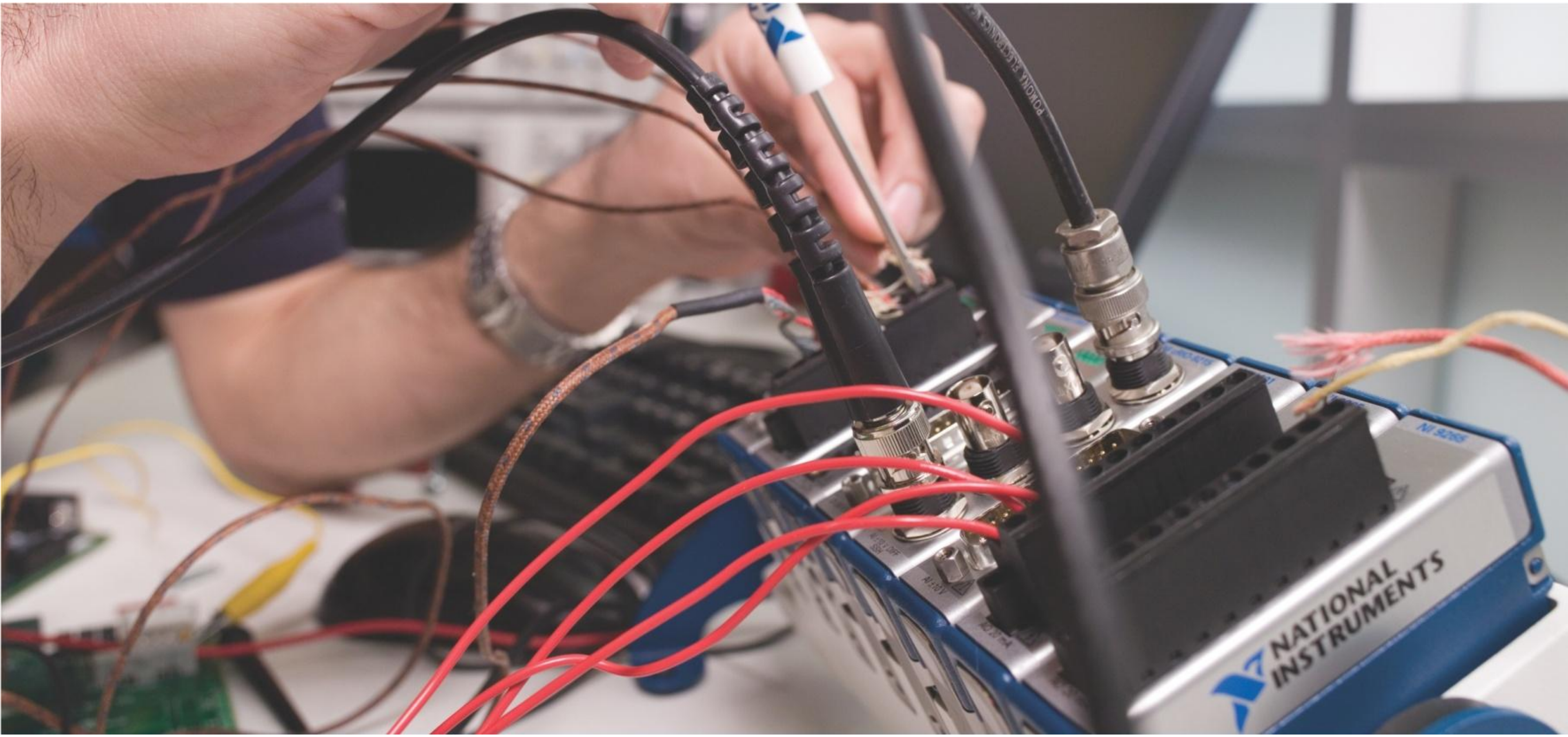
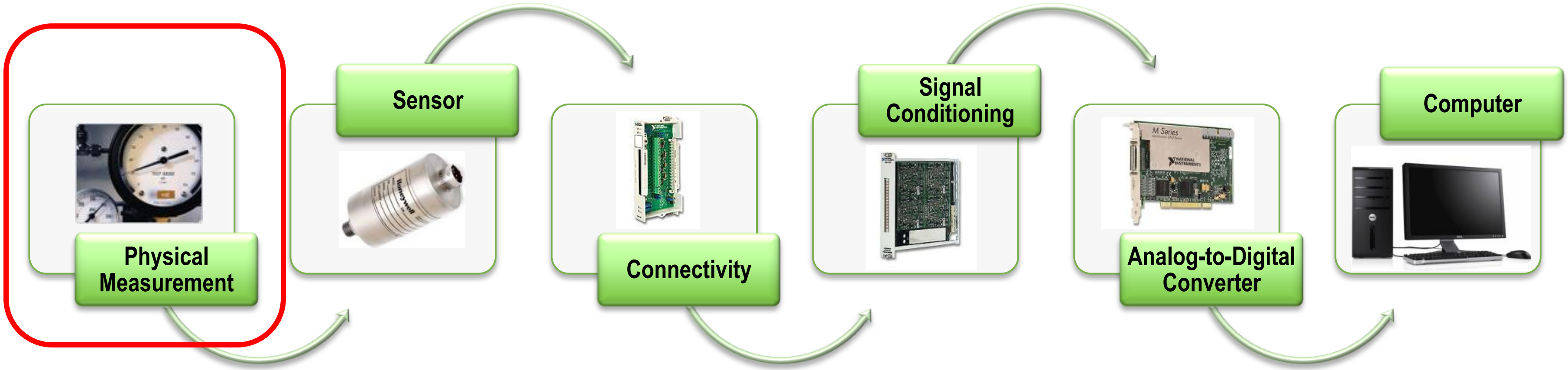


Sensor Measurement Fundamentals Series

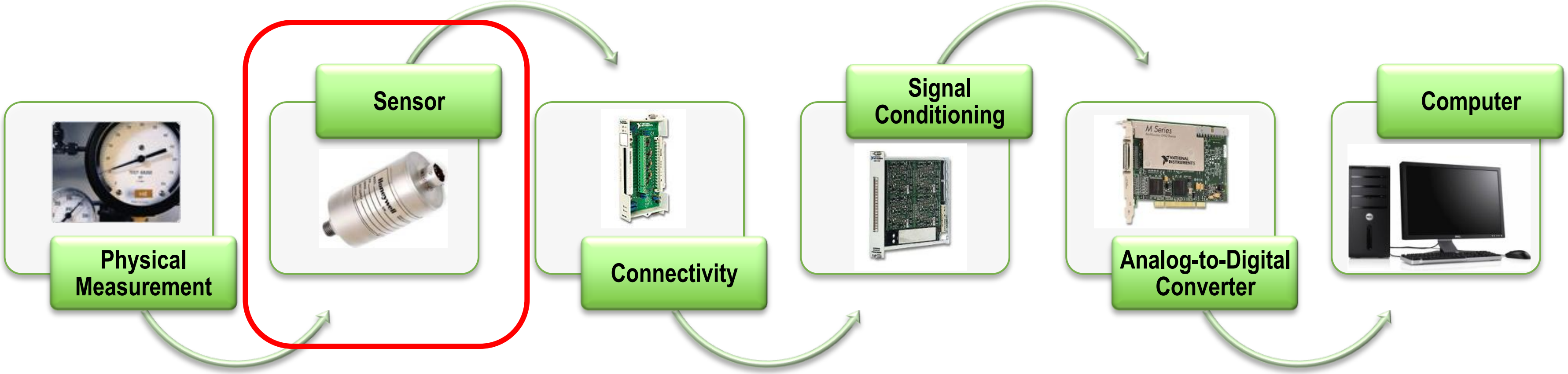
How to Build Better Test Systems for Load, Pressure, and Torque

