INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Senzory a měření

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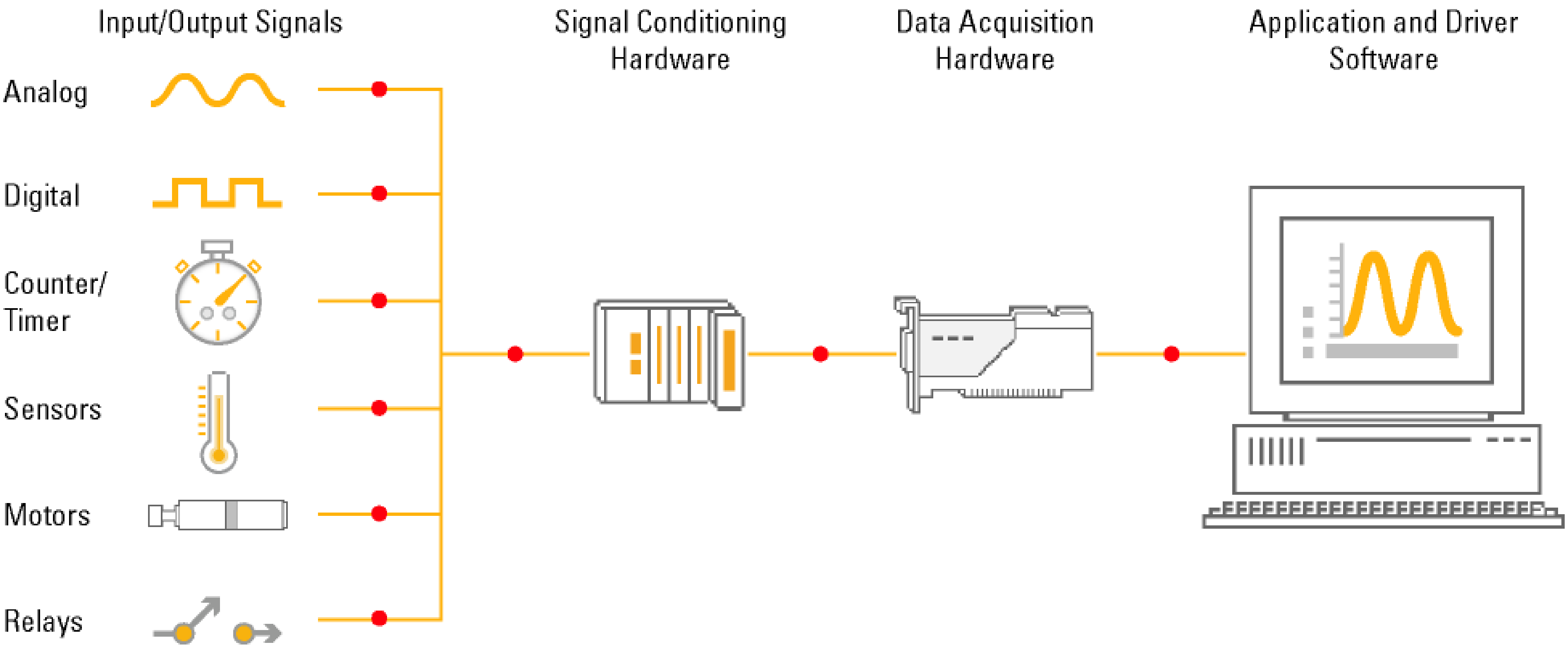
12. 2. 2010

Tato prezentace je spolufinancována Evropským sociálním fondem a státním rozpočtem České republiky.

Agenda

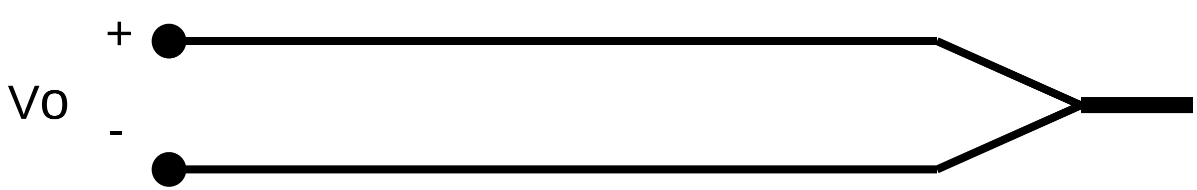
- Components of a DAQ system
- Sensors
- Signal conditioning
- Measurements

PC-Based Data Logging System

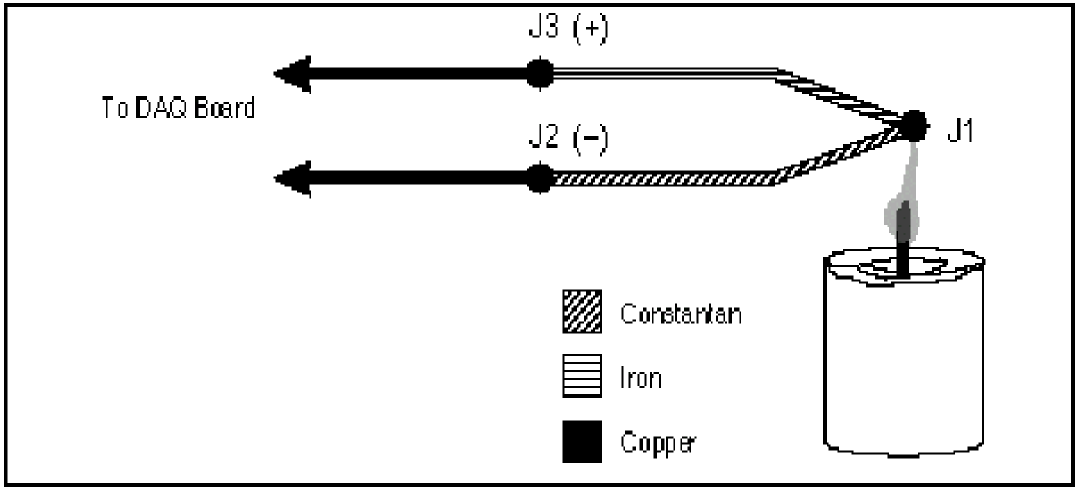


Thermocouple Operation

- Due to the "Seebeck Effect," dissimilar metals in contact produce a voltage proportional to the temperature difference between the hot and cold junctions (mV)
- Voltage is added to the thermocouple at the cold junction
- CJC (Cold Junction Compensation) accounts and corrects for this added voltage

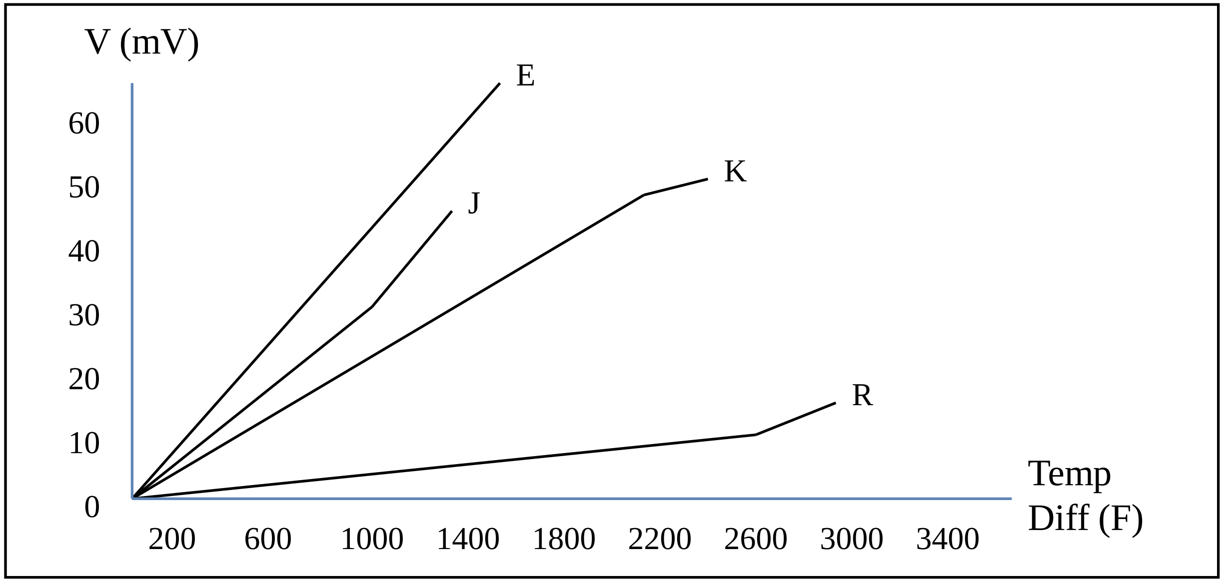


Thermocouple Construction



- 2 wires twisted and bonded together made of *dissimilar metals*
  - J1: “hot” junction, T_{HJ}
  - J2 & J3: “cold” junctions, T_{CJ}

Thermocouple Output



- Voltage signal of a thermocouple is proportional to
- temperature at the hot junction
- The voltage vs. temperature relationship is nonlinear over
- large temperature ranges

Thermocouple Color Codes

Type	Material		Color Code		Overall Jacket		Range (°C)	
Thermocouple Grade	*Positive Wire*	*Negative Wire*	*Positive Wire*	*Negative Wire*	*Extension*	*Overall Jacket*	*min*	*max*
J	Iron	Constantan	White	Red	Black	Brown	0	750
K	Chromel	Alumel	Yellow	Red	Yellow	Brown	-200	1250
T	Copper	Constantan	Blue	Red	Blue	Brown	-200	350
E	Chromel	Constantan	Purple	Red	Purple	Brown	-200	900

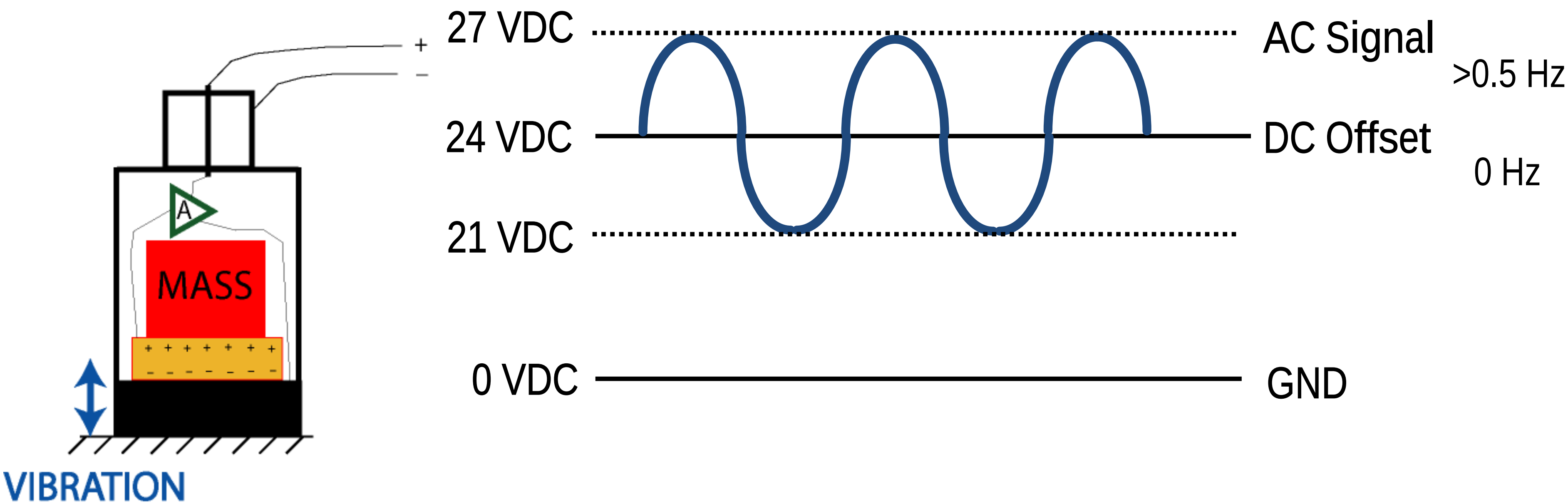
- **Note:** Unlike most leads, the red lead for thermocouples is negative

Accelerometers

- Measure
  - Acceleration
  - Velocity and displacement (via integration versus time)
- Result is expressed in units of *g* or *m/s*^{2}
  - 1 g = acceleration at the surface of Earth
  - 1 g = 9.81 m/s^2

- Construction
  - Stainless steel, welded, isolated, sealed
- Sensitivity ranges
  - 50 mV/g, 100 mV/g, 200 mV/g, 500 mV/g

Accelerometer Operation – IEPE, ICP...



- When exposed to vibration, the accelerometer generates an analog output signal, which is proportional to the acceleration of the applied vibration
- Excitation: 2 to 20 mA constant current; 18 to 30 VDC

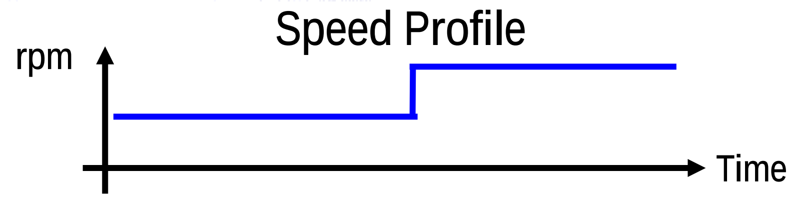
Proximity Probe

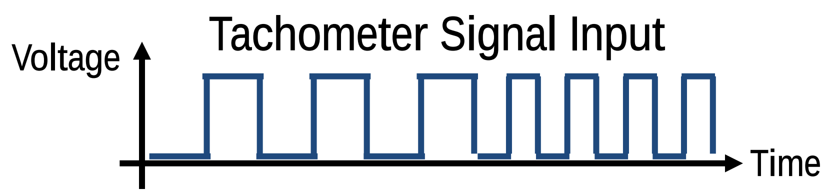
- Measure
  - Distance or displacement
- Result is expressed in *mils* or *mm*
  - 1 mil = 0.001 in.
- Uses
  - Journal bearing vibration, imbalance, misalignment
- Sensitivity ranges
  - 50 mV/mil, 200 mV/mil

Image courtesy of Metrix Corp.

Tachometers

- Measure
- Angular position and speed (rpm)
- Output
- Square wave/pulse train (analog tachometer)
- Used for
- Order analysis
- Order tracking
- Angular averaging





Laser tachometer courtesy of PCB Piezotronics

Resistance

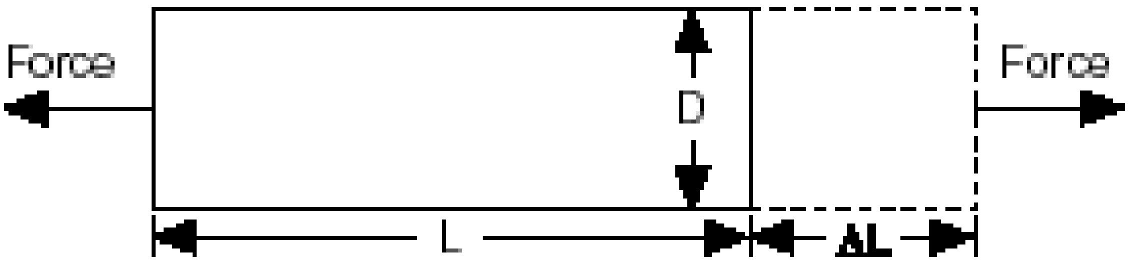
- Resistance measurements are used for the following measurements:
  - DMM
  - RTD
  - Thermistor
  - Potentiometer

- By using Ohms Law Voltage = Current * Resistance
- find
- Resistance = Voltage / Current

- Apply a known current (typically 20ma) across an unknown resistance and measure the resultant voltage.

Strain

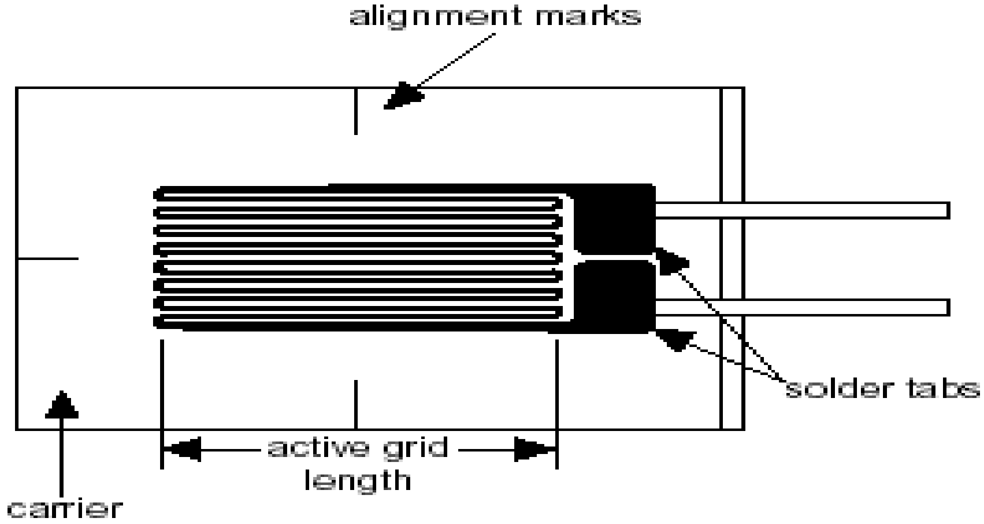
– Strain is the amount of deformation of a body due to an applied force
– Strain (ε) is defined as the fractional change in length as shown below



$$\varepsilon = \frac{\Delta L}{L}$$

Strain Gage Construction

- Thin wire or metal foil in a zigzag pattern is fastened to a “carrier”



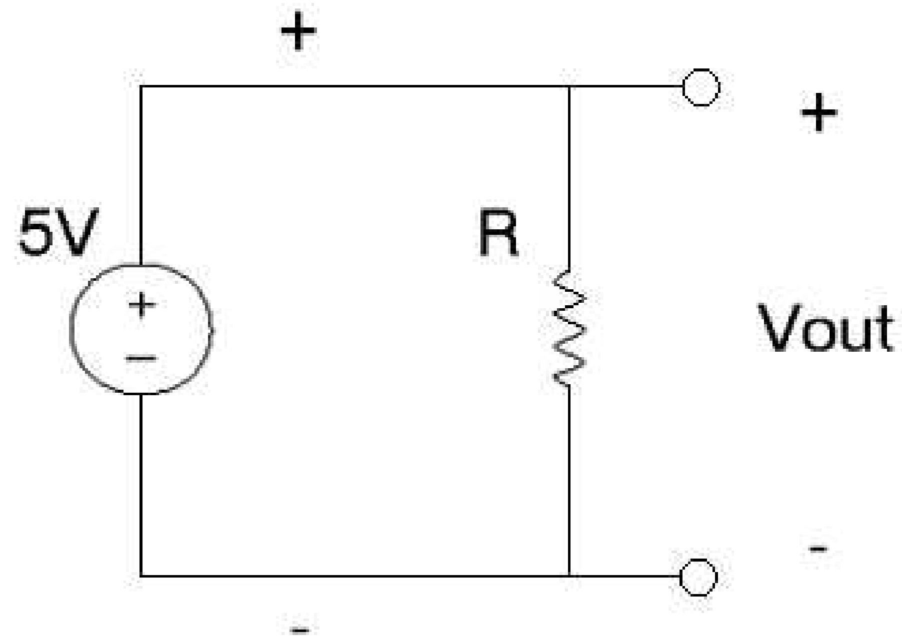
Strain

- Fundamental parameter of the strain gage is its sensitivity to strain
- Expressed as the gage factor (GF)
- Gage factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain)

