NIWeek

ENGINEER NEXT

MAY 22-25, 2017 | AUSTIN, TEXAS

Improve Measurement Accuracy for your Application

<Name>

<Designation>

Accuracy Matters

Calculating and Understanding the Accuracy of Your DAQ

- Accuracy/Precision
- Resolution
- Code Width/LSB/Sensitivity
- Quantization & Dithering
- Types of Accuracy
- Gain and Offset Error
- INL Error
- Temperature Drift
- Noise Uncertainty
- Calculating Accuracy
- CMRR/Crosstalk
- Specification Terminology

Types of Accuracy

- **Accuracy**
- **Relative accuracy**
- **Absolute accuracy**
- **System accuracy**

What's the difference?

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**: factors in accuracy of the DAQ, but also the sensors and other environmental factors

AI Absolute Accuracy Tables and Formulas

The values in the following tables are based on calibrated scaling coefficients, which are stored in the onboard EEPROM.

Accuracy summary

Nominal Range (V)	Absolute Accuracy at Full Scale* (μV)	Random Noise, σ (μVrms)	Sensitivity† (μV)
±10	6,230	240	[illegible]
±5	3,230	116	[illegible]
±1	690	26	10.4
±0.2	174	[illegible]	[illegible]

* Absolute accuracy values at full scale on the analog input channels assume the device is operating within 70 °C of the last external calibration and are valid for averaging 100 samples immediately following internal calibration. Refer to the *Absolute accuracy formulas* for more information.

† Sensitivity is the smallest voltage change that can be detected. It is a function of noise.

- Accuracy specified on the datasheet of the Data Acquisition Device will be the Absolute accuracy of the DAQ.
- In case the input signal itself is noisy, the measurement device will measure the noisy signal with the accuracy specified. The measurement device does not factor external noise sources while calculating accuracy.

Tip:
Best way to check whether your DAQ device is out of calibration(or faulty) or the input signal itself is noisy is to loopback the GND to the Analog Input Line and check whether the readings are within the accuracy specs or not

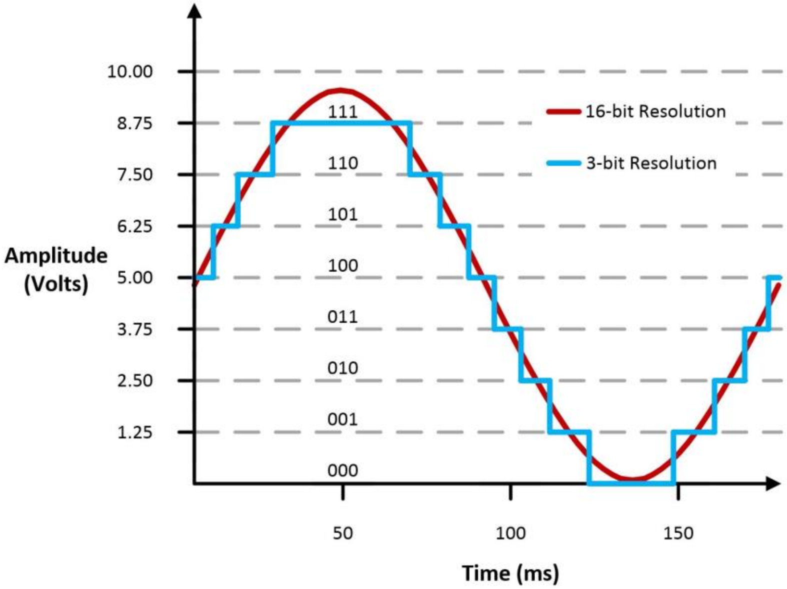
What should you be looking at: Resolution vs ENOB

Are all 16-bit resolution devices equal?

Resolution

- **Resolution**: determines the number of unique vertical levels.
- Limited by the ADC on the device.

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



- Resolution limits the precision of a measurement; the higher the resolution, the more precise the measurements.
- Higher the resolution ≠ higher accuracy!

Effective Number of Bits (ENOB)

- Measure of the actual performance of an ADC after including its various noise sources & non-linearities.
- Not all DAQ devices having the same resolution of the ADC have equal ENOB.

Vendor X: PXI-2xx5

- 16-bit
- 500 kS/s
- ±10 V input range
- Effective Number of bits = 10.5 bits
- Accuracy = 13mV

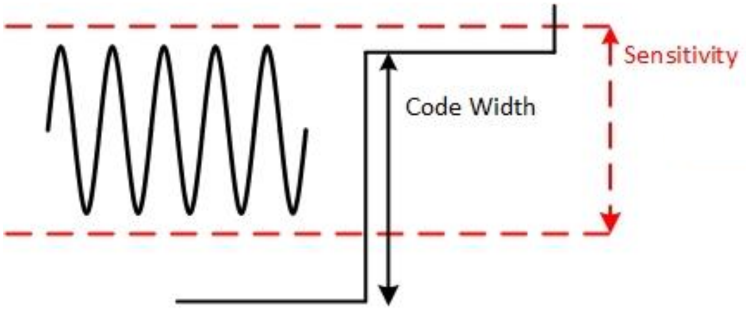
NI PXIe-6341

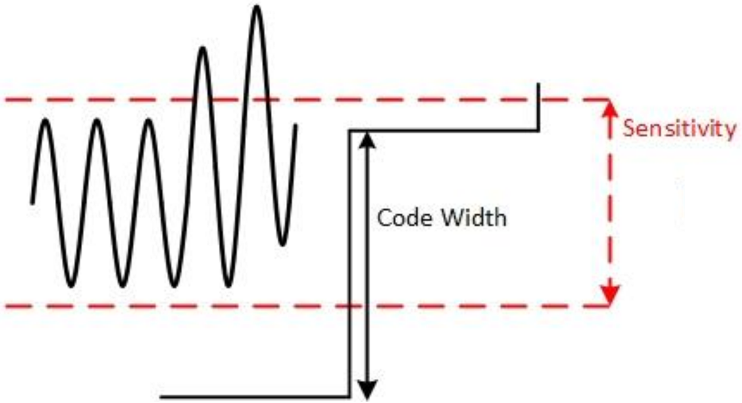
- 16-bit
- 500 kS/s
- ±10 V input range
- Effective Number of bits = 13 bits
- Accuracy = 2.19mV

Tip:
While selecting a DAQ Device for an application, the accuracy requirements should be mapped to the accuracy specs of the device and not the resolution of the device as the final accuracies of 2 devices from different vendors may differ a lot.

