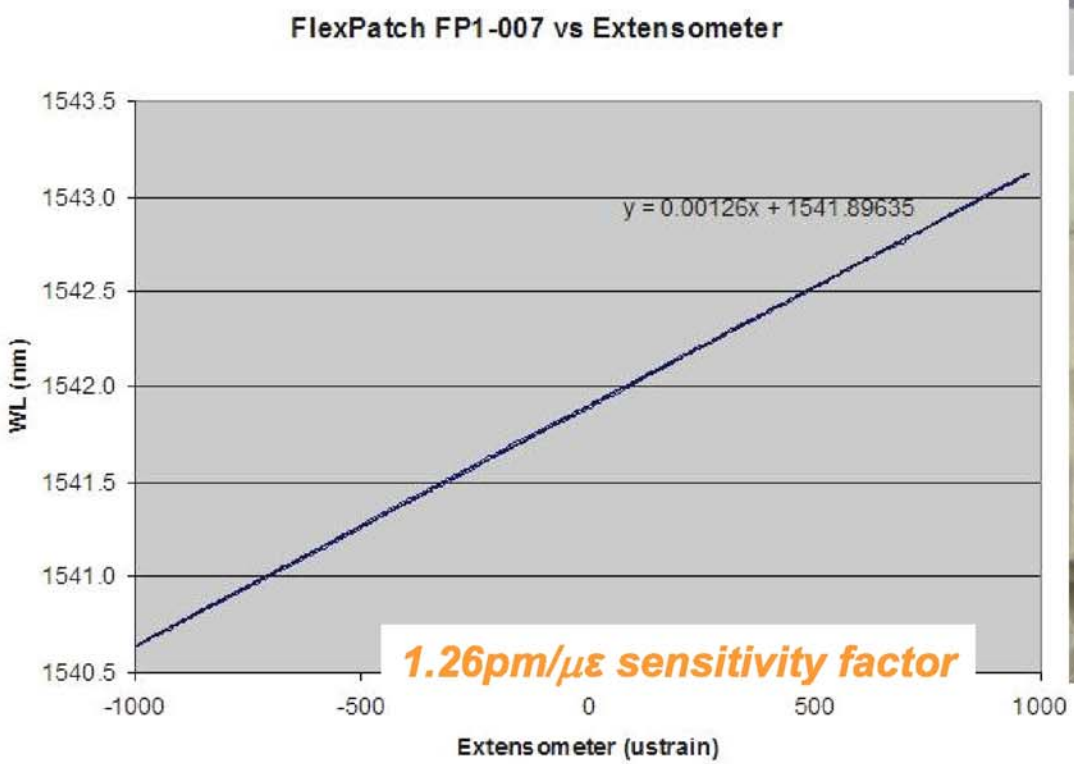
Strain Response

Sensor mounted on a constant stress test beam fitted with a reference foil gage and extensometer.





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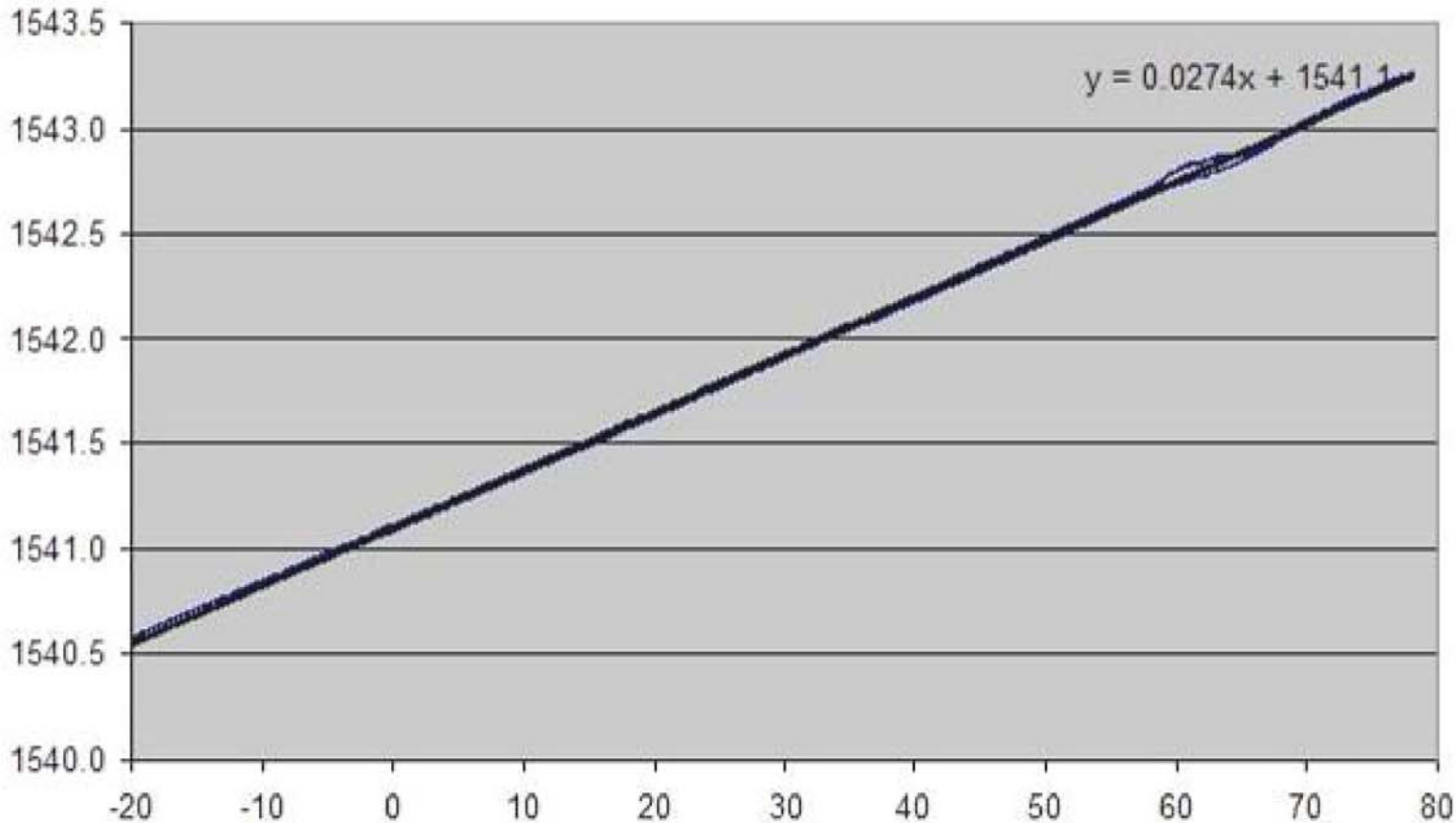
Temperature Response:
Unmounted Sensor (ΔT of 100˚C)

