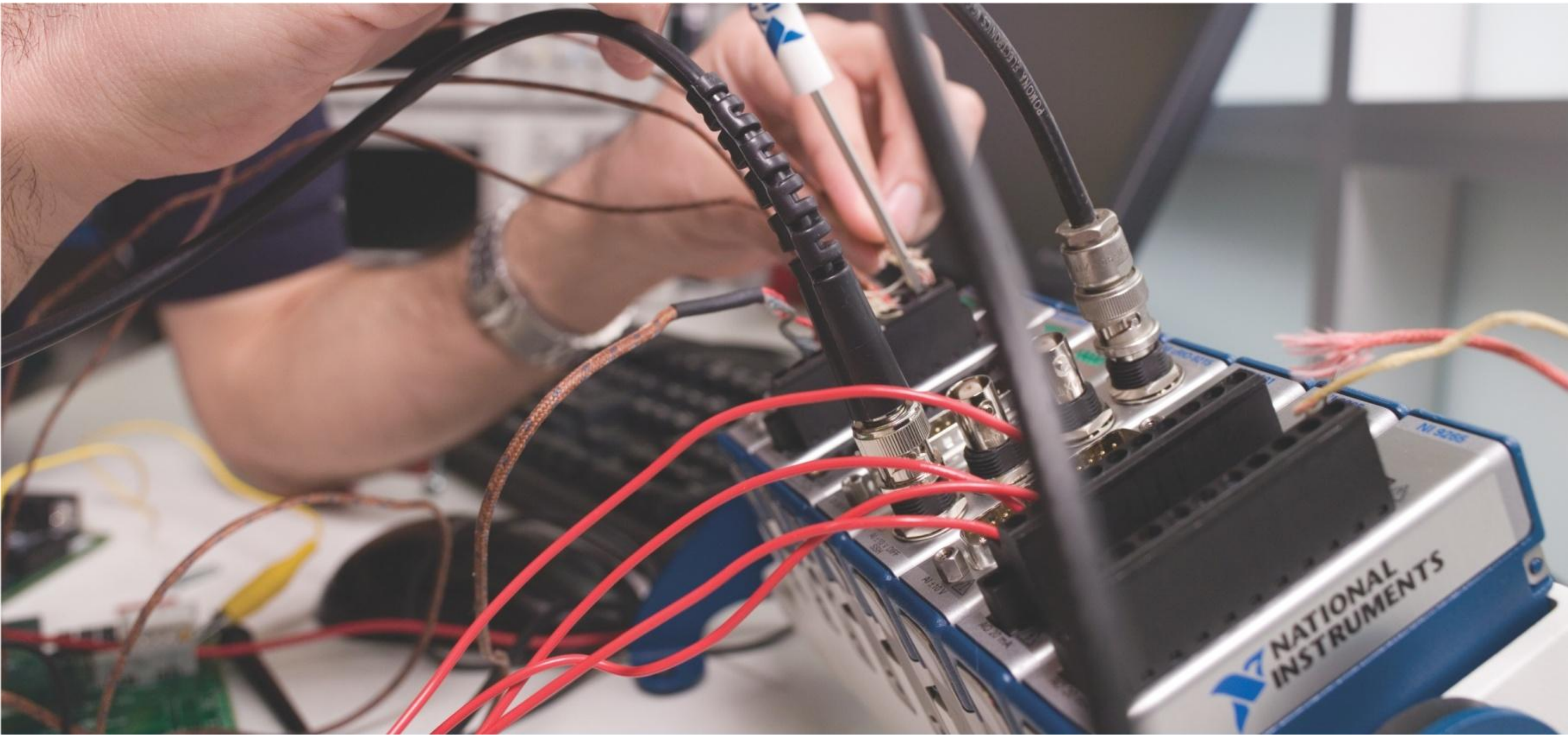


Sensor Measurement Fundamentals Series

NATIONAL INSTRUMENTS™

Strain Gage Measurements

Doug Farrell
Product Manager
National Instruments

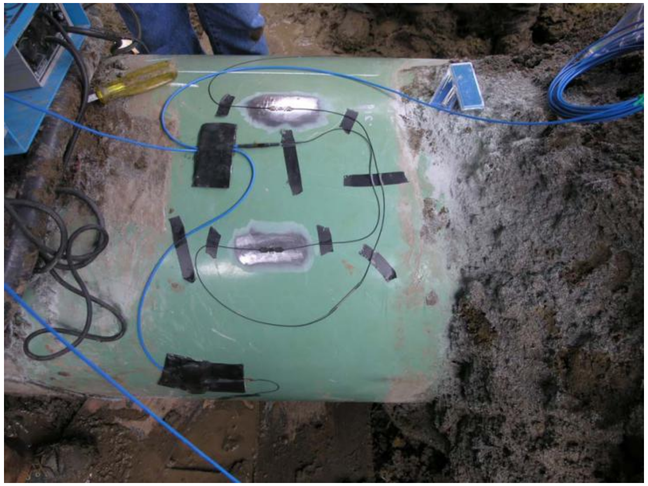
Key Takeaways

- Strain gage fundamentals
- Bridge-based measurement fundamentals
- Measurement error reduction
- Fiber-optic strain measurement

Strain Applications

Structural Fatigue Monitoring

Hydro Turbine Test



Oil Pipeline Monitoring

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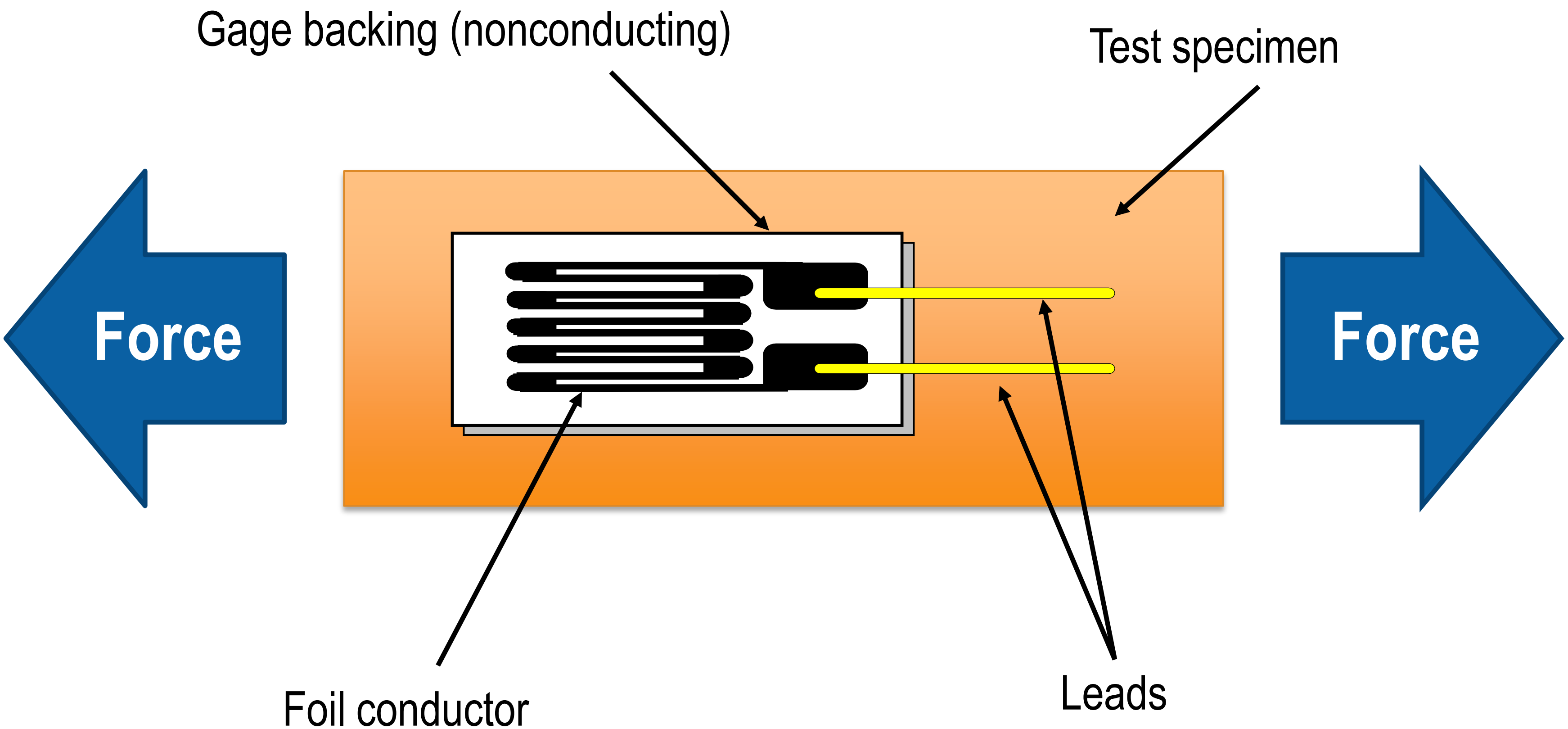
Strain Gage