Aaron Ortbals
Product Manager
National Instruments

Measurement Components



Measurement Components



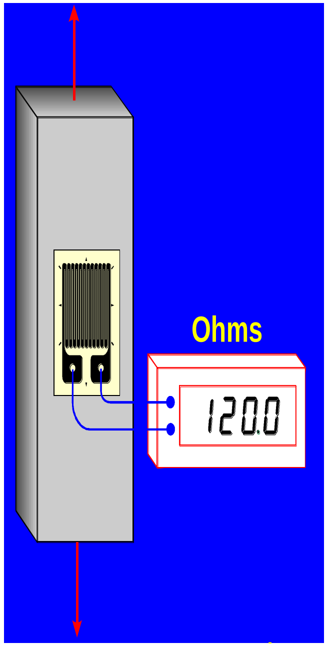
Wheatstone Bridge

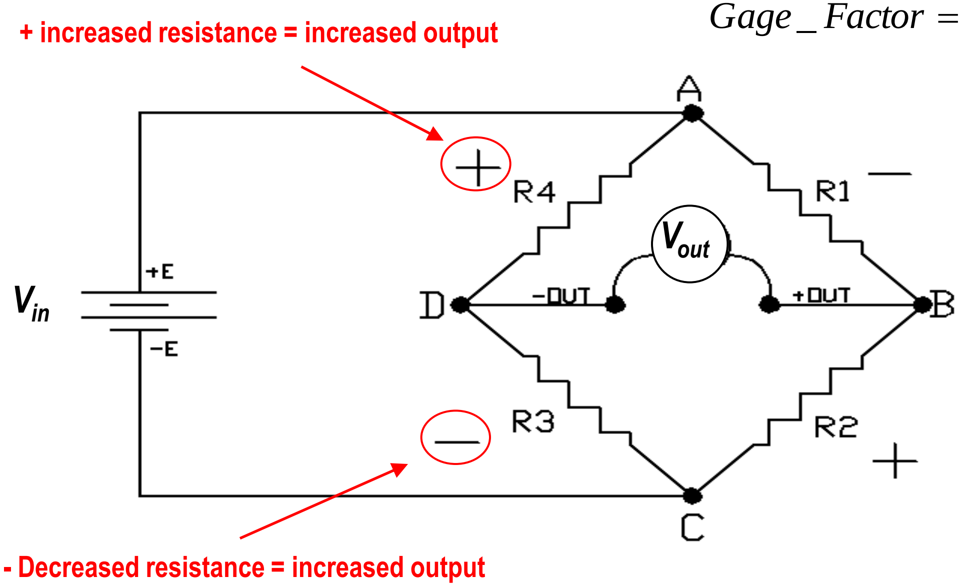
- The gage resistance changes as strain is induced.

$$Strain = \varepsilon = \frac{\Delta L}{L} \propto \frac{\Delta R}{R}$$

- Gage factor is the ratio of resistance change to strain change. A specific DR in the gage = specific DL on the base material.

$$Gage\_Factor = F = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} = \frac{\frac{\Delta R}{R}}{\varepsilon} \longrightarrow \Delta R = RF\varepsilon$$





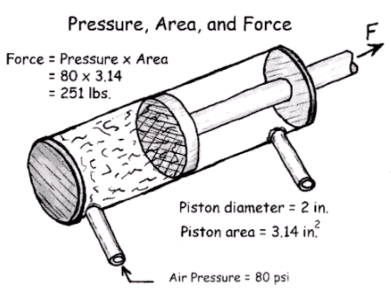
$$V_{out} = V_B - V_D$$

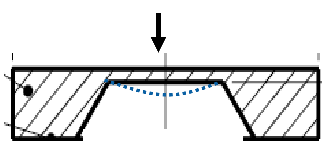
Understanding Pressure Sensors

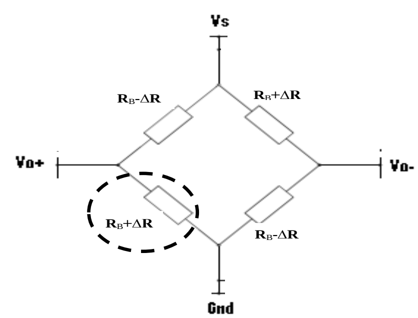
- Pressure is defined as force per unit area
- All pressure sensors use a force-summing device to convert the pressure into a stress or displacement proportional to the pressure
- The stress or displacement is then applied to an electrical transduction element to generate the required signal
- The examples below are generally related to silicon piezo resistive pressure

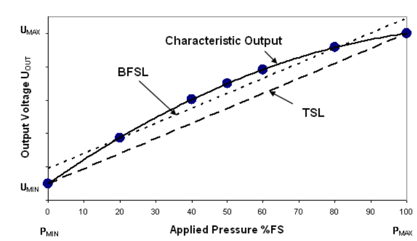
Pressure (force/area) → Deformation of Sense Element → Change in Electrical Properties → Change in Output

Examples…



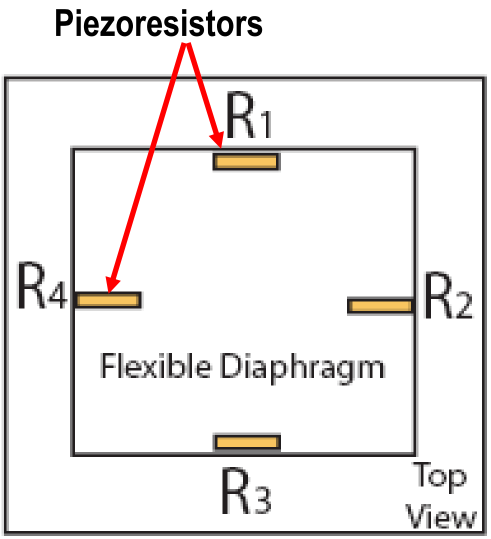




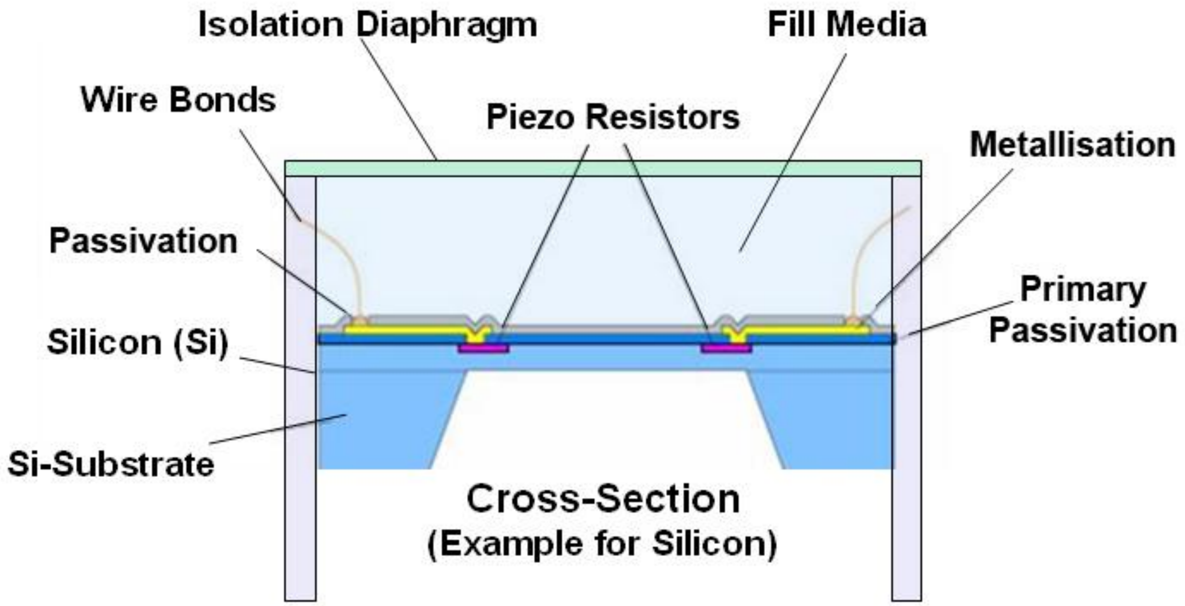


Piezoresistive Pressure Sensors

- In piezoresistive pressure sensors, the transduction elements that convert the stress from the diaphragm deflection into an electrical signal are piezoresistors
- Piezoresistance = changing electrical resistance due to mechanical stress
- As shown here, typically 4 piezoresistors are used—connected in a Wheatstone bridge circuit—to provide an output that changes primarily with pressure

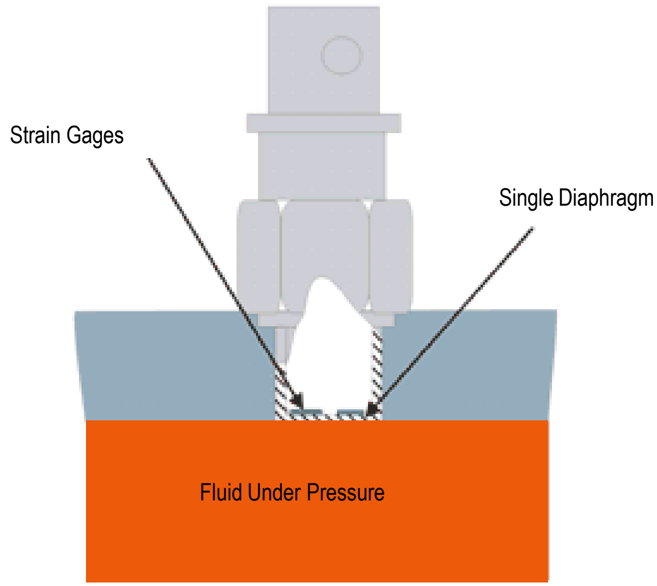


Top View

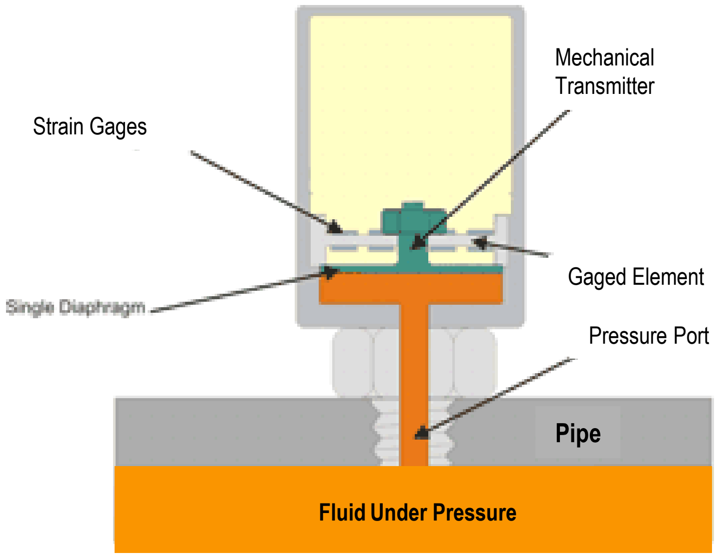


Foil-Based Pressure Sensors

Two basic types of foil-based pressure sensors
- •Diaphragm
- •Force Sensor-based



