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Low Level Seminar

4 Steps to Precision Measurements

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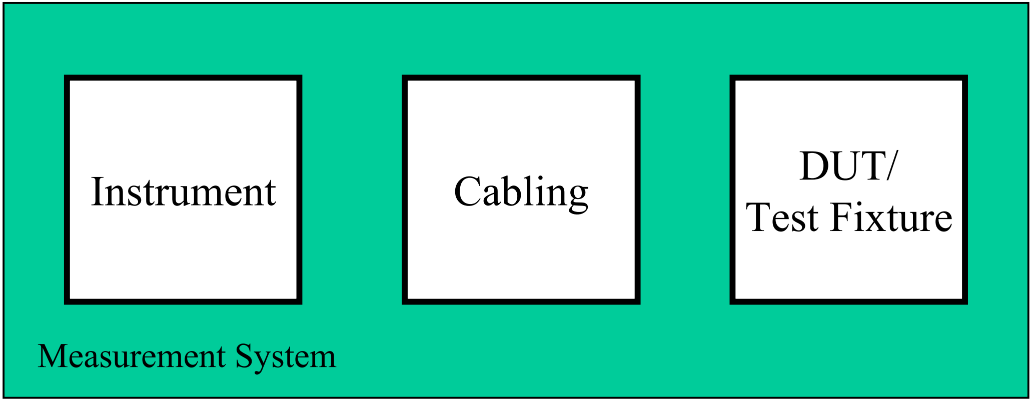
Measurement System



What limits your Results

- *The material or device under test (DUT) itself?*
- *The connections between the DUT and instruments (including cables, fixtures, switching, etc.)?*
- *The measuring instrument?*

4 Step Measurement Process

1. Define required measurement quality
   - Accuracy, Repeatability, Timing, …
2. Design measurement system
   - Select equipment and fixtures
3. Build and verify performance
   - Techniques to improve measurements
4. Use system to gather desired information

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Measurement Basics

- Resolution
- Sensitivity
- Accuracy
- Repeatability

Resolution

- The smallest *portion* of the signal that can be observed
- 12-bit resolution = 1 part in 4096
- 4 1/2 digits = 1 part in 20000 counts (00000 to 19999)
- 7 1/2 digits = 1 part in 20,000,000 counts (00000000 to 19999999)

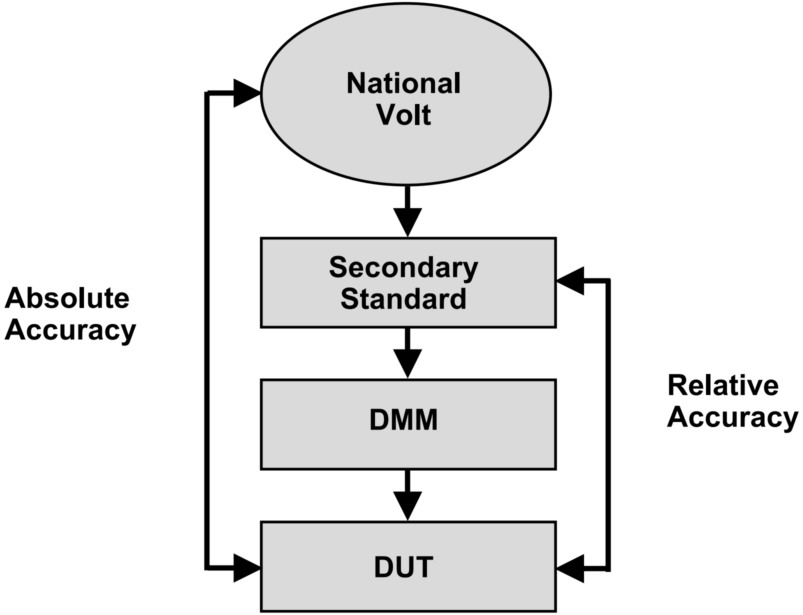
Sensitivity

- The smallest *change* that can be detected
- Specified in units of the measured value
  - Volts, ohms, degrees
- Examples:
  - 3 1/2 digits (2000) on 2V range = 1 mV
  - 4 1/2 digits (20000) on 2Ω range = 100 μΩ
  - 16-bit (65536) A/D on 2V range = 30 μV
  - 8 1/2 digit on 200 mV range = 1 nV

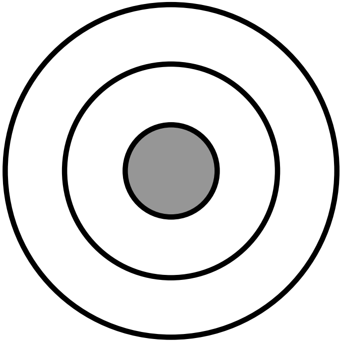
Accuracy

- Absolute accuracy
  - A measure of the closeness of agreement between a measured value and that of a primary standard value
- Relative accuracy
  - A measure of the closeness of agreement between a measured value and that of a locally established reference value

Accuracy


National
Volt
Secondary
Standard
DMM
DUT
Absolute
Accuracy
Relative
Accuracy

Resolution, Accuracy, Repeatability



Resolution **Accuracy** **Repeatability**

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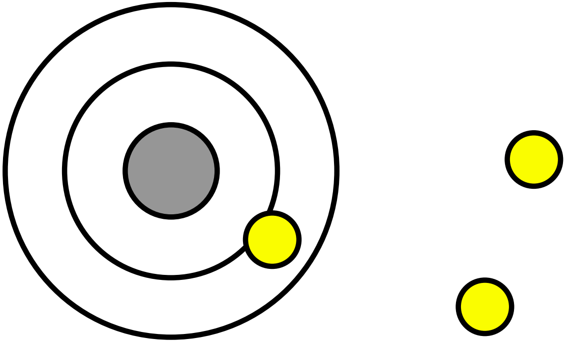