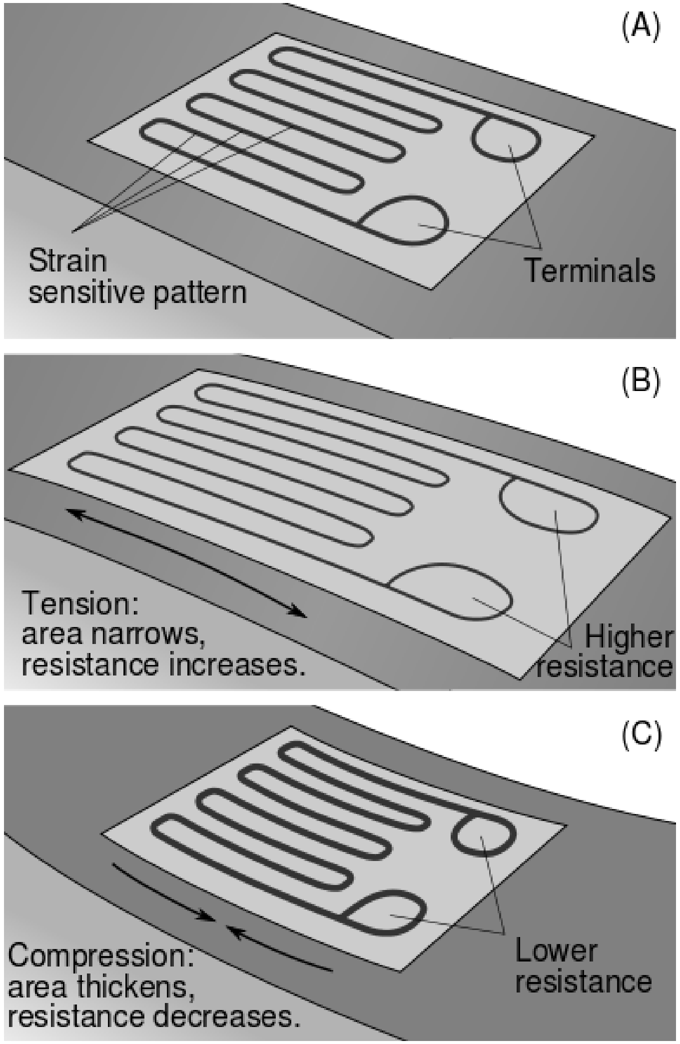


Gage backing (nonconducting)
Test specimen
Force
Force
Foil conductor
Leads

Foil Strain Gage Operation

- Strain gages are variable resistive sensors
- Resistance changes with strain
- How much the resistance changes is dependent on the sensors **gage factor**

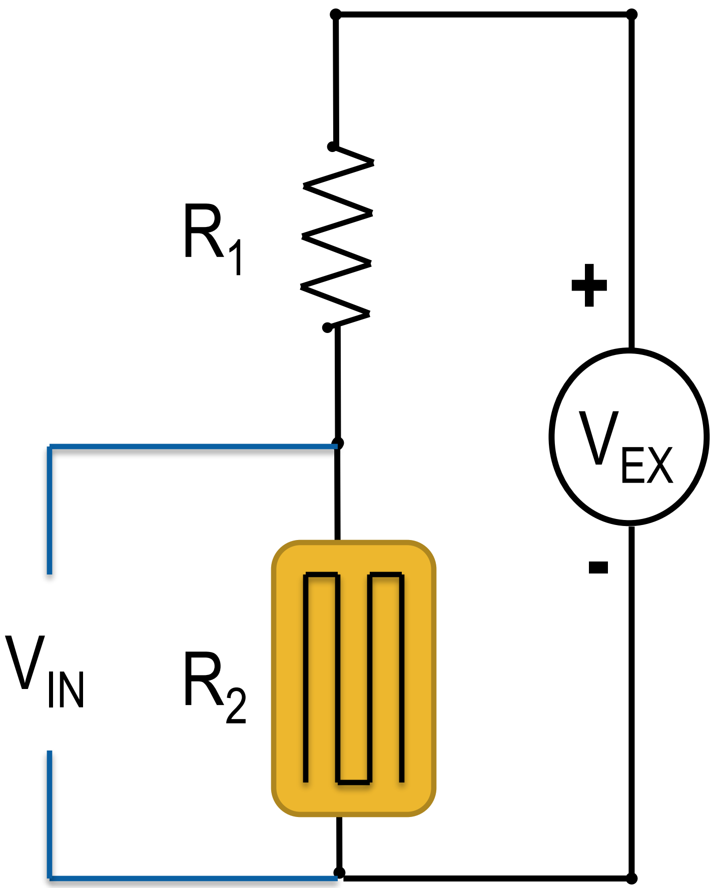
$$\varepsilon = \frac{\Delta L}{L} = \frac{\Delta R}{R} = GF \times \varepsilon$$



Voltage Divider

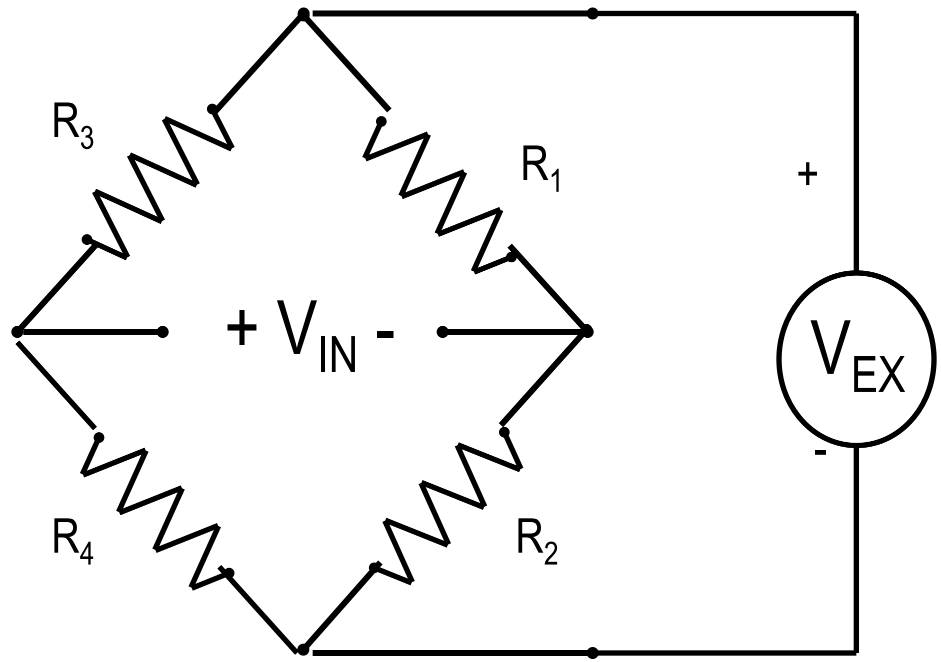
- Divides the voltage across a linear circuit

$$V_{IN} = V_{EX} \frac{R_2}{(R_1 + R_2)}$$



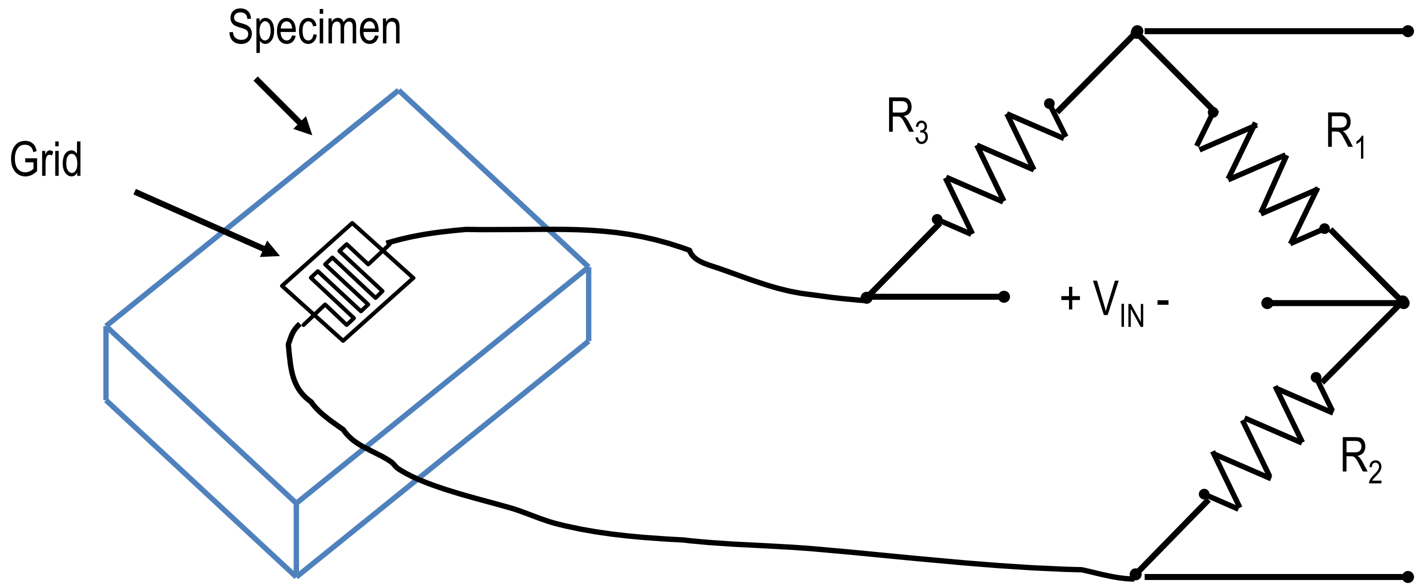
The Wheatstone Bridge

- Used to measure resistive devices
  - $V_{IN} = 0$ if $R_1/R_2 = R_3/R_4$
  - $V_{IN} \neq 0$ if change in resistance (strain)
- Requires voltage excitation