Sensitivity

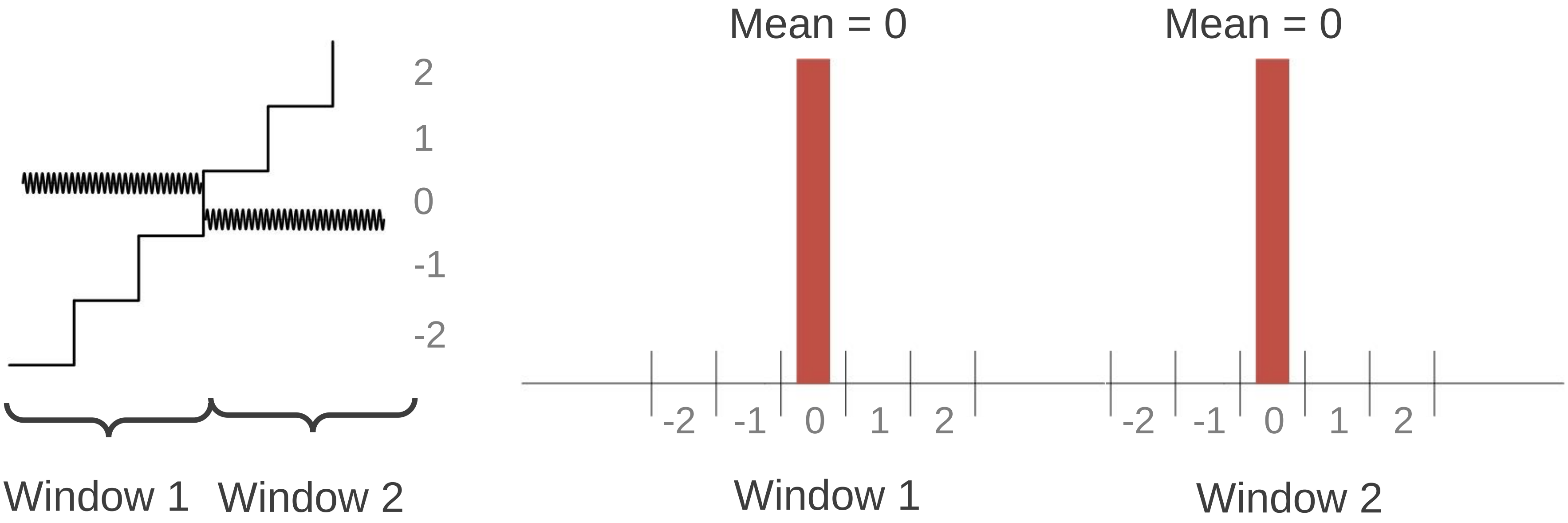
- **Sensitivity**: minimum change in voltage needed to register a change in value.





Quantization Error

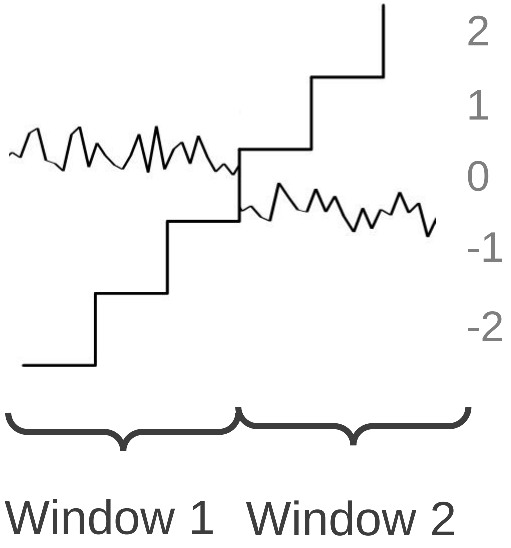
- **Quantization Error**: Error due to rounding.

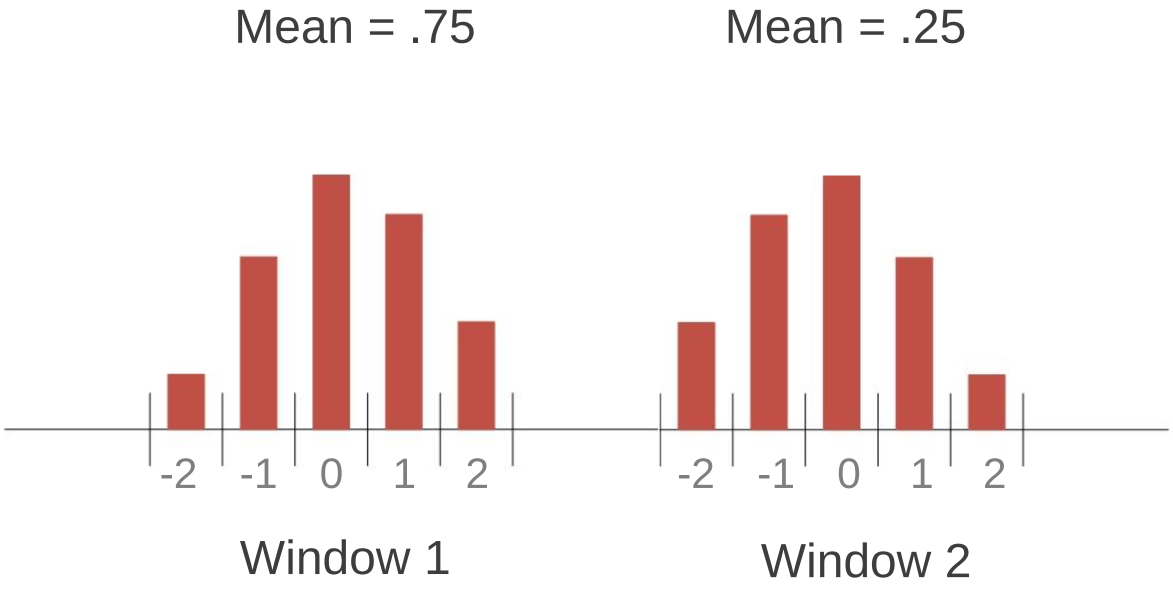


How can you have an effective sensitivity that is less than code width?

