DAQ Coaching Day

Name

Title

Goals of Today

1. Learn how to understand and calculate your NI or third-party hardware data acquisition system's accuracy.

2. Understand the importance of collecting data in a logical, well documented way and know where to get more information.

3. Get hands-on with different software and the NI CompactDAQ system

Agenda

- Does accuracy matter?
- Accuracy vs. Precision
- Types of accuracy
- Resolution, Code Width, and Sensitivity
- Gain and Offset Error
- Integral Non-Linearity (INL) Error
- Temperature Drift
- Noise Uncertainty
- Calculating accuracy

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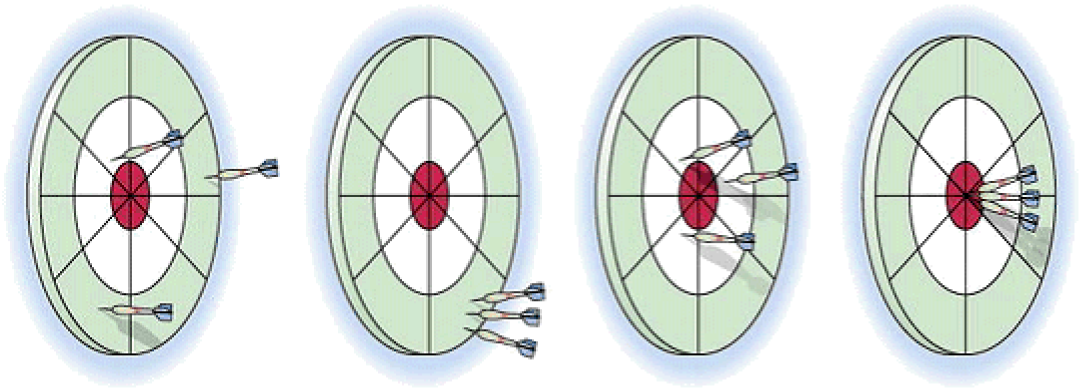
Why Does Accuracy Matter?

- Inability to answer research questions accurately
- Inability to repeat and validate experiments
- Misleading other researchers to pursue fruitless avenues of investigation
- Compromising decisions for public policy
- Causing harm to human participants and animal subjects

Accuracy and Precision



Precision: An instrument's capability to produce the same measurement results repeatedly for the same input signal; stability of the instrument

Accuracy: how close a measured signal is to the actual input signal

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Types of Accuracy

Accuracy: How close a measurement is to the correct value

Relative Accuracy: Accuracy factoring in the accuracy of the calibration device

Absolute Accuracy: Calculated theoretical accuracy with worst-case error

System Accuracy: Considers the whole measurement chain; factors in not only the accuracy of the DAQ device itself but also the sensors and other environmental factors

What's the difference?

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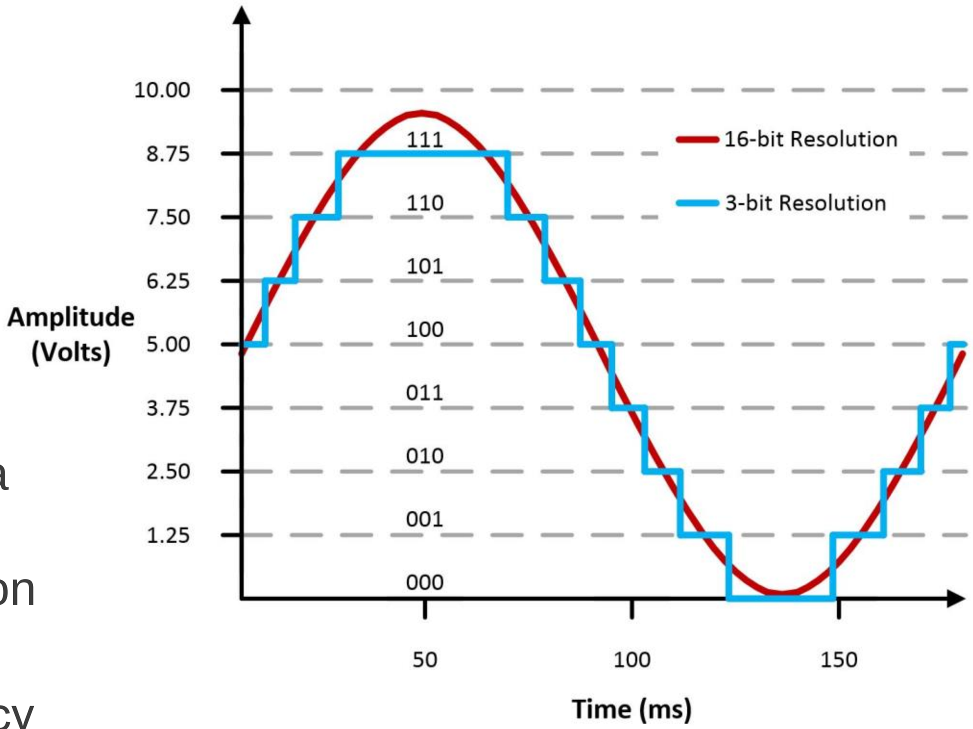
Resolution