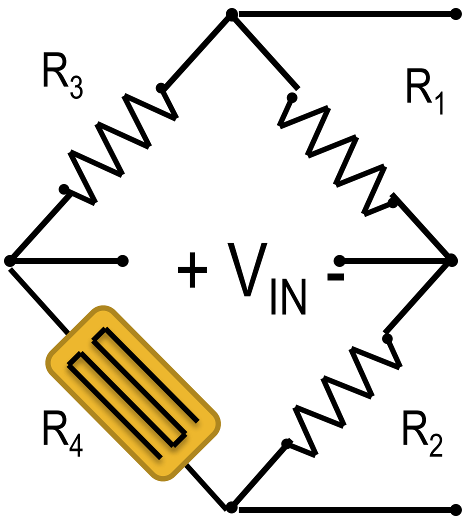


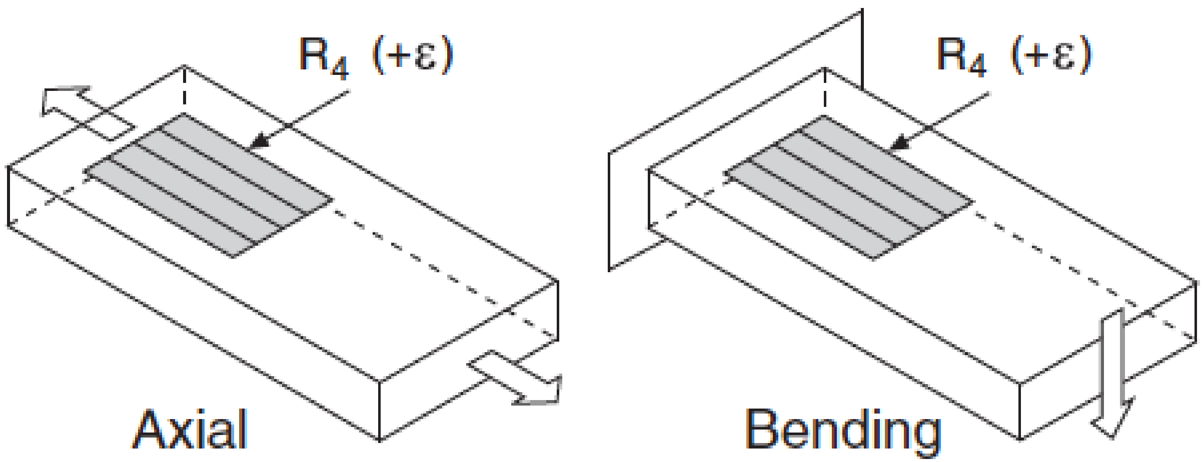
Quarter-Bridge Strain Gage

- One gage
- R_1, R_2, and R_3 are fixed resistors
- R_3 is called the quarter-bridge completion resistor