27.4pm/°C Temperature coefficient



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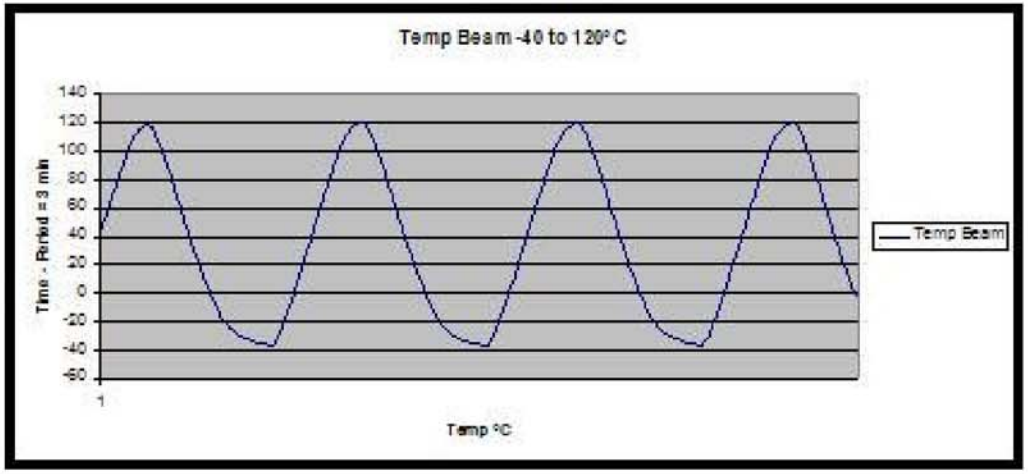
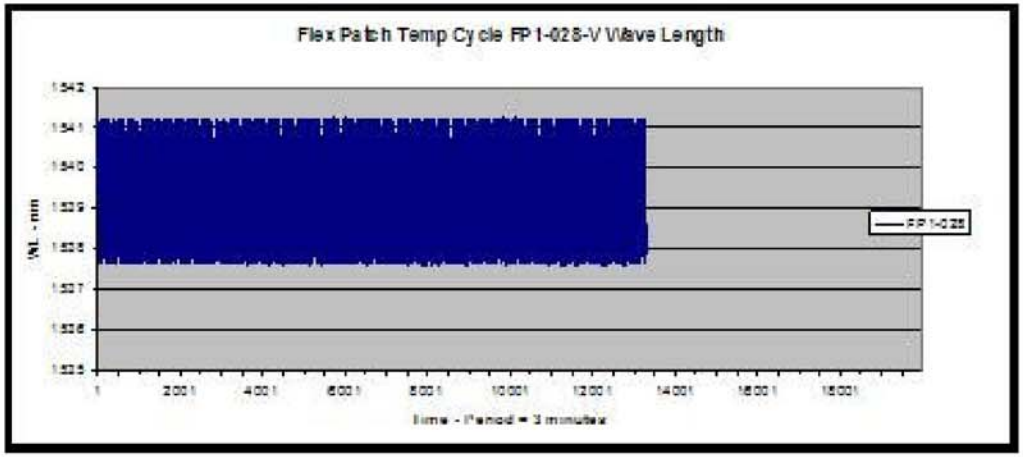
Temperature Cycling





Constant strain: 1,600με
500 cycles

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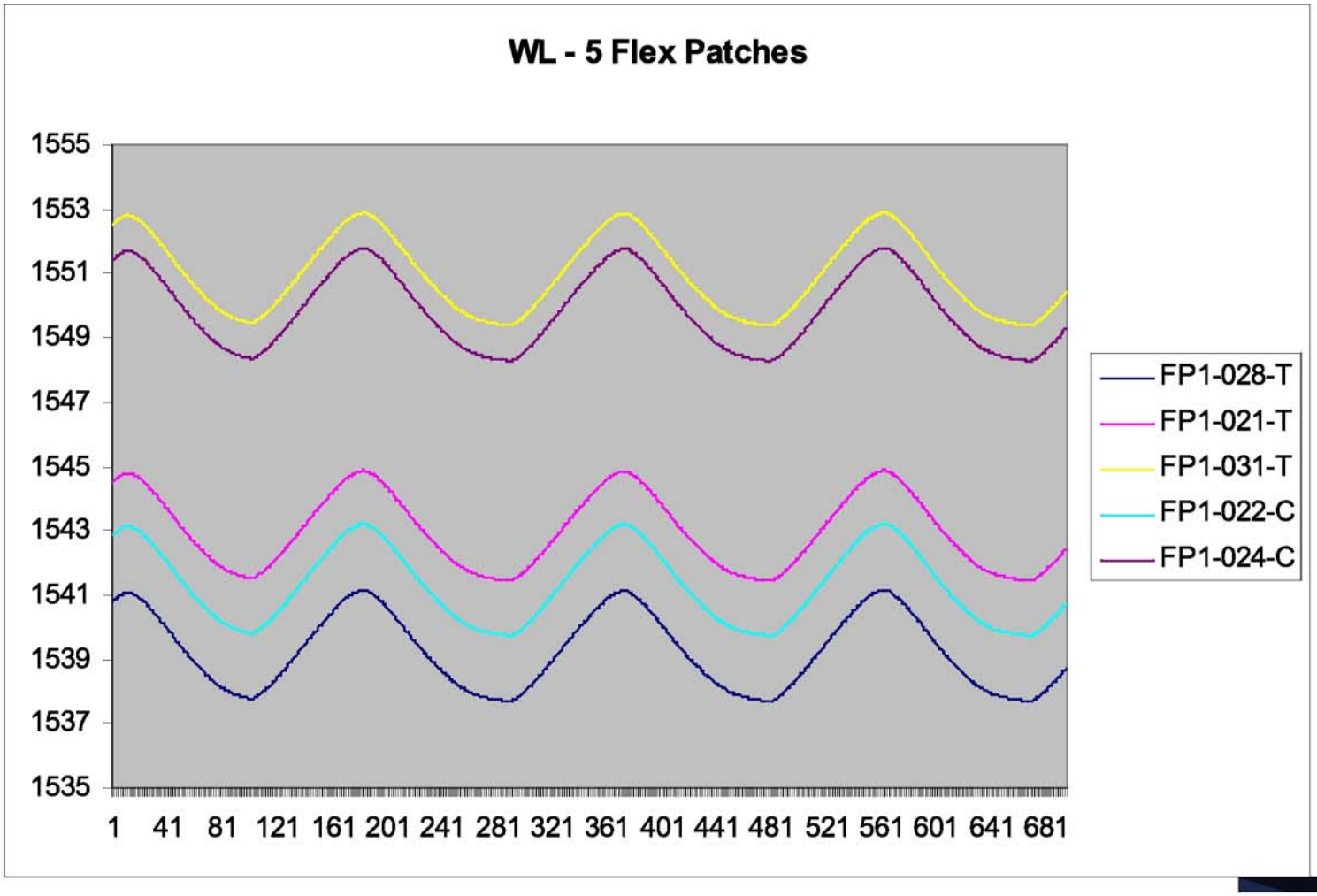
5 Mounted Gages
ΔT of 140˚C