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

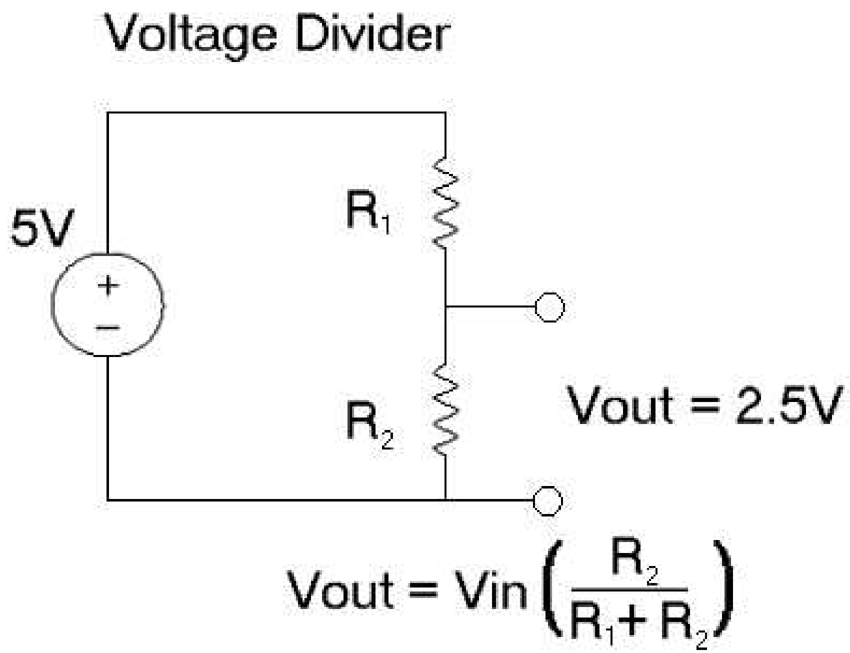
Strain – Circuit Basics

The voltage drop across the resistor is equal to the sourced voltage (5V)



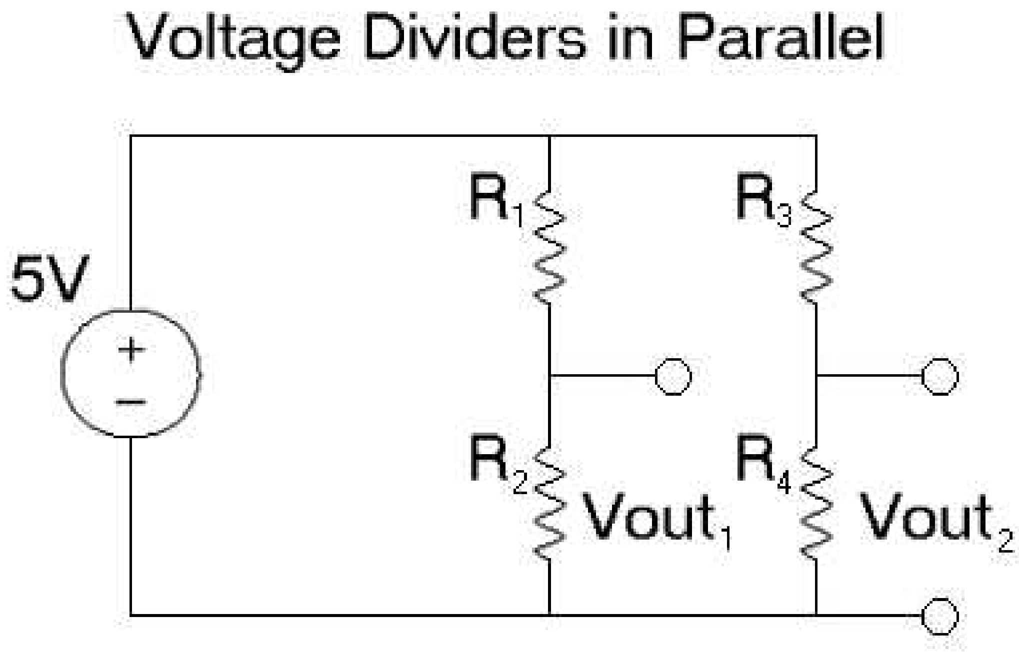
Strain – Circuit Basics

If R_1=R_2 then voltage is dropped equally across the resistors (2.5V across each)



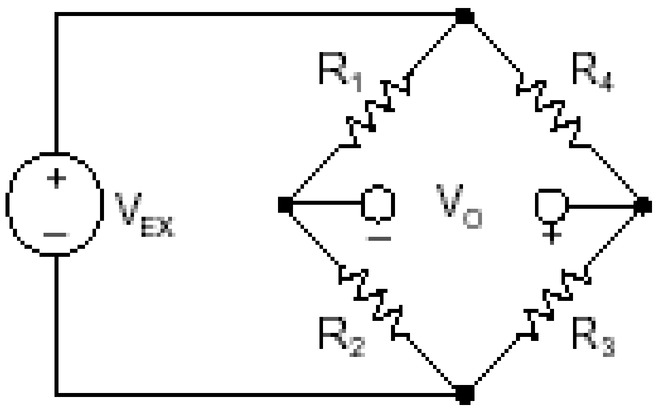
Strain – Circuit Basics

If all resistors are equal then voltage is dropped equally across them (2.50 V across each)



Strain – Circuit Basics

Wheatstone Bridge



$$V_o = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right] \bullet V_{EX}$$

If all resistors are equal then no voltage is read.

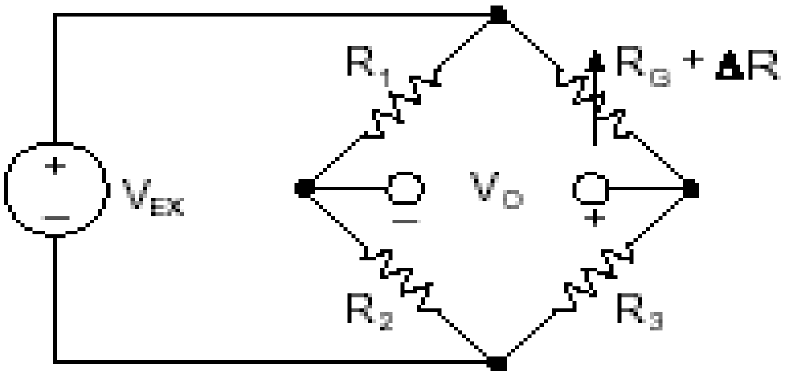
If one or more resistors change, voltage is returned.

- Wheatstone Bridge measures small changes in resistance

Strain – Circuit Basics

- If you replace a resistor with an active strain gage in the Wheatstone Bridge, any changes in the strain gage resistance will unbalance the Bridge

Quarter Bridge Strain Gage



$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{4}\left(\frac{1}{1 + GF \bullet \frac{\varepsilon}{2}}\right)$$

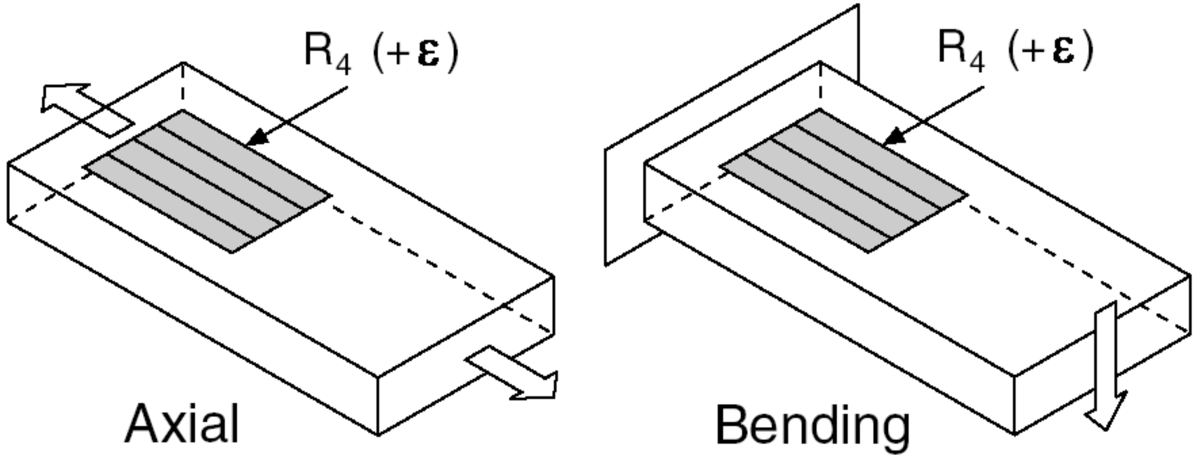
Bridge Terminology

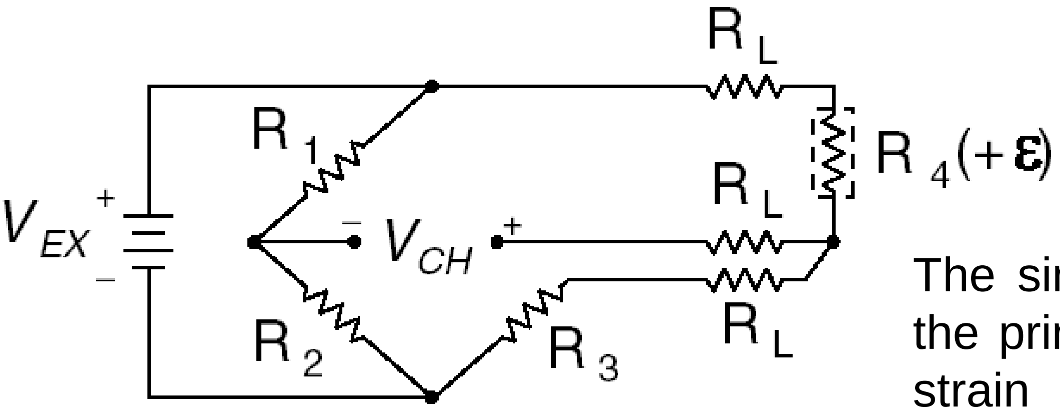
- Three types of Bridge Configurations
  - Quarter
  - Half
  - Full

Configuration	# of Active Elements	# of Active Elements outside Terminal Block
Quarter-bridge	1	1
Half-bridge	2	2
Full-bridge	4	4

- Alignment and wiring of active elements can enhance or minimize certain strains

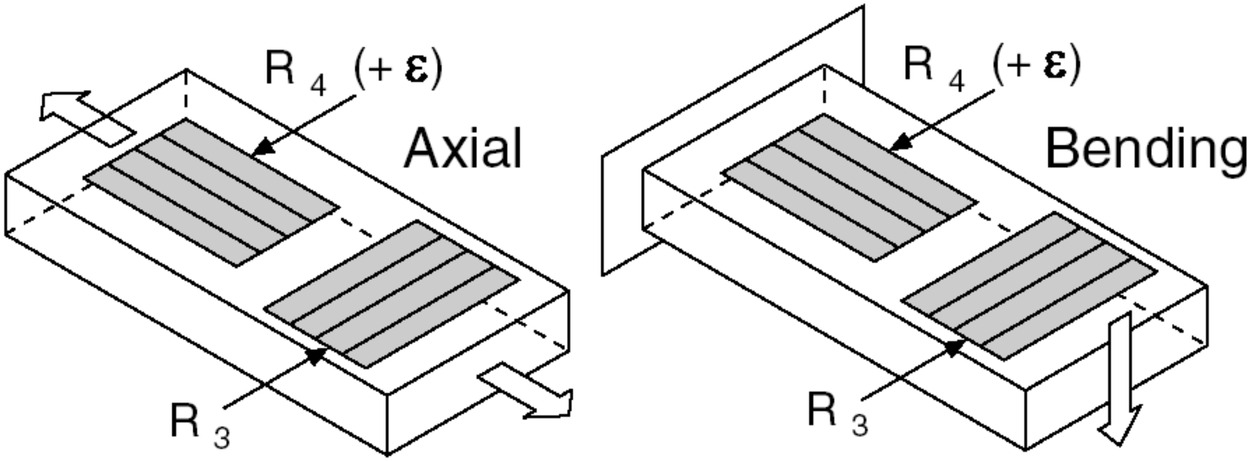
Quarter Bridge I



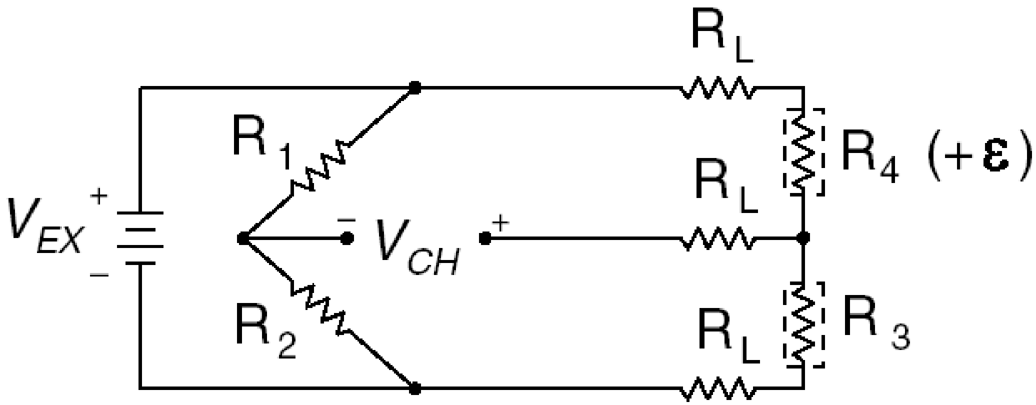


The single active element is mounted in the principle direction of axial or bending strain

Quarter Bridge II

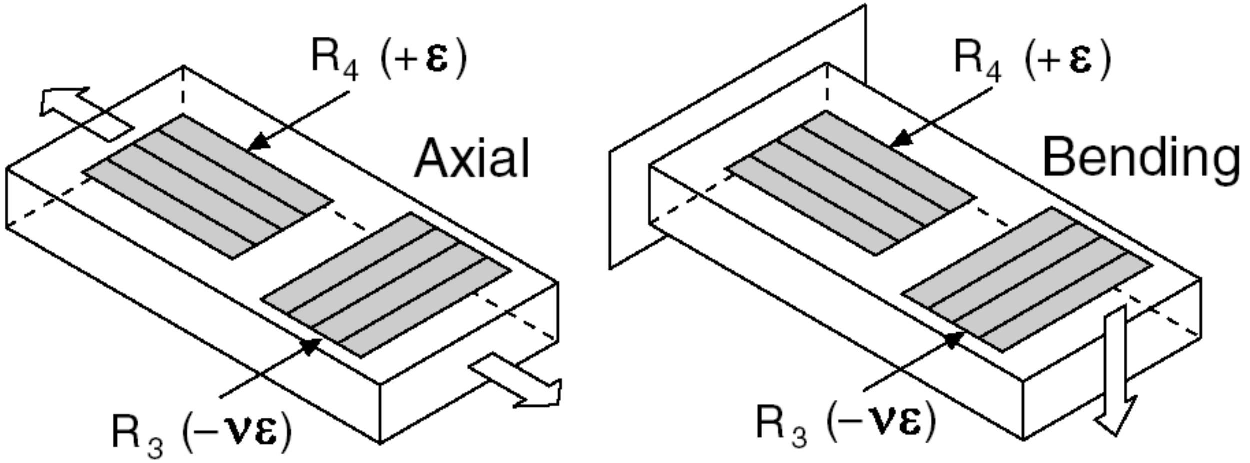


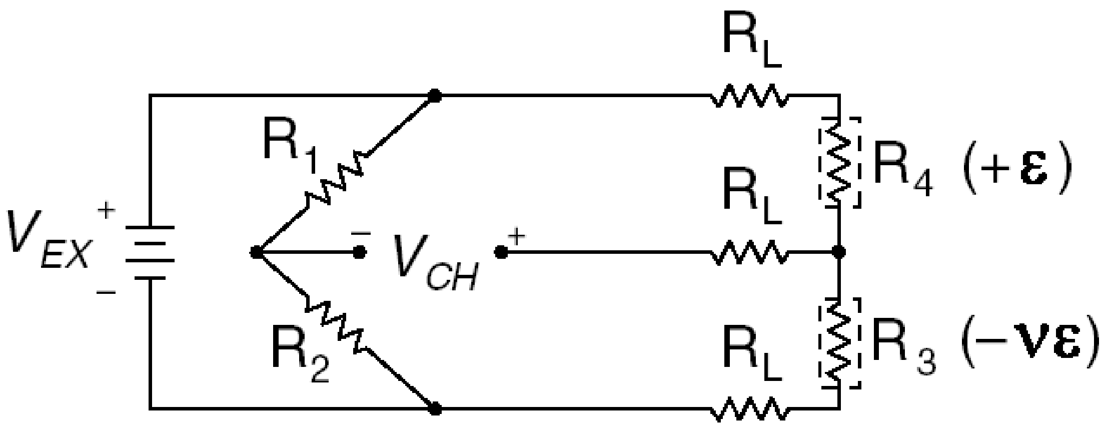
- R4 is mounted in the direction of axial strain – measures tensile strain (+ε)



- R3 (dummy) is mounted in close thermal contact with strain specimen, but not bonded to it – **compensates for temperature**