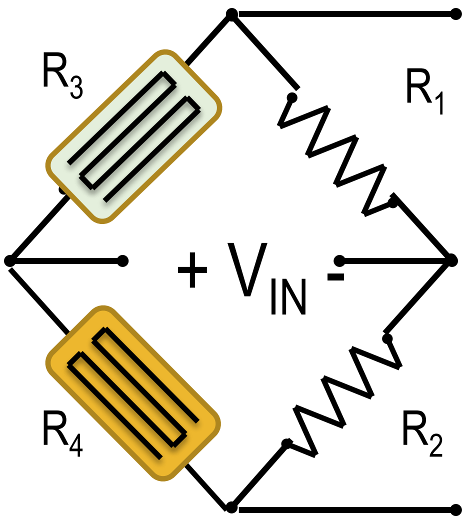


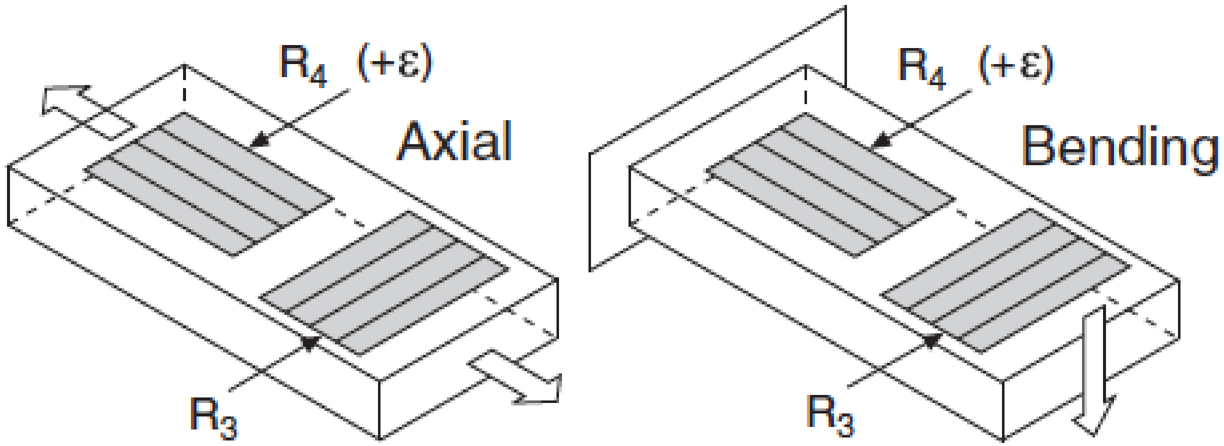
Quarter-Bridge Type I





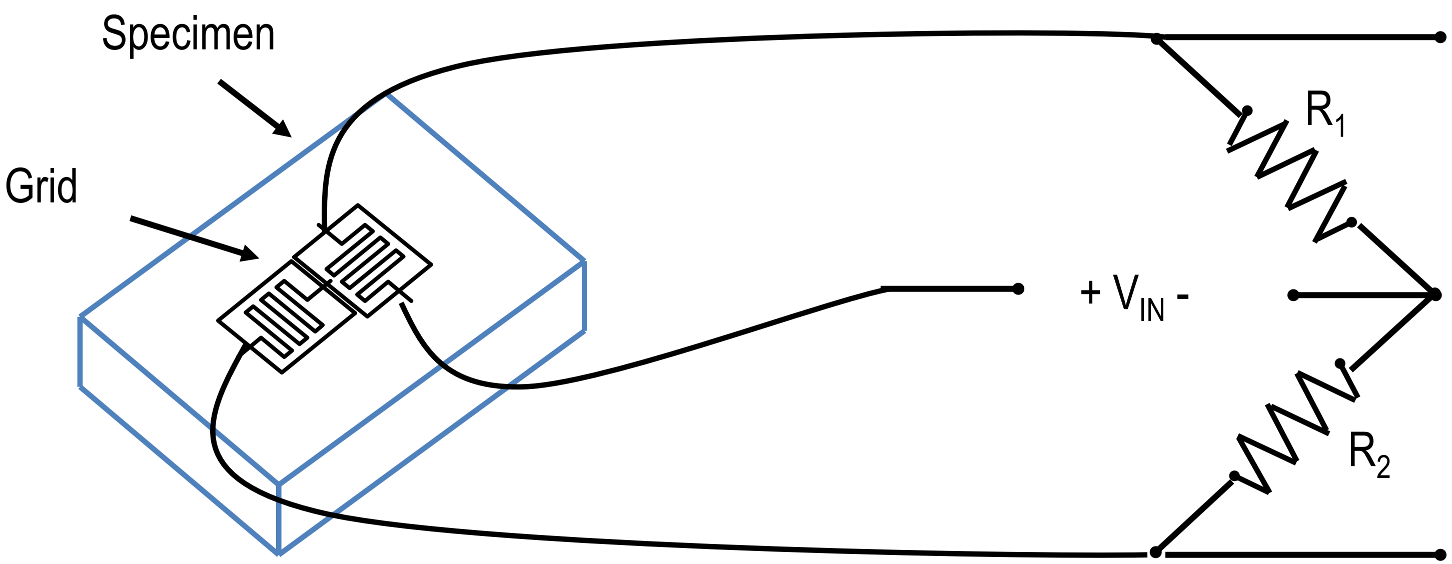
Quarter-Bridge Type II



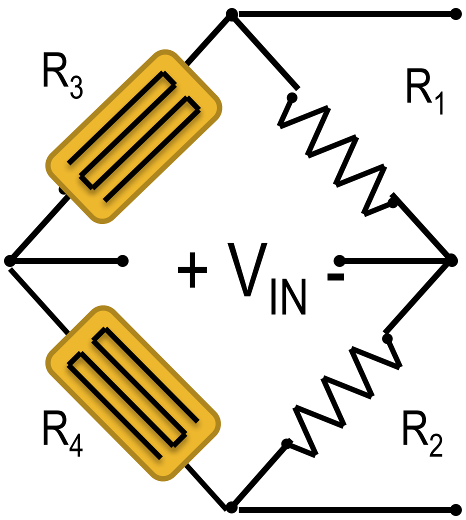


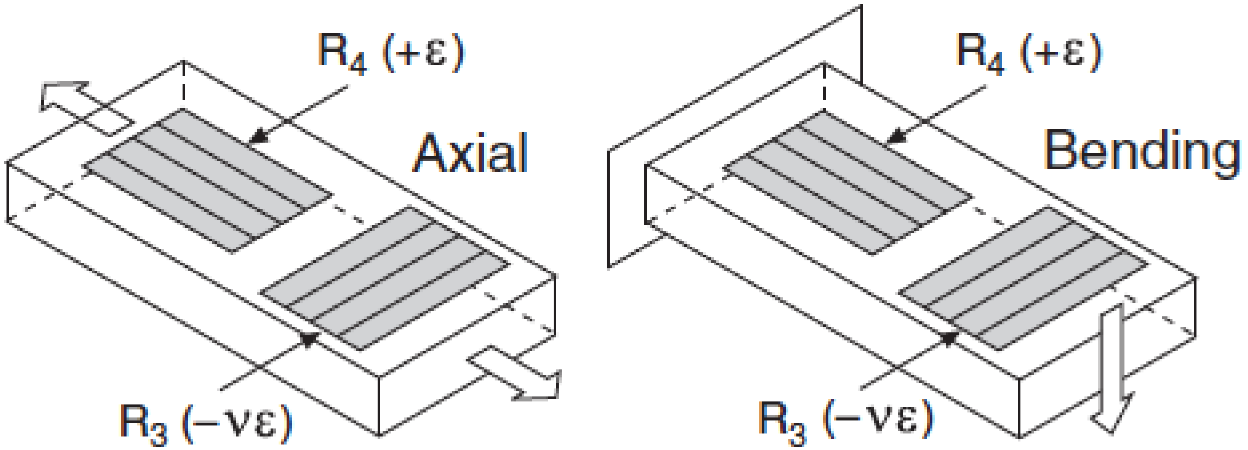
Half-Bridge Strain Gage

- Two gages
- R_1 and R_2 are fixed resistors

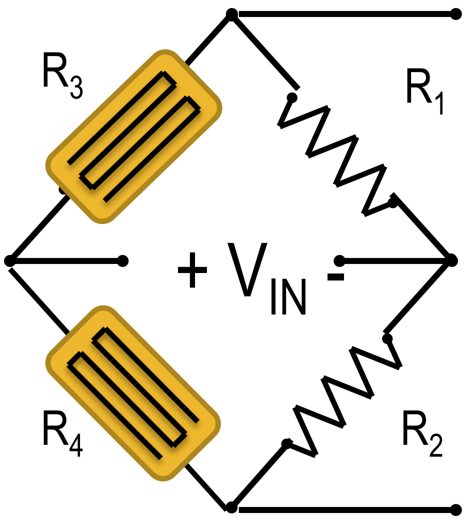


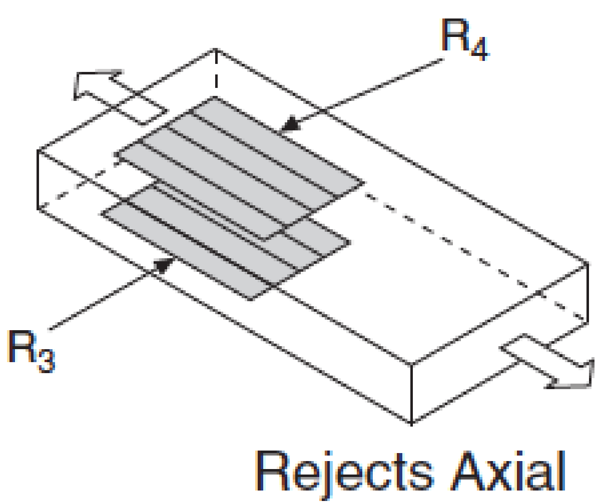
Half-Bridge Type I

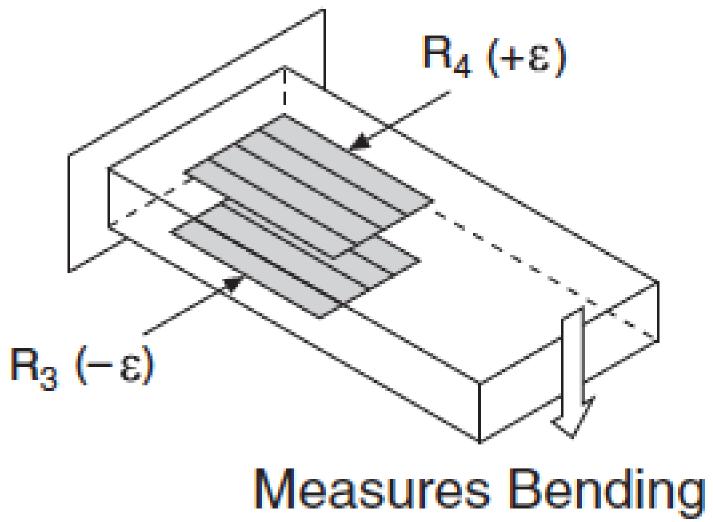




Half-Bridge Type II

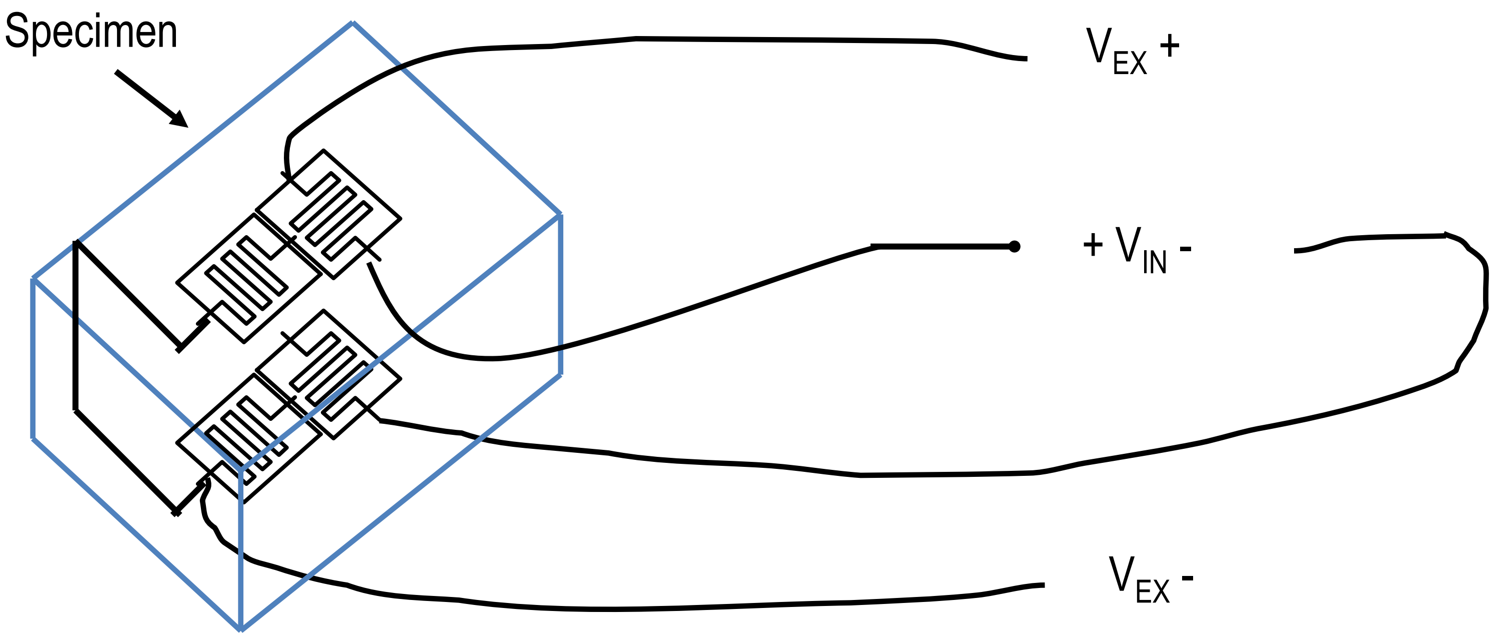




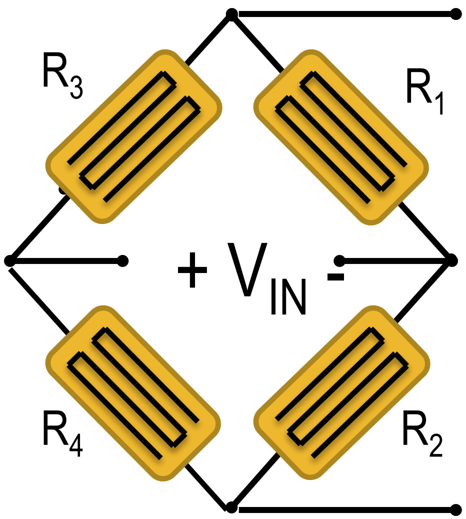


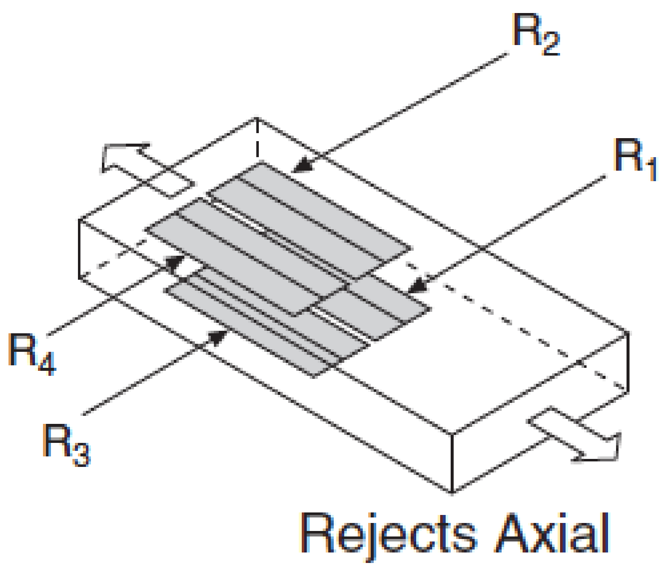
Full-Bridge Strain Gage

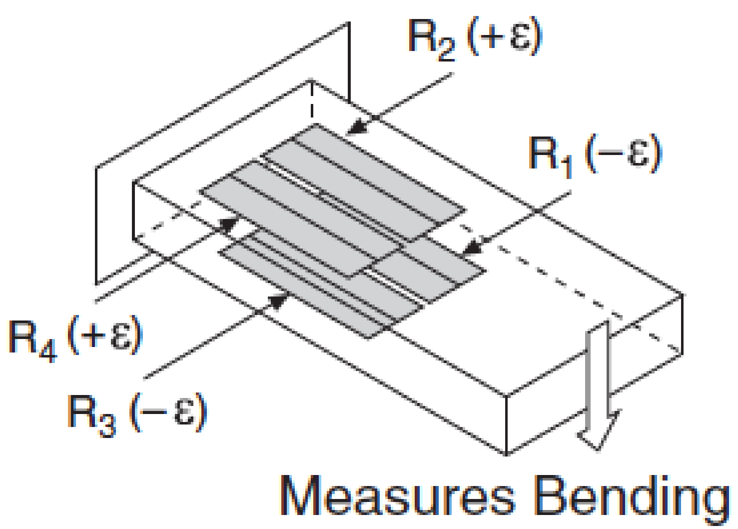
- Four gages
- All resistors in the Wheatstone Bridge are strain gages
- Generally two sensors on top, two on bottom