Gaged Diaphragm



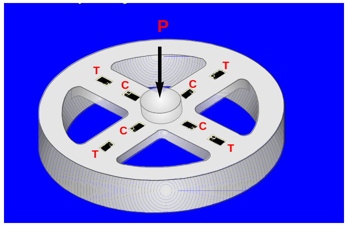
Gaged Force Sensor With Mechanical Transmitter

Understanding Load Cells

- Load cells measure direct force
- Strain gage technology is a key function of load cells
- The structure (spring element) is the most critical component
    - -Multiple-bending beam design
    - -Multiple-column design
    - -Shear-web design
- Load cells feature duty cycle ratings
    - -Fatigue resistant
    - -General purpose

Multiple-Bending Beam Design

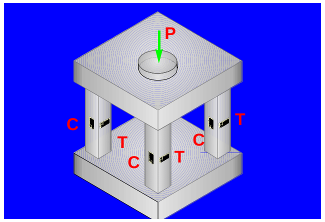
Low capacity: 20 – 20K N



4 active arms with pairs subjected to equal and opposite strains

Multiple-Column Design

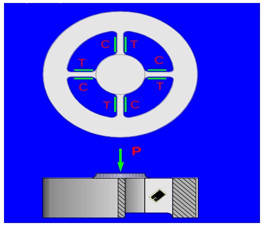
High capacity: 110K – 9M N



4 active arms in uniaxial stress field—2 aligned with maximum strain, 2 "Poisson" gages

Shear Web Design

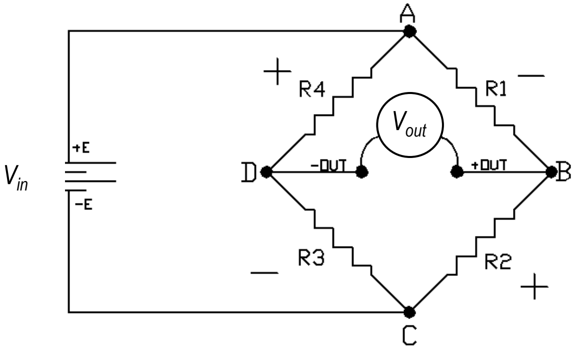
Capacity: 2K – 1M N



4 active arms with pairs subjecte to equal and opposite strains

Strain Gage

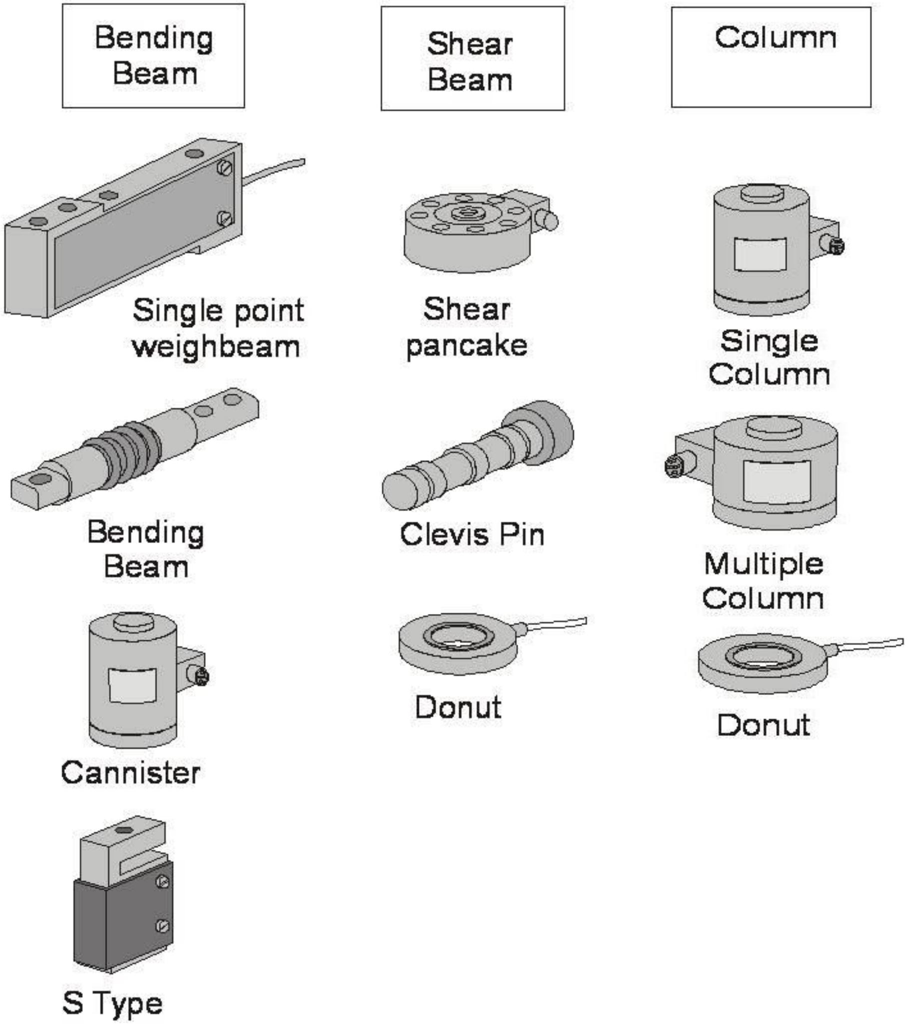
(Wheatstone Bridge or Electrical Circuits)



Types of Load Cells

3 Main Categories of Load Cells

- Bending beam
- Shear beam
- Column



Understanding Torque

What is torque?

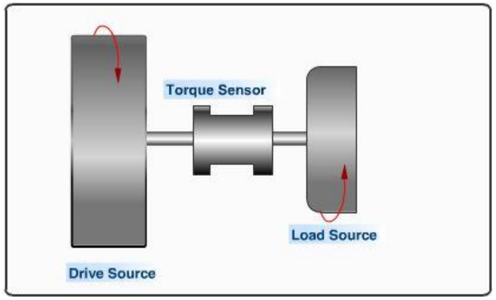
Torque = Force * Distance

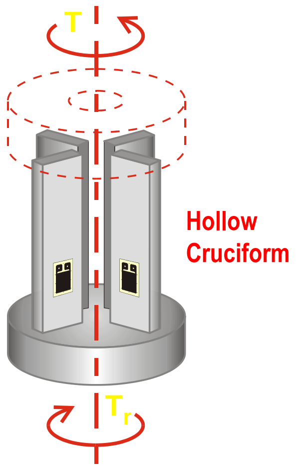
4 Main Torque Sensor Designs

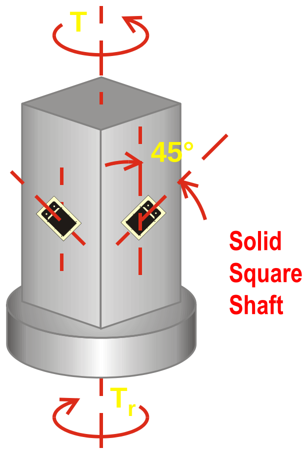
- Hollow cruciform
- Solid square shaft
- Radial spoke
- Hollow tubular

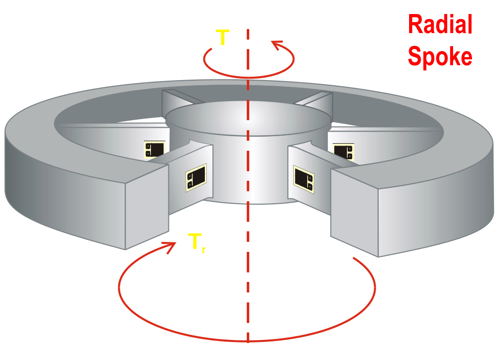
What is a torque sensor?