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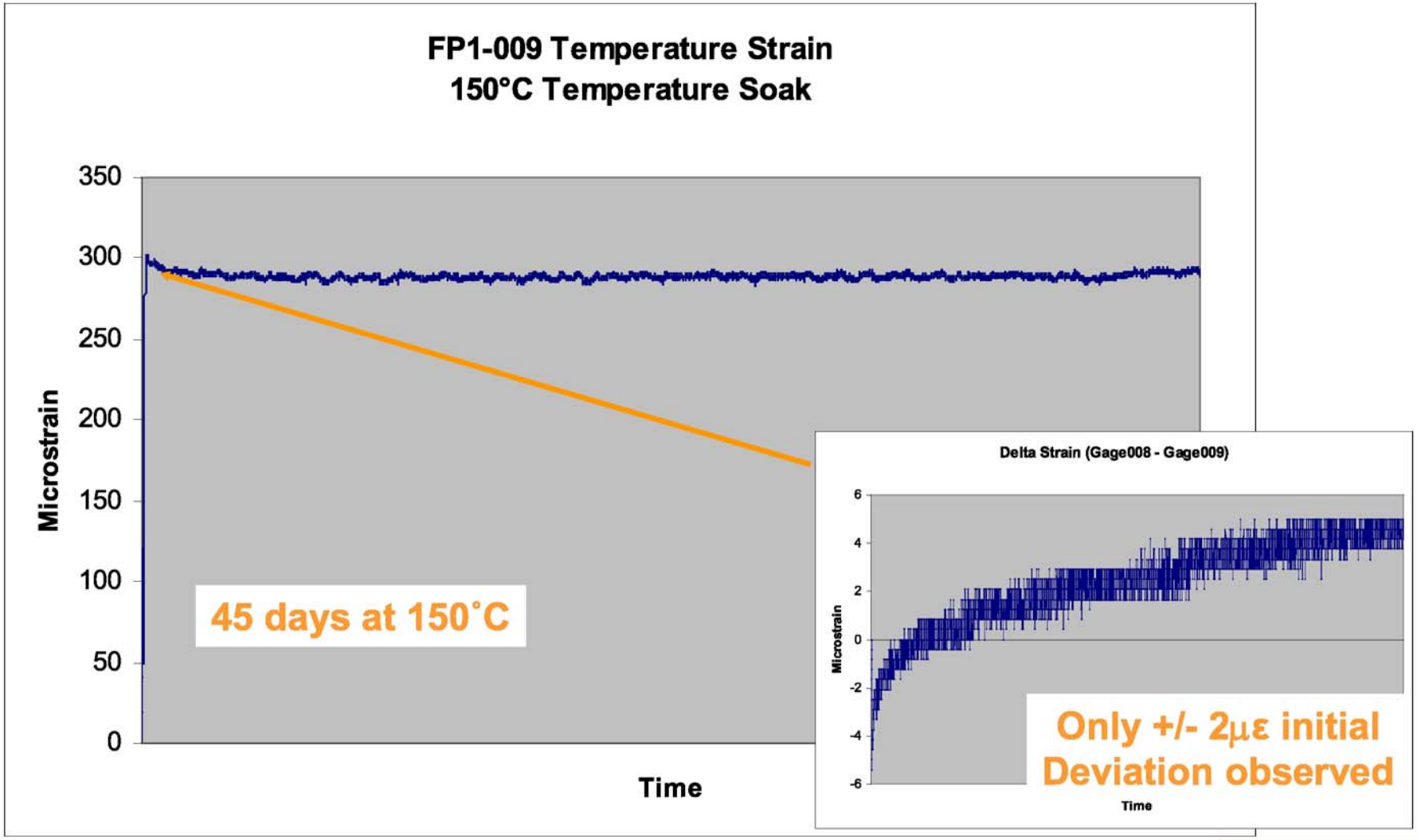
High Temperature Soak



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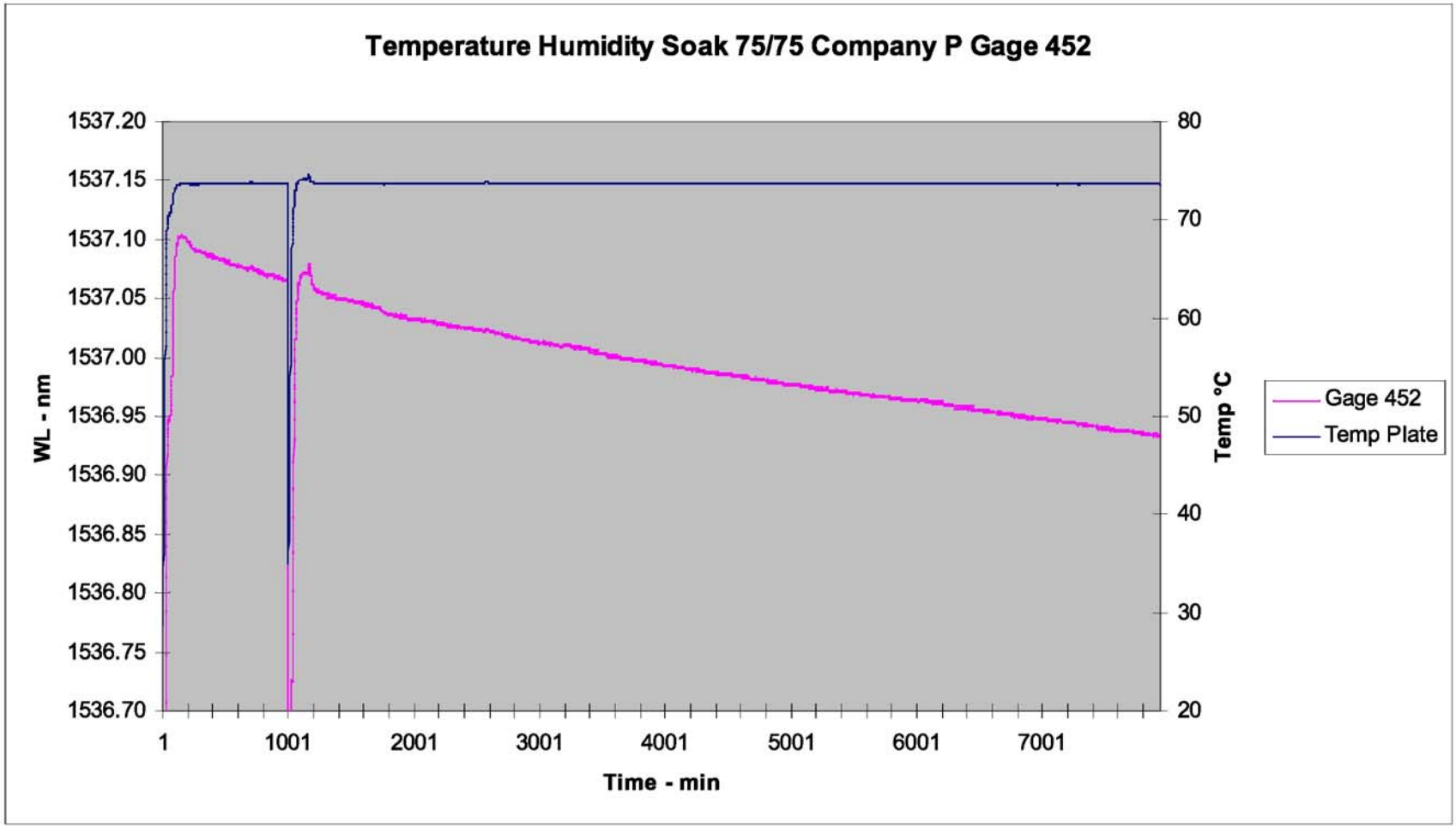
Humidity Soak – Remember This?