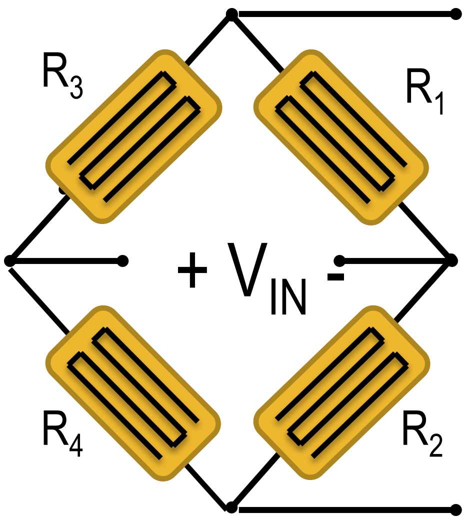
Full-Bridge Type I

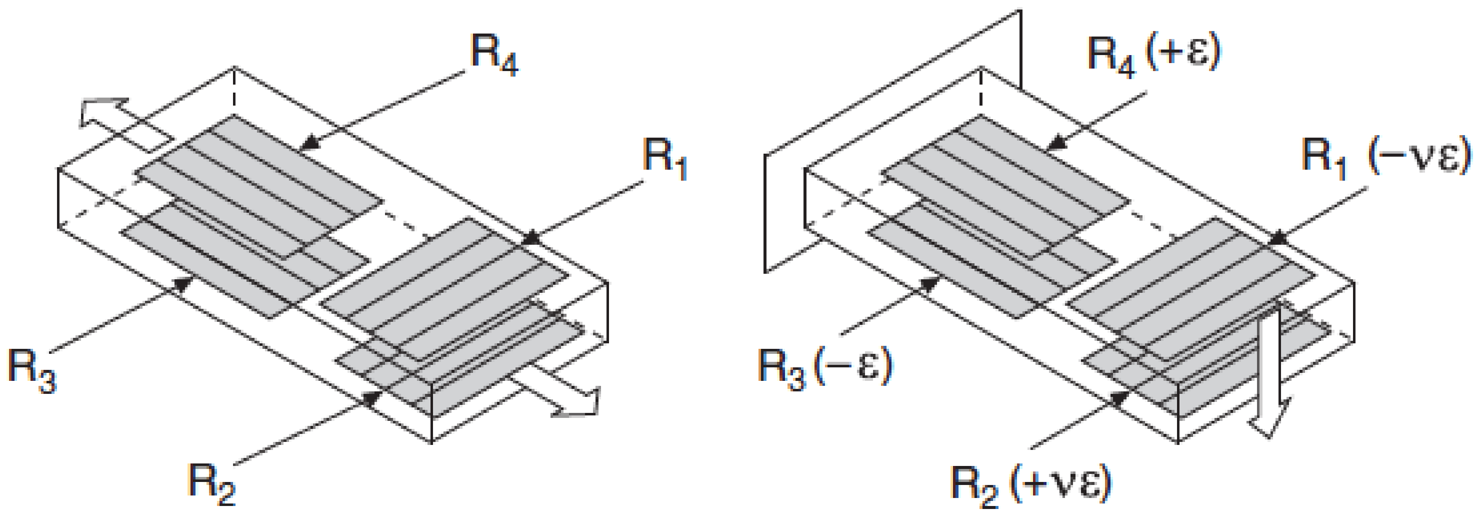






Full-Bridge Type II

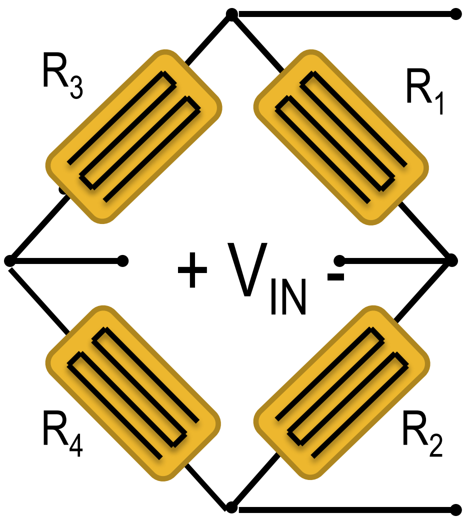


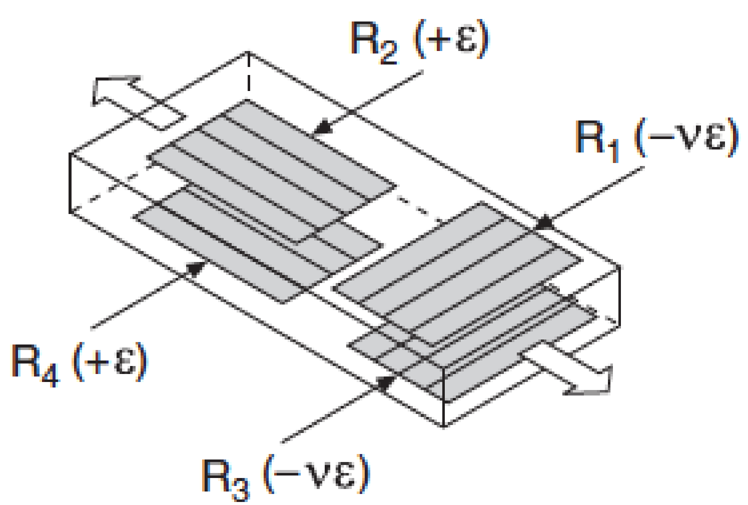


Rejects Axial

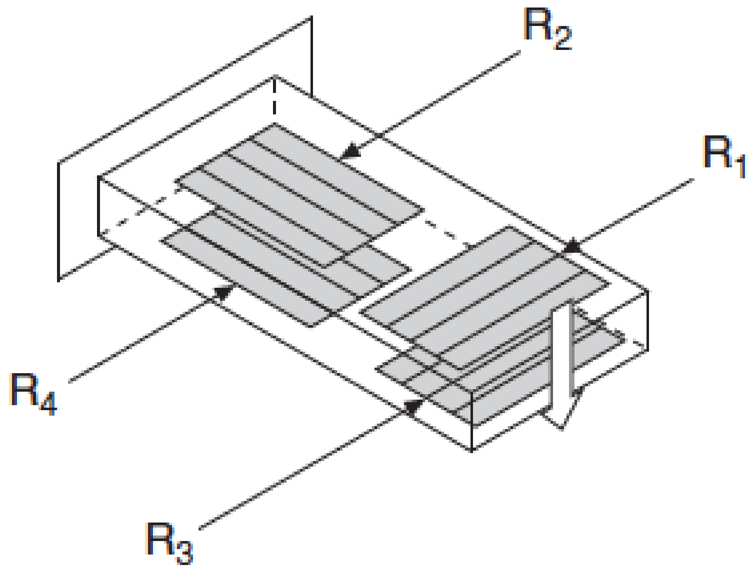
Measures Bending

Full-Bridge Type III





Measures Axial



Rejects Bending

Bridge Configurations

Measurement Type	Quarter-Bridge		Half-Bridge		Full-Bridge		
	Type I	Type II	Type I	Type II	Type I	Type II	Type III
Axial Strain	Yes	Yes	Yes	No	No	No	Yes
Bending Strain	Yes	Yes	Yes	Yes	Yes	Yes	No
Compensation							
Temperature	No	Yes	Yes	Yes	Yes	Yes	Yes
Transverse Sensitivity	No	No	Yes	No	No	Yes	Yes
Sensitivity		ß					
Sensitivity at 1,000 ue	~0.5 mV/V	~0.5 mV/V	~0.65 mV/V	~1.0 mV/V	~2.0 mV/V	~1.3 mV/V	~1.3 mV/V
Installation							
Number of Bonded Gages	1	1*	2	2	4	4	4
Mounting Location	Single Side	Single Side	Single Side	Opposite Sides	Opposite Sides	Opposite Sides	Opposite Sides
Number of Wires	2 or 3	3	3	3	4	4	4
Bridge Completion Resistors	3	2	2	2	0	0	0

* A second strain gage is placed in close thermal contact with the structure but not bonded.