Averaging

- Average samples to get effective sensitivity less than a code width.

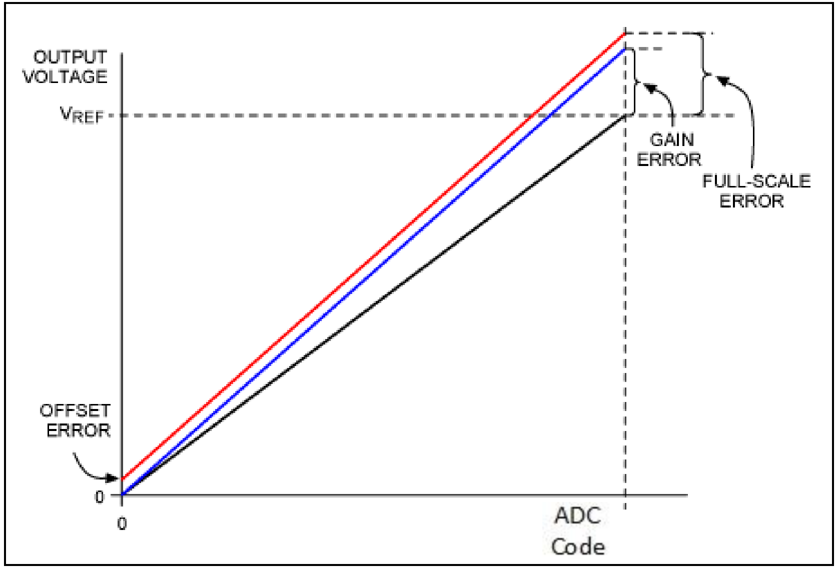




Gain and Offset Error

- **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 calibration; the **residual** error is inherent to the instrument and will exist after calibration.

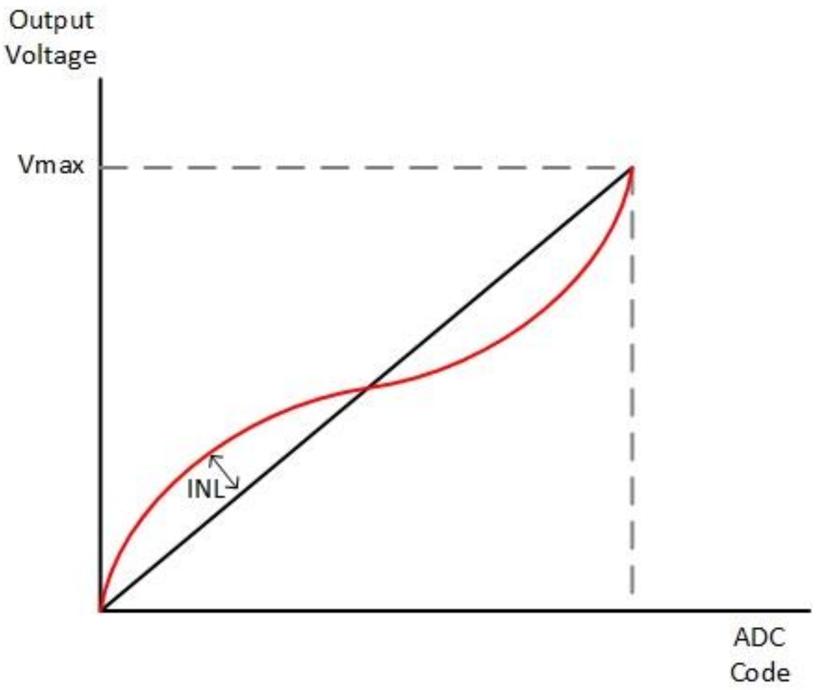


What is Self Calibration?

Self-calibration can be done without any external connections. This procedure involves routing a known internal reference voltage to all channels of the board.

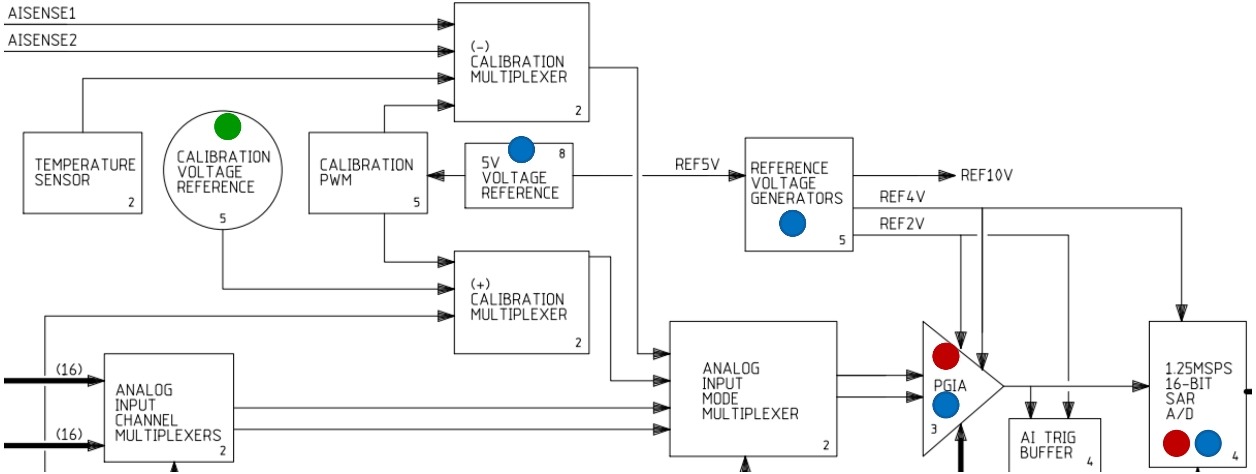
INL Error

- **Integral nonlinearity (INL) error:** how far from the ideal, excluding offset and gain