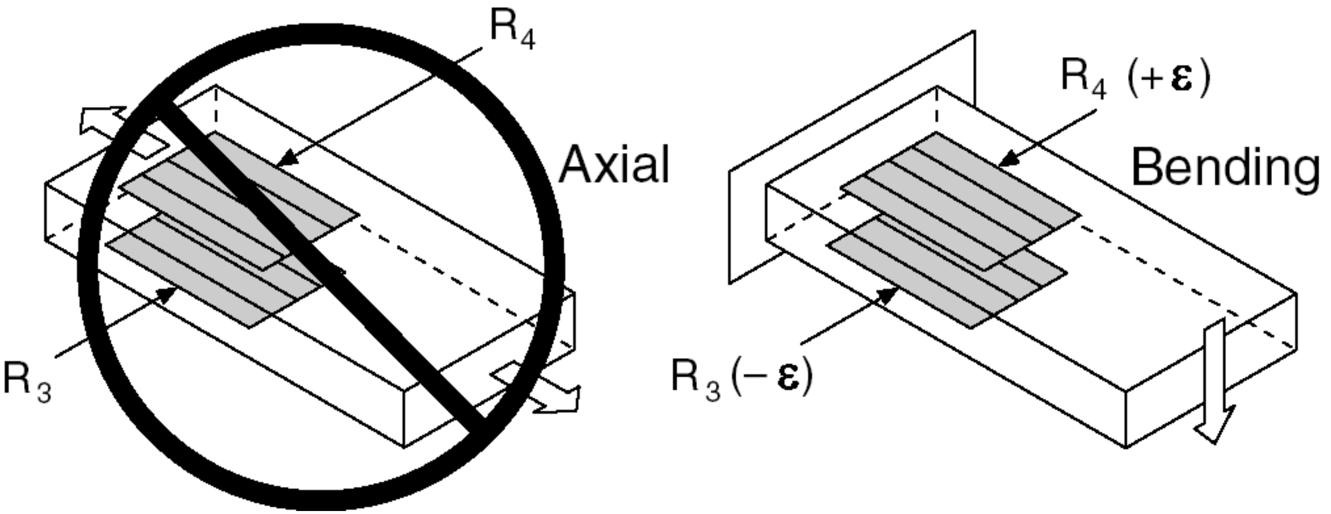
Half Bridge I

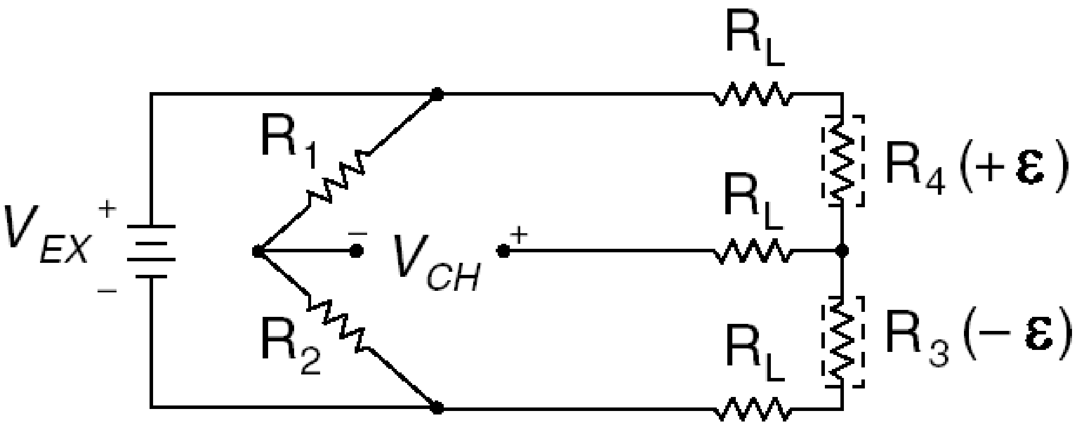




- R4 is mounted in the direction of axial strain – measures tensile strain (+ε)
- R3 measures compression from Poisson effect (-υε)

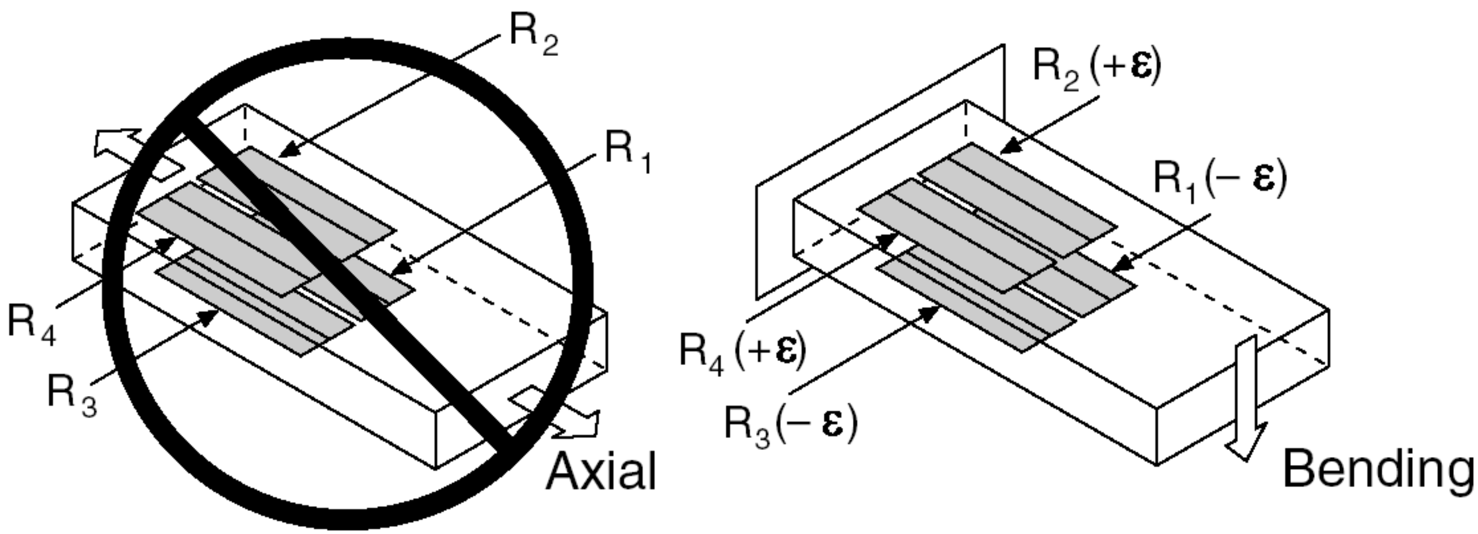
Half Bridge II

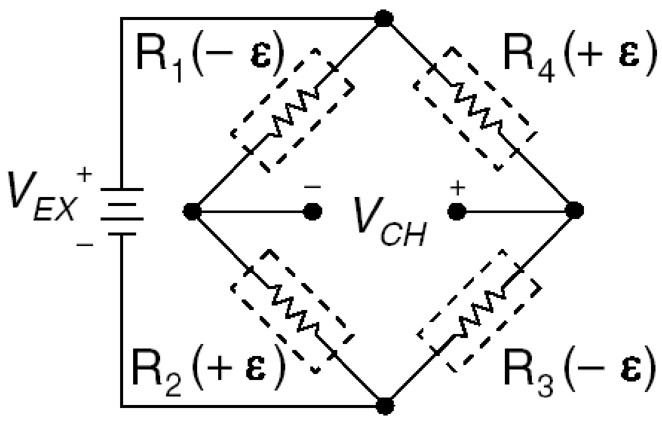




- R4 is mounted on top – measures tensile strain (+ε)
- R3 is mounted on bottom - measures compressive strain (-ε)

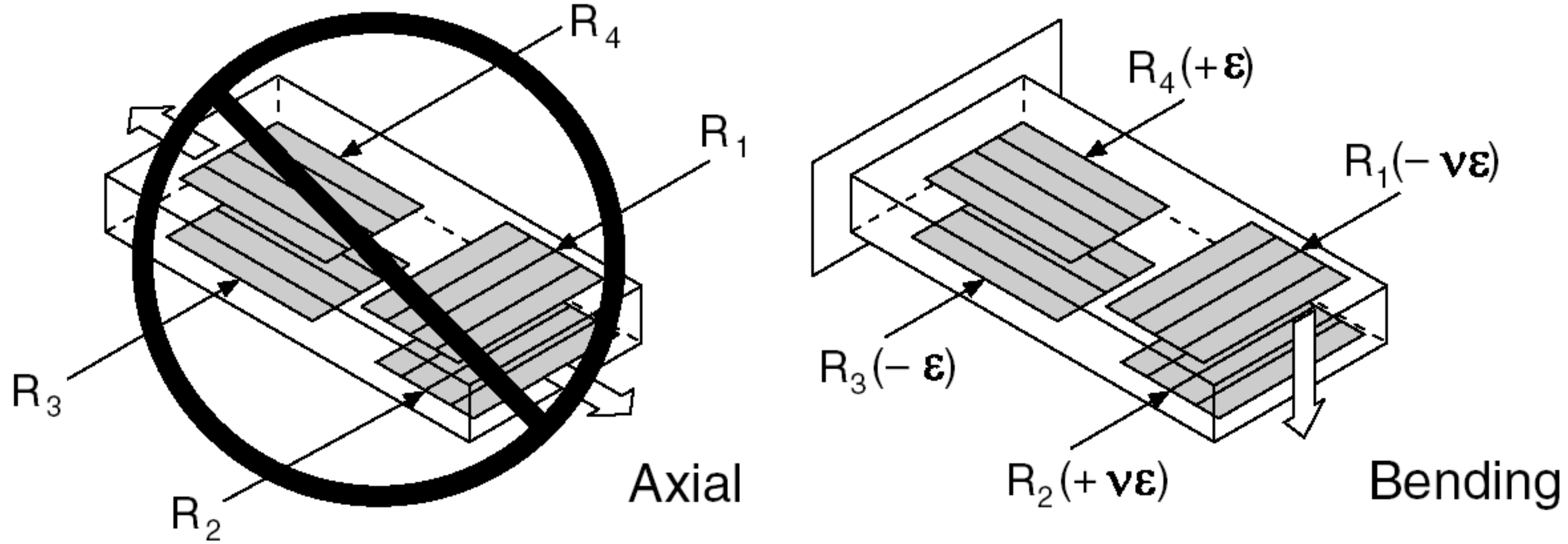
Full Bridge I

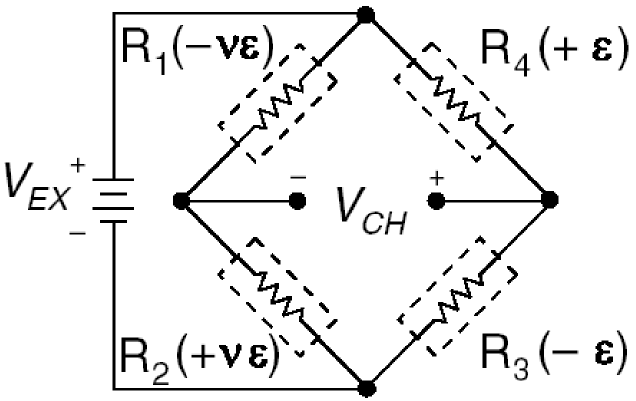




- R2 and R4 measure tensile strain (+ε)
- R1 and R3 measure compressive strain (-ε)

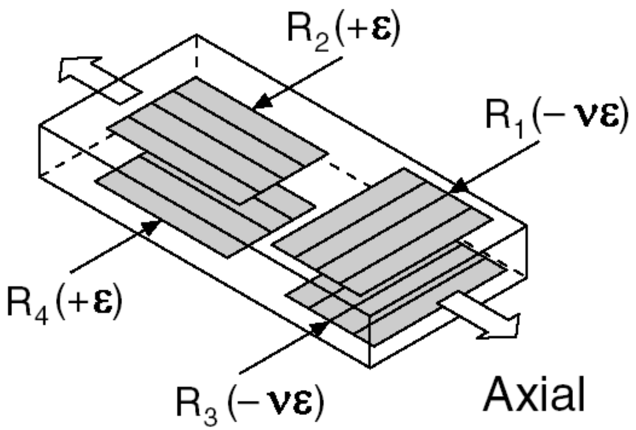
Full Bridge II

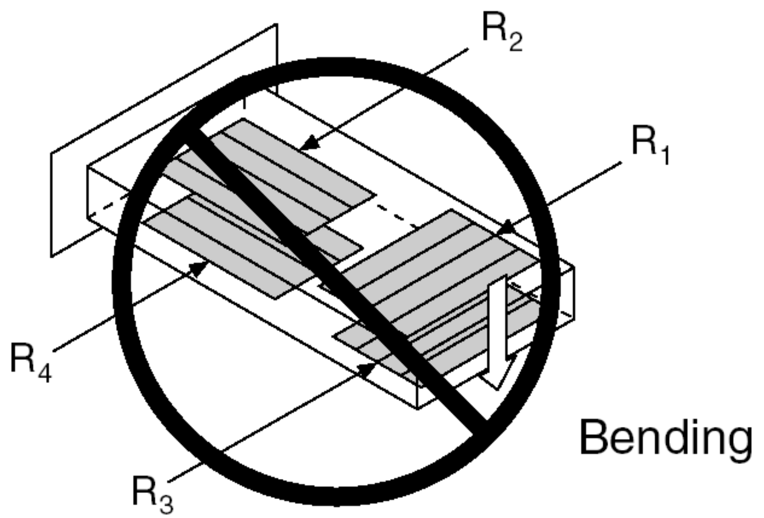


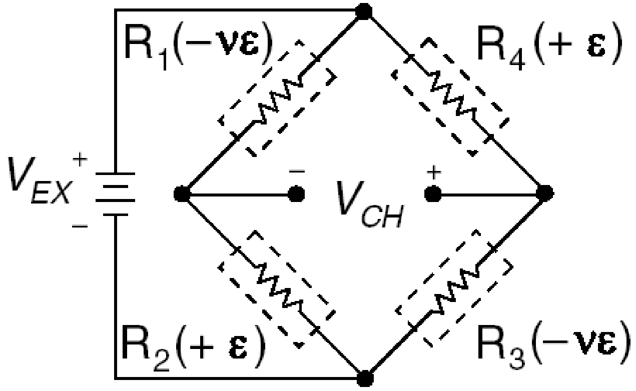


- R1 measures compressive Poisson effect (-υε)
- R2 measures tensile Poisson effect (-υε)
- R3 measures compressive strain (-ε)
- R4 measures tensile strain (+ε)

Full Bridge III







- R1 measures compressive Poisson effect ($-\upsilon\varepsilon$)
- R2 measures tensile strain ($+\varepsilon$)
- R3 measures compressive Poisson effect ($-\upsilon\varepsilon$)
- R4 measures tensile strain ($+\varepsilon$)

Null Compensation

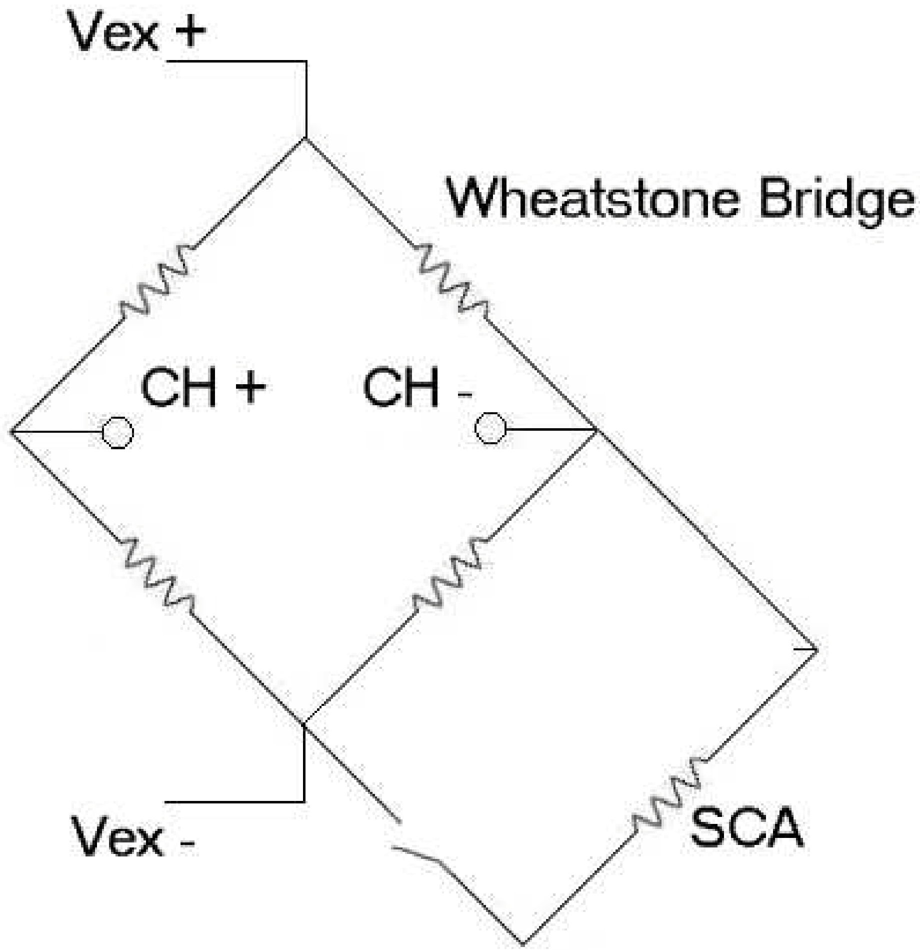
– Essentially an offset calibration
– Ensures that ~zero volts are produced at rest
– Can be performed in HW or SW
– Compensates for inherent bridge imbalance
– Coarse and fine potentiometers are used to perform nulling in hardware

Shunt Calibration

- Essentially a gain calibration
- Known resistance is introduced to the circuit and the measured strain is compared to the expected value
- Correction factor is applied to all subsequent readings
- Strain gage virtual channel only supports one shunt circuit

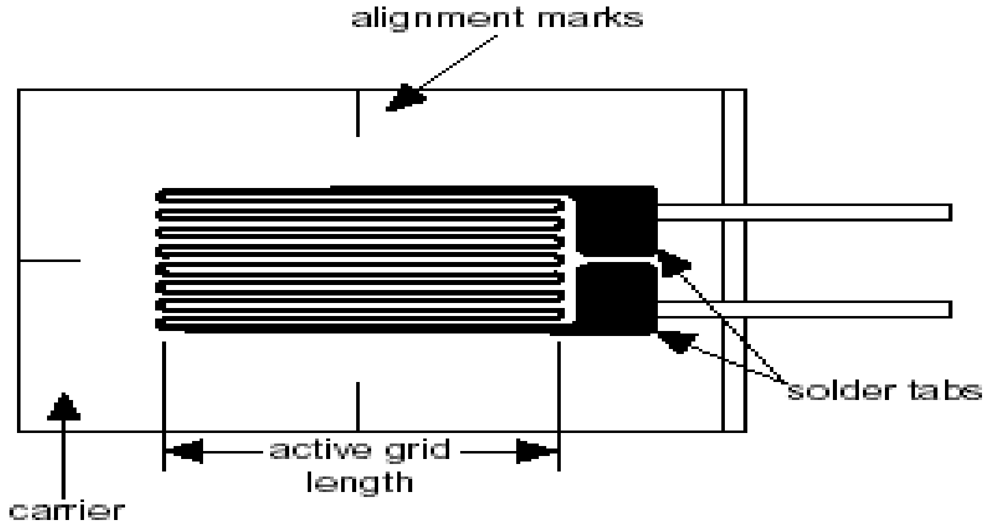
Shunt Calibration Circuit

- Shunt resistor is in parallel to one of the bridge resistors
- The shunt circuit is engaged when the switch is closed (done programmatically)



Strain - Strain Gage Construction

• Strain is the amount of deformation of a body due to an applied force

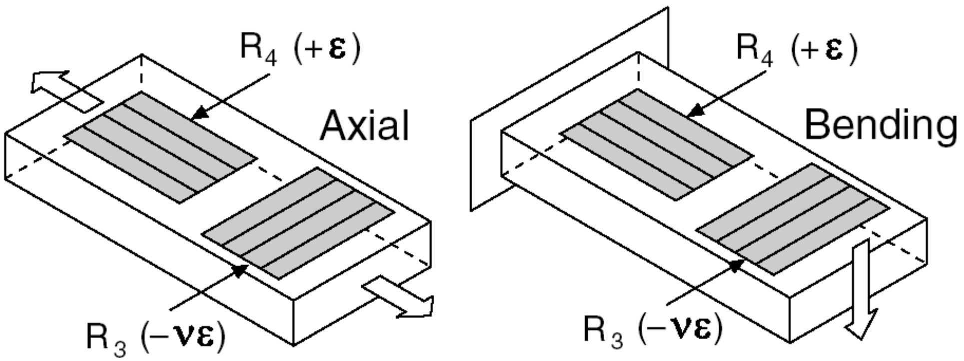


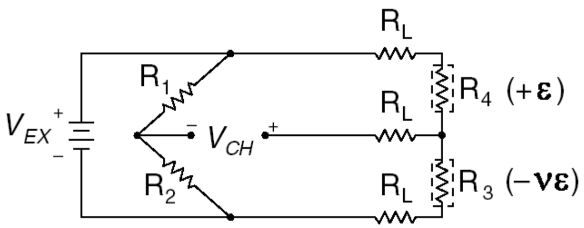
• Thin wire or metal foil in a zigzag pattern is fastened to a "carrier"