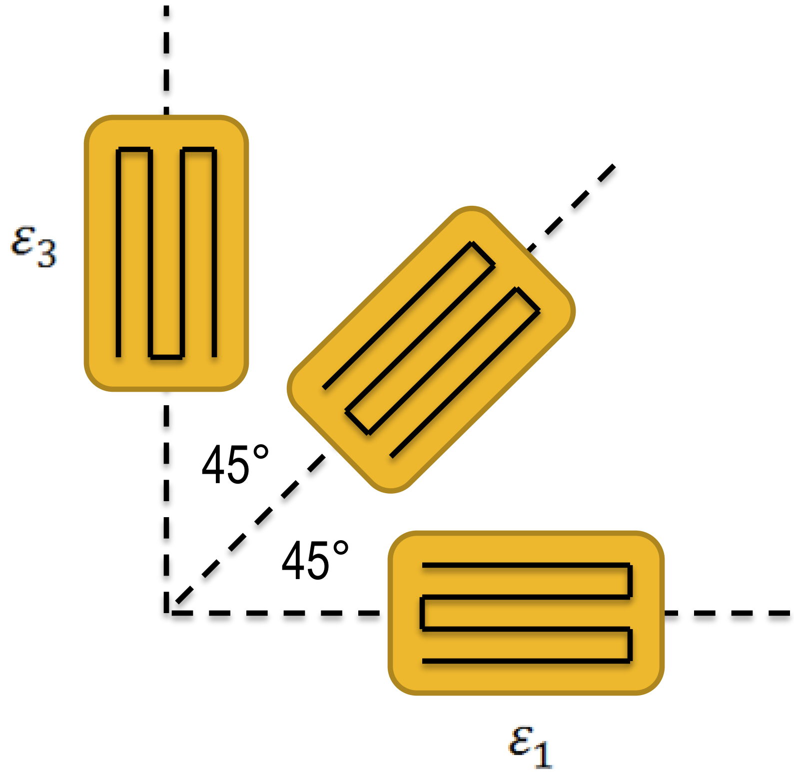
Rosette

- Specific layout used in plane strain applications

$$\varepsilon_x = \varepsilon_1$$

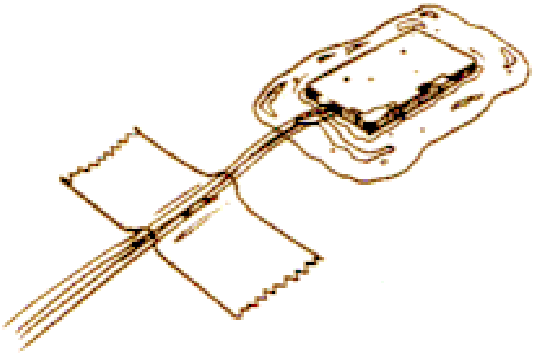
$$\varepsilon_y = \varepsilon_3$$

$$\varepsilon_{xy} = \varepsilon_2 - \frac{\varepsilon_1 + \varepsilon_3}{2}$$



Mounting Strain Gages

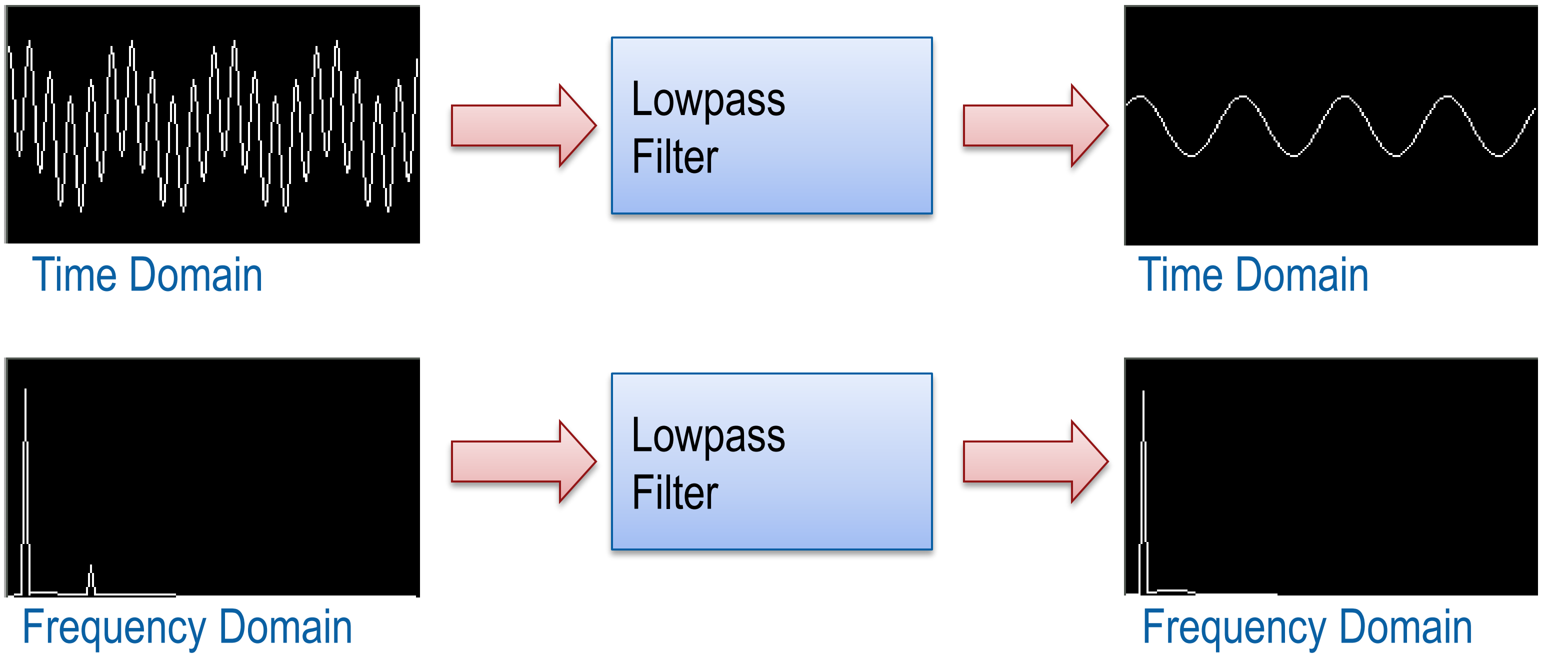
- Surface Preparation
- Gage Bonding
- Lead Wire Attachment
- Protective Coating



Sources of Error

- High-frequency noise
  - Filtering, excitation level
- Sensor self-heating
  - Gage type, excitation level, structure
- Lead wire and bridge arm resistance
  - Remote sensing, shunt calibration
- Improper calibration
  - Offset nulling, shunt calibration
- Excitation source stability
  - Compensation, ratiometric architecture

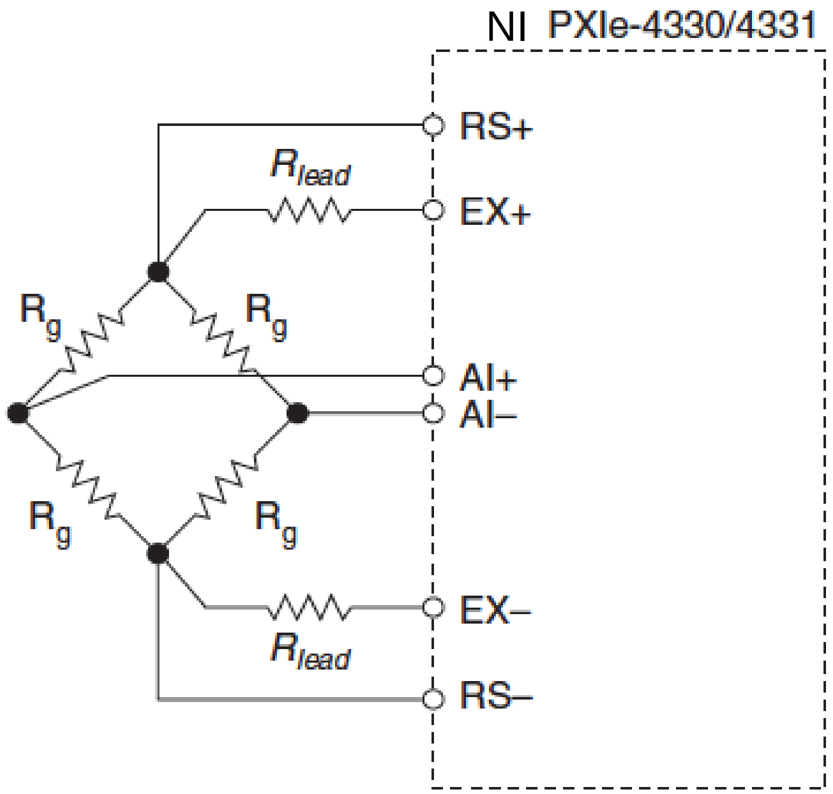
Filtering


Lowpass Filter
Time Domain
Time Domain
Lowpass Filter
Frequency Domain
Frequency Domain

Excitation Level

- Signal-to-noise ratio (SNR)
  - Higher excitation delivers better SNR
- Impacts gage self-heating
  - Higher excitation leads to self-heating
    - Introduces thermocouple effects
    - Changes the adhesive's ability to transfer strain
    - Changes gage resistivity and sensitivity
      - Bridge configuration dependent