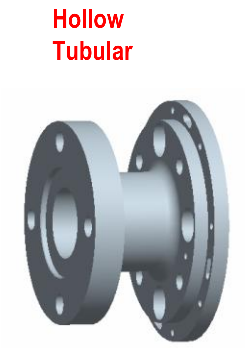
A torque sensor measures the twist or windup between a rotating drive source and load source such as an engine crankshaft or a bicycle pedal.





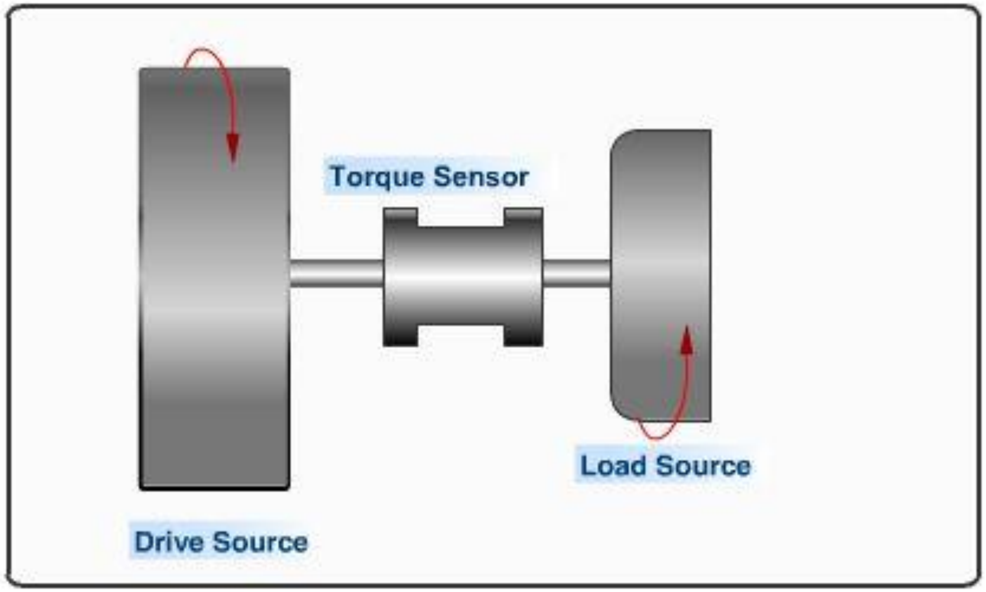






Types of Torque Sensors

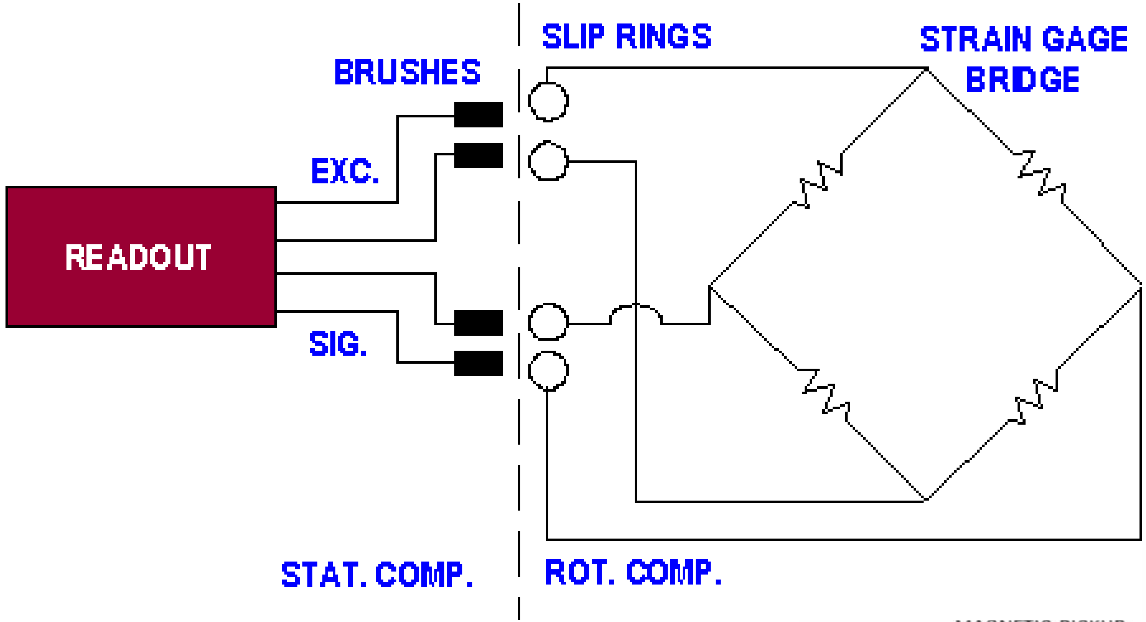
Reaction Torque Sensors

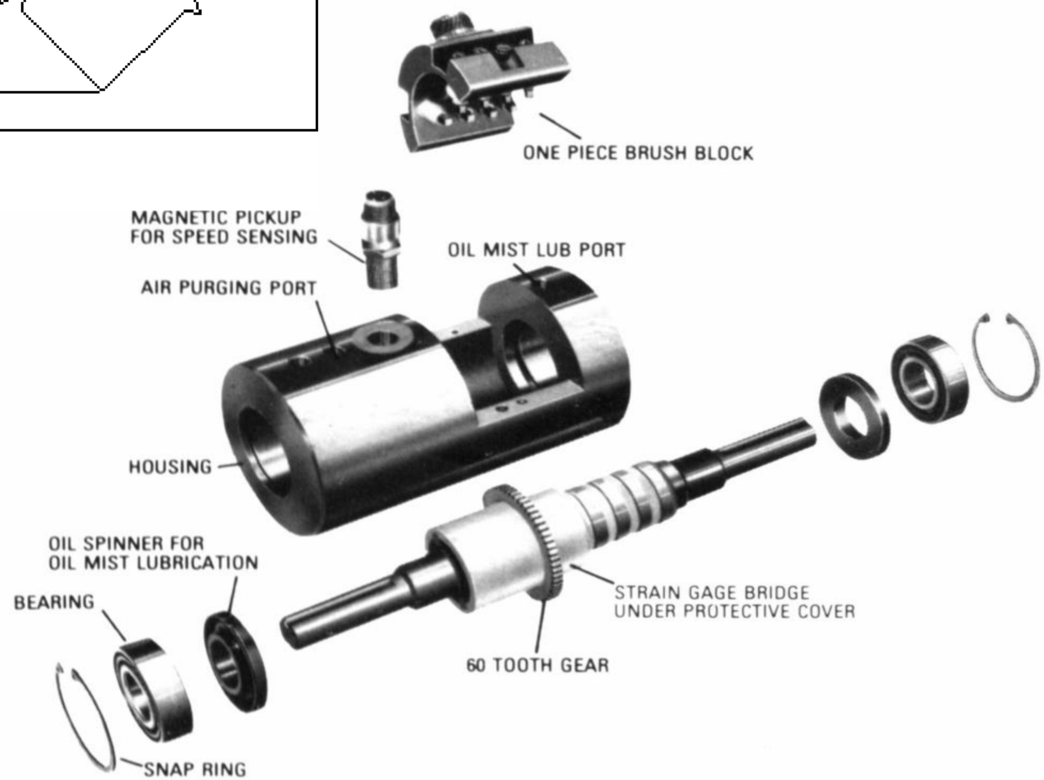


Rotary Torque Sensors

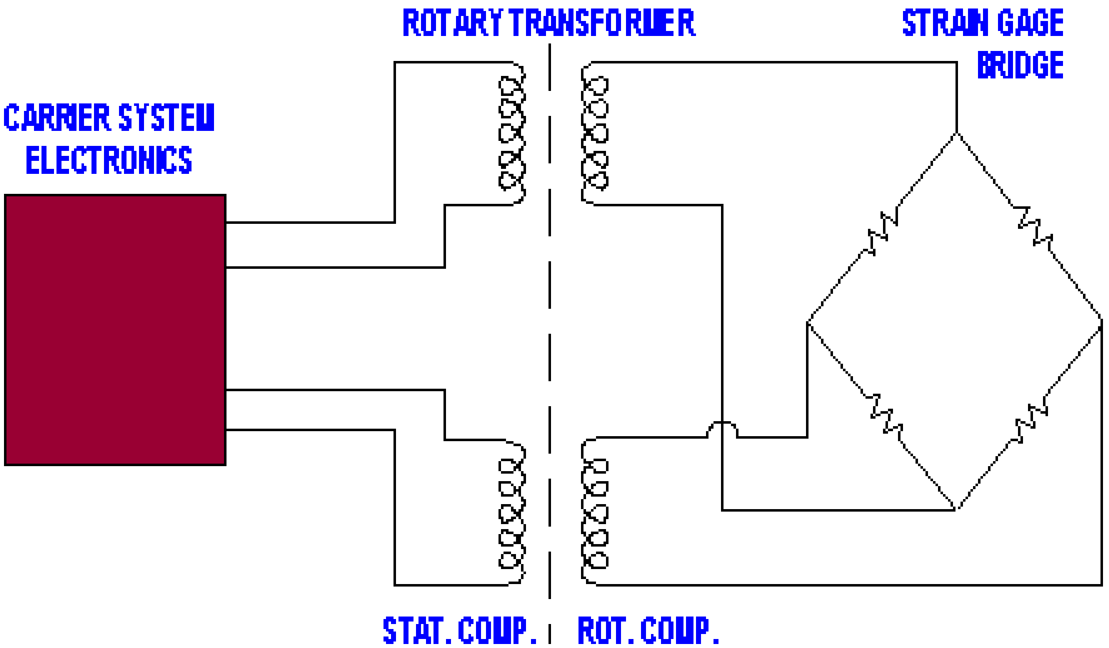
- Slip ring
- Rotary transformer
- Telemetry