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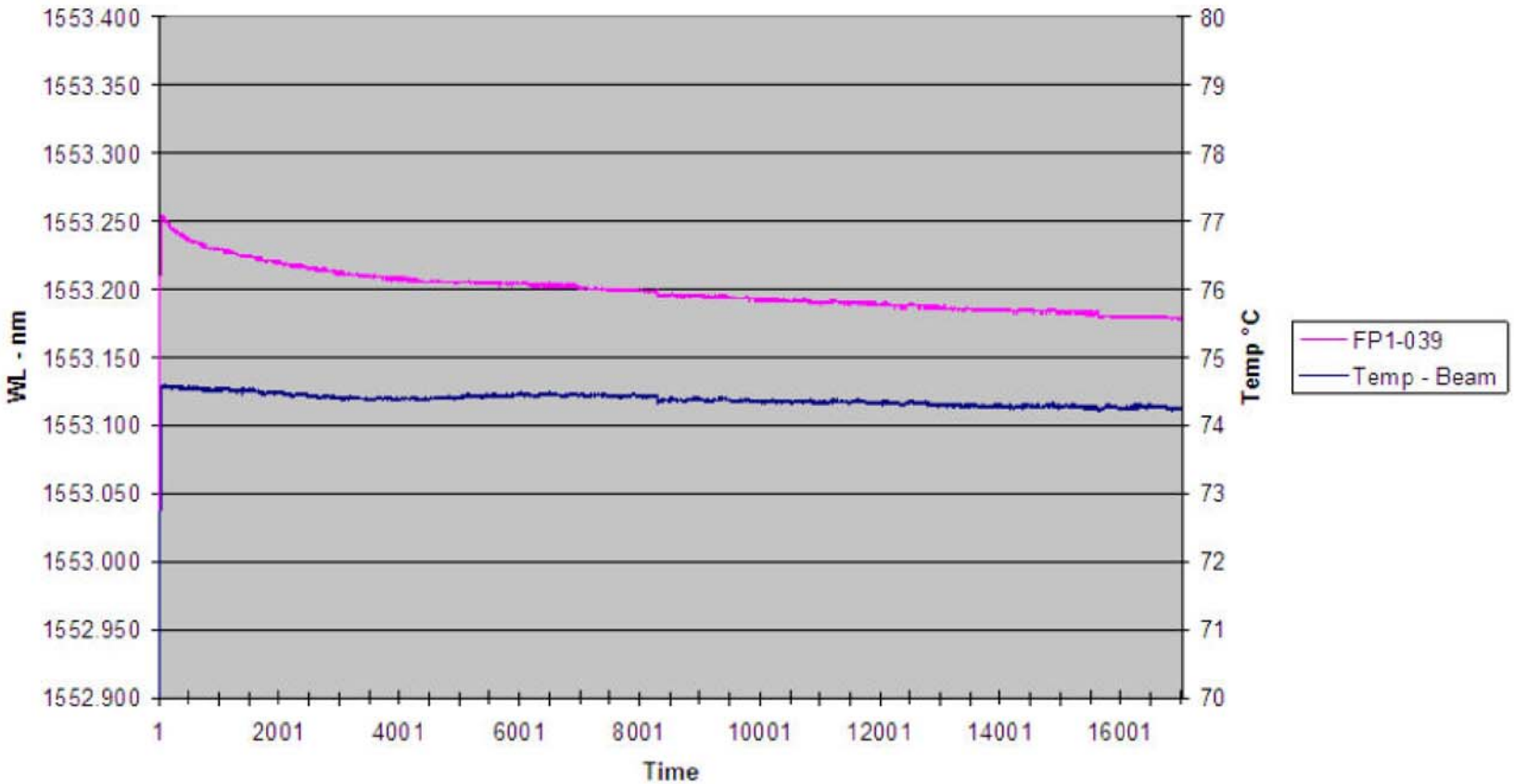
Humidity Soak

75°C/75% RH for 1000 Hours



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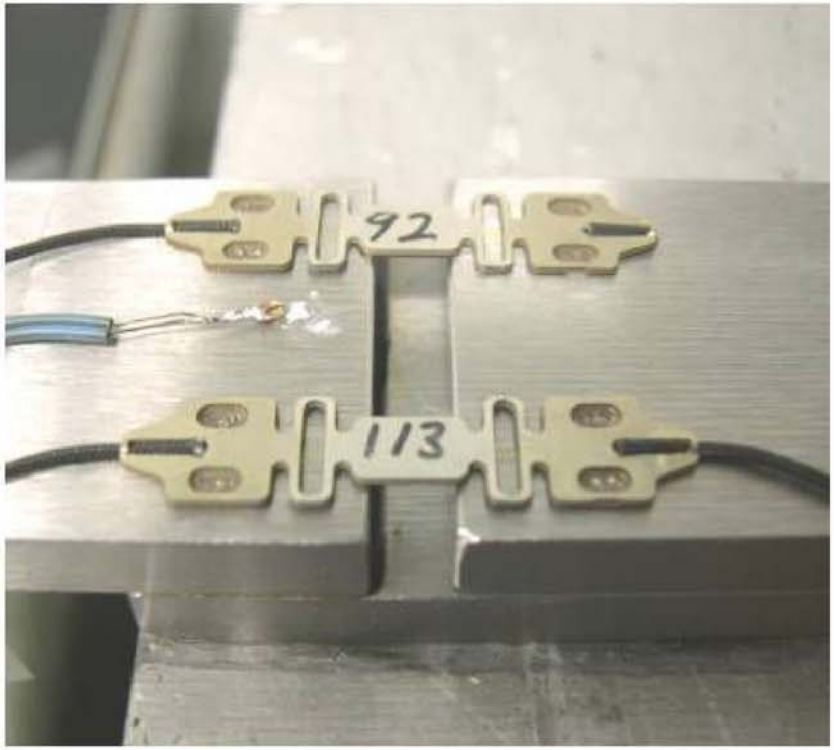
Cyclic Fatigue