- Determines the number of unique vertical levels

$$\# \text{ of levels} = 2^{\text{Resolution}}$$

- Limited by the Analog-to-Digital Converter (ADC) on the device
- Resolution limits the precision of a measurement;
  Higher resolution = higher precision
- Higher resolution ≠ higher accuracy



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Code Width or LSB

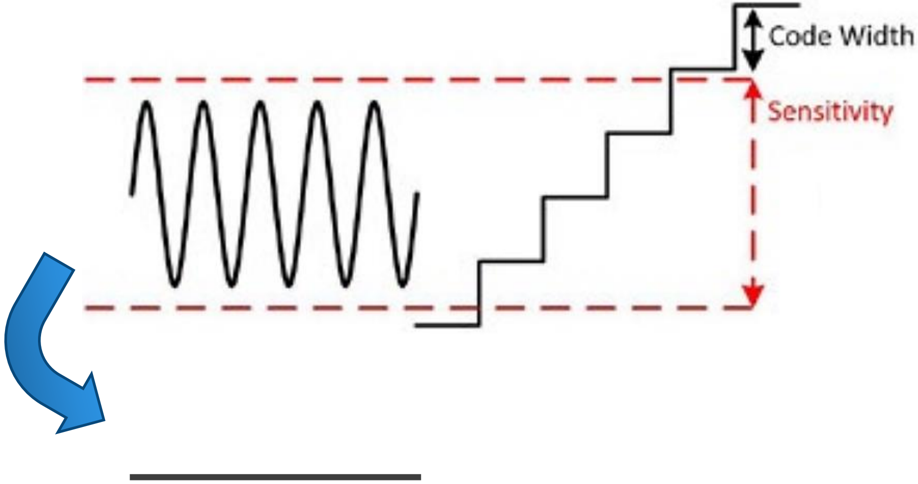
- **Code width**: discrete level at which the instrument displays a value; defined by resolution; also called the least significant bit (LSB)

$$\text{Code width} = \text{LSB} = \frac{\text{Device Input Range}}{2^{\text{Resolution}}}$$

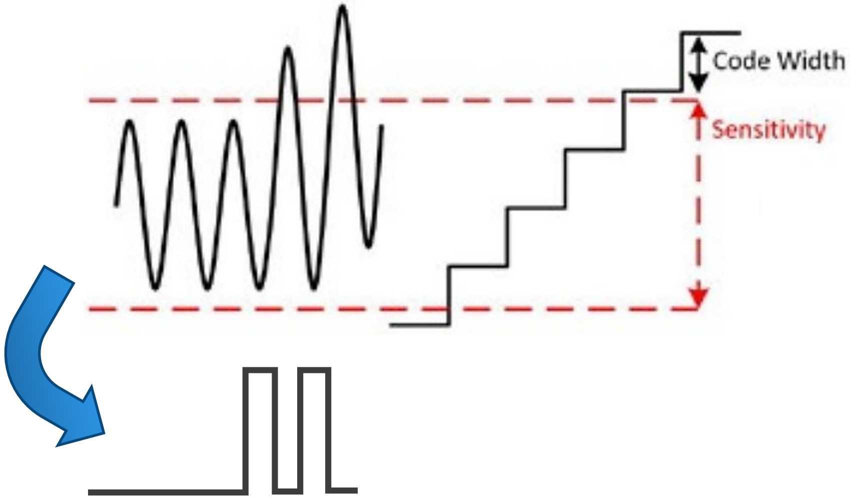
- Example: device range is 0V..10V
  - Code width of 3-bit device: 10V/8 = 1.25 V
  - Code width of 16-bit device: 10V/65,536 ≈ 152.6 μV