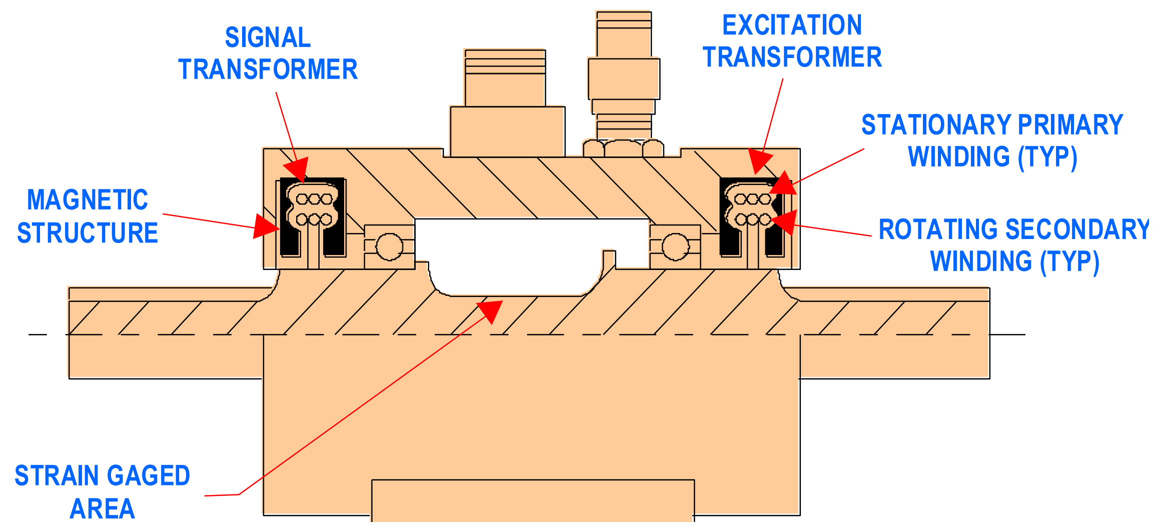
Rotary Torque Sensors: Slip Ring



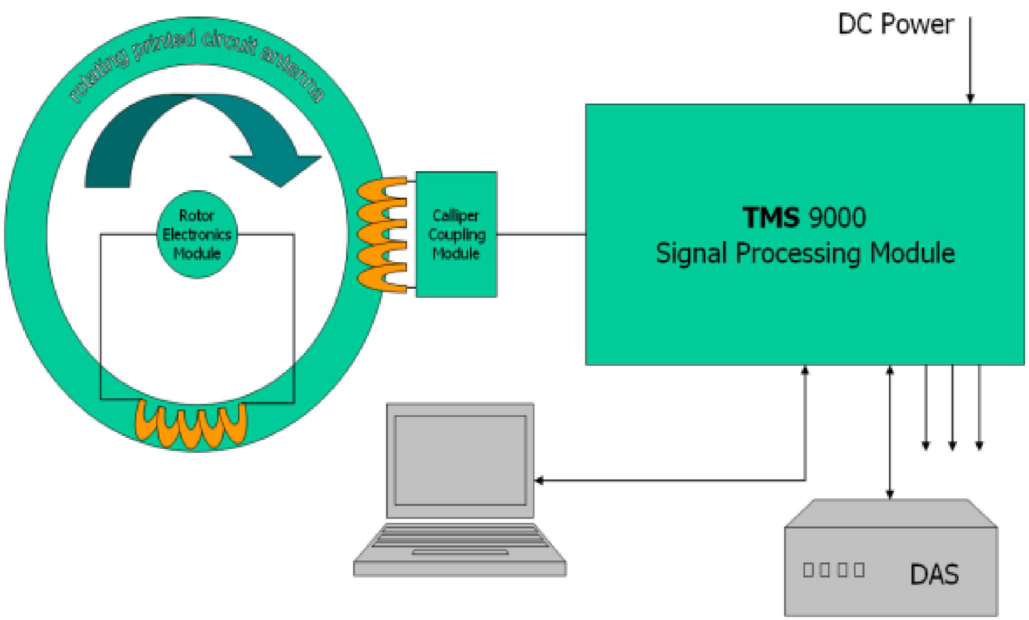


Rotary Torque Sensors: Rotary Transformer

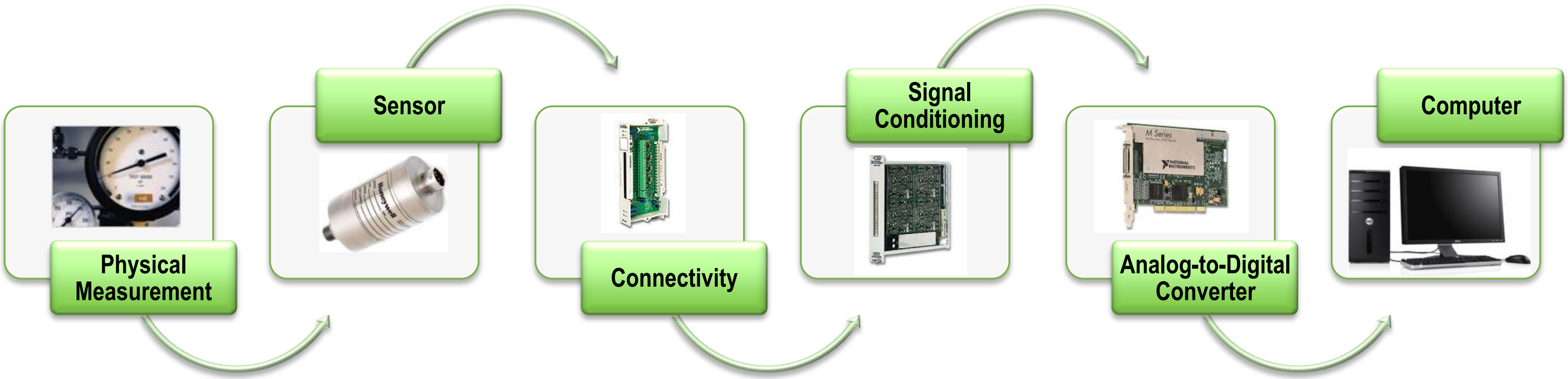




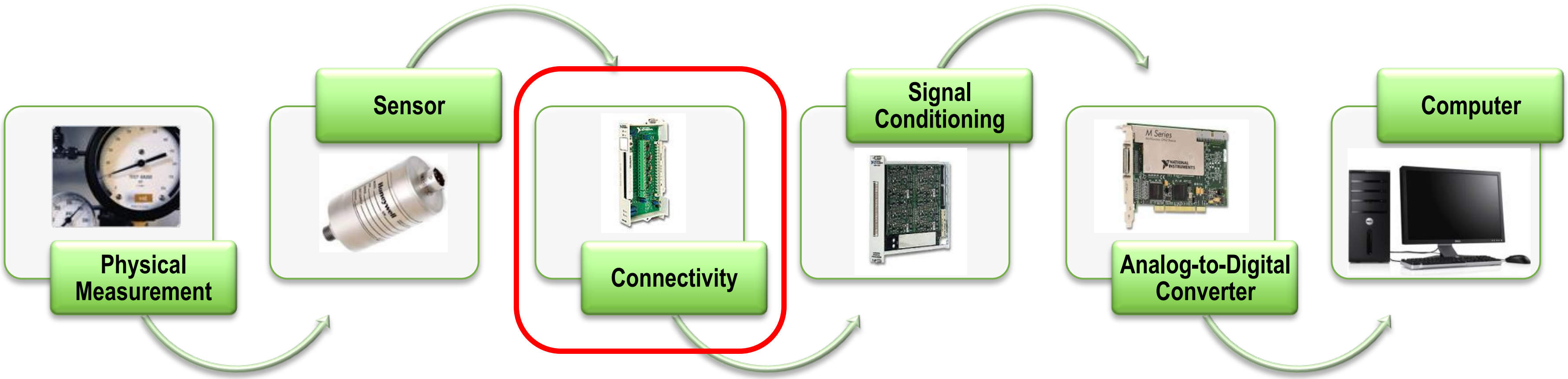
Rotary Torque Sensors: Telemetry



Measurement Components

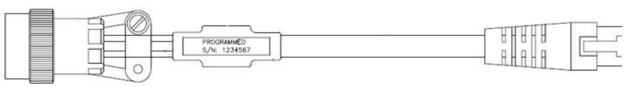


Measurement Components



Honeywell → NI Connectivity

Honeywell Sensors



TEDS-Enabled Cable Assembly
(from Honeywell)