20 Hz, 100 million cycles, +/- 3,000με, 0 Failures!!



Sensors mounted across sliding plates

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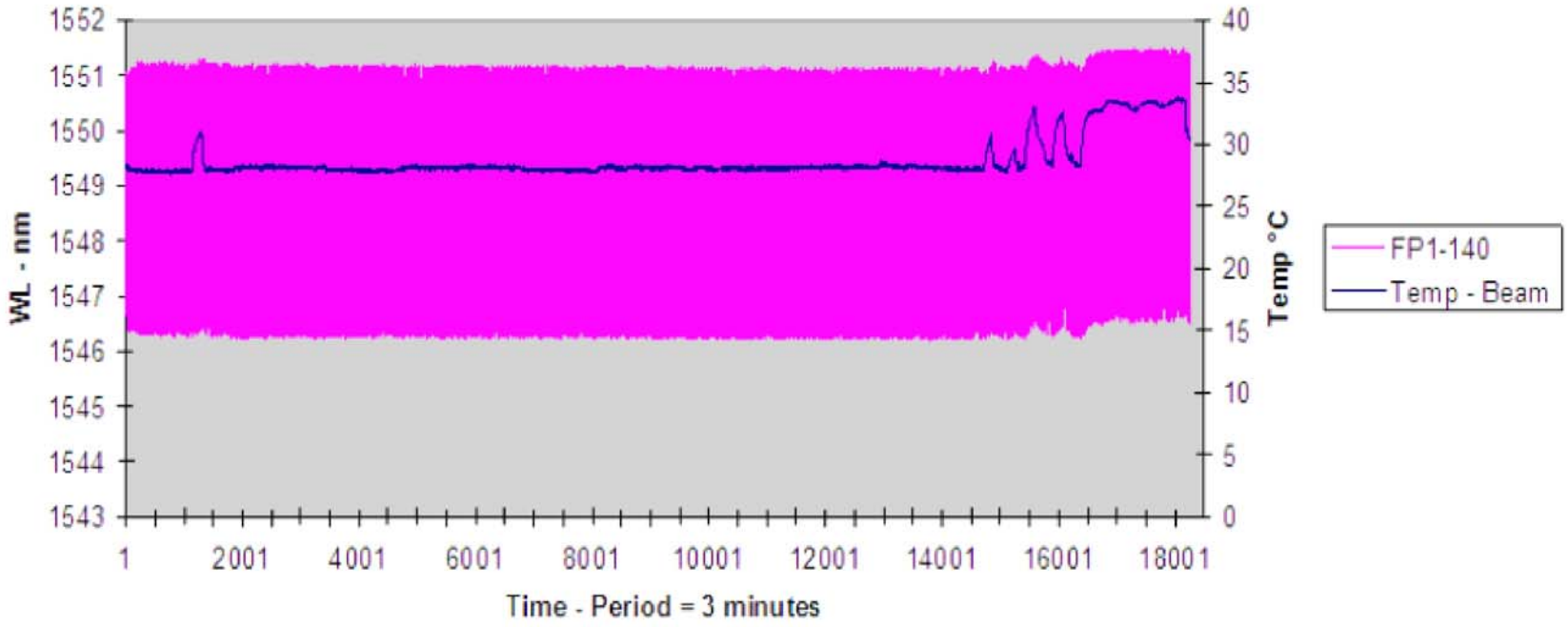
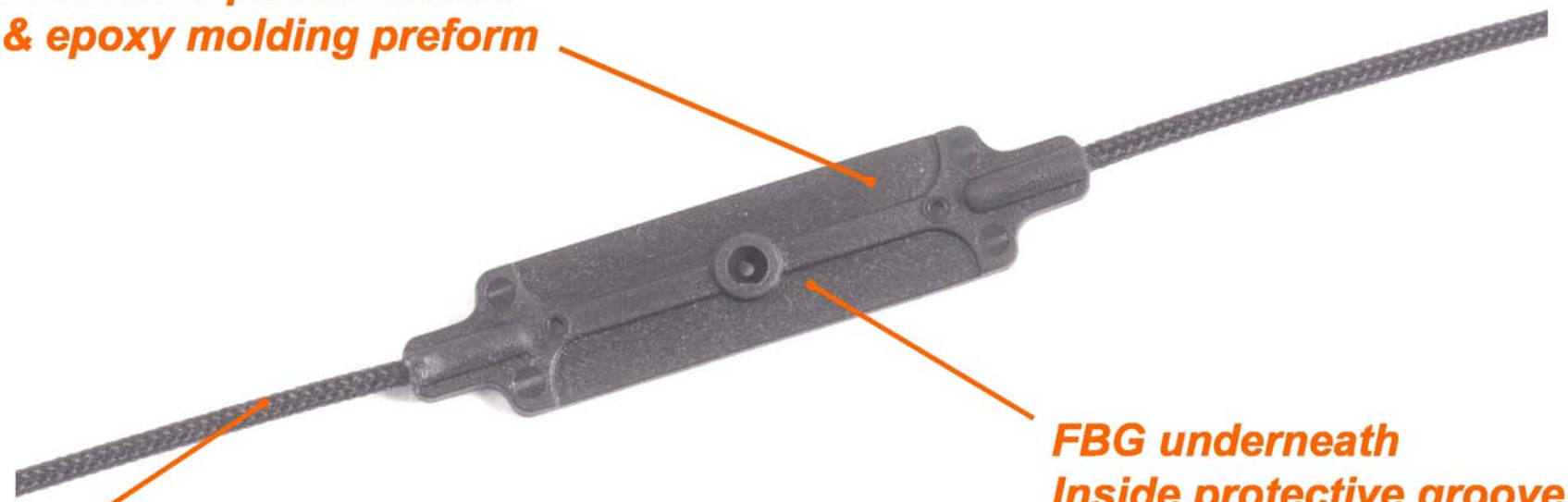
Cyclic Fatigue –



New FBG Strain Sensor:

os320 - Dielectrically Packaged Design



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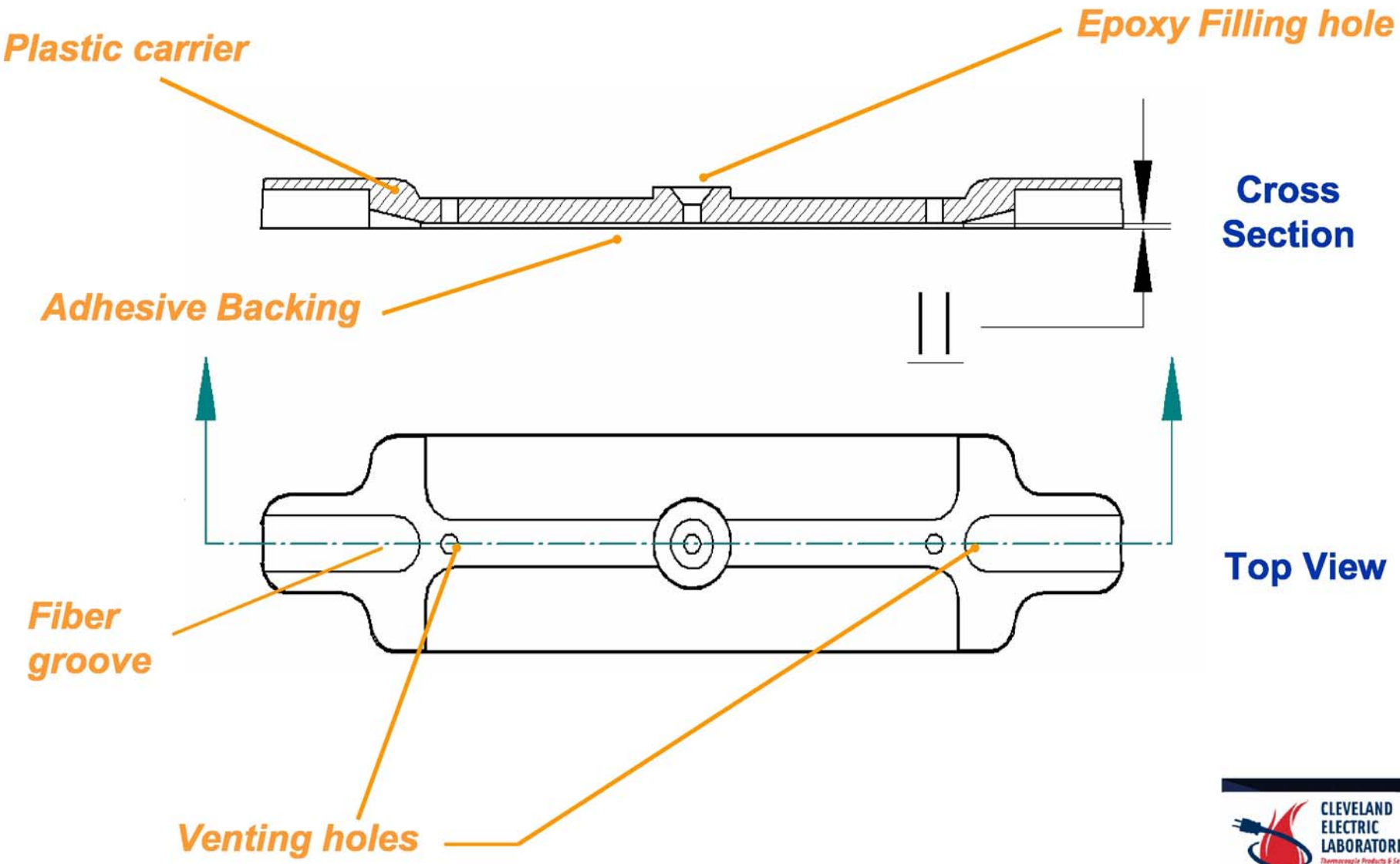
All-Dielectric FBG Strain Sensor:

os320 - Sensor Design & Construction



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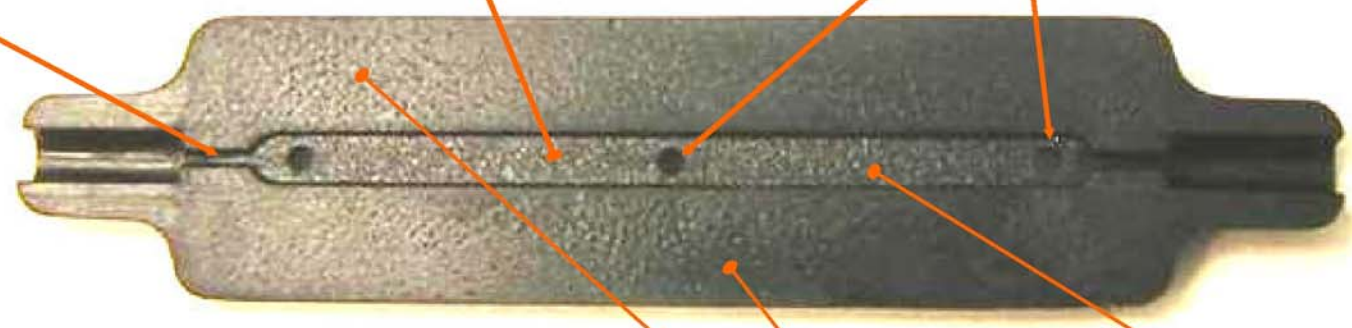
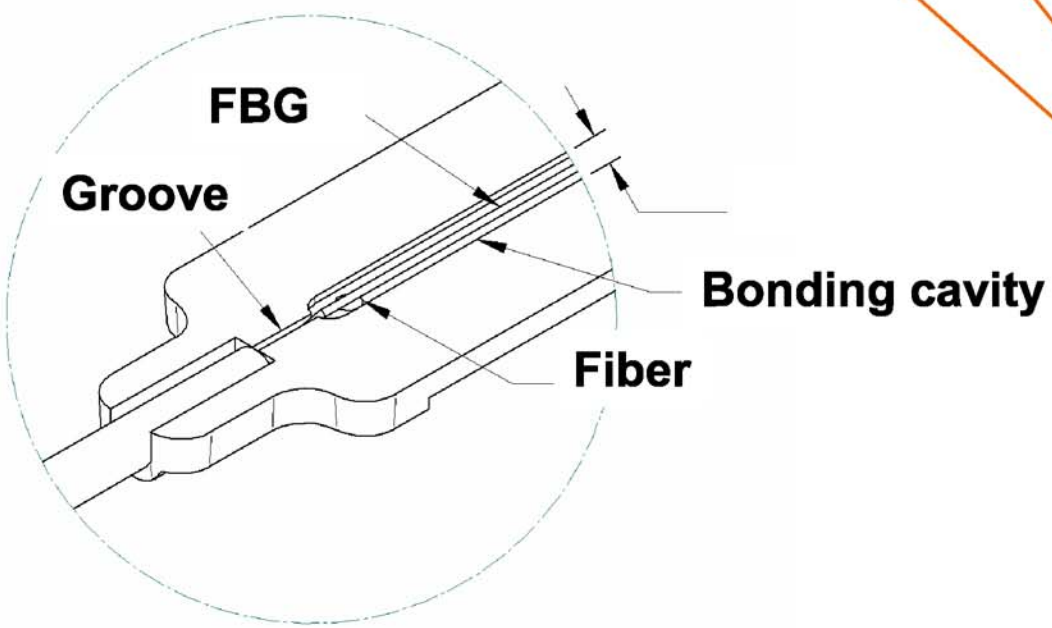
All-Dielectric FBG Strain Sensor:

os320 - Sensor Design & Construction





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All-Dielectric FBG Strain Sensor:

os320 - Installation

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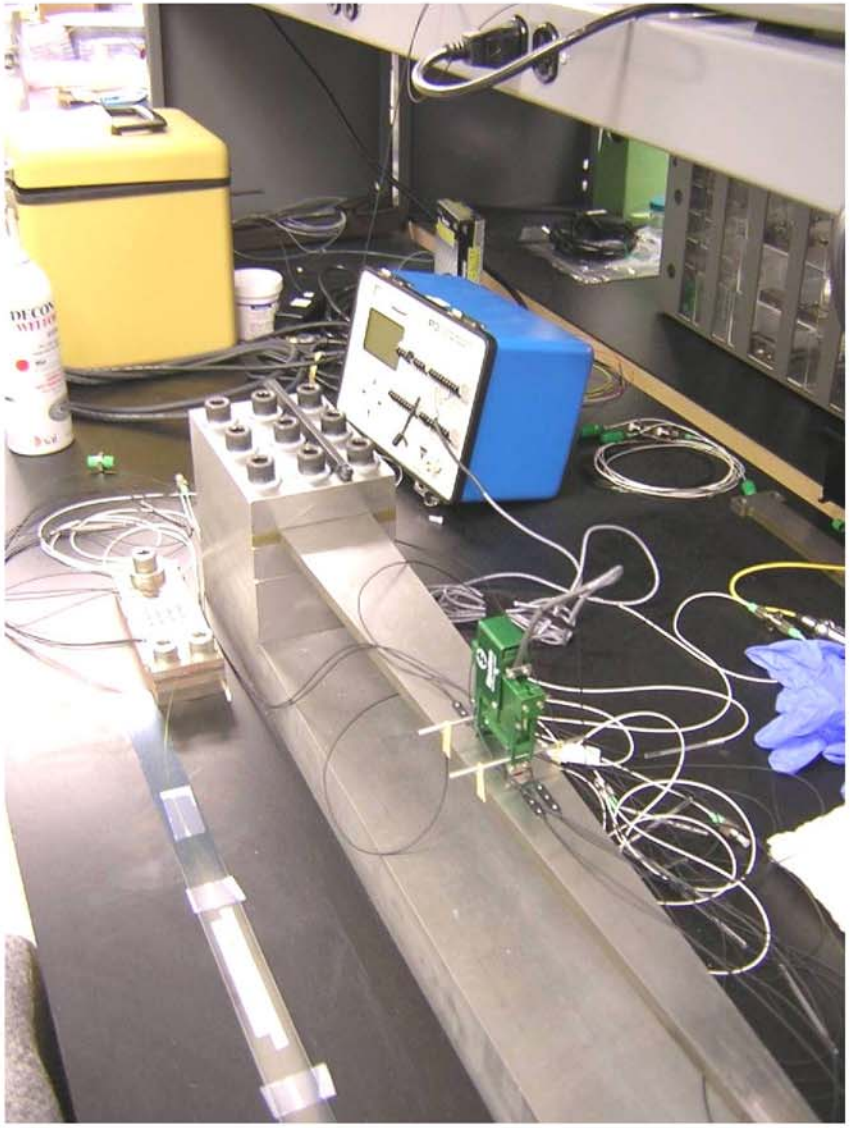
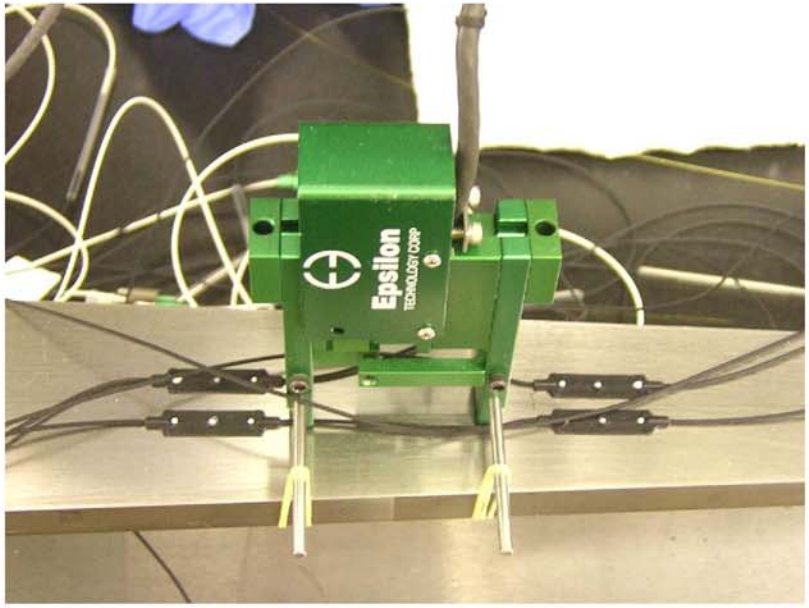
Strain Response:
Qualification Procedure