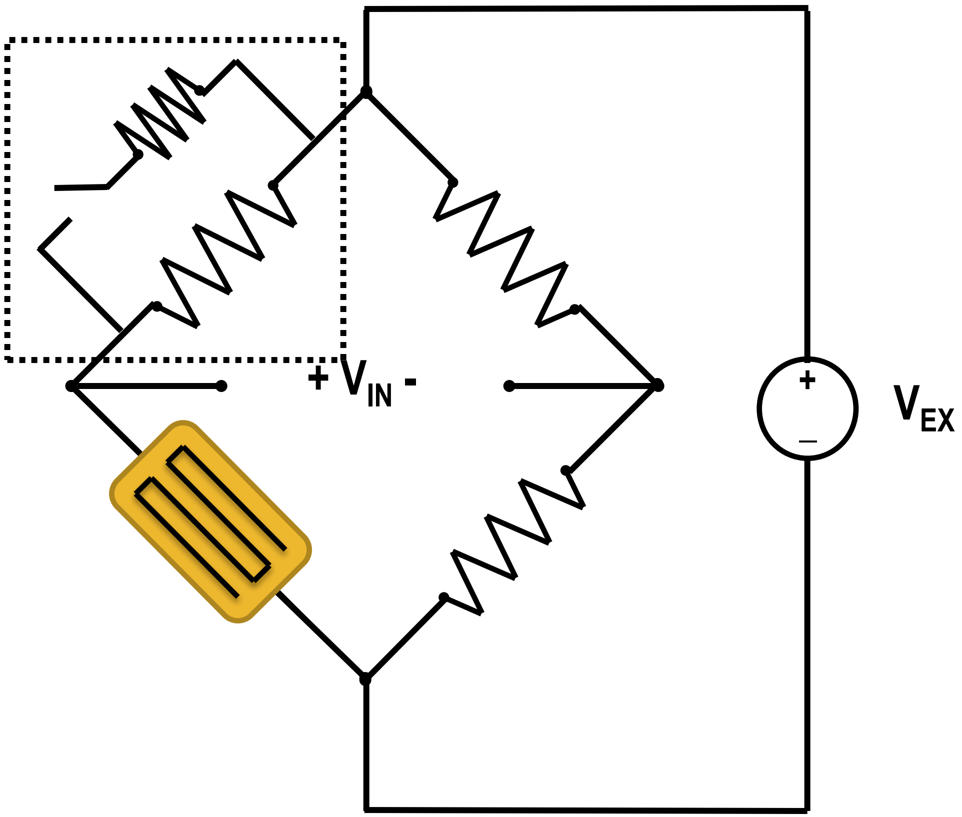
Remote Sensing



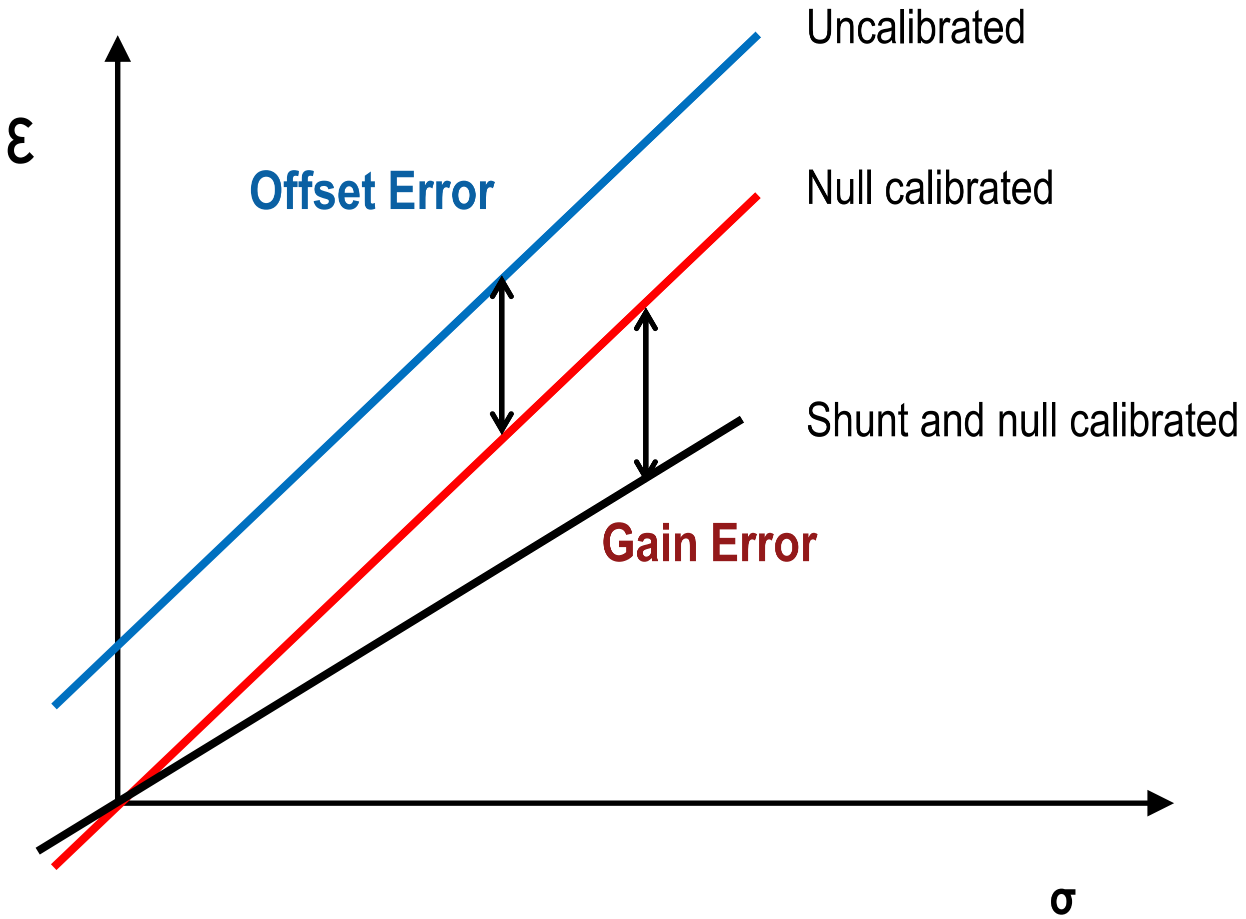
Null Calibration

- Removes offsets
- Ensures that ~0 V are measured when gage is unstrained
- Compensates for inherent bridge imbalance
- Can be performed in hardware or software

Shunt Calibration



Null and Shunt Calibration



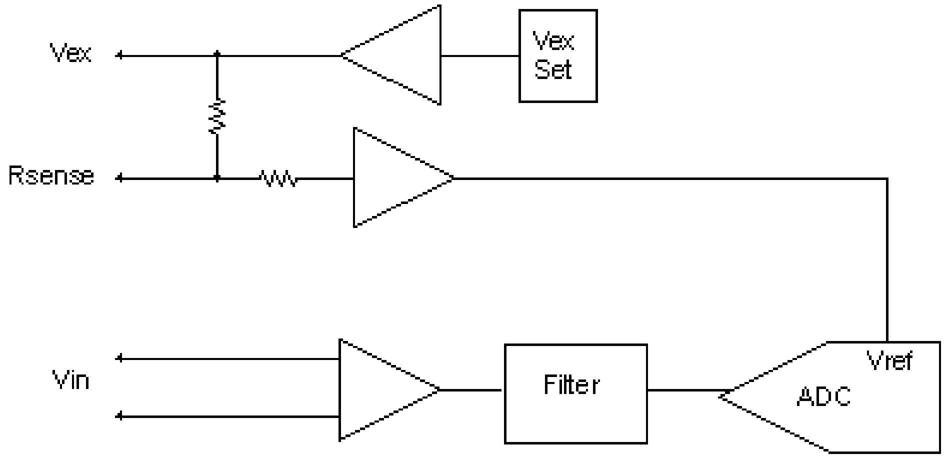
Hardware Demonstration

Stability of Excitation

- Voltage ratio is used in all equations to compute strain

$$(V_{strained} - V_{unstrained}) \,/\, V_{excitation}$$

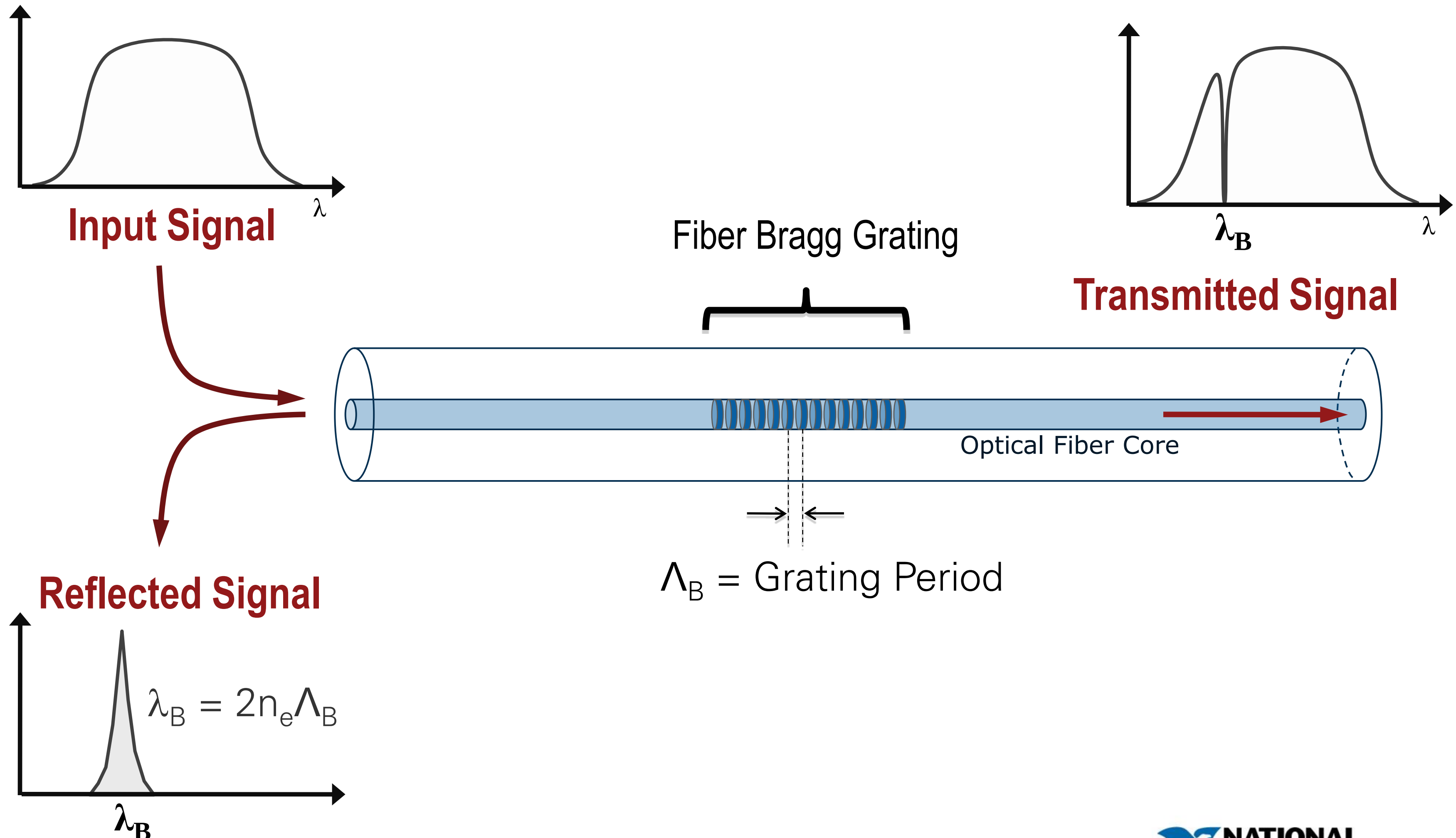
- Unstable excitation causes errors in reading



Advantages

High accuracy and low susceptibility to excitation temperature drift
Reduced regulation design requirements allow for increased channel count

Fiber Bragg Gratings (FBGs)



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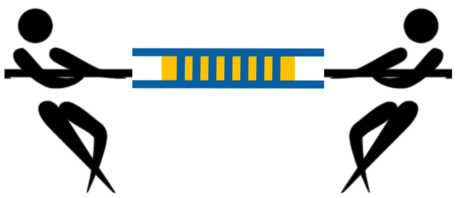
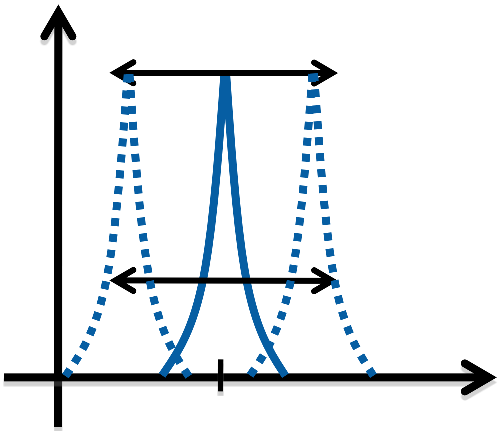
Temperature and Strain



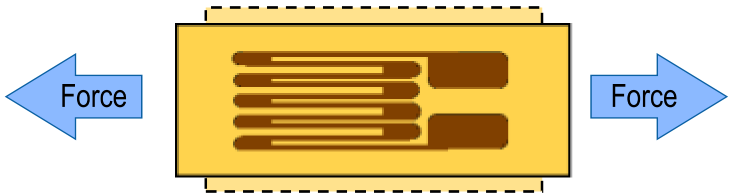
Strain
Change Λ



$$\lambda = 2n\Lambda$$

Analogous Measurement: Strain Gages

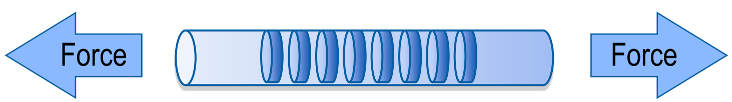
Resistive (Foil) Gage



Strain: $\varepsilon = \frac{\Delta L}{L} \qquad \frac{\Delta R}{R} = GF \cdot \varepsilon$