Bridge Terminology – Configuration-example

- Quarter-bridge:
  - Quarter Bridge I
  - Quarter Bridge II
- Half-bridge:
  - Half Bridge I
  - Half Bridge II
- Full-bridge:
  - Full Bridge I
  - Full Bridge II
  - Full Bridge III

Half Bridge I

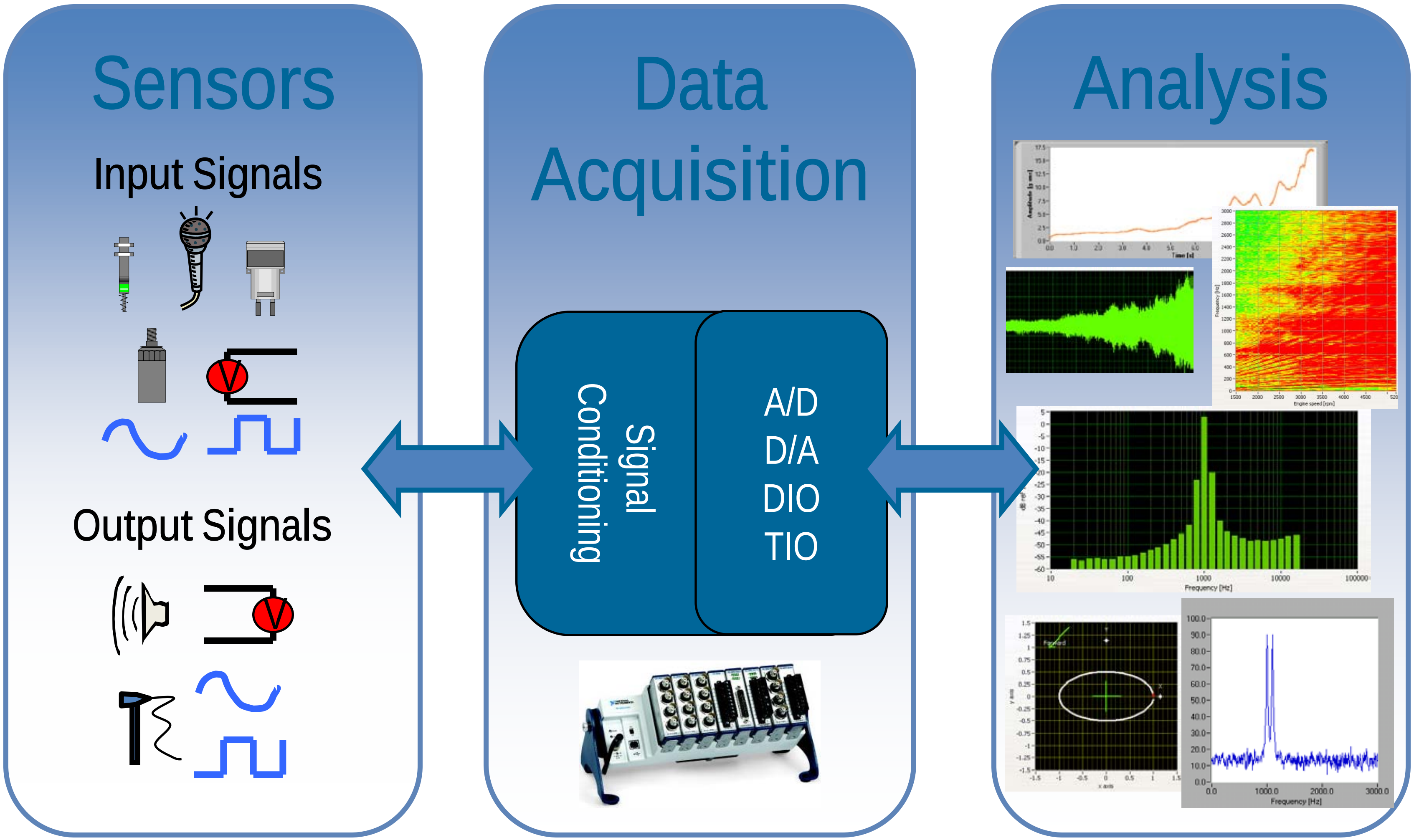




$$F = \frac{\varepsilon\, E\, b\, h^2}{6\, l}$$

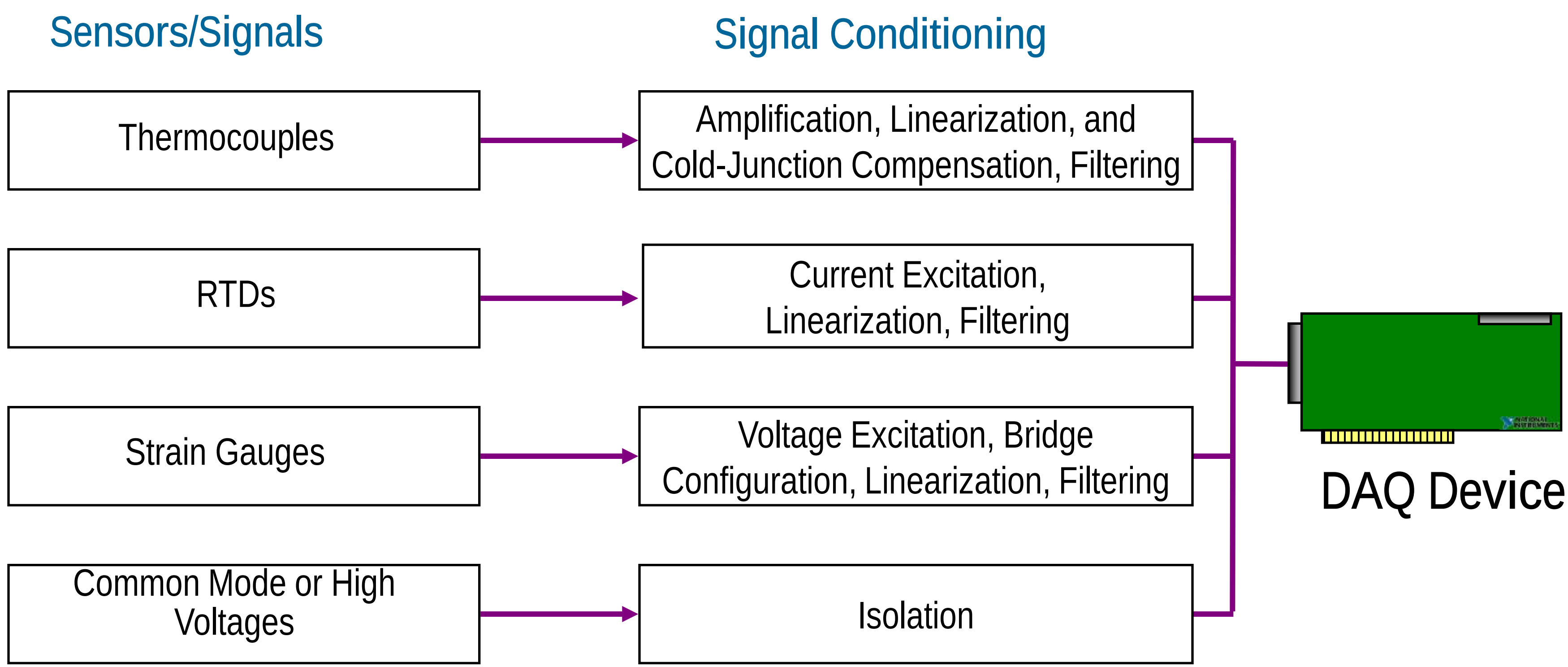
- R4 is mounted in the direction of axial strain – measures tensile strain (+ε)
- R3 measures compression from Poisson effect (-ε)

Data Acquisition System Components



Analog Input – Signal Conditioning

High voltage signals and most sensors require signal conditioning to properly read the signal



Signal Conditioning Hardware Options

Modular Signal Conditioning

SCC

SCXI

USB / Ethernet DAQ

Integrated Signal Conditioning

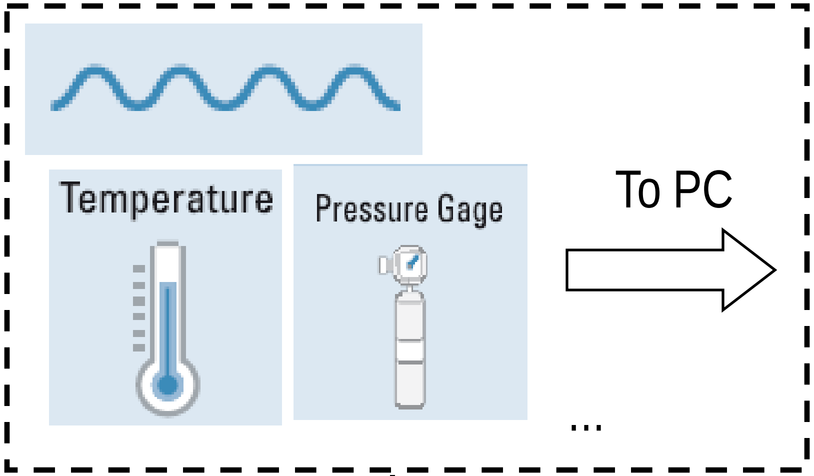
PXI Instruments

CompactRIO

CompactDAQ

Analog Input - Measuring Analog Input Signals

Important Factors to Consider



Analog Input

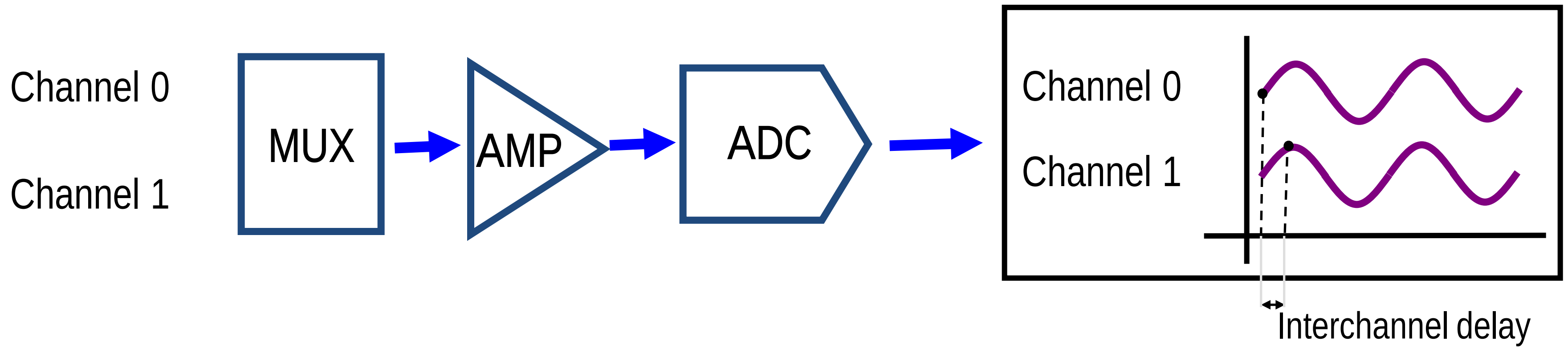
Architecture

- multiplexed
- simultaneous sampling

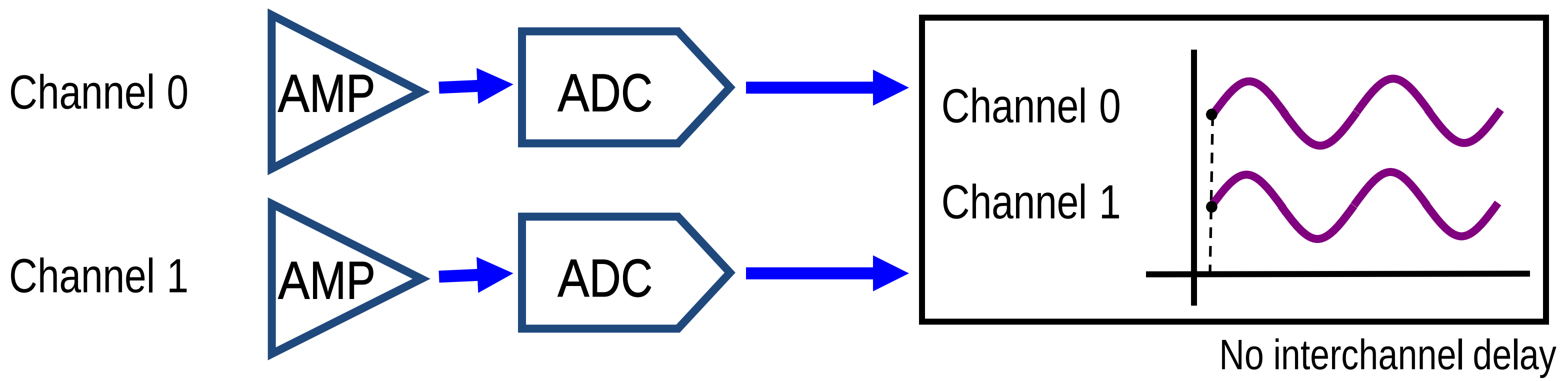
- **Sampling rate**
- **Accuracy**
  - Resolution
  - Absolute accuracy
  - Range and amplification
  - Noise and filtering
  - Dynamic range
- **Sensors and high voltage measurements/Signal Conditioning**

Analog Input - Architectures

Multiplexed

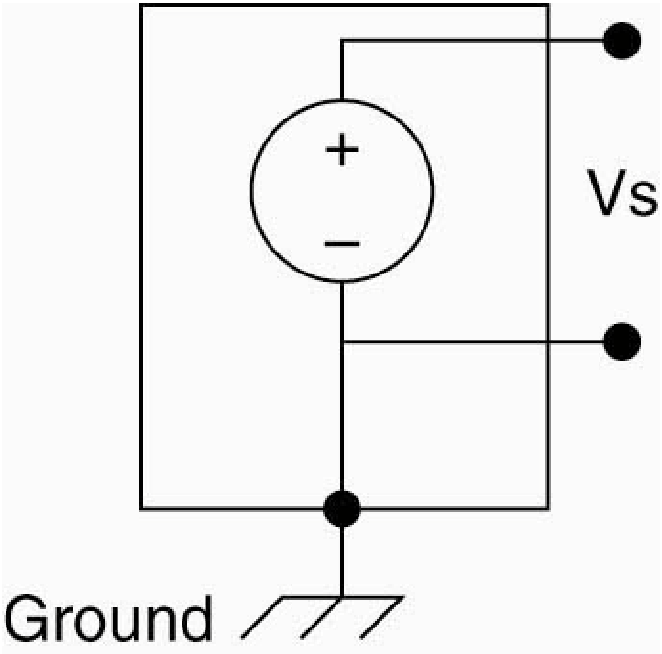


Simultaneous sampling



Measurement Concepts – Grounded Signal Source

- Voltage signals are referenced to a system ground, such as the earth or a building ground
- Because such sources use the system ground, they share a common ground with the measurement device
- Common examples are devices that plug into a building
  ground through wall outlets, such as signal
  generators and power supplies

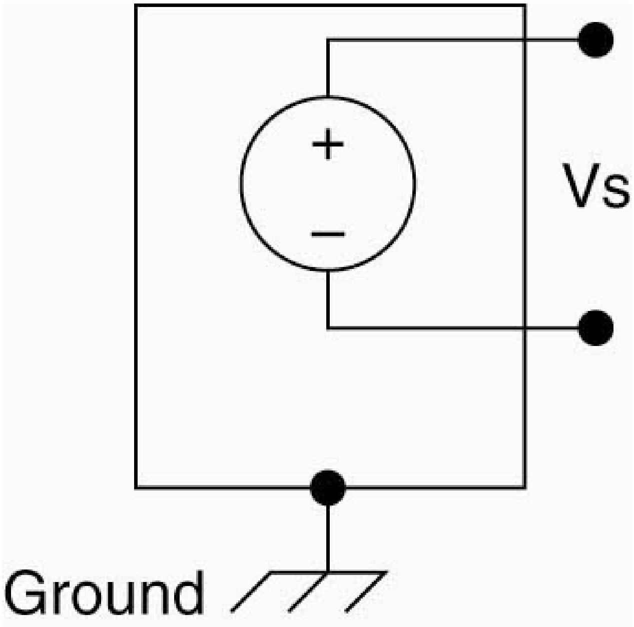


Measurement Concepts – Ground Loop

- The grounds of two independently grounded signal sources generally are not at the same potential
- The difference in ground potential between two instruments connected to the same building ground system is typically 10–200 mV
- The difference can be higher if power distribution circuits are not properly connected

Measurement Concepts – Floating Signal Source

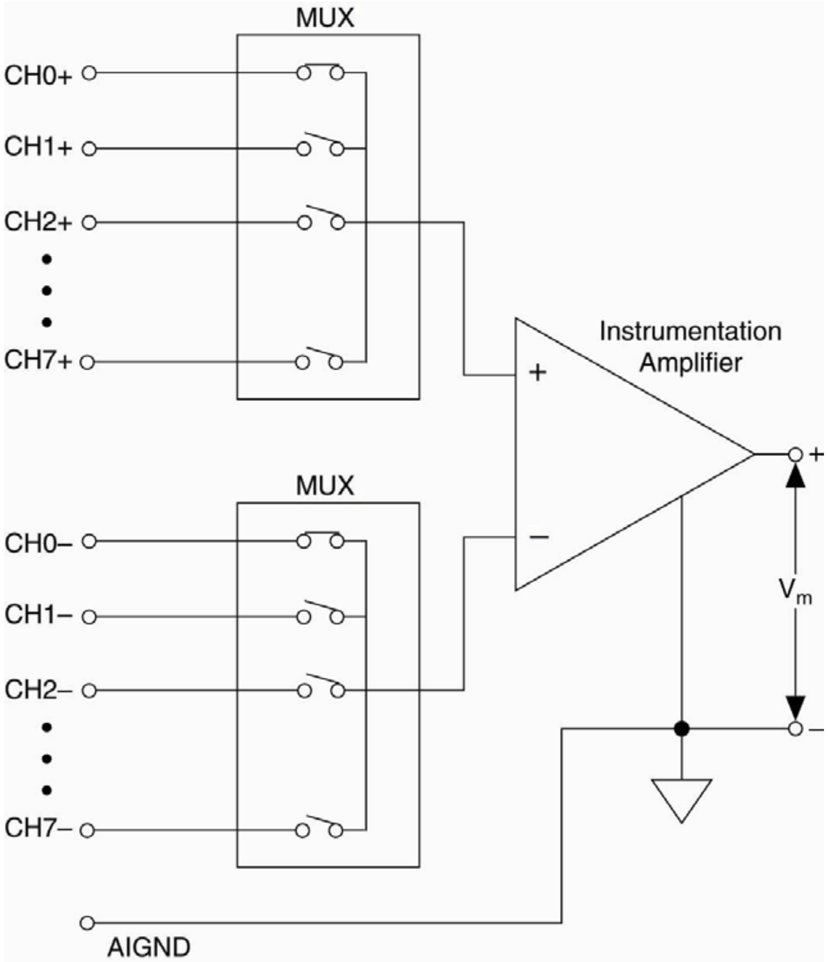
- In a floating signal source, the voltage signal is not referenced to any common ground, such as the earth or a building ground
- Some common examples of floating signal sources are batteries, thermocouples, transformers, and isolation amplifiers