Sensor mounted on a constant stress test beam fitted with a reference extensometer.

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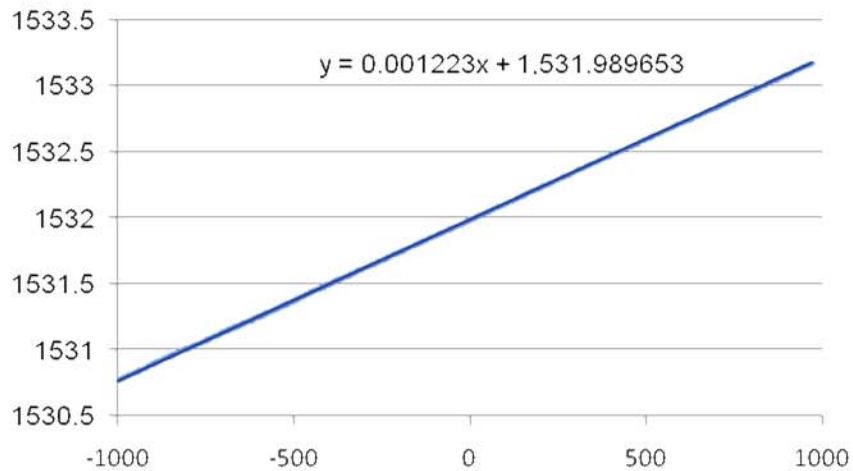
Strain Response:

Consistent, Wavelength Specific Gage Factor



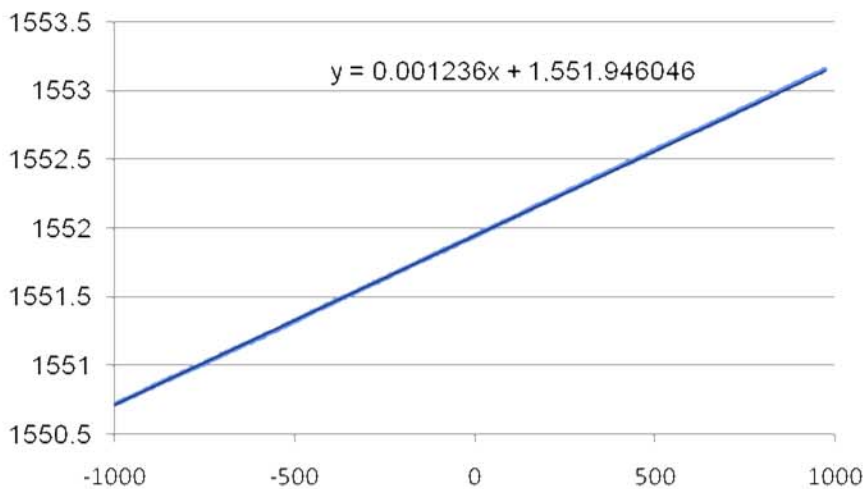
Using:

$$F_{G\lambda 2} = F_{G\lambda 1} * \frac{\lambda_2}{\lambda_1}$$

Calculate

Fg = 1.239

=> Theoretical factor matches measured factor to within 0.2%



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os320 FBG Strain Sensor:
Sensor Specifications

Maximum Temp. Range:	**- 40 to 80°C**
Recommended Temp. Range:	**- 40 to 60°C**
Strain Range:	**+/- 2500 με standard** **+/- 5000 με available**
Gage Factor:	**~1.2 pm/με**
Thermal Cycling Stability ***- 40 to 60°C:***	**12 – 24 pm typical,** **~10 – 20 με**
Fatigue Lifetime:	**TBD, expected to be** **> 20M cycles**

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FBG Strain Sensors:
Sensor Design Comparison

os3100: Metallic Flexure

- Epoxy free construction
- Simple bond or weld installation
- Braided fiberglass protection
- Immune to transverse strains
- Pre-strained, +/-2500 με
- Flat surface geometry
- 20M+ cycle fatigue life, +/- 1000 με
- -40 to 120 °C, 150 °C short term
- Long term absolute and static strain

os3200: Dielectric Pre-form

- Non-metallic construction
- Rapid installation process
- Braided fiberglass protection
- Minimized transverse strains, distortions
- Tension and compression, +/- 5000 με
- Applicable to curved surface geometry
- Expected 20M+ cycles, > +/-1000 με
- -40 to 60 °C recommended, 80 °C Max
- Static strains

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NOVAKINETICS, LLC

CMS
Chandler Monitoring Systems Inc.

CEL Official Integrator

Proposed Solutions

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THE RIGHT TECHNOLOGY makes a world of difference.

Networking Entire Wind Mill Farms

Multiplexed Sensors

High Temperature

Strain Sensors

Accelerometers

Split Rotary Optical Ring

High Speed Optical Equipment

Mounted within the grid control cabinet all data is gathered and processed through Ethernet connection so information can be sent to a central control station.