Temperature Drift

- **Temperature coefficient (tempco):** how temperature affects the measurement
  - Gain tempco: how temperature impacts the gain.
  - Offset tempco: how temperature impact the offset.
  - Reference tempco: how temperature affects on board calibration reference; contributes to gain tempco.



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.

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

Calculating Accuracy

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

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

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

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

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 Example* section.

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

- **Internal calibration**: self calibration
- **External calibration**: regular calibration

What if something isn't specified?

Contact the manufacturer and ask!!

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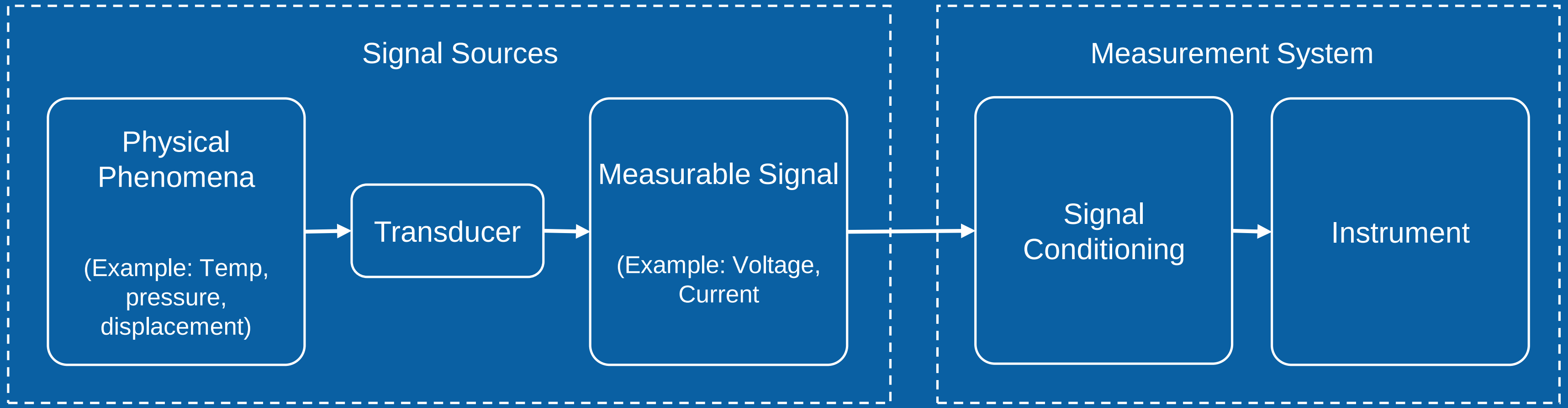
Components of Data Acquisition System



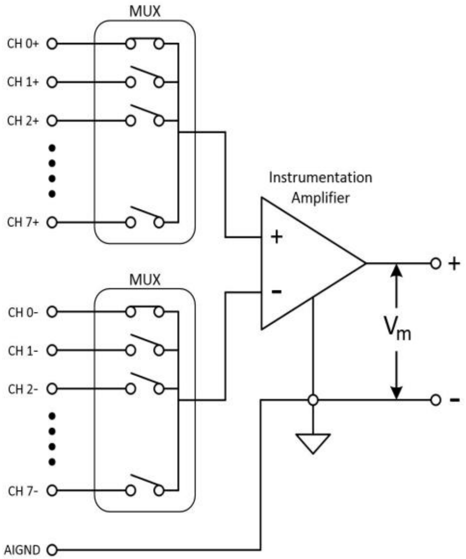
Important Factors that Affect Measurement

- Grounding

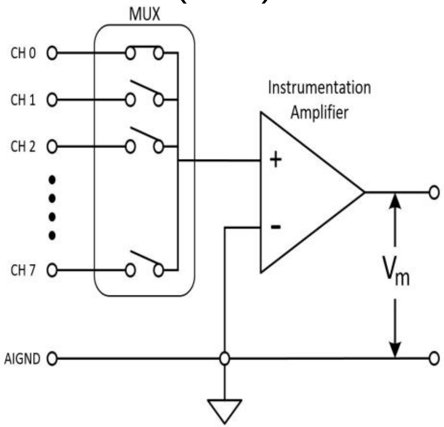
Types of Signal Sources

Types of Measurement Systems

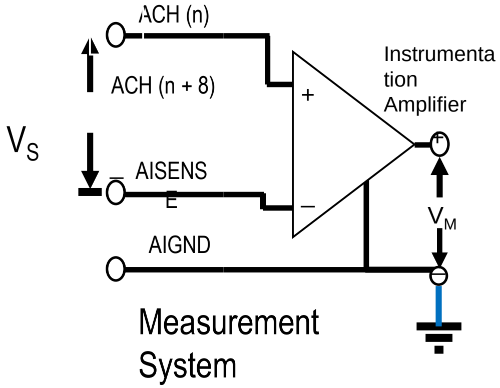
Differential
Measurement System



Ground-Referenced
Measurement System
(RSE)



Non-Referenced Single Ended
Measurement System
(NRSE)