- Neither terminal of the source is connected to the electrical outlet ground - each terminal is independent of the system ground

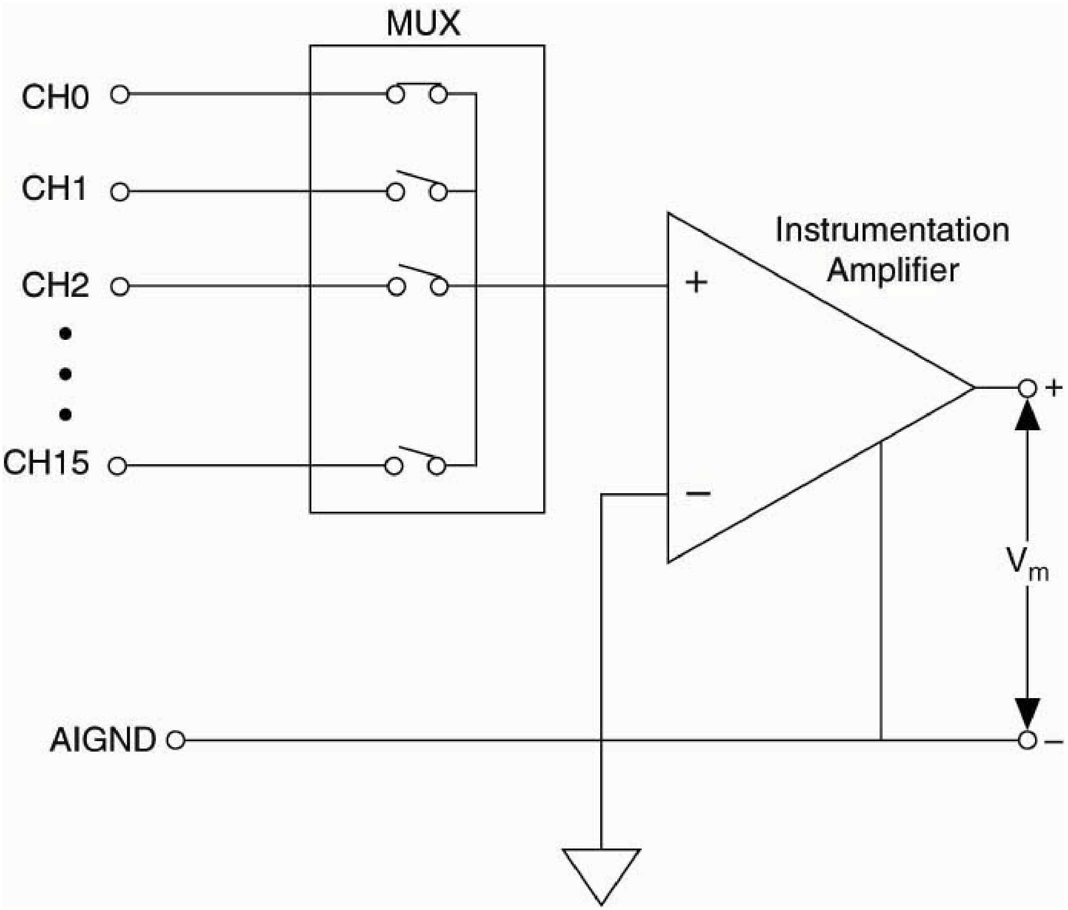
Measurement Concepts – Measurement Systems

- Differential
- AIGND (analog input ground) pin is the measurement system ground
- Requires two channel pins to measurement a signal



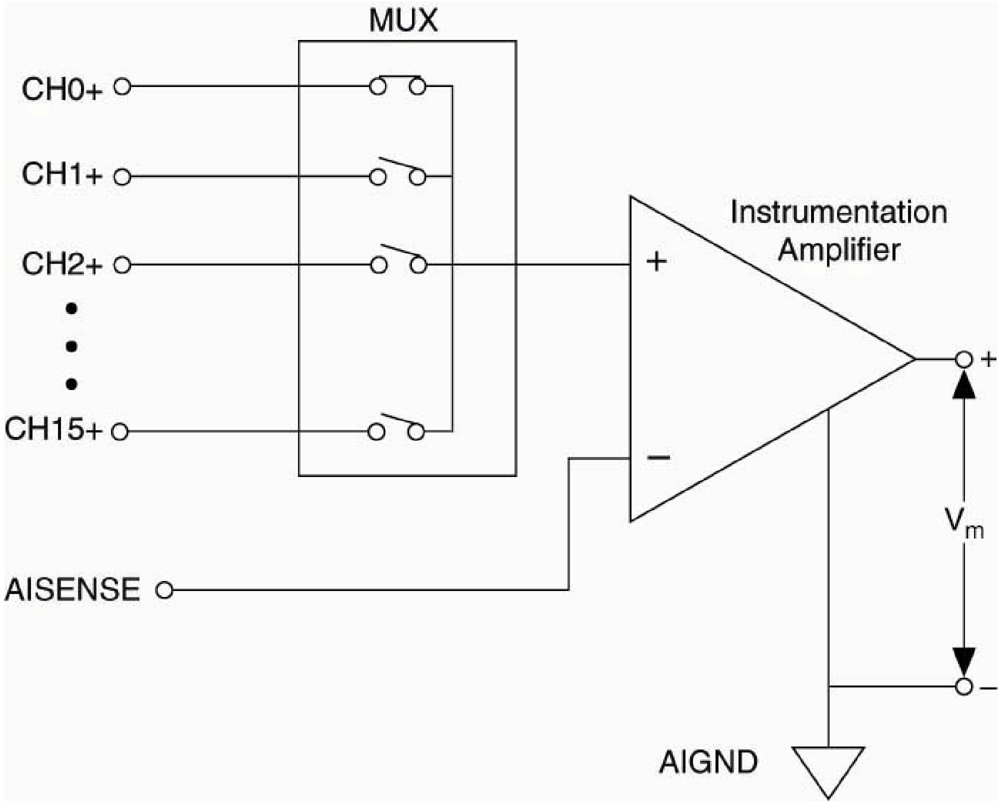
Measurement Concepts – Measurement Systems

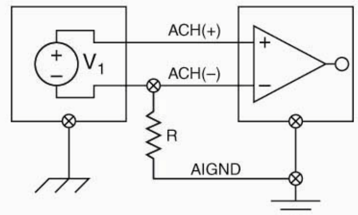
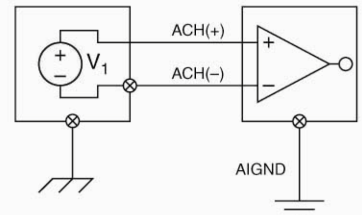
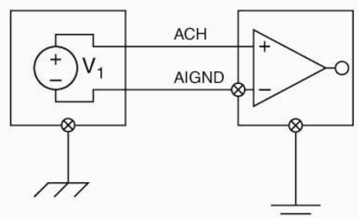
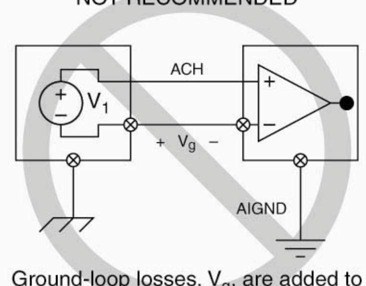
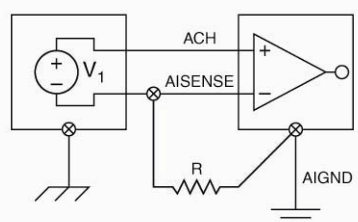
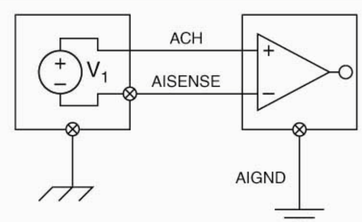
- Referenced Single-Ended (RSE)
- AIGND is the measurement system ground
- Need only one channel to measure a signal



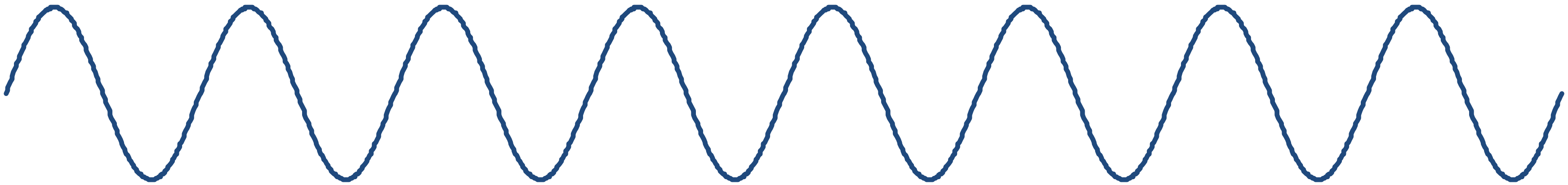
Measurement Concepts – Measurement Systems

- Non-referenced Single-Ended (NRSE)
- AISENSE pin is the measurement system ground
- Need one channel and AISENSE to a measure a signal



Input	Signal Source Type	
	Floating Signal Source (Not Connected to Building Ground)	**Grounded Signal Source**
	Examples • Ungrounded Thermocouples • Signal Conditioning w/Isolated Outputs • Battery Devices	Examples • Plug-in Instruments with Nonisolated Outputs
Differential (DIFF)	 See text for information on bias resistors.	
Single-Ended — Ground Referenced (RSE)		NOT RECOMMENDED  Ground-loop losses, V_g, are added to measured signal.
Single-Ended — Nonreferenced (NRSE)	 See text for information on bias resistors.	

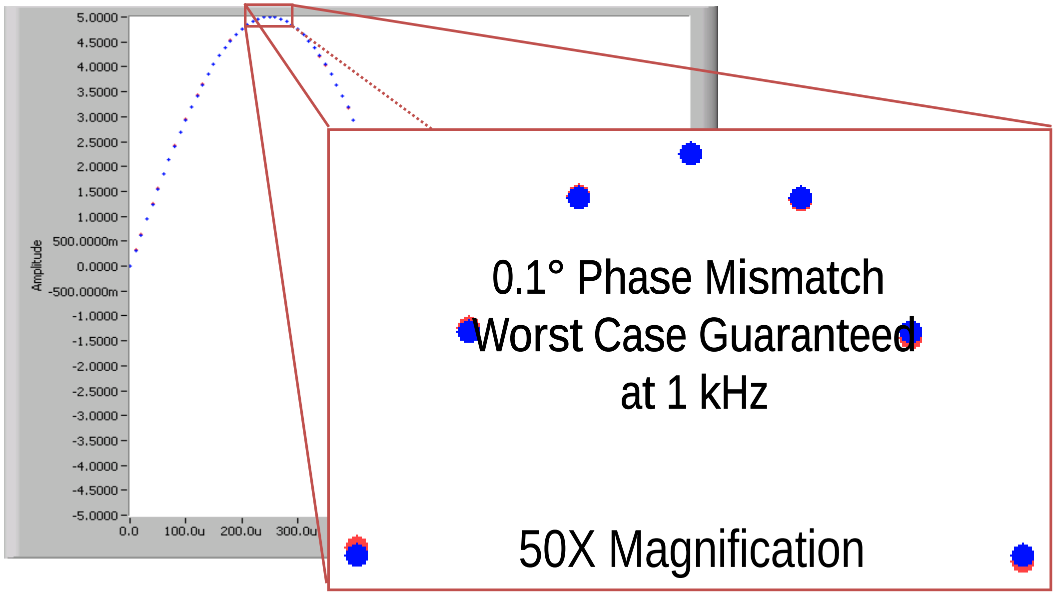
Analog Input - Sampling Rates



- Undersampling may result in the misrepresentation of the measured signal (**aliasing**).
- After a signal is aliased, it is impossible to reconstruct the original signal.
- For accurate frequency representation:
  - Sample at least 2x the highest frequency signal being measured.
- For accurate shape representation
  - Sample 5–10x the highest frequency signal being measured.

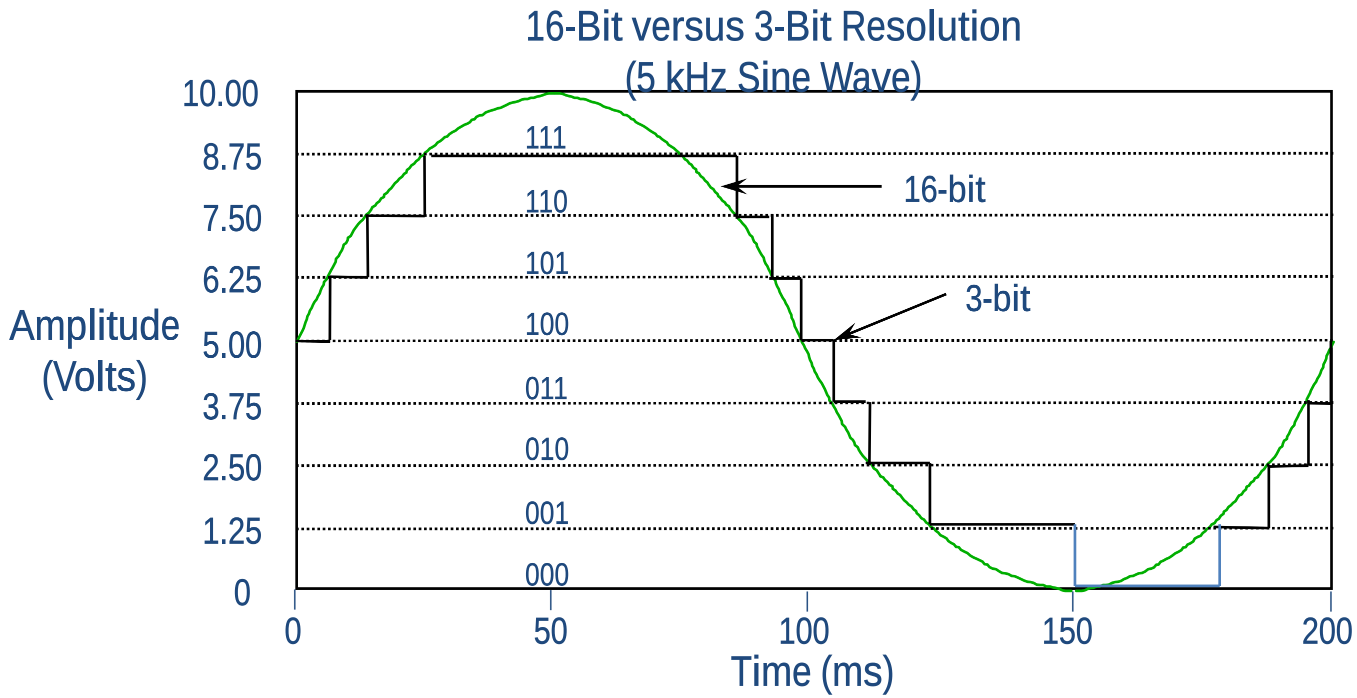
Multichannel Simultaneous Sampling

- A/D conversion is performed at the same instant from 2 to 5,000 channels
- No skew between channels to guarantee phase matching
- Required for
  - Orbit plots
  - Tacho synchronization
  - Balancing
  - Order analysis



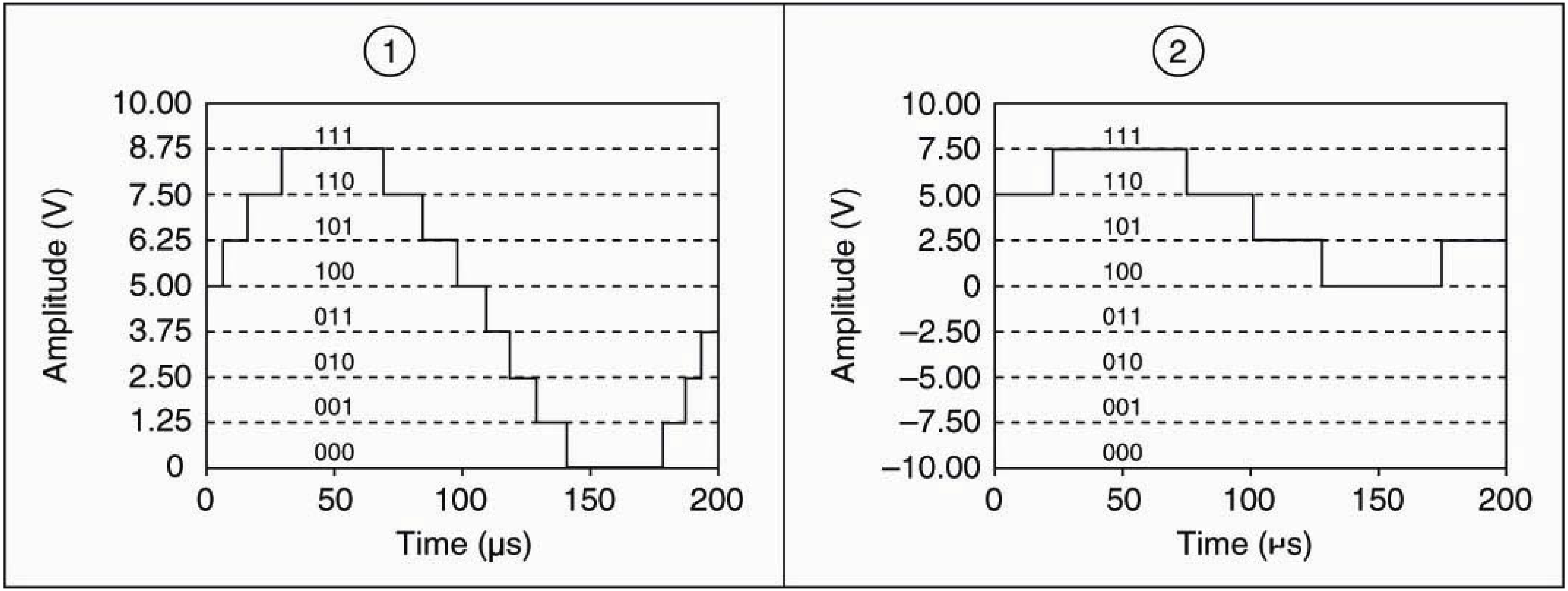
Analog Input - Resolution

- Number of bits analog-to-digital converter (ADC) uses to represent a signal
- Higher resolution – detect smaller voltage changes