NI 9237

TEDS Technology

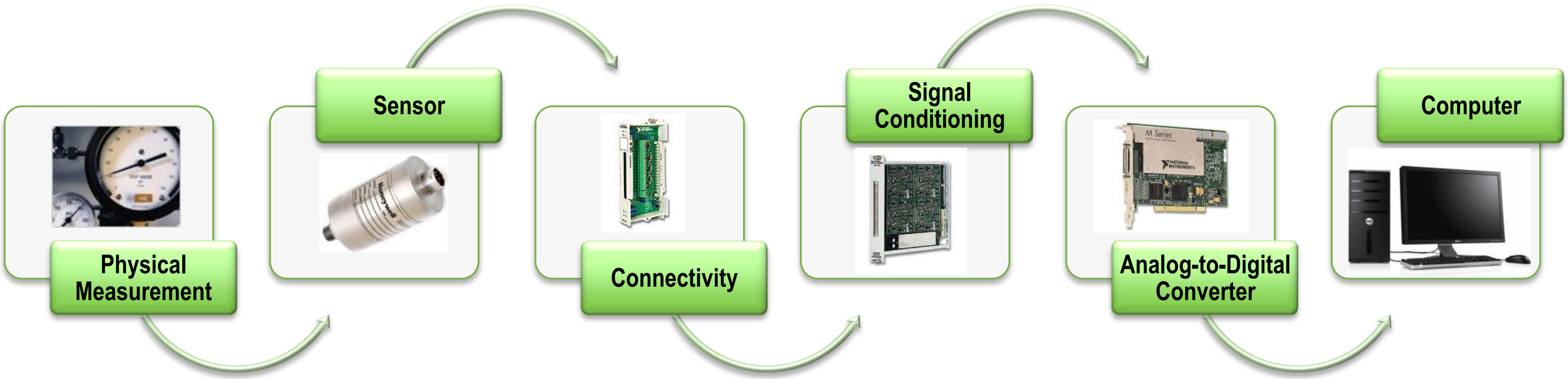
- IEEE standardized template
- Stores sensor-specific information in EPROM onboard sensor
- Instrumentation must be able to read TEDS chip

TEDS Properties	Values
Manufacturer ID	Sensotec (ID# 40)
Model Number	41
Version Number	0
Version Letter	R
Serial Number	1185518
Transducer Electrical Signal Type	Bridge Sensor
Minimum Force/Weight	-1.000000E+2 lb
Maximum Force/weight	1.000000E+2 lb
Minimum Electrical Value	-1.008900E-3 V/V
Maximum Electrical Value	1.008900E-3 V/V
Mapping Method	Linear
Bridge type	Full
Impedance of each bridge element	3.520000E+2 Ohm
Response Time	1.009457E-3 sec
Excitation Level (Nominal)	1.000000E+1 V
Excitation Level (Minimum)	1.000000E+0 V
Excitation Level (Maximum)	2.000000E+1 V
Calibration Date	1/24/2008
Calibration Initials	MK
Calibration Period (Days)	1797 days
Measurement location ID	0
Calibration date	1/1/1998
Sensitivity @ Fref	1.000000E-4 V/(m/s²)
Fref	1.017502E+1 Hz
F hp electrical	1.000000E-2 Hz

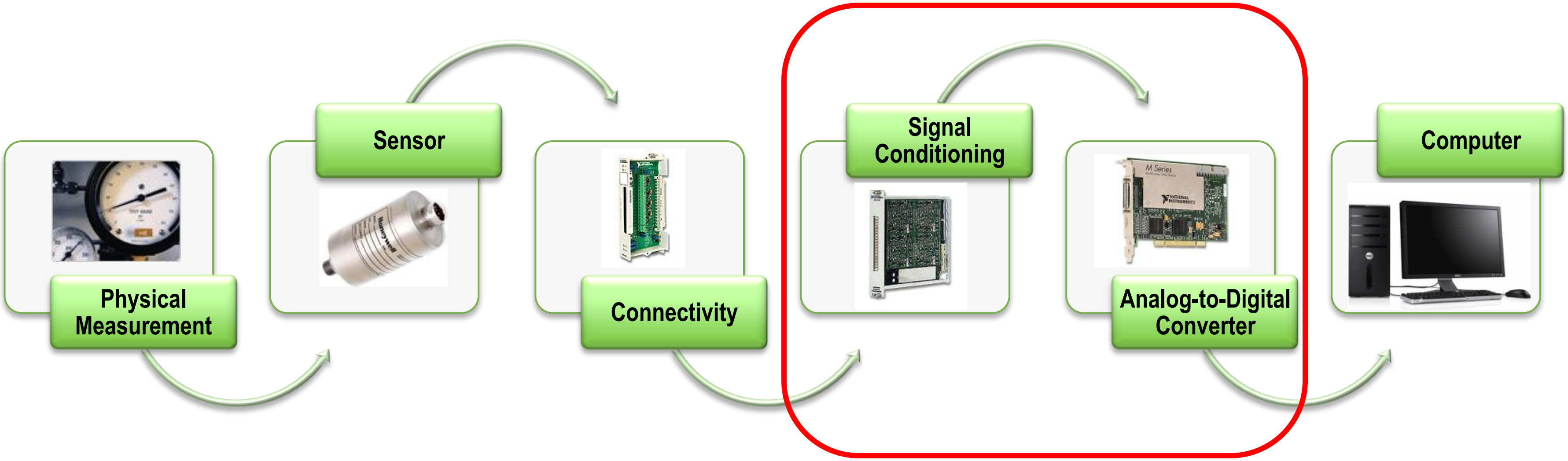
TEDS Advantages

- Sensor tracking
  - Calibration periods
  - Tie data back to a specific sensor
- Reduce system configuration time
  - Scale and calibration information automatically loaded into software
  - Plug any sensor cable into any instrument channel
- Store sensor location in “user data”
  - Eg. “hydraulic press feedback sensor,” “left wingtip force”