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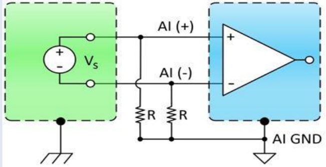
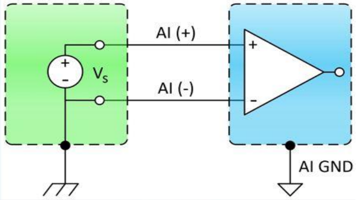
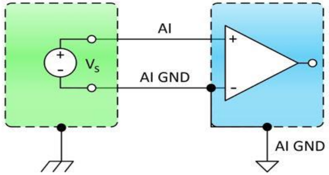
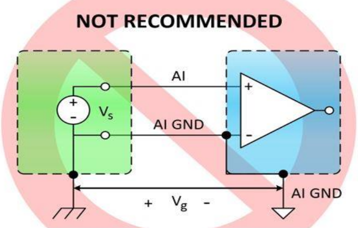
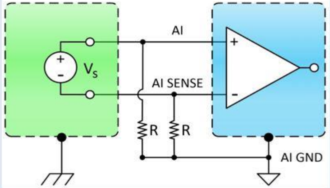
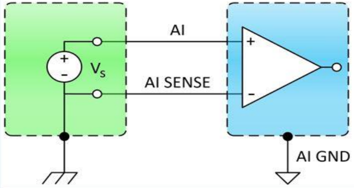
Recommended Input Terminal Configurations

<table>
<tr><td></td><td colspan="2">Signal Source Type</td></tr>
<tr><td>Input Configuration</td><td>Floating Signal Source
Examples:
• Thermocouples
• Signal conditioning with isolated inputs
• Battery-powered devices</td><td>Grounded Signal Source
Example:
• Plug-in instruments without isolated inputs</td></tr>
<tr><td>Differential (DIFF)</td><td>

Two resistors (10 kΩ < R < 100 kΩ) provide return paths to ground for bias currents</td><td>
</td></tr>
<tr><td>RSE</td><td>
</td><td>

Ground-loop potential difference, V_g, is added to measured signal</td></tr>
<tr><td>NRSE</td><td>
</td><td>
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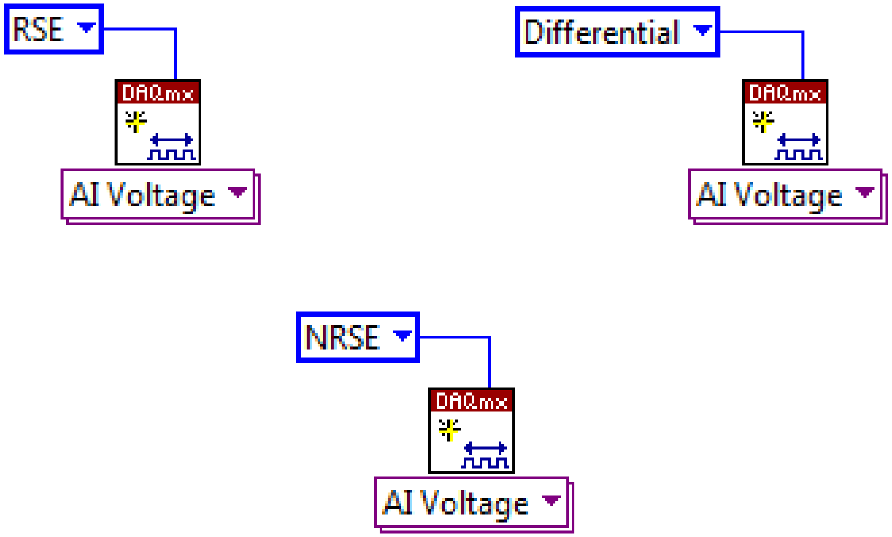
Importance of Software Configuration