Achieving Smallest Detectable Change

- Range



Analog Input - Accuracy versus Resolution

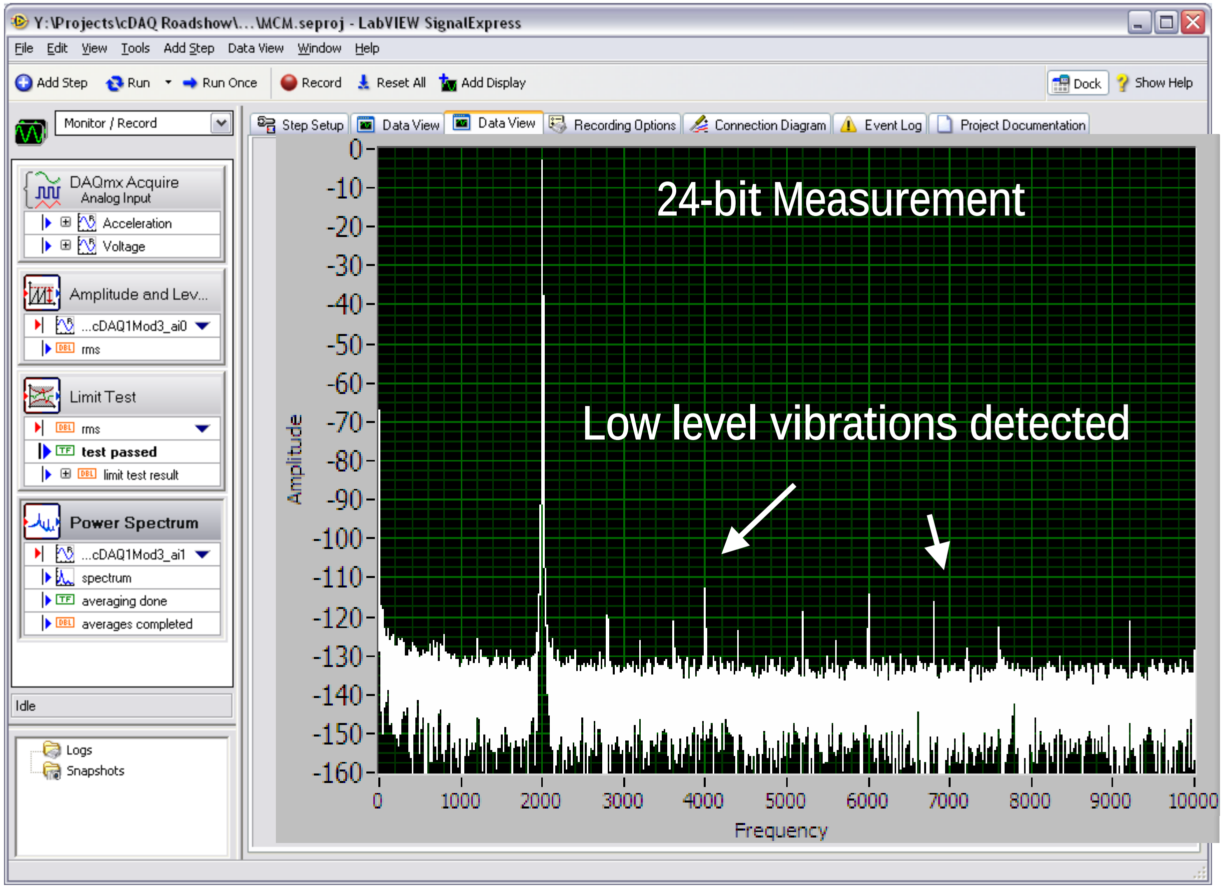
- Resolution
  - A property of the ADC
- Accuracy
  - A specification of the entire DAQ device or system
  - Includes many components and factors
    - ADC nonlinearities
    - Temperature
    - System noise
    - Amplifier gain and offset errors
- Higher resolution does not always equal more accurate!
  - Look for **Absolute Accuracy** specification

A/D Resolution and Dynamic Range

With high dynamic range, you can detect both strong and weak signal components at the same time.

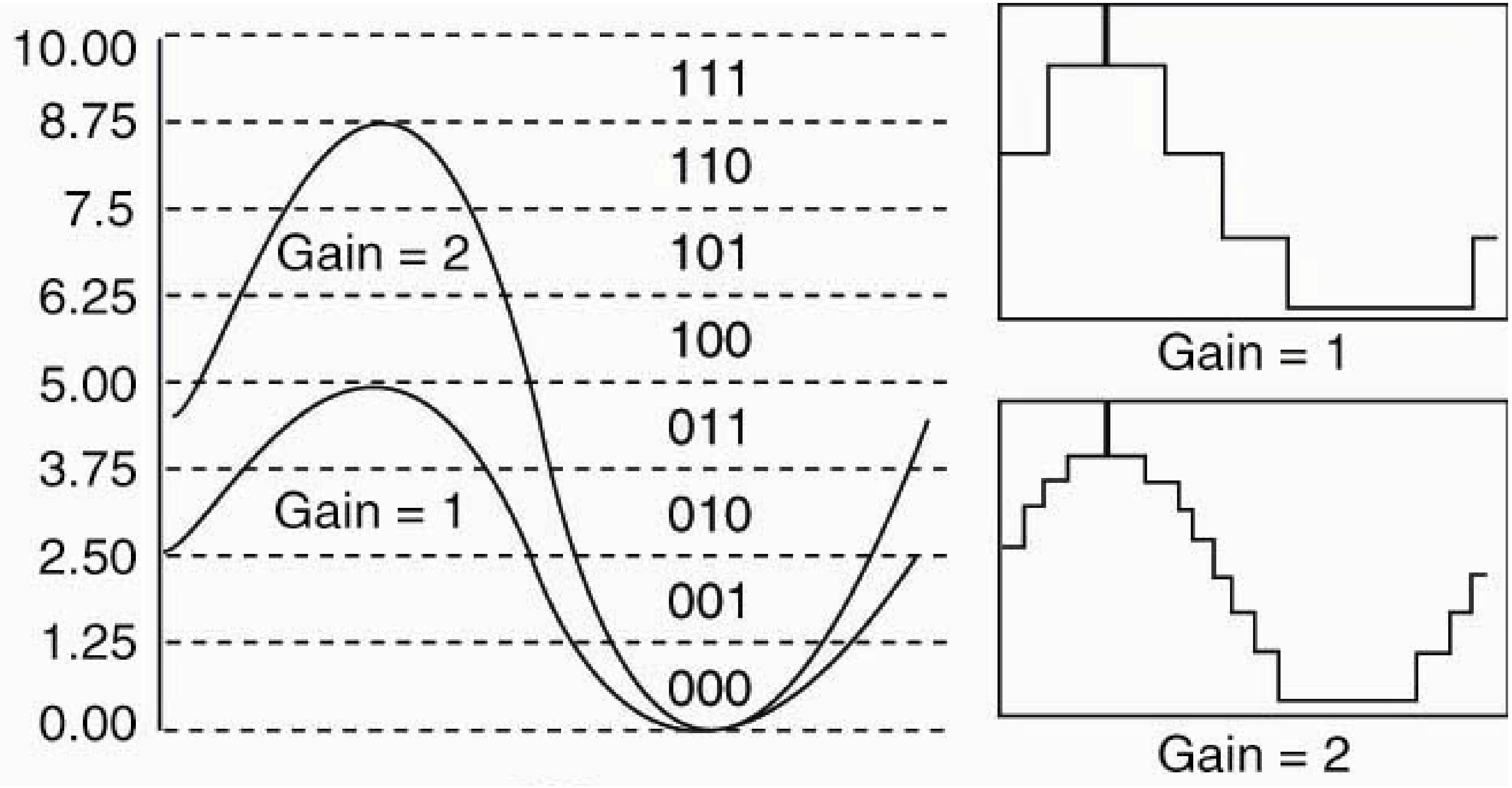
90 dB →

140 dB →

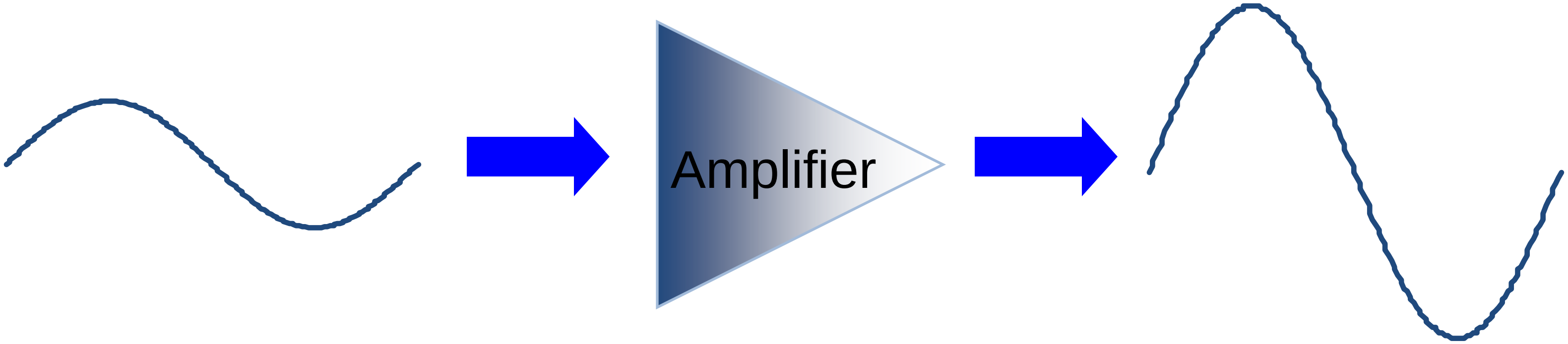


Achieving Smallest Detectable Change

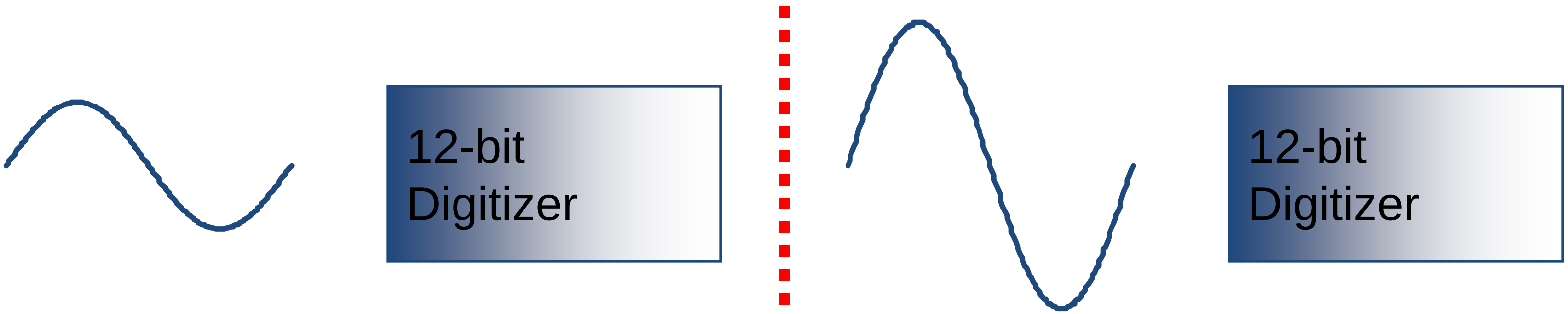
- Amplification



Signal Amplification

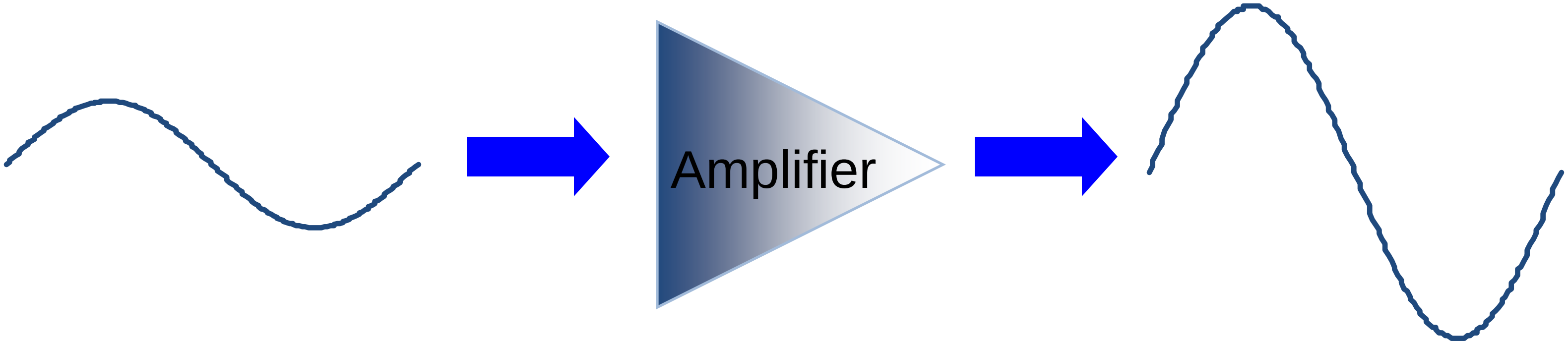


- Increases measurement resolution

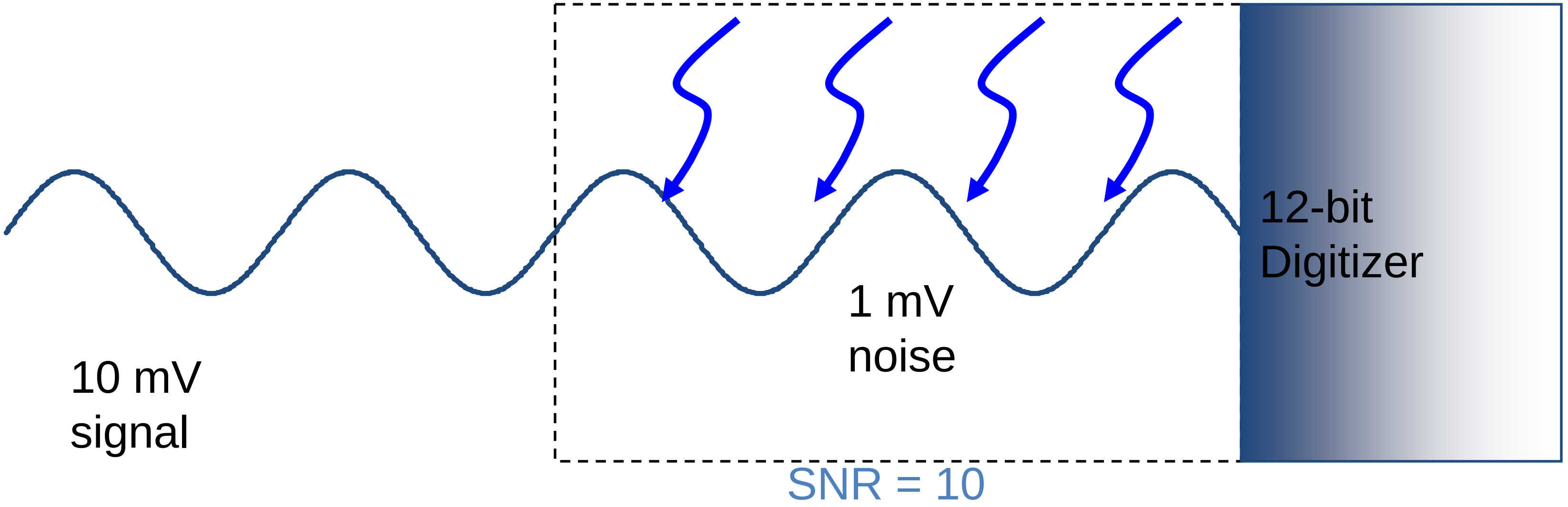


10 mV signal	4 levels of resolution (2-bits)	10 V signal	4096 levels of resolution (12-bits)

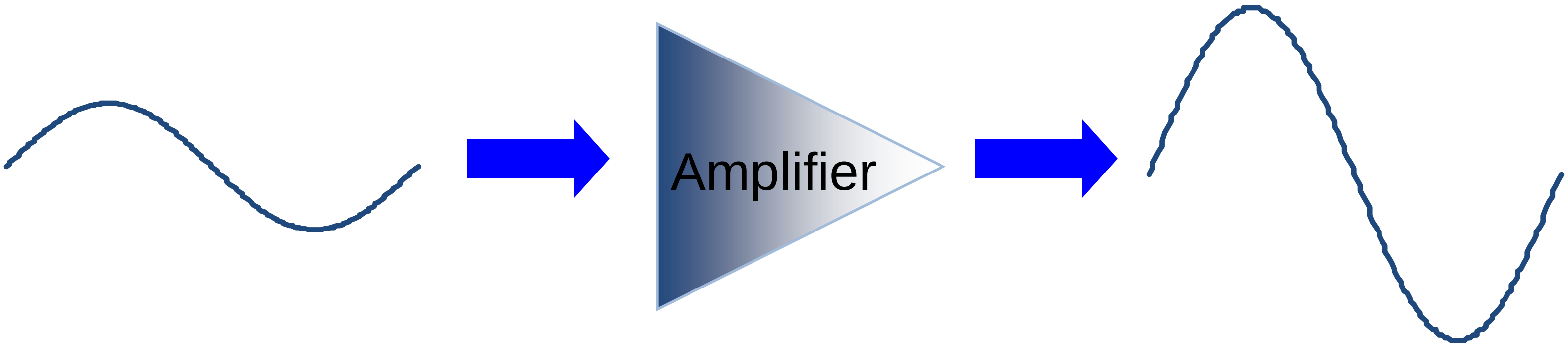
Signal Amplification



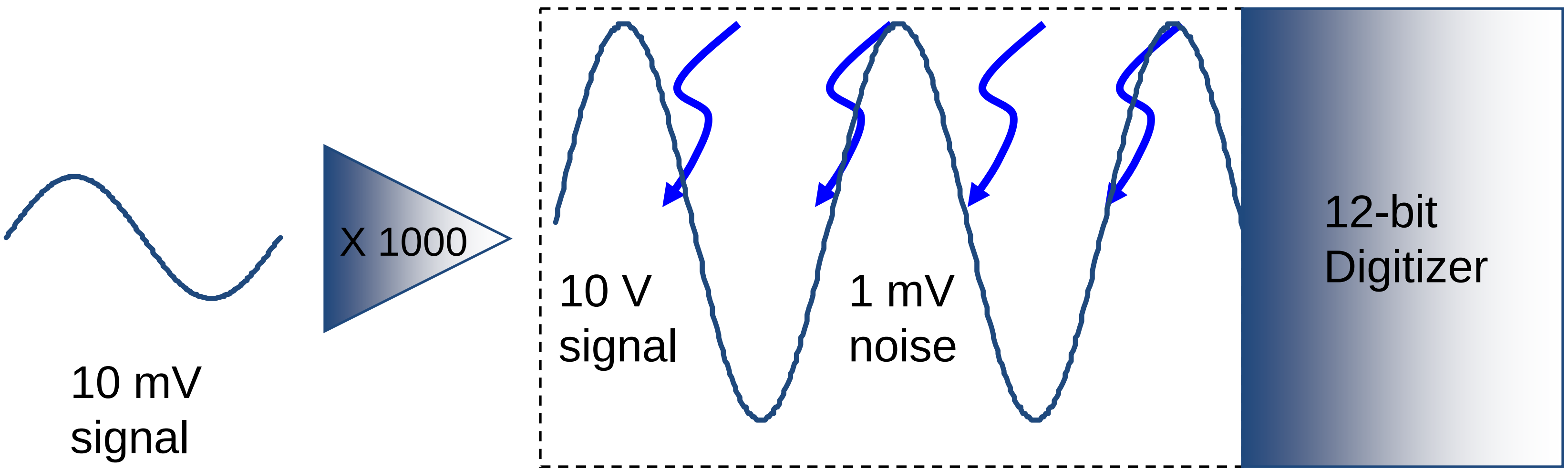
- Increases Signal-to-Noise Ratio (SNR)