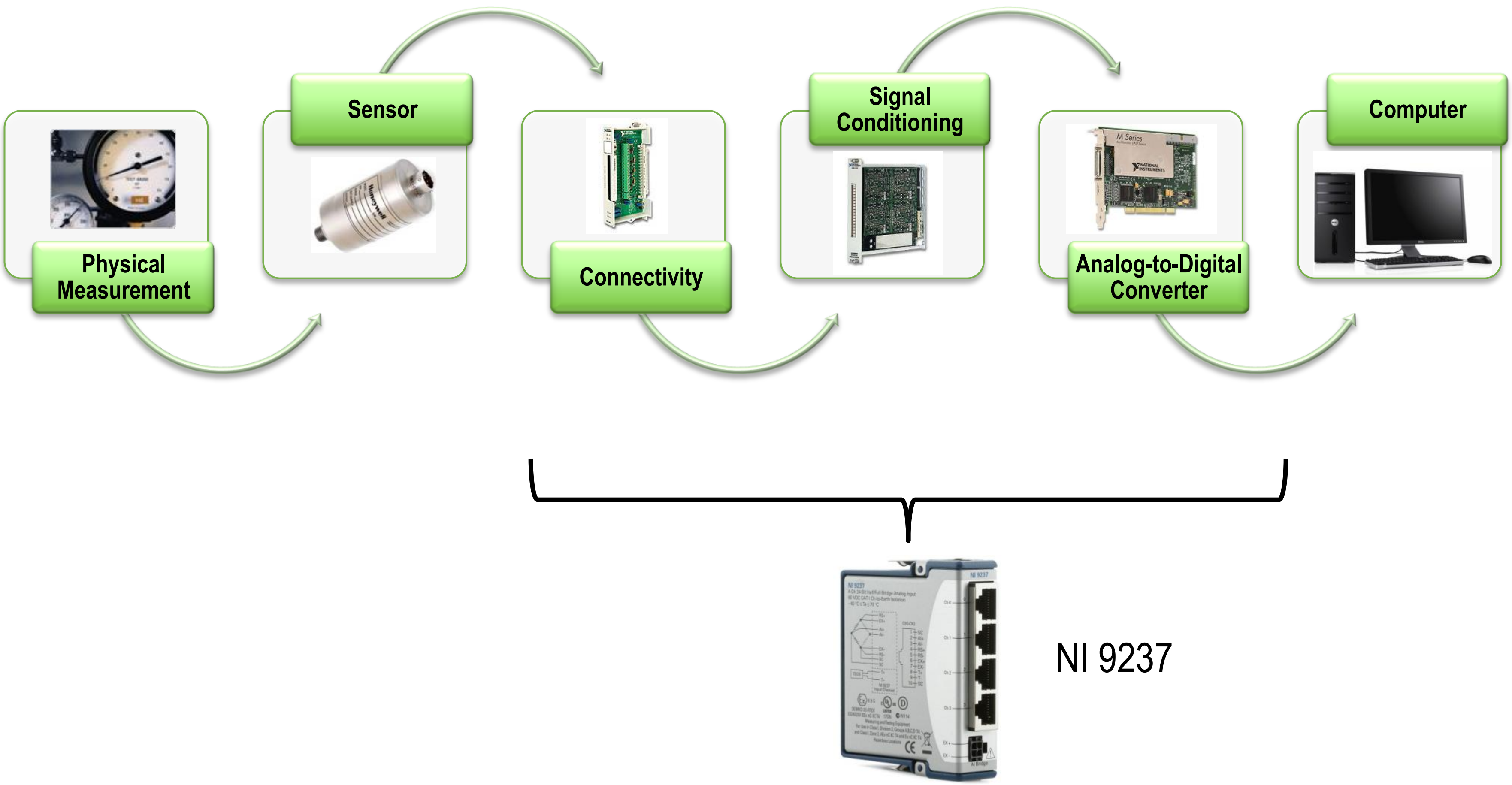
Measurement Components



Measurement Components



Measurement Components



Measuring Bridge-Based Sensors

- Excitation to power the bridge
- ADC to measure signal
- Remote sense (optional)
- Shunt calibration (optional)

Excitation

To detect a change in resistance, voltage (excitation) must be applied.

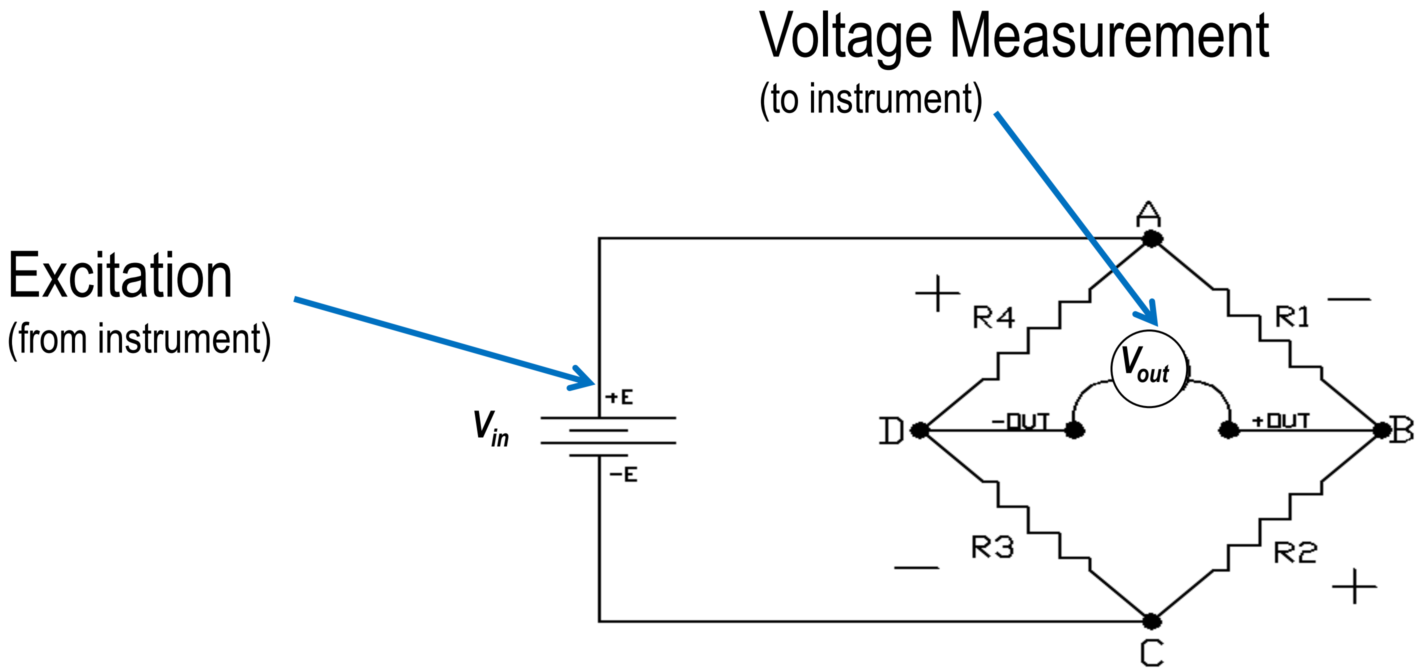
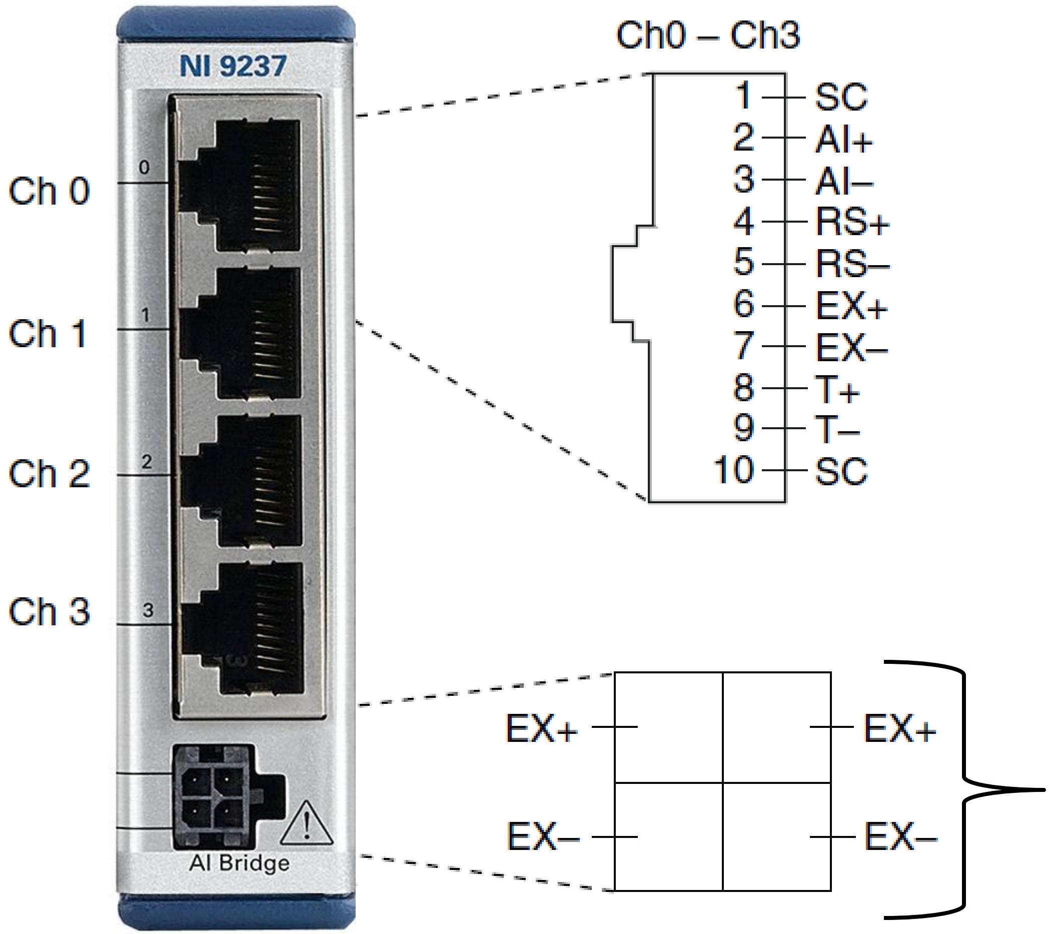


Diagram of Full Bridge Inside Load, Pressure, or Torque Sensor

Example Device Pinout

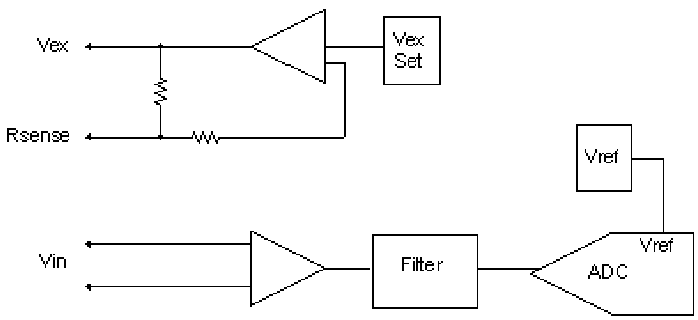


SC = Shunt Calibration
AI = Signal Input
RS = Remote Sense
EX = Power for Sensor
T = TEDS Communication

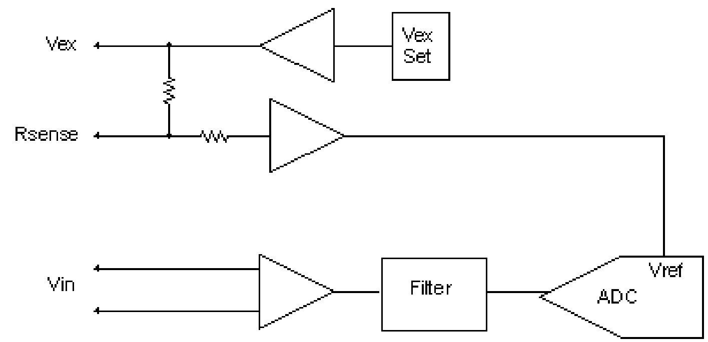
Unique to NI 9237. Provides external excitation input to pass through to sensors (optional).