Important Factors that Affect Measurement

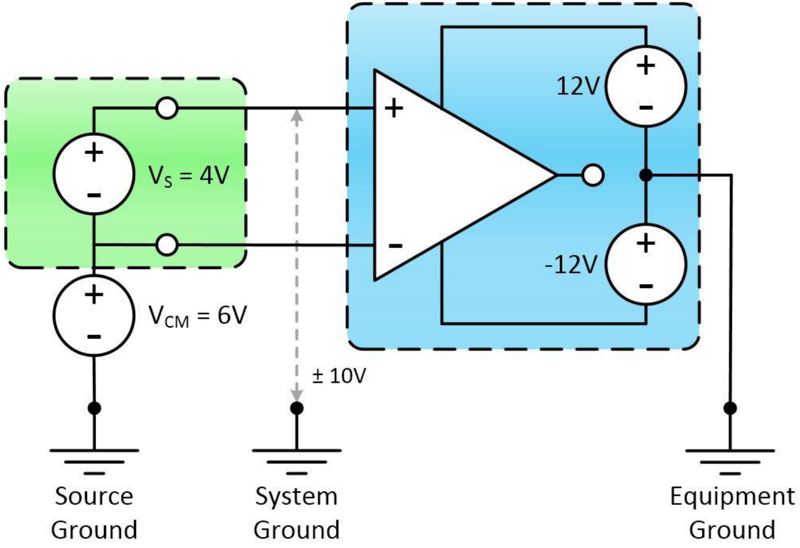
- Grounding
- Isolation

Importance of Isolation

- Increase Common Mode Range
- Ground Loop Removal
- Safety

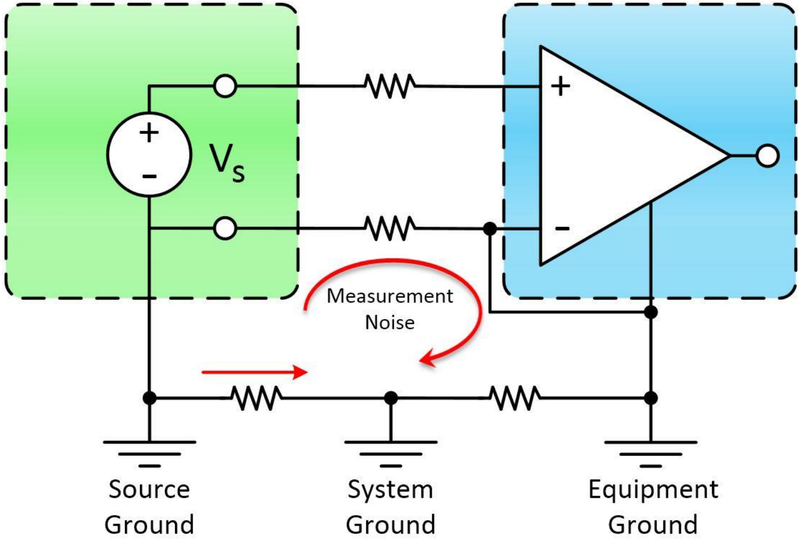
- Isolation Architectures
  1. Channel-to-Earth Isolation
  2. Channel-to-Bus (Bank) Isolation
  3. Channel-to-Channel Isolation

Increase Common Mode Voltage Range

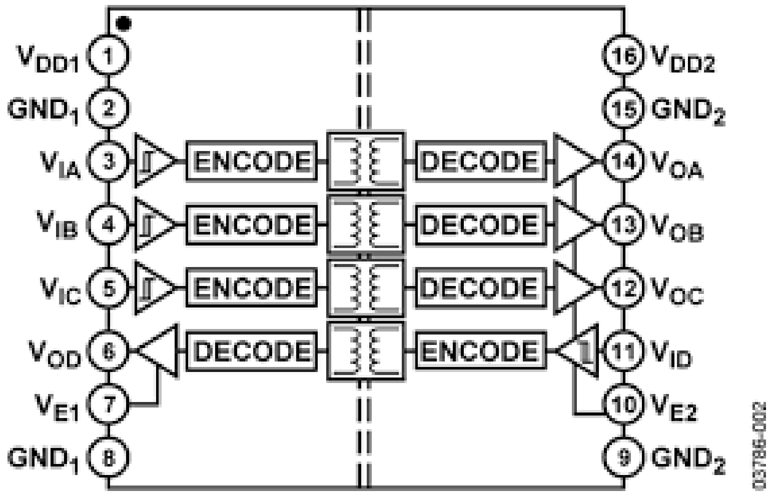


Increase Common Mode Voltage Range

Ground Loop Removal



Isolation components



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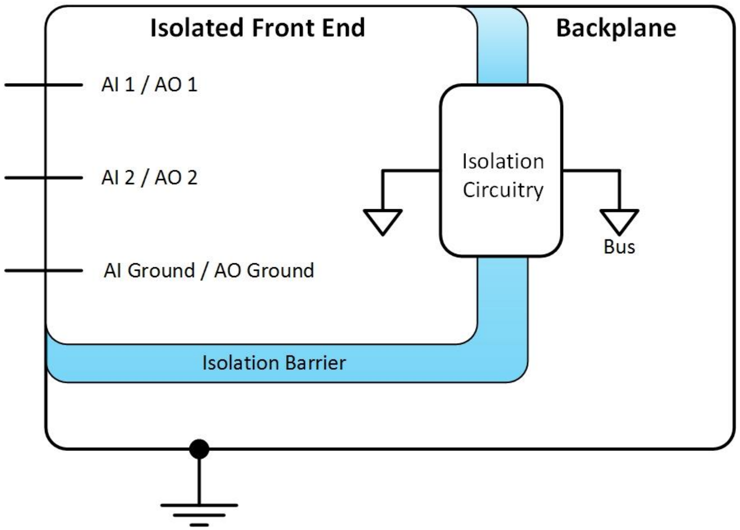
Isolation Architectures

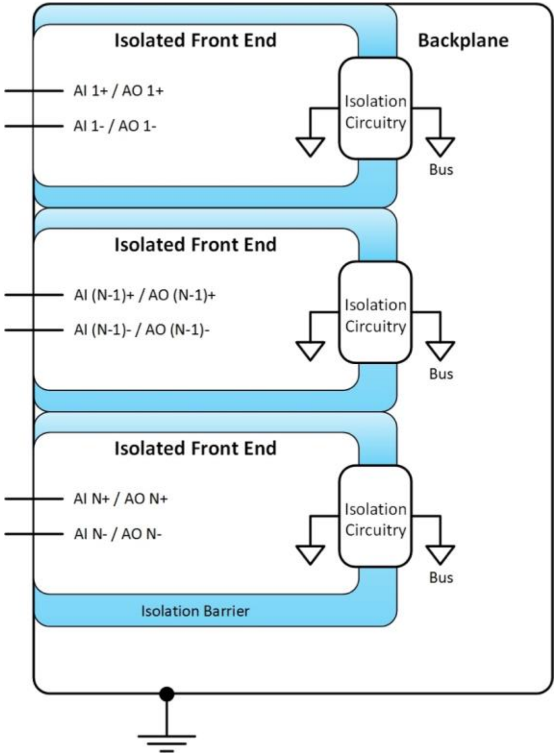
Channel-to-Earth Isolation



- Lowest protection level of isolation for an instrument
- Breaks ground loops between channels and instrument ground
- Induced voltages between channels are possible