Signal Amplification



- Increases Signal-to-Noise Ratio (SNR)



SNR = 10,000

Measurement Concepts – Linearization

- Many transducers, such as thermocouples, have a nonlinear response to changes in the physical phenomena you measure
- LabVIEW can linearize the voltage levels from transducers so you can scale the voltages to the measured phenomena
- LabVIEW provides scaling functions to convert voltages from strain gages, RTDs, thermocouples, and thermistors

Measurement Concepts – Excitation

- Signal conditioning systems can generate excitation, which some transducers require for operation
- Strain gages and RTDs require external voltage and currents, respectively, to excite their circuitry into measuring physical phenomena
- This type of excitation is similar to a radio that needs power to receive and decode audio signals

Measurement Concepts – Isolation

- Isolates the transducer signals from the computer for safety purposes
- When the signal you monitor contains large voltage spikes that could damage the computer or harm the operator, do not connect the signal directly to a DAQ device without some type of isolation

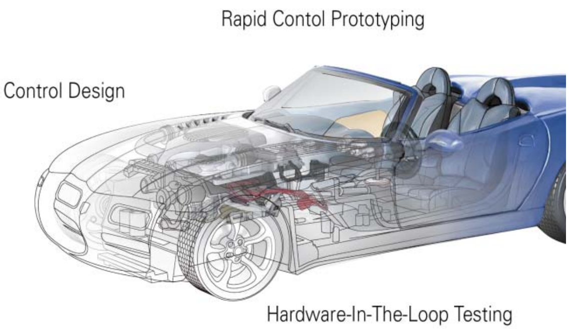
Measurement Concepts – Isolation

- **You also can use isolation to ensure that differences in ground potentials do not affect measurements from the DAQ device**
  - If the potential difference between the signal ground and the DAQ device ground is large, damage can occur to the measuring system
  - Isolating the signal eliminates the ground loop and ensures that the signals are measured accurately

Virtual Instrumentation Use in Industry

Consumer Electronics

Military and Aerospace



Automotive

Communications

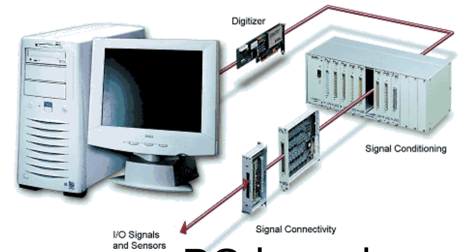
Semiconductor

Medical

Evolution of Data Logging Systems

Paper and pencil

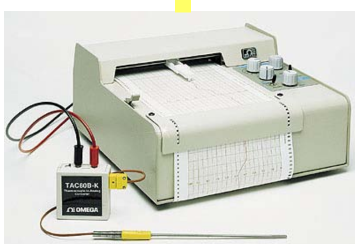
Stand-alone data loggers



PC-based systems

… 1900 – … 1970 – … 1990 – … 2004 – … 2006 – …

Strip Chart Recorder



High performance stand-alone systems

Easy –to-use USB data logging

Advantages of PC Based Acquisition

- Integrate traditional logging tasks:
  - Acquisition
  - Logging
  - Display
- Provides new capabilities:
  - Multiple measurement types and locations
  - Custom analysis
  - Reporting
  - Network integration

Acquisition Hardware Considerations

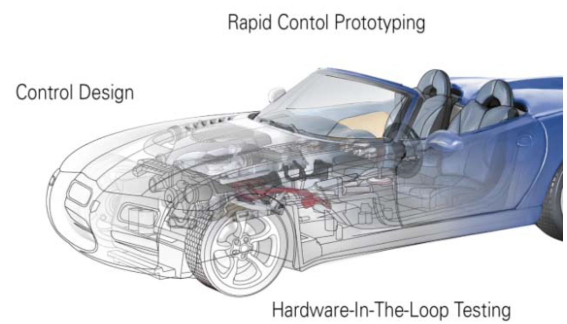
- What types of sensors do you have?
- How many channels do you need?
- What accuracy and resolution are required?
- How fast do you need to log?
- Do you need end-to-end calibration?
- Will you need to expand in the future?
- Would you like to control any outputs?

DAQ Hardware Options

Distributed

Desktop

Rugged and Modular Test



Portable

Multifunction DAQ

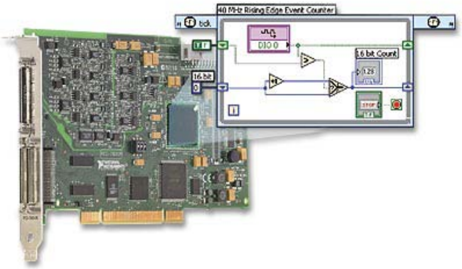
M, X Series – Multiplexed DAC Data Acquisition

- Configurable triggering, timing, and onboard decision making
- Up to 18-bit resolution and 2 MS/s

S, X Series Simultaneous-Sampling

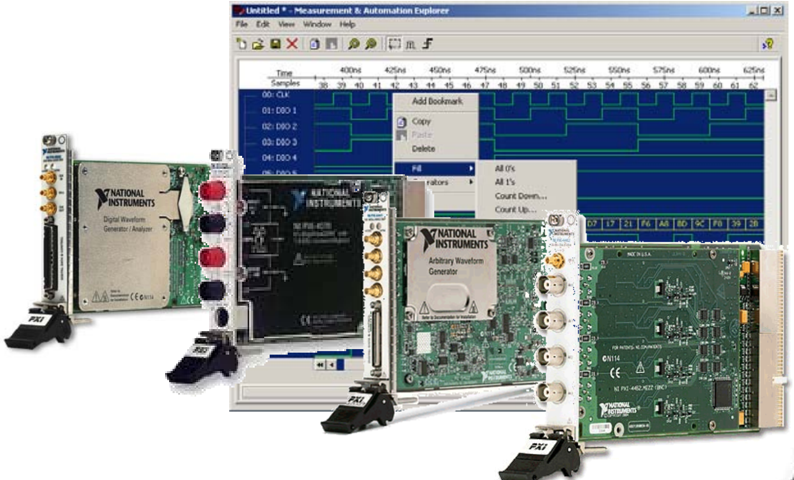
- Simultaneous sampling with dedicated A/D converter per channel
- Up to 16-bit resolution and 60 MS/s

R Series Intelligent DAQ Devices



- Analog I/O with onboard digital signal processing for filter design and high-speed control
- User-configurable with the LabVIEW FPGA Module

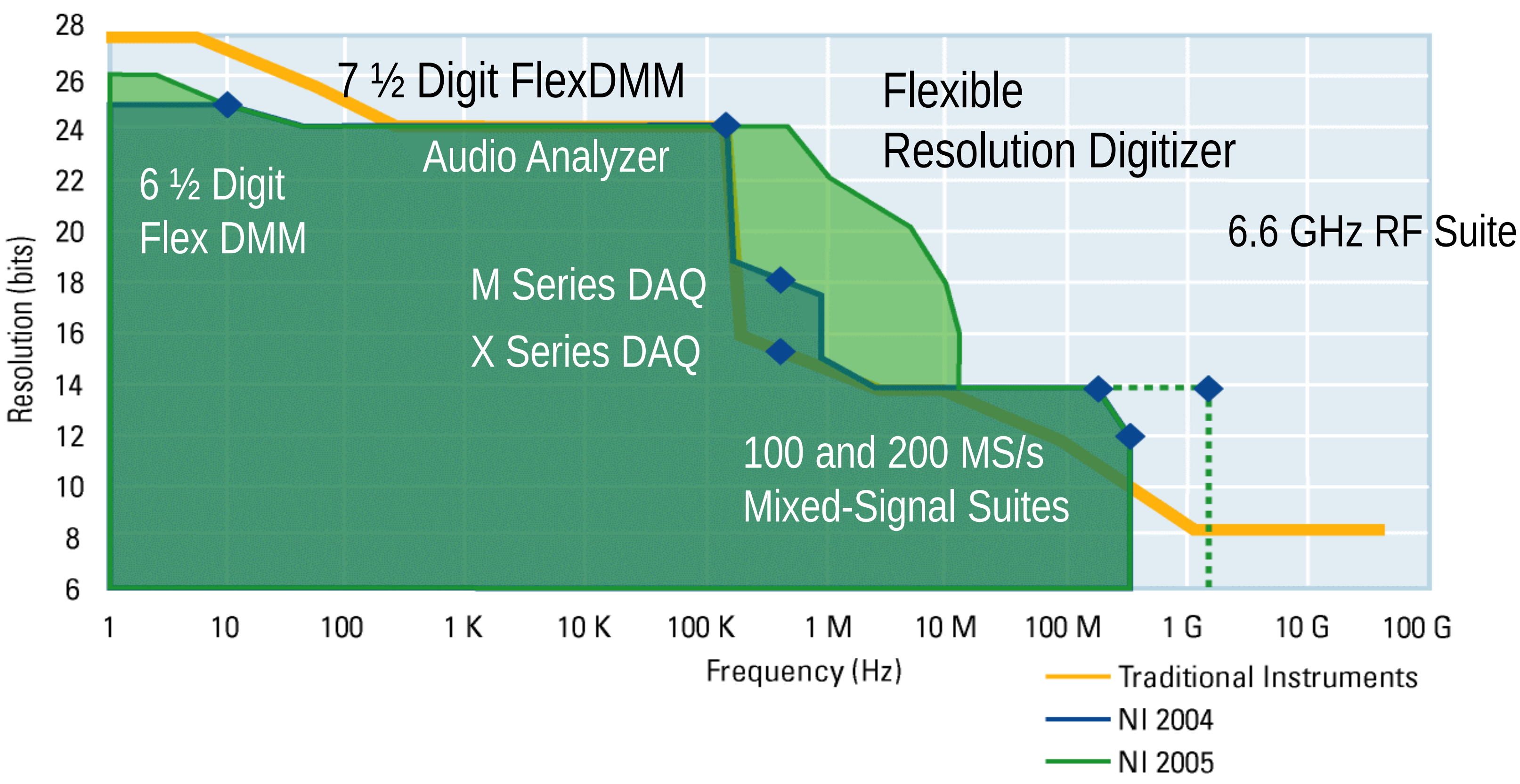
NI Modular Instrumentation for Mixed Signal Testing



- Digital waveform generators/analyzers
- Voltage, Current, Resistance and LC
- Signal Generation
- Dynamic Signal Acquisition
- High Speed Digitizing/Oscilloscope
- Switching
- Programmable Power Supply

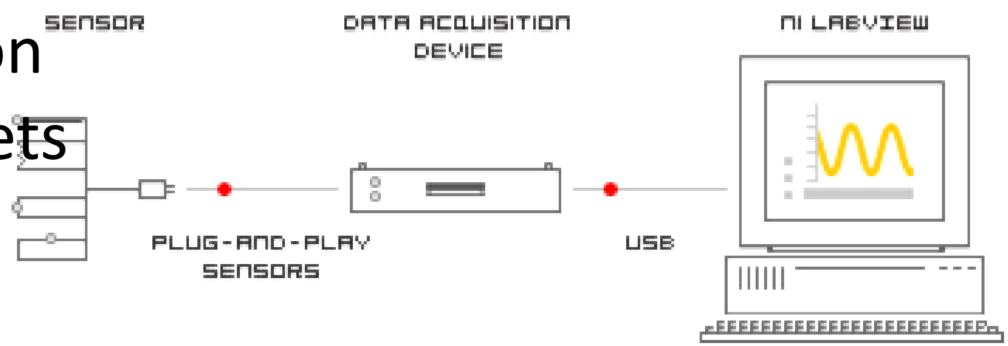
Over 1500 different modules from more than 70 manufacturers

Leverage of Commercial Technology



Plug&Play DAQ Systems

- **USB DAQ**
  - Plug-and-play installation
  - Automatic driver association
  - No rebooting computer
- **Sensors Plug&Play**
  - Based on TEDS–IEEE 1451.4
  - Confirm sensor connection
  - Eliminate paper data sheets
  - Remove data entry errors
- **Faster setup**
  - Decrease setup steps by up to 50%



Considerations for USB DAQ in Industrial Environments

Reliability of USB Bus

- Flimsy connectors
- Short cable length
- Low cost, high volume
- Consumer peripherals
- Noise Immunity
- Reliable Protocol

NI Signal Streaming technology: Sustaining High-Speed Data Streams on USB

***stream·ing [stree**-ming]* – verb

1. The act of transferring data to or from an instrument at a rate high enough to sustain continuous acquisition or generation.

PCI/PXI Express

- Continual extension of the PXI platform
- Improves PXI platform performance
  - Increased throughput
  - Improved latency and synchronization
  - Backward compatibility
- Solves new applications
  - High frequency, resolution IF / RF systems
  - High throughput, channel count
  - High Speed Imaging

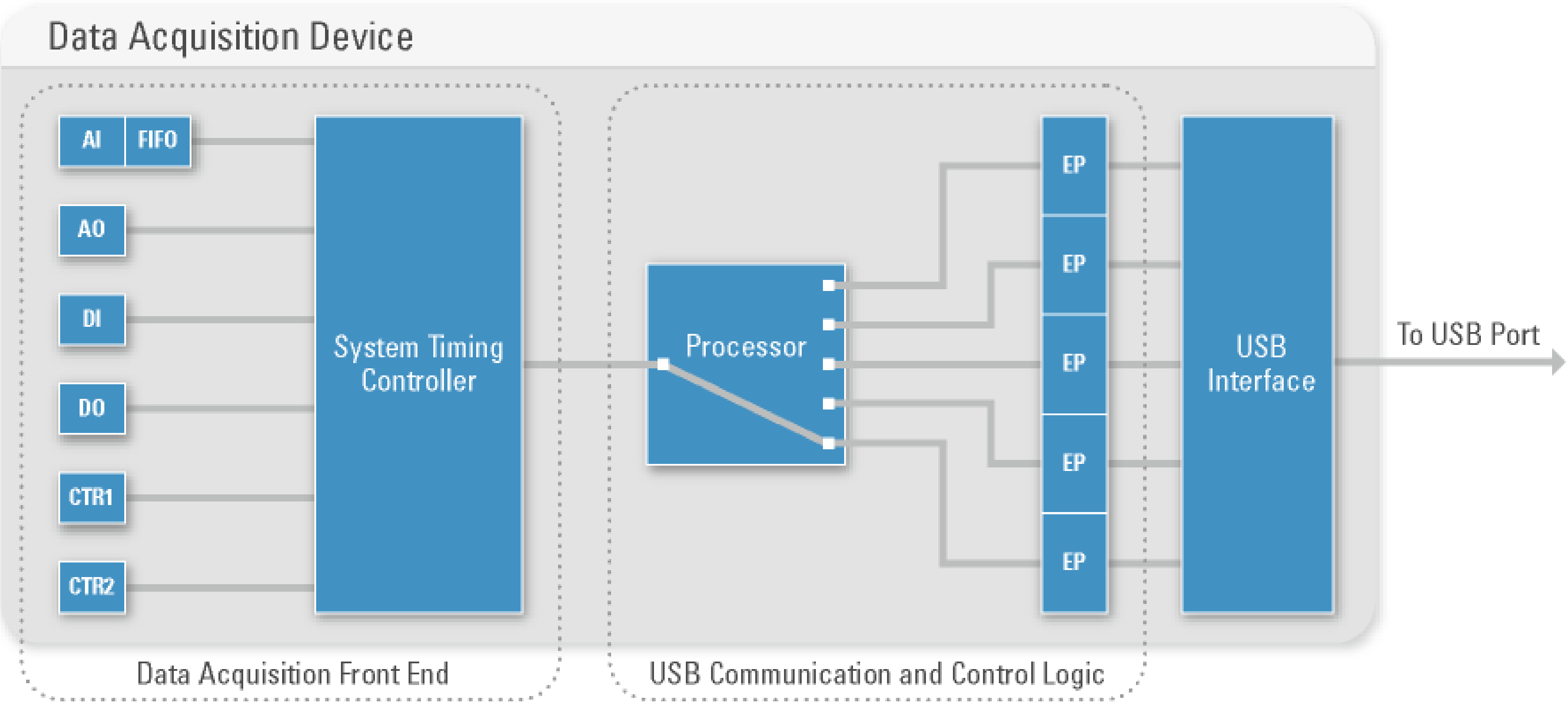
PCI EXPRESS™

PXI Express™

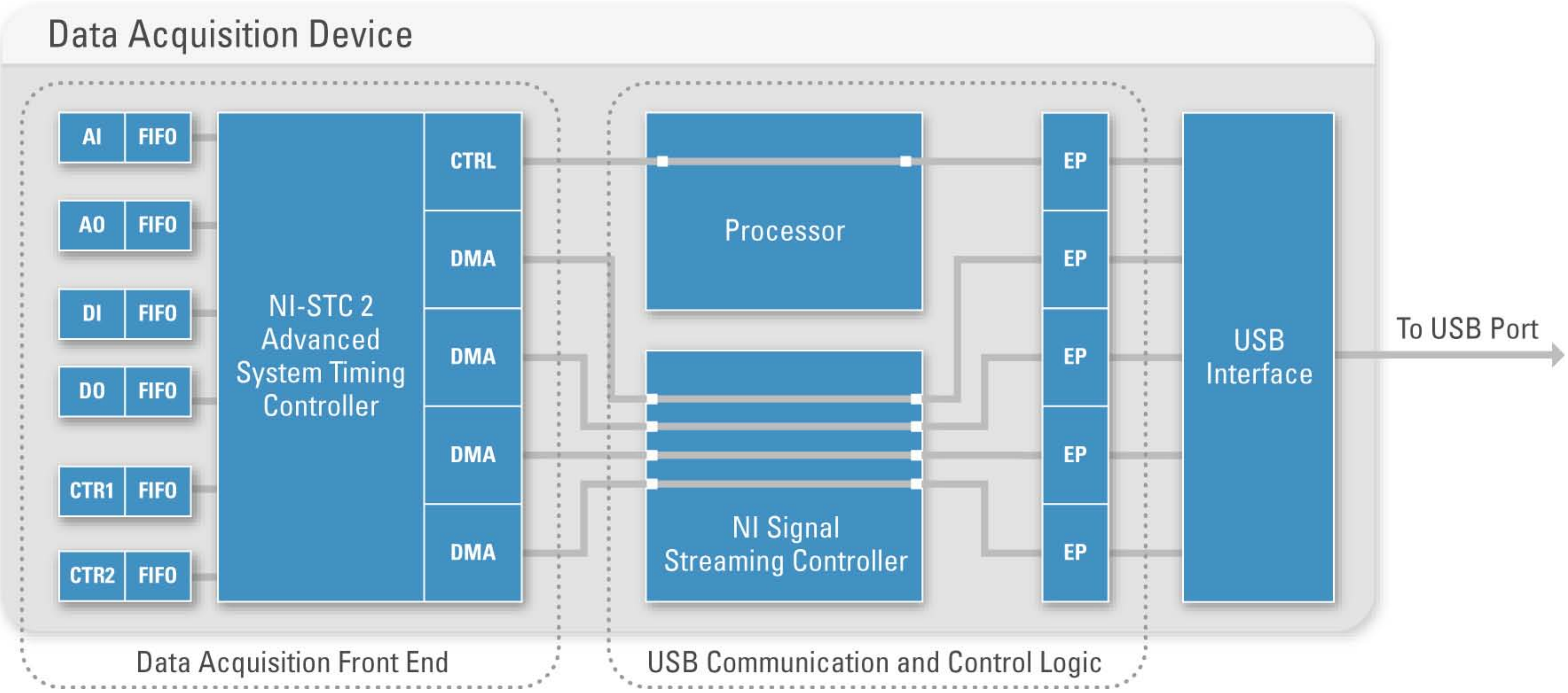
NI PCIe-6251/6259
NI PXIe-6251/6259

- Up to 32 channels, 16-bit, 1.25 MS/s analog inputs
- Dedicated bandwidth per device
- Backward software compatibility