Grid Control Cabinet

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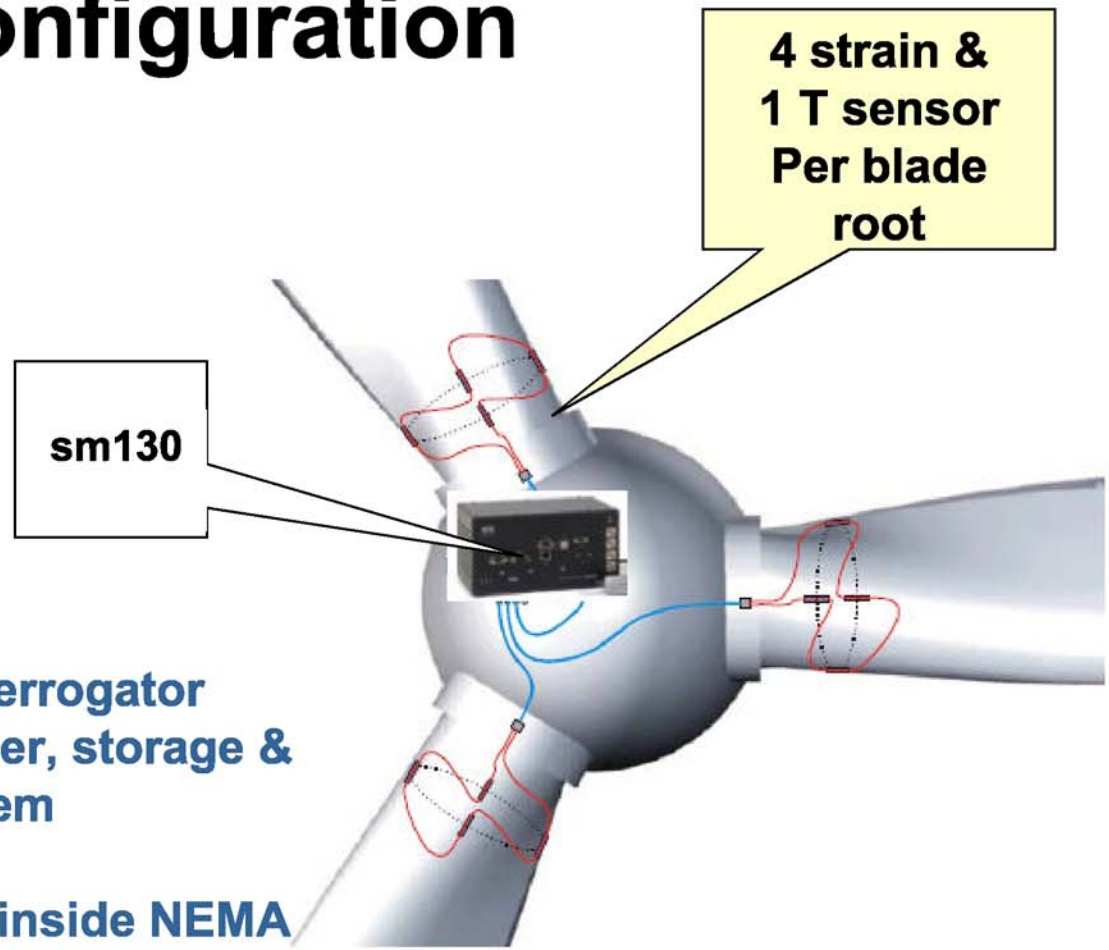
System Configuration



Use sm130-200 as interrogator
Use sp130 as controller, storage &
Data acquisition system

Protect sm130/sp130 inside NEMA
Box for environmental control

Use E2000 fiber connectors

Use pre-installed & connected FBG strain sensors

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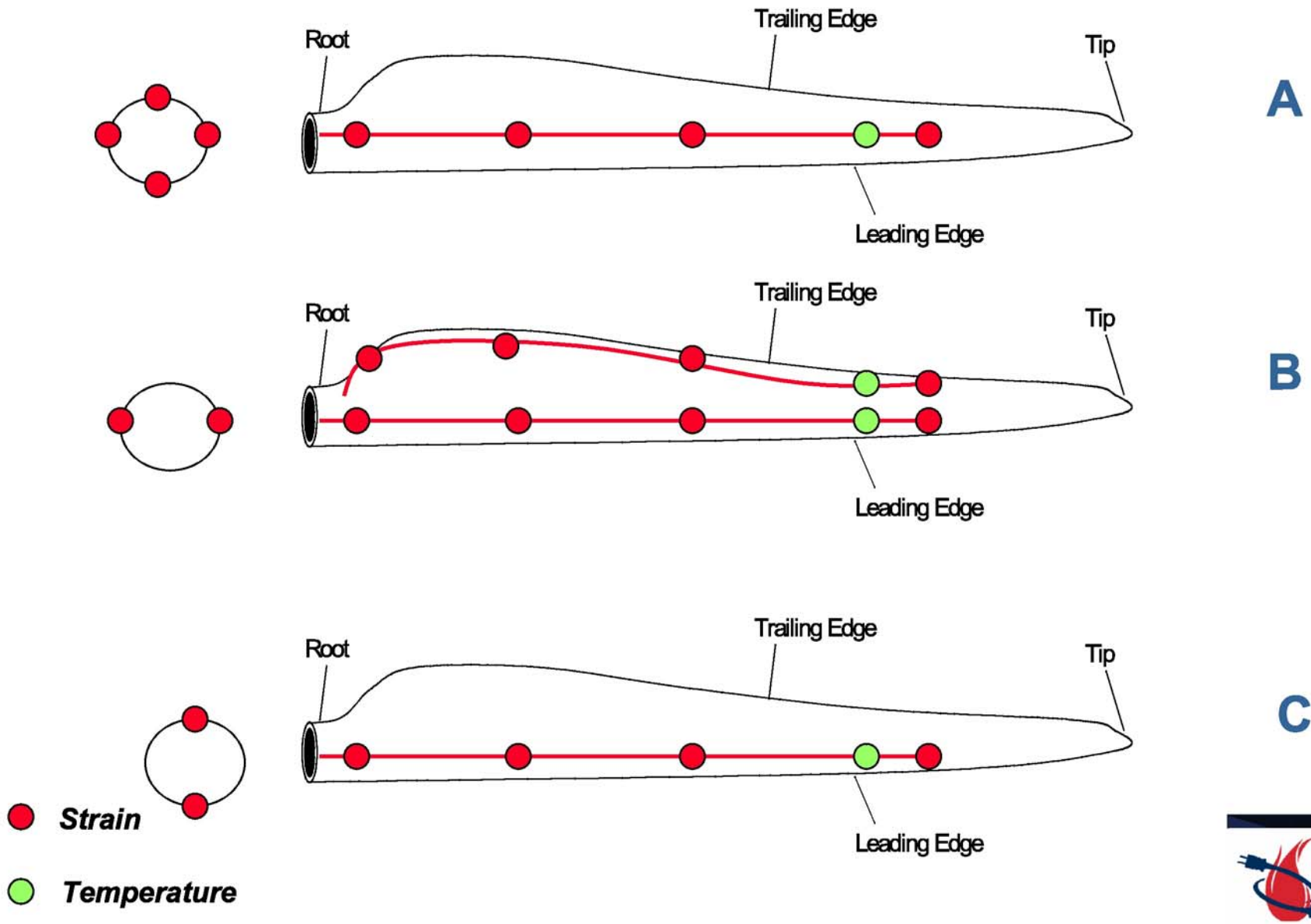
System Configuration



Proposed Solution

- **Instrumentation**
  - sm130-200 +3xtra channels (4Channel, 80nm, 100 Hz)
  - si325-500 (4 Channel, 1Hz, 80nm, Full-Spectrum)
  - sp130 (data acquisition processor)
  - NEMA box

- **Sensors**
  - os110 (10 pcs) bare fiber FBG sensor
  - os 120 (5 pcs) 5 element FBG array
  - os 310 strain sensor (10 pcs)
  - os 420 temperature sensor (5 pcs)
  - os 770 vibration sensor (3pcs)

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