Isolation Architectures

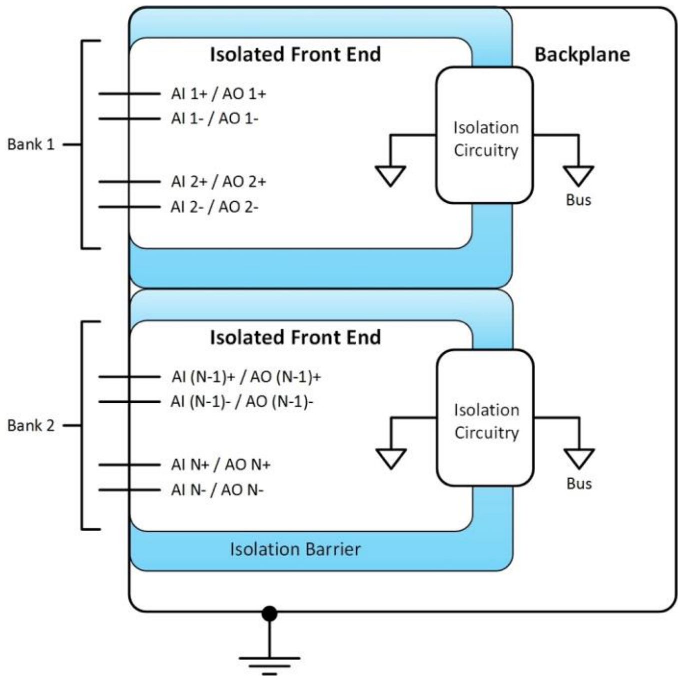
Channel-to-Channel Isolation



- Highest protection level of isolation for an instrument
- Breaks ground loops between
  - Channels and ground
  - Different channels
- Induced voltages between channels, in the same bank, are not possible

Isolation Architectures

Channel-to-Bus (Bank) Isolation

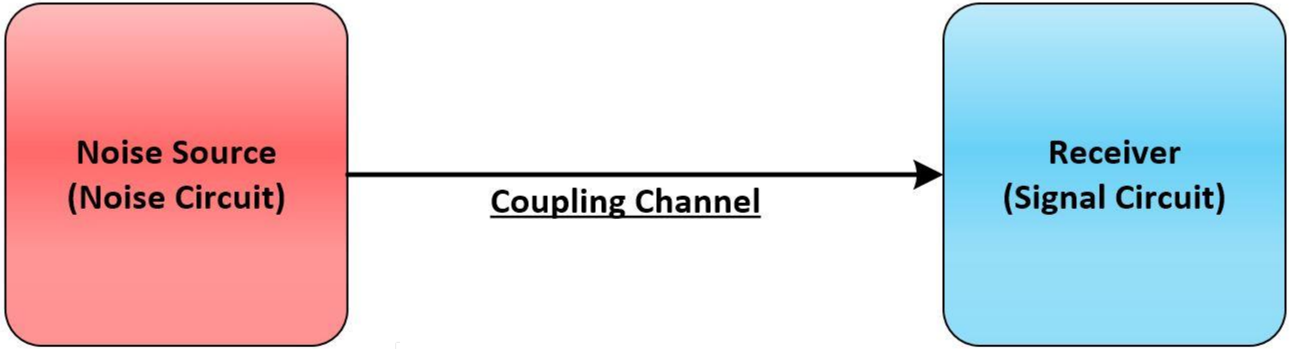


- Physical lines are built into groups called banks
- Breaks ground loops between
  - Channels and ground
  - Channels in different banks
- Induced voltages between channels, in the same bank, are possible

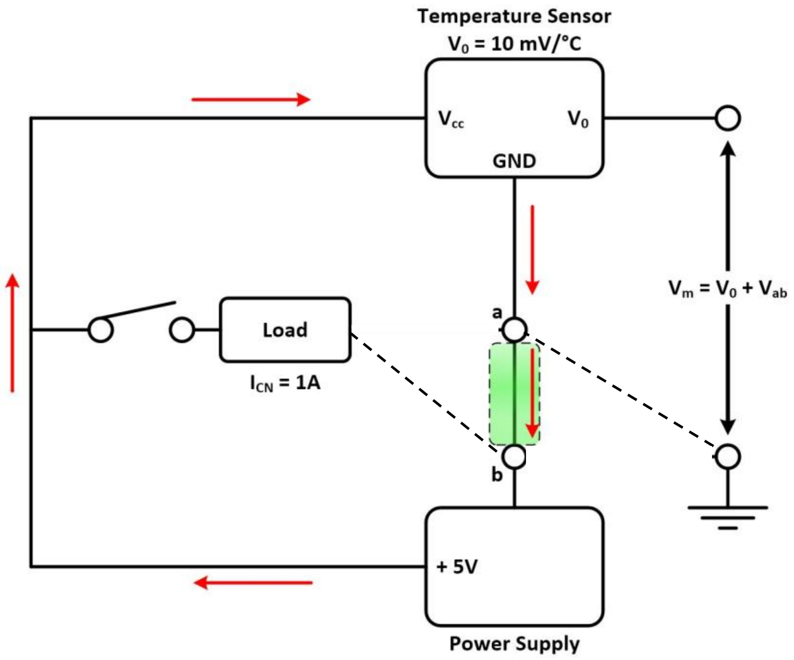
Important Factors that Affect Measurement

- Grounding
- Isolation
- Shielding

Noise Coupling



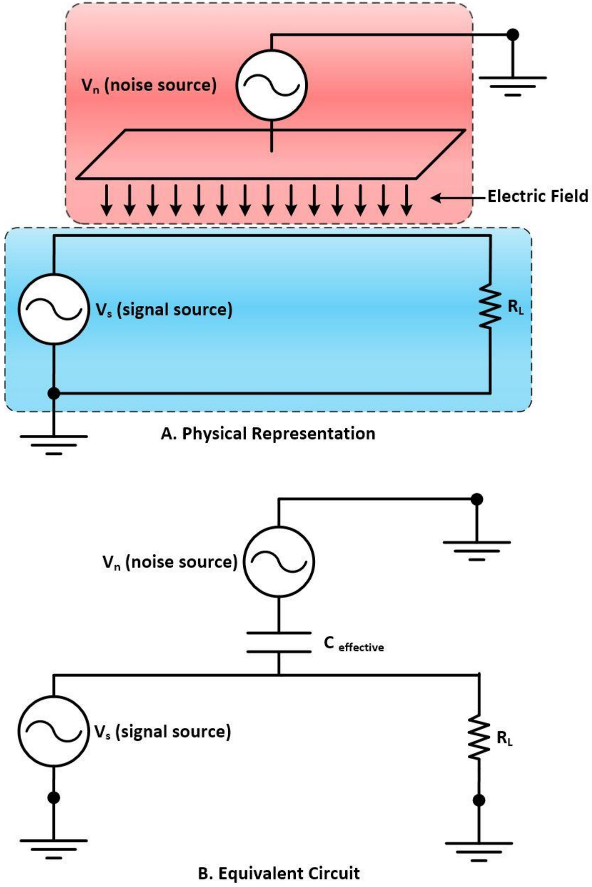
Conductively Coupled Noise



- Common ground return path
- To Resolve:
  - Break ground loops
  - Provide separate ground return paths