Sensitivity

Sensitivity: The least amount of change in voltage needed to register a change in value



(Digital Representation)



(Digital Representation)

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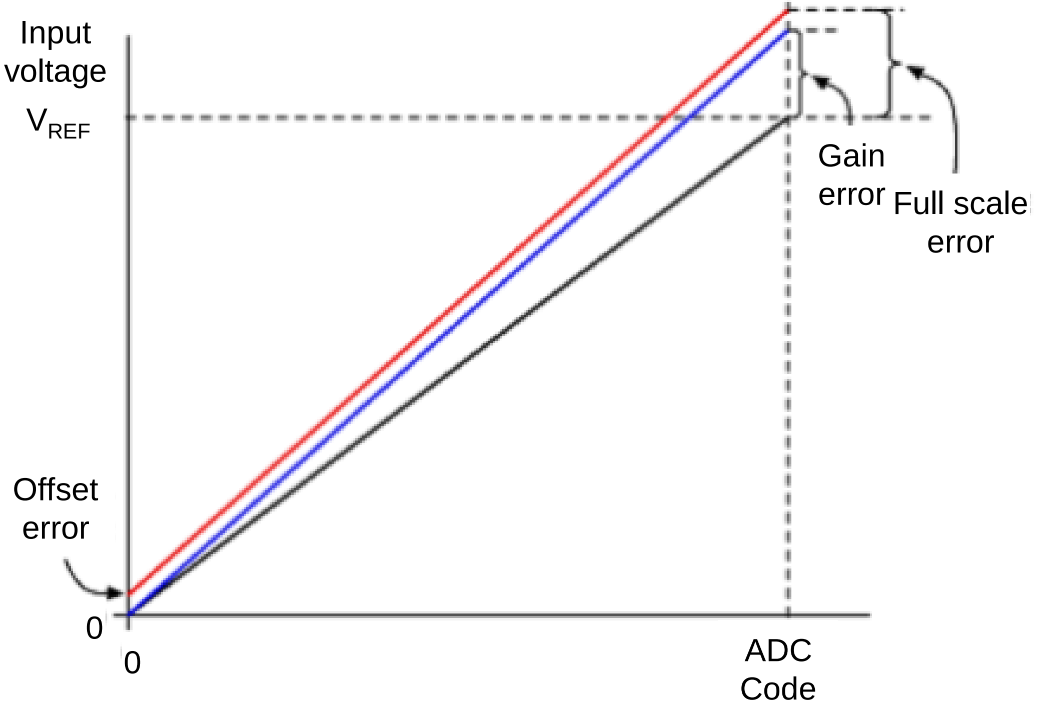
Gain and Offset Error

- **Offset error**: deviation from the ideal code 0 voltage
- **Gain error**: deviation in slope from the ideal function
- **Full scale error**: offset voltage plus gain error at the maximum output voltage

A portion of offset and gain error can be eliminated through self-calibration; the **residual** error is inherent to the instrument and will exist after calibration.



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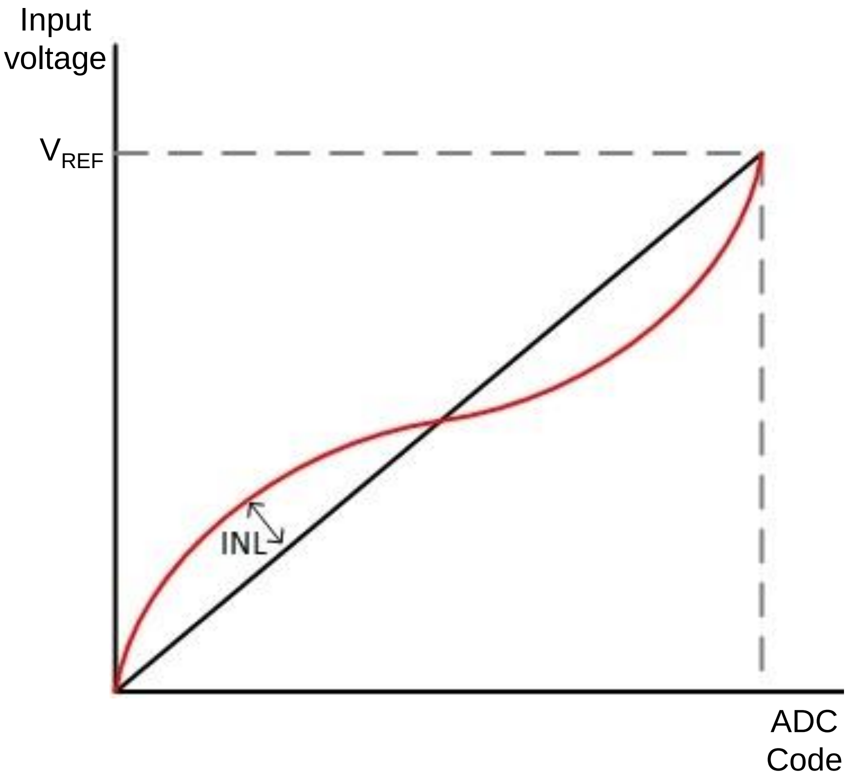
INL Error