$GF \approx 2$

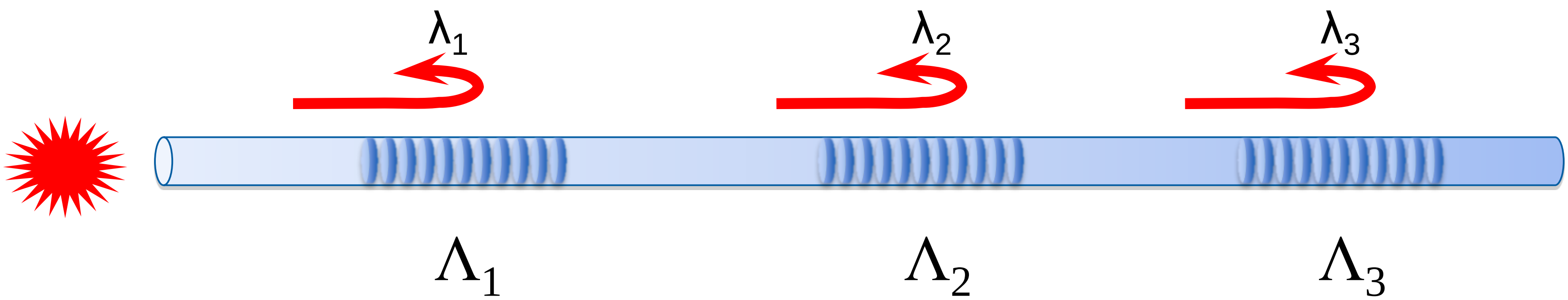
Optical FBG Gage



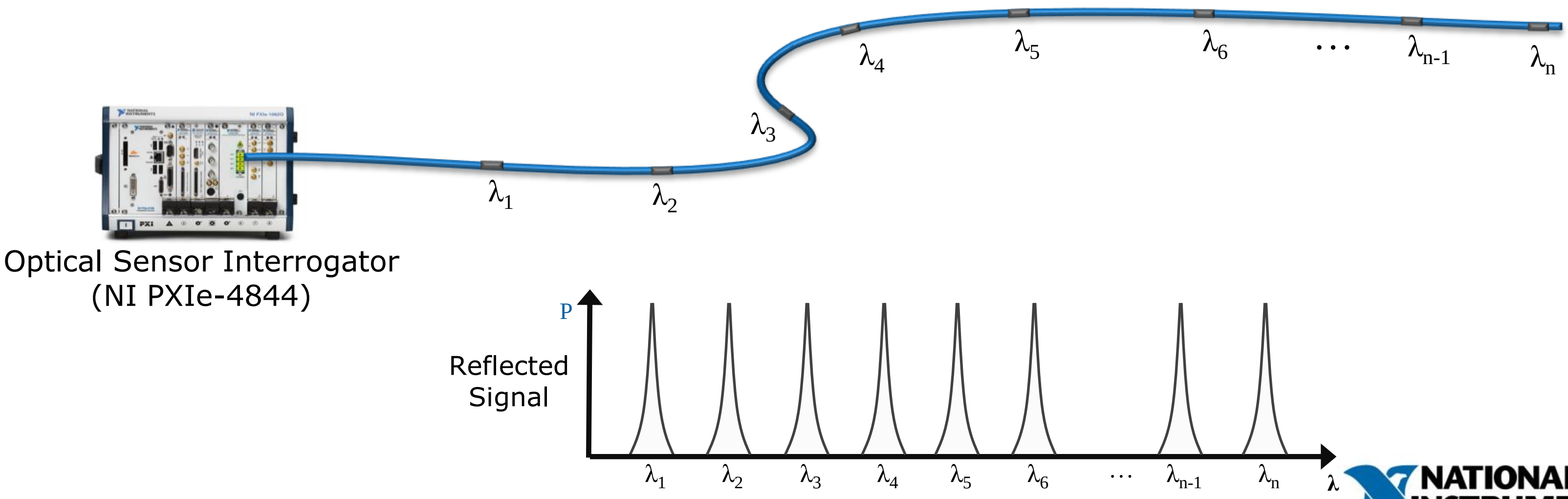
Strain: $\varepsilon = \frac{\Delta L}{L} \qquad \frac{\Delta \lambda}{\lambda} = K \cdot \varepsilon$

$K \approx 0.8$

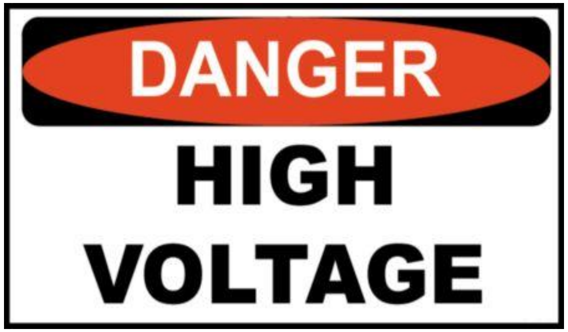
Wavelength-Division Multiplexing



- Multiplex multiple FBG sensors at unique wavelengths on a single optical fiber



Benefits of FBG Optical Sensing



- Electrically nonconductive and passive
  - Immune to high voltages, EMI
  - Nonexplosive
- Environmentally stable
  - Insensitive to corrosive and caustic media
- Multiplexed sensors
  - Dozens of sensors per fiber reduces cabling
  - Allows for long distance signal transmission (km)
- Very small and lightweight
  - Reduced weight/drag effect

Acquiring the Measurement

SC Express
- High Channel Count
- High Performance

NI CompactDAQ
- Portable Measurements
- USB, Ethernet, WiFi

NI CompactRIO
- Rugged
- Headless Operation

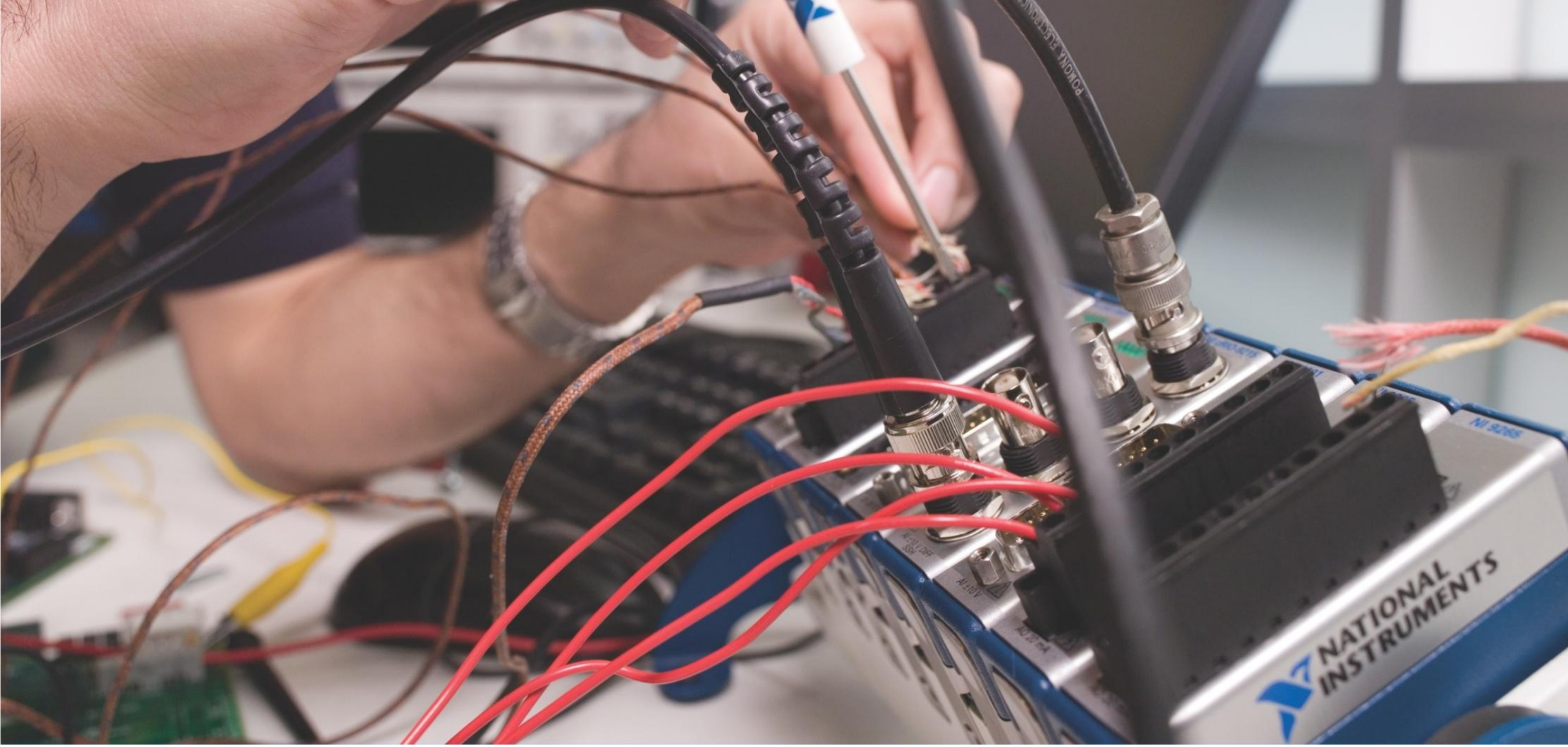
Measuring the Effects of Earthquakes on Bridges

The Challenge

Building a test that best measures how a vehicle's suspension interacts with a bridge during an earthquake.

The Solution

Measuring strain, force, and displacements to characterize the behavior of the vehicles and bridges.



ni.com/strain