Capacitively Coupled Noise

- Electric field coupling can be modeled as capacitance between two circuits
- To Resolve:
  - Reduce signal circuit impedance
  - Use capacitive shielding
    - Must be grounded only on the signal side



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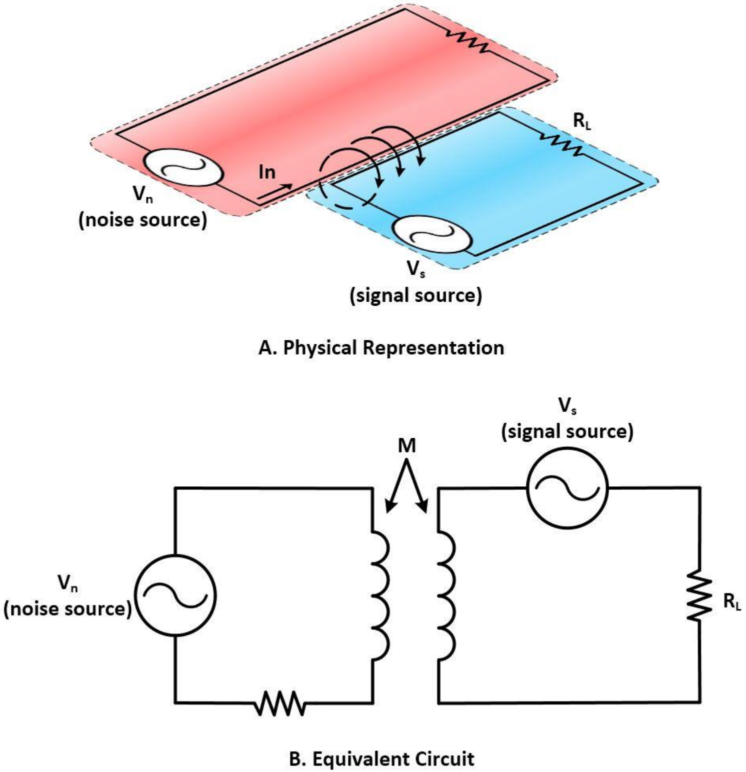
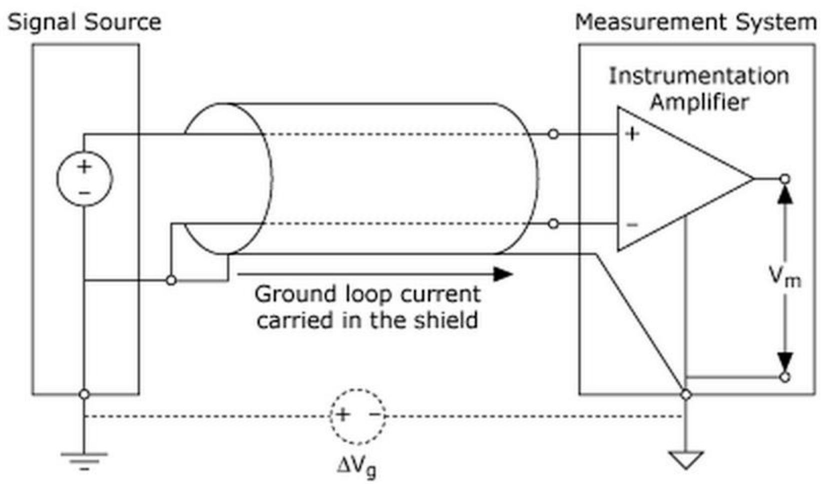
Inductively Coupled Noise



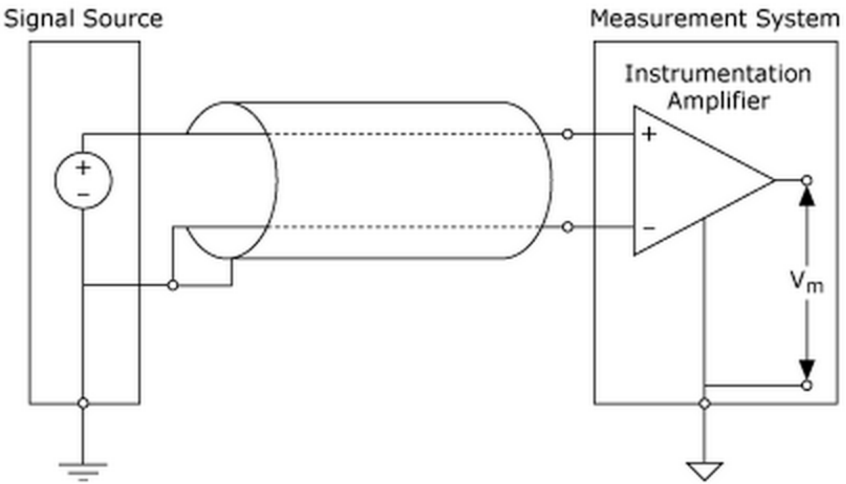
- Magnetic flux coupling can be modeled by inductors on the noise and signal circuit
- To Resolve:
  - Increase separation between circuits
  - Minimize signal loop area
    - Use twisted pair wiring
  - Use magnetic shielding

DEMO

Proper Shielding



Improper Shielding



Proper Shielding

Thank You