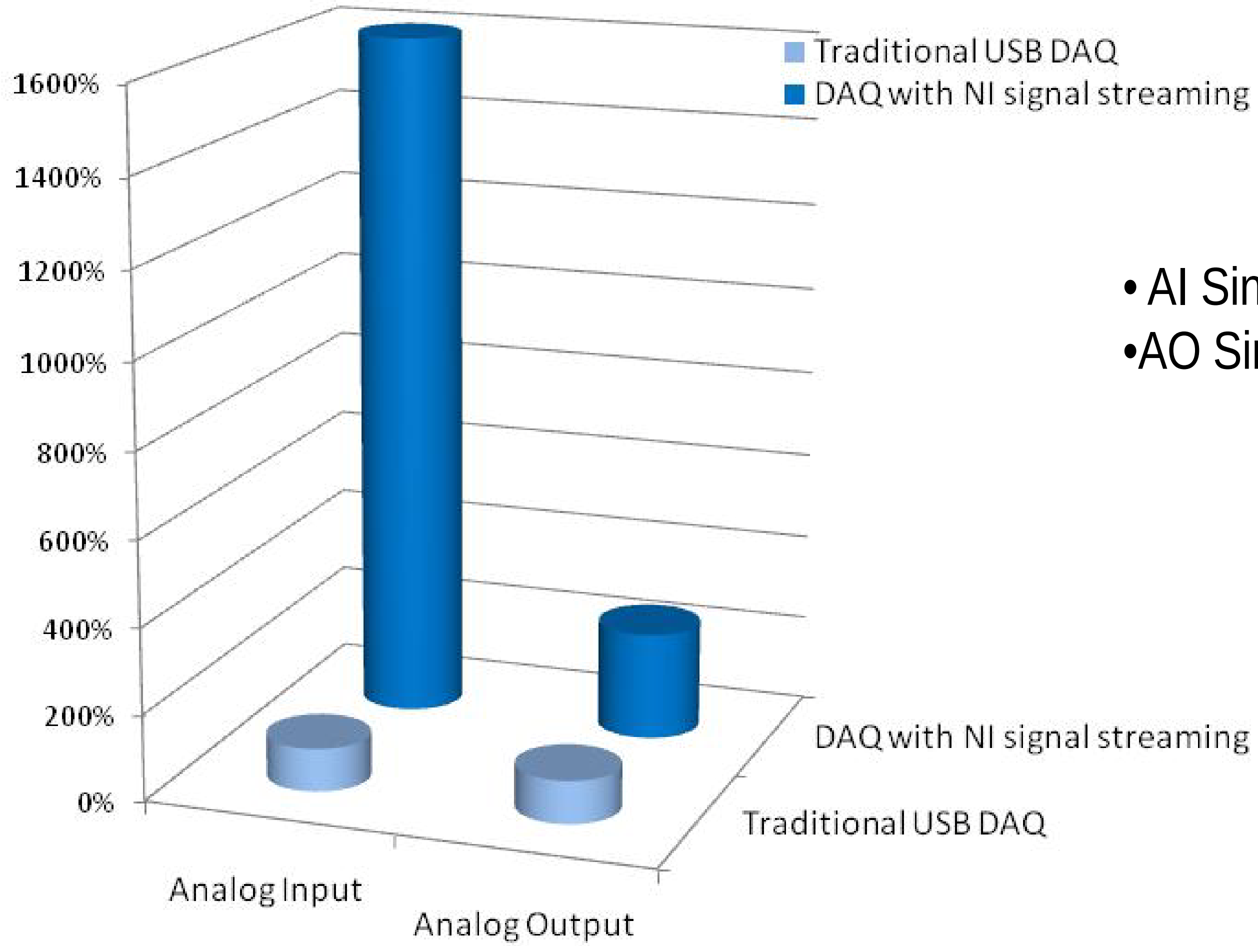
Traditional USB DAQ Transfer Architecture



NI Signal Streaming Technology

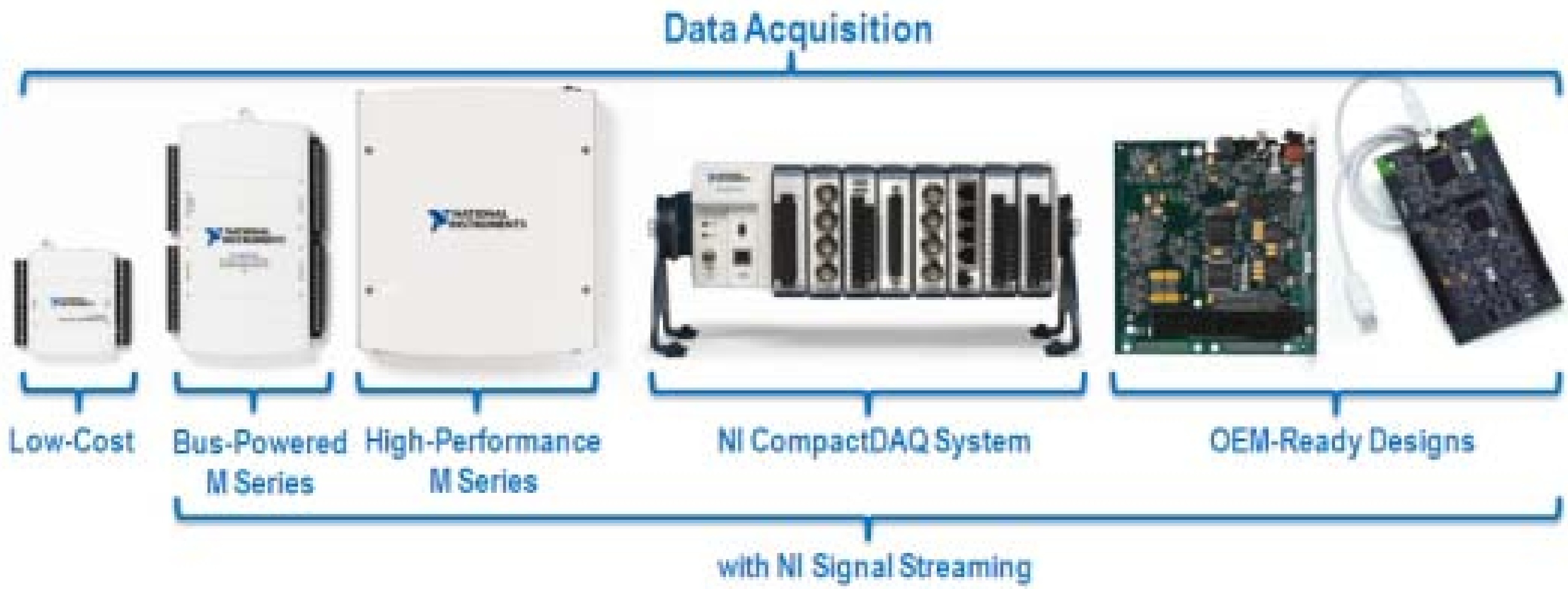


NI Signal Streaming



- AI Single point up to 16x
- AO Single point up to 2,5x

USB Data Acquisition Platforms



NI CompactDAQ – Simple, Complete, USB Data Acquisition

Convenience and Performance of USB 2 HS

Advanced ADCs and Isolators

Modularity with Direct Connectivity, HotSwapable

Built in triggers

Flexible, Easy-to-Use Software

8/4 slot versions

Analog I/O, Digital I/O and Sensors

Industrial Measurements

- ✓ Accelerometer
- ✓ Strain Gauge
- ✓ Load Cells
- ✓ Digital I/O (TTL-250V)
- ✓ Thermocouples
- ✓ 4 to 20mA
- ✓ High Voltage (300V)
- ✓ High Current (10Amp)
- ✓ RTD (Pt100...)

PXI (PCI eXtensions for Instrumentation)

At The Forefront of Virtual Instrumentation

PXI Controller
- Embedded PC or remote PC interface
- Runs all standard software

Chassis

PXI Backplane
- PCI bus
- Synchronization

Peripheral Slots

PXI Chassis

- 3U, 6U, and 3U/6U combo
- 4 through 26 slots
- Portable, benchtop, and rack mount
- AC and DC power options
- Application specific
    - Ultra rugged, integrated signal conditioning, integrated LCD, etc.

Embedded PXI System Controllers

General Purpose OSs

- Windows, Linux, etc.
- High performance
- Integrated peripherals
  - Gigabit Ethernet, USB 2.0, ExpressCard, etc.
- Ethernet / LAN control of PXI

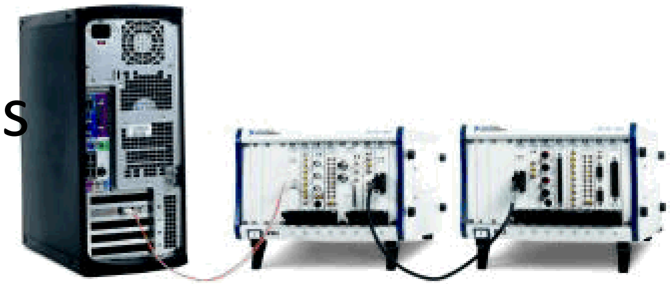
Real-Time OSs

- LabVIEW Real-Time, VxWorks, etc.
- Determinism and reliability
- Headless operation

Remote PXI System Controllers

PC Control of PXI

- Use latest high-performance PCs
- Build multichassis PXI systems



Laptop Control of PXI

- Control portable applications
- Use with DC-powered chassis for mobile systems

PXI Products. . .Over 1,500 and Counting

Data Acquisition and Control

Multifunction I/O
Analog Input/Output
Digital I/O
Counter/Timer
FPGA/Reconfigurable I/O
Machine Vision
Motion Control
Signal Conditioning
Temperature
Strain/Pressure/Force/Load
Synchro/Resolver
LVDT/RVDT
Many More. . .

Modular Instrumentation

Digital Waveform Generator
Digital Waveform Analyzer
Digital Multimeter
LCR Meter
Oscilloscope/Digitizer
Source/Signal Generator
Switching
RF Signal Generator
RF Signal Analyzer
RF Power Meter
Frequency Counter
Programmable Power Supply
Many More. . .

Bus Interfaces

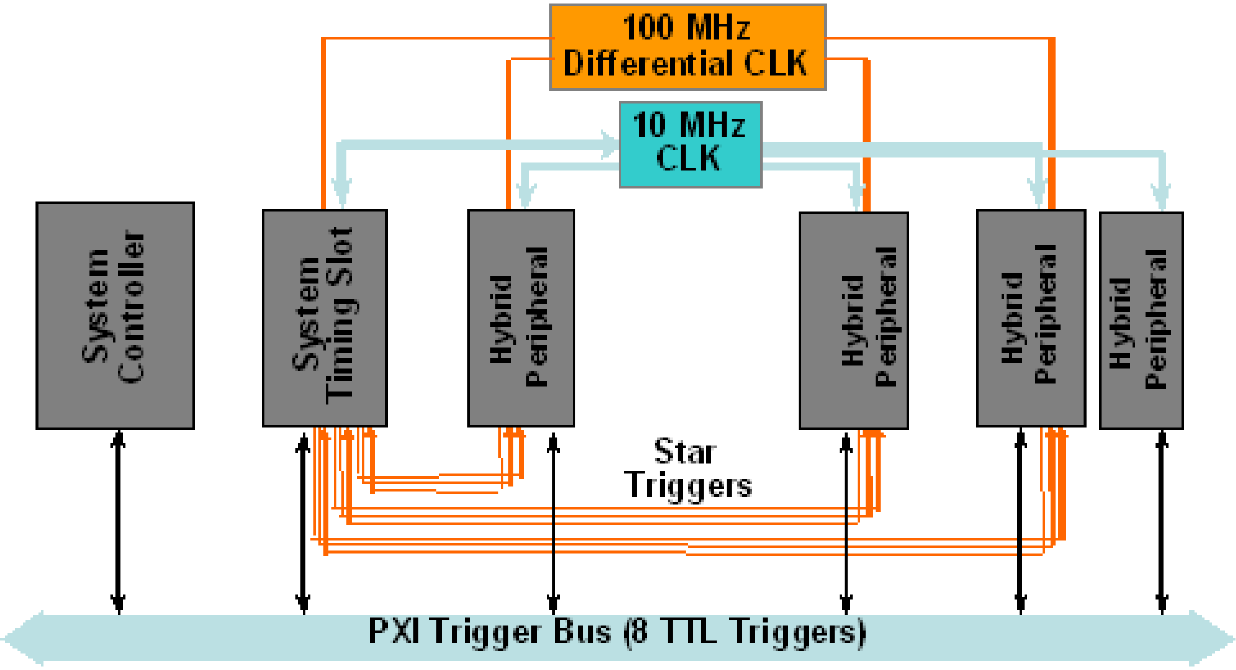
Ethernet, USB, FireWire
SATA, ATA/IDE, SCSI
GPIB
CAN, DeviceNet
Serial RS-232, RS-485
VXI/VME
Boundary Scan/JTAG
MIL-STD-1553, ARINC
PCMCIA/CardBus
PMC
Profibus
LIN
Many More. . .

Others

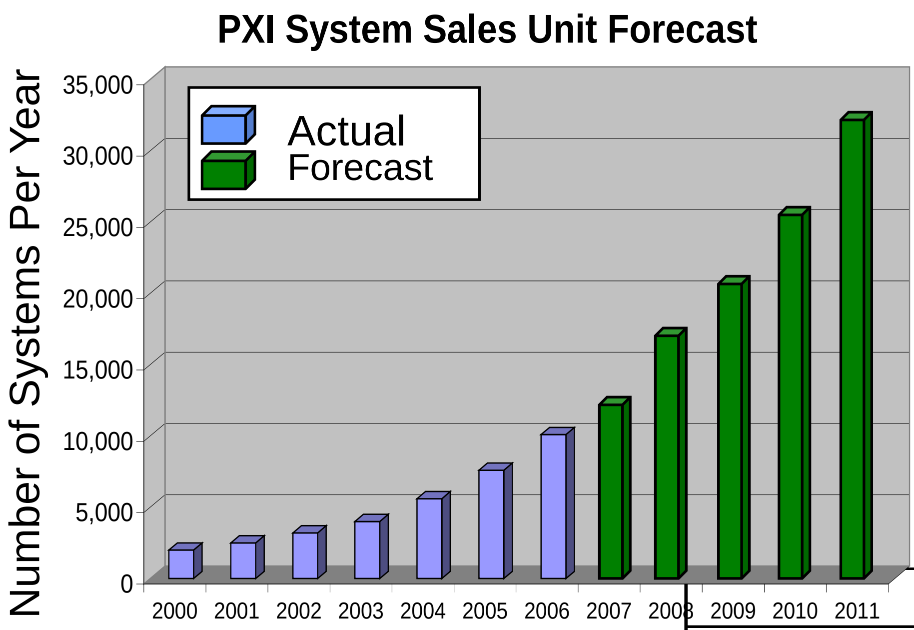
IRIG-B, GPS
Direct-to-Disk
Reflective Memory
DSP
Optical
Resistance Simulator
Fault Insertion
Prototyping/Breadboard
Graphics
Audio
Many More. . .

Timing and Synchronization Features of PXI

- PXI Trigger Bus
  - 8 TTL
  - Trigger, Clock, and Handshaking Signals
- System Reference Clock
  - 10 MHz TTL or 100 MHz Differential
  - Phase Lock Looping
  - Equal-Length Traces (< 200 ps skew)
- Star Trigger
  - Differential
  - Equal-Length Traces (< 150 ps Skew)



PXI – The Fastest Growing Standard in Test



23% CAGR forecast for 2006 – 2012

Source: World VXI & PXI Test Equipment Markets, Frost & Sullivan, September 2006

More than 1,500 PXI Products Available!

	VXI	PXI
Est Market Revenue ($Mil) in '06	255	170
Est # of Systems (Units) in '06	3600	10100
Avg System Price ($K)	70.8	16.8
2005-2010 CAGR	4.2%	25.1%
# of Products	<1000	>1200

Source: Frost & Sullivan, World PXI and VXI Test Equipment Markets, April 2005, P

NI 3110 Industrial Controller

Provide Connectivity to NI Test and Measurement Platforms

- The NI 3110 features an Intel SL9JT L2400 1.66 GHz Core Duo Processor
- The NI 3100 features an Intel 1.06 GHz Celeron M 423 processor
- Both controllers are configured with the Windows XP operating system
- Controllers can be used as an interface to control remote I/O with hardware such as NI CompactDAQ, NI PXI, and NI plug-and-play PCI and PCI Express devices

PAC Platform for Control – CompactRIO

Real-Time OS

400 MHz PowerPC
Reliable embedded control, analysis, and logging

Reconfigurable FPGA Circuitry

Custom hardware reliability; flexible timing, triggering, synchronization

Networked

Ethernet 10/100 BaseT. embedded Web and file servers; connectivity to modems

Extreme Durability

-40 to 70 C temperature range
50 G shock, Industrial certifications

Small Size, Low Power Consumption

179.6 x 88.1 mm (7.07 x 3.47 in)
11 to 30 VDC power, 17 W max (7-10 W typ.)

Measurement I/O Modules

Isolated, industrial and high-precision options

Industrial Measurement&Control

- ✓ Accelerometer
- ✓ Strain Gauge
- ✓ Load Cells
- ✓ Digital I/O
- ✓ Thermocouples
- ✓ 4 to 20mA
- ✓ RTD

- ✓ High Voltage (+/-400V or 300Vrms)
- ✓ High Current (10Amps)
- ✓ Brushed DC drive
- ✓ CAN communication
- ✓ Relay
- ✓ Pulse genaration
- ✓ Programmable Sinking Digital Output
- ✓ TEDS

NI Wireless Sensor Networks

Low Power. Reliable.

- 16-bit voltage input node
- 24-bit thermocouple node
- Up to 3-year battery life
- 2.4 GHz, IEEE 802.15.4 radio (ZigBee)
- Data Rate: 250 kbits/s
- Range: 300 m
- Typical battery life: 2-3 years
- RF Channels: 14 Channels (11-24)

Structure of Data Logging Systems