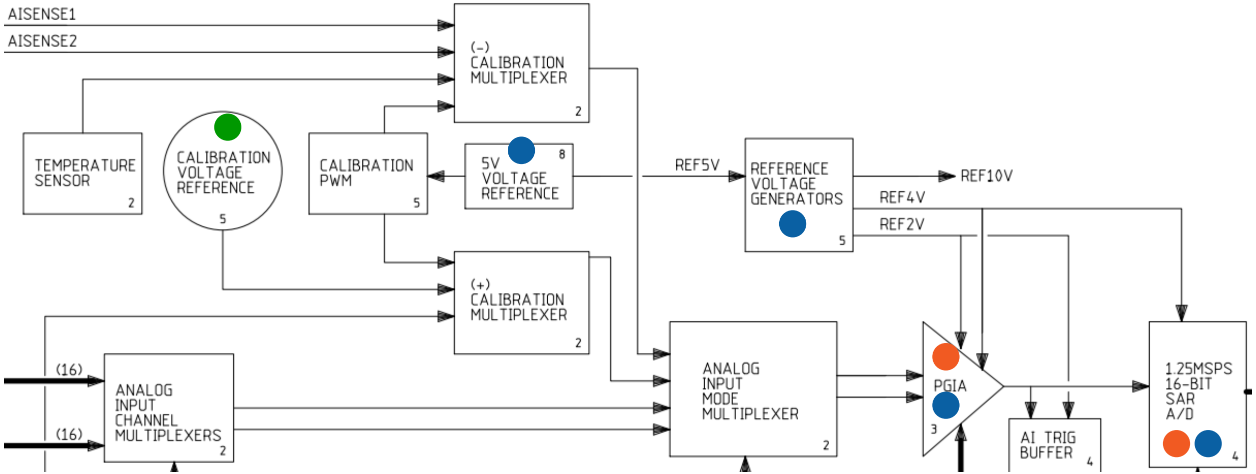
- **Integral Non-Linearity (INL) Error**: how far from the ideal after removing offset and gain error



Temperature Drift

Temperature coefficient (tempco): how temperature affects the measurement

- Gain tempco: how temperature impacts the gain
- Offset tempco: how temperature impacts the offset
- Reference tempco: how temperature affects the onboard calibration reference and contributes to gain tempco



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System Noise/Noise Uncertainty

- **Random/system noise of the instrument**: additional system noise generated by the analog front end; measured by grounding the input channel

$$\text{Noise Uncertainty} = \frac{\text{Random Noise} \ * \text{Coverage Factor}}{\sqrt{\text{\# of samples}}}$$

- Example: For a Coverage Factor of 3 σ and averaging over 10.000 samples:

$$\text{Noise Uncertainty} = \frac{\text{Random Noise} \ * 3}{\sqrt{10000}}$$

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- Calculating accuracy

Calculating Accuracy

Table 1. AI Absolute Accuracy

Nominal Range Positive Full Scale	Nominal Range Negative Full Scale	Residual Gain Error (ppm of Reading)	Residual Offset Error (ppm of Range)	Offset Tempco (ppm of Range/°C)	Random Noise, σ (μVrms)	Absolute Accuracy at Full Scale (μV)
10	-10	48	13	21	315	1,660
5	-5	55	13	21	157	870
2	-2	55	13	24	64	350
1	-1	65	17	27	38	190
0.5	-0.5	68	17	34	27	100
0.2	-0.2	95	27	55	21	53
0.1	-0.1	108	45	90	17	33

For more information about absolute accuracy at full scale, refer to the *AI Absolute Accuracy*

Source: NI-6363 Device Specifications

$$AbsoluteAccuracy = Reading \cdot (GainError) + Range \cdot (OffsetError) + NoiseUncertainty$$

$$GainError = ResidualGainError + GainTempco \cdot (TempChangeFromLastInternalCal) + ReferenceTempco \cdot (TempChangeFromLastExternalCal)$$

$$OffsetError = ResidualOffsetError + OffsetTempco \cdot (TempChangeFromLastInternalCal) + INLError$$

$$NoiseUncertainty = \frac{\text{Random Noise} \cdot 3}{\sqrt{10,000}}$$ for a coverage factor of 3 σ and averaging 10,000 points.

	13 ppm/°C
	1 ppm/°C
	60 ppm of range

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Calculating Accuracy

Example:

- Measured signal: 10 mV (0.01 V)
- Range: -0.1 V to +0.1 V
- Temp. difference to last self-calibration: 2 K
- Temp. diff. to last external calibration: 5 K
- Averaging: 10k samples

$$AbsoluteAccuracy = Reading \cdot (GainError) + Range \cdot (OffsetError) + NoiseUncertainty$$

$$AbsoluteAccuracy = 0.01\ \text{V} \cdot (GainError) + 0.1\ \text{V} \cdot (OffsetError) + NoiseUncertainty$$

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For more information about absolute accuracy at full scale, refer to the *AI Absolute Accuracy Example* section.

Gain tempco	13 ppm/°C
Reference tempco	1 ppm/°C
INL error	60 ppm of range

$$GainError = ResidualGainError + GainTempco \cdot (TempChangeFromLastInternalCal) + ReferenceTempco \cdot (TempChangeFromLastExternalCal)$$

$$\text{GainError} = 108\ \text{ppm} + 13\ {}^{\text{ppm}}/_{\text{K}} * 2\ \text{K} + 1\ {}^{\text{ppm}}/_{\text{K}} * 5\ \text{K} = 139\ \text{ppm}$$

$$AbsoluteAccuracy = 0.01\ \text{V} \cdot 139\ \text{ppm} + 0.1\ \text{V} \cdot (OffsetError) + NoiseUncertainty$$

NATIONAL INSTRUMENTS

Calculating Accuracy

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For more information about absolute accuracy at full scale, refer to the *AI Absolute Accuracy Example* section.

Gain tempco	13 ppm/°C
Reference tempco	1 ppm/°C
INL error	60 ppm of range

$$OffsetError = ResidualOffsetError + OffsetTempco \cdot (TempChangeFromLastInternalCal) + INLError$$

$$\text{OffsetError} = 45\text{ ppm} + 90\,{}^{\text{ppm}}/_{\text{K}} * 2\text{ K} + 60\text{ ppm} = 285\text{ ppm}$$

$$AbsoluteAccuracy = 0.01\text{ V} \cdot 139\text{ ppm} + 0.1\text{ V} \cdot 285\text{ ppm} + NoiseUncertainty$$

NATIONAL INSTRUMENTS

Calculating Accuracy

Example:

- Measured signal: 10 mV (0.01 V)
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For more information about absolute accuracy at full scale, refer to the *AI Absolute Accuracy Example* section.

Gain tempco	13 ppm/°C
Reference tempco	1 ppm/°C
INL error	60 ppm of range

$$NoiseUncertainty = \frac{\text{Random Noise} \cdot 3}{\sqrt{10,000}}$$

$$\text{Noise Uncertainty} = \frac{17\ \mu\text{V} * 3}{\sqrt{10000}} = 0.51\ \mu\text{V}$$

$$AbsoluteAccuracy = 0.01\ \text{V} \cdot 139\ \text{ppm} + 0.1\ \text{V} \cdot 285\ \text{ppm} + 0.51\ \mu\text{V}$$

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Calculating Accuracy

Example:

- Measured signal: 10 mV (0.01 V)
- Range: -0.1 V to +0.1 V
- Temp. difference to last self-calibration: 2 K
- Temp. diff. to last external calibration: 5 K
- Averaging: 10k samples

$$AbsoluteAccuracy = 0.01\ \text{V} \cdot 139\ \text{ppm} + 0.1\ \text{V} \cdot 285\ \text{ppm} + 0.51\ \mu\text{V}$$

$$= 30.4\ \mu\text{V}$$

Actual measured signal: (10 ± 0.0304) mV ≈ 10 mV ± 0.3%

Calculating Accuracy

Example 2:

- Measured signal: 10 mV (0.01 V)
- Range: -0.1 V to +0.1 V
- Temp. difference to last self-calibration: ~~2 K~~ 5 K
- Temp. diff. to last external calibration: ~~5 K~~ 10 K
- Averaging: 10k samples

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For more information about absolute accuracy at full scale, refer to the *AI Absolute Accuracy Example* section.

Gain tempco	13 ppm/°C
Reference tempco	1 ppm/°C
INL error	60 ppm of range

$$AbsoluteAccuracy = 0.01\text{ V} \cdot 183\text{ ppm} + 0.1\text{ V} \cdot 555\text{ ppm} + 0.51\ \mu\text{V}$$

$$\approx 57.8\ \mu\text{V}$$

Actual measured signal: (10 ± 0.0578) mV ≈ 10 mV ± 0.6%

~~Actual measured signal: (10 ± 0.0304) mV ≈ 10 mV ± 0.3%~~

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What If Something Is *Not* Specified?

Contact the manufacturer and ask!

Summary

- Accuracy is important to getting good data from your system
- There are lots of different terms associated with accuracy
- Being able to calculate the accuracy helps you choose the correct DAQ device

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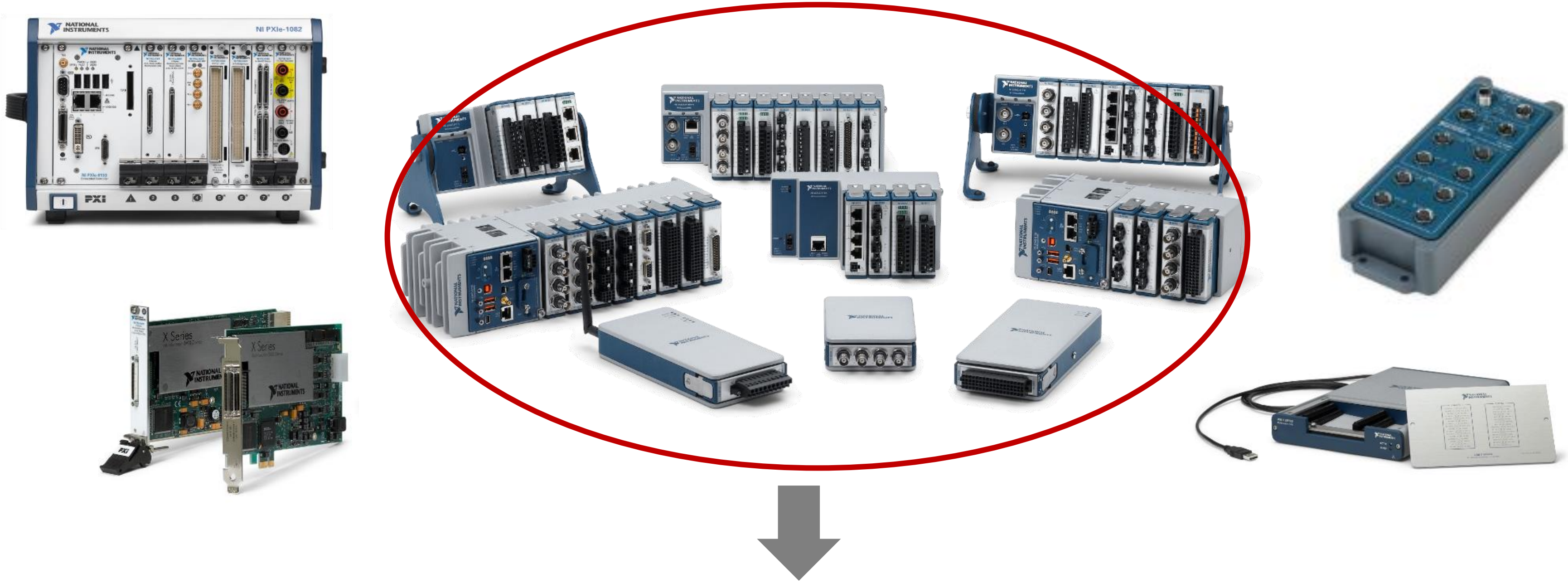
Considerations for Your Application

- Channel count
- Types of measurements
- Signal conditioning
- Analysis
- Customization
- Synchronization
- Communication bus
- Ruggedness
- Additional components/peripherals


NI PXIe-1082
X Series

Sensor Measurements With CompactDAQ

Any Bus, Any Form Factor

USB, Ethernet, or wireless

Accurate Conditioned Measurements

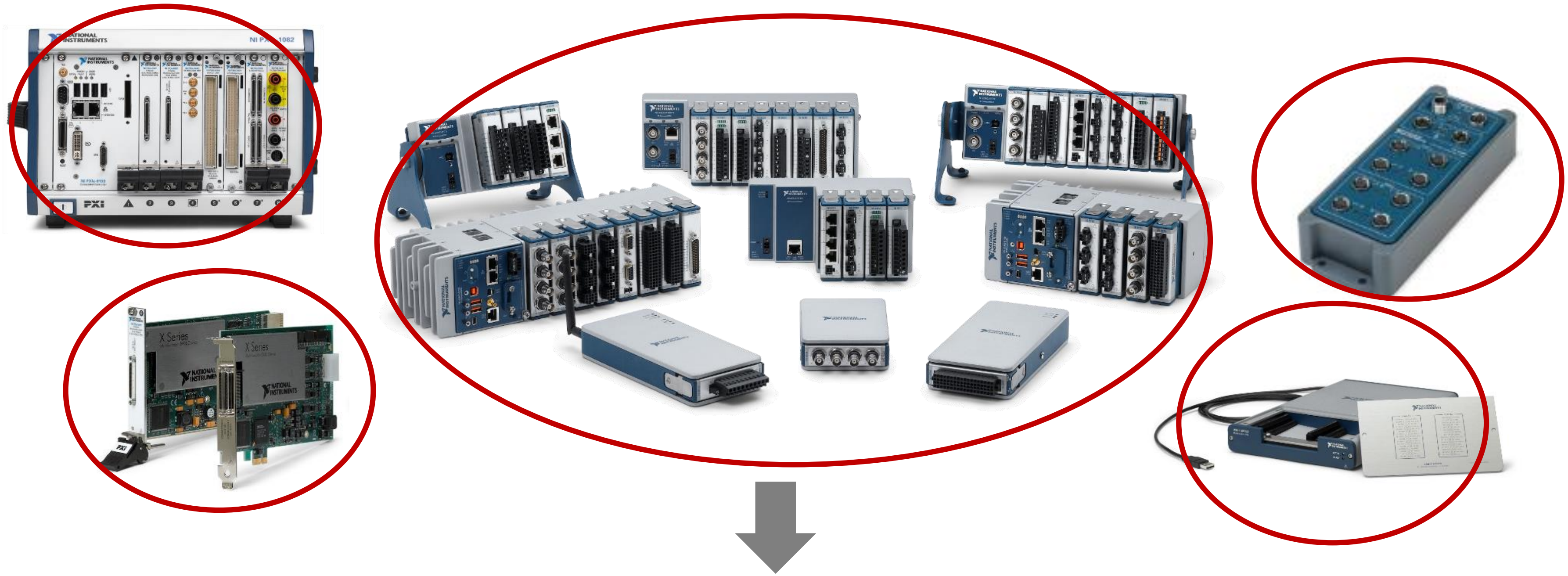
60+ sensor-specific modules with integrated signal conditioning

Synchronized, Distributed Architecture

Time Sensitive Networking enabled Ethernet chassis for distributed measurements

Deploy Closer to Your Sensor

Rugged form factors with -40 °C to 70 ° C, 50 g shock,
5 g vibration


X Series
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FieldDAQ

- Rugged Design
  - Up to IP67 ingress protection
  - -40 to 85 °C temperature range
  - 100g shock/10 grms vibration
  - 1 kV withstand Ch-Ch isolation
- Sensor specific signal conditioning for strain, voltage, and thermocouple measurements
- 24 bits resolution up to 100 kS/s sample rate
- Anti-alias filters to reduce external interference
- Link redundancy for reliability