Ratiometric Bridge Measurements

Traditional Approach



Ratiometric Approach



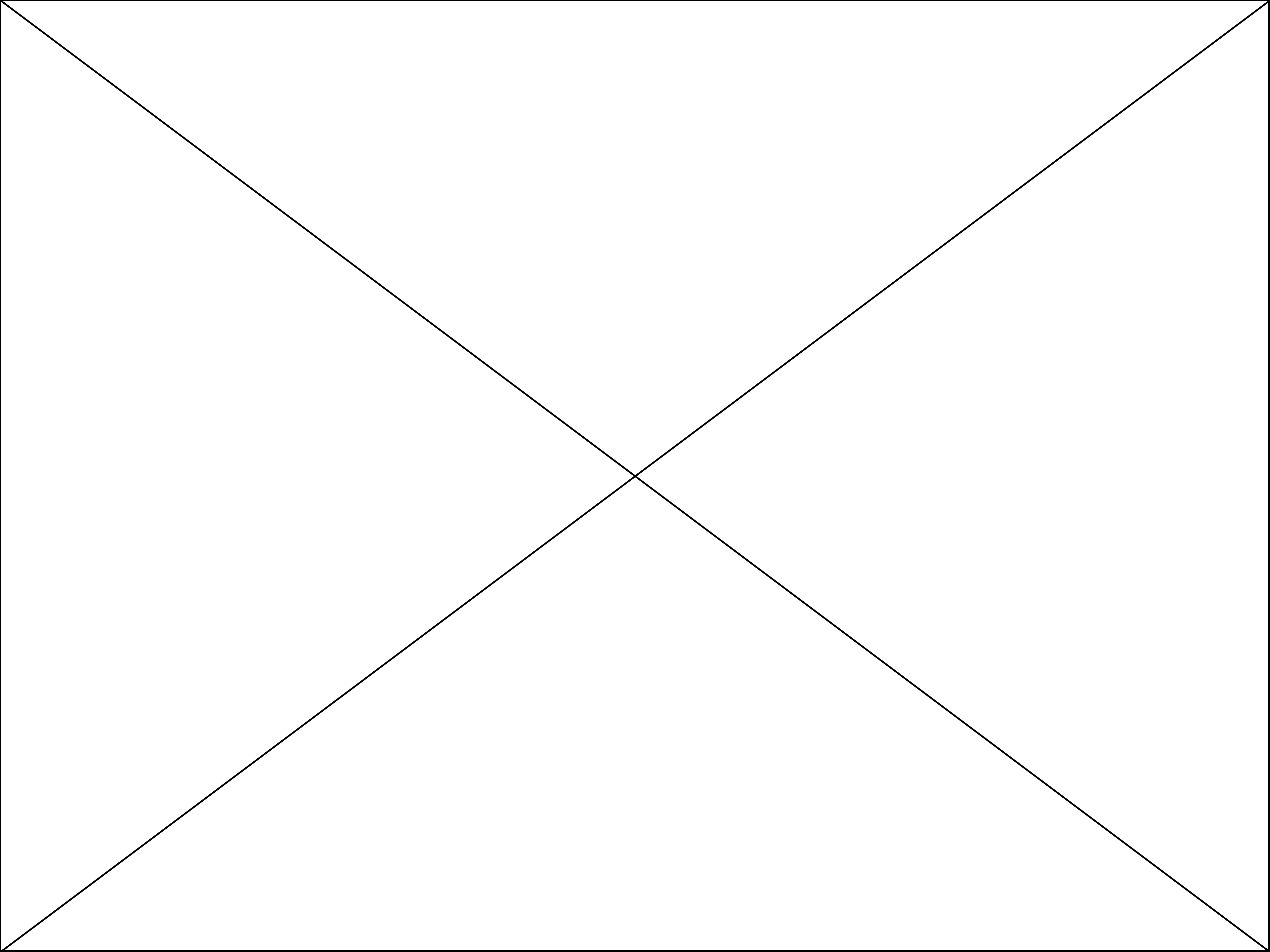
Advantages

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

High Resolution ADC

Weighing nickels with a load cell

Hardware Demonstration



NI Solutions for Bridge Measurement

NI CompactDAQ

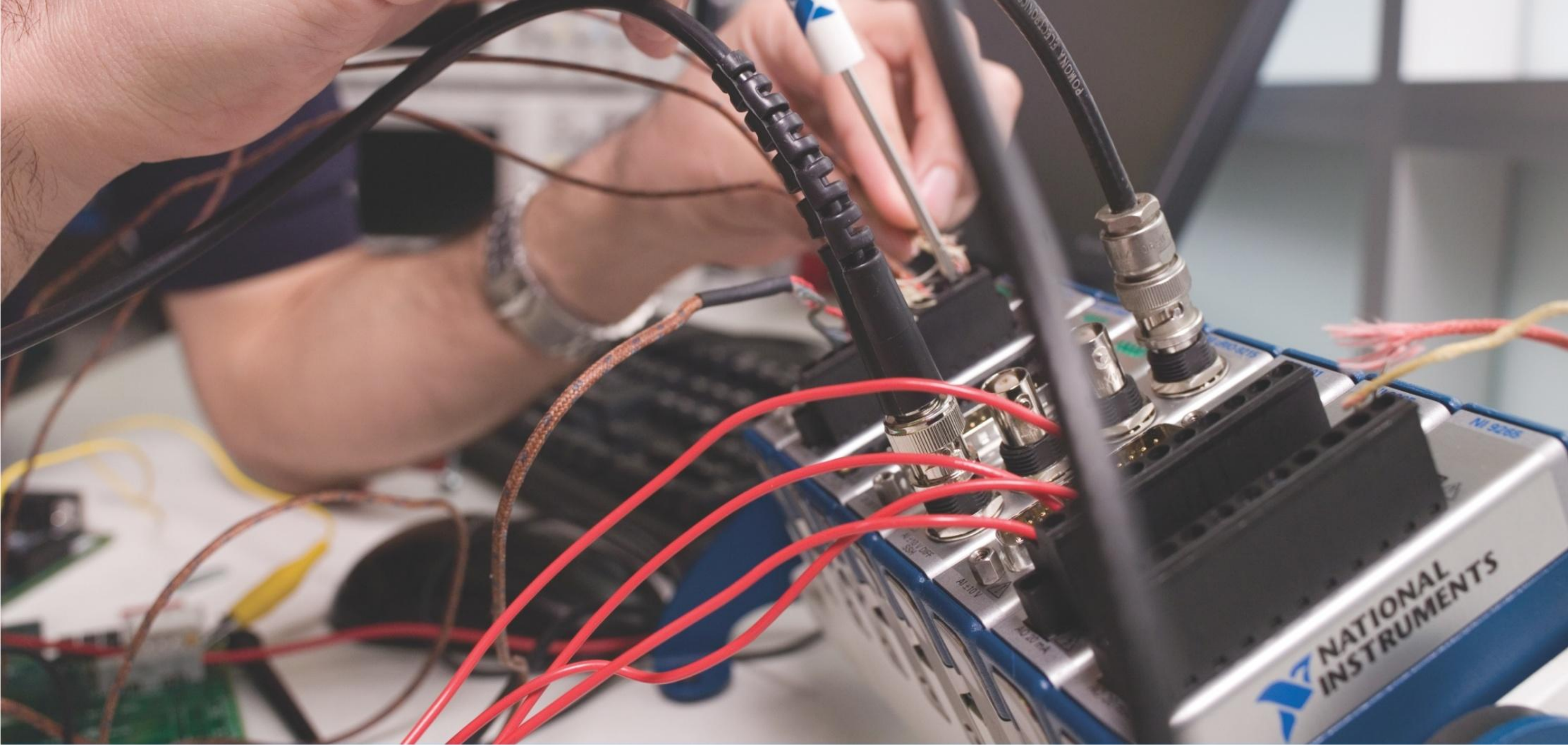
- **NI 9237** universal strain module
- **NI 9235/36** high-density quarter-bridge modules

- Rugged, compact
- USB, wireless, Ethernet
- Synchronized

PXI

- **NI PXIe-4330** universal strain module

- Best accuracy
- Best synchronization
- Highest bandwidth



ni.com/data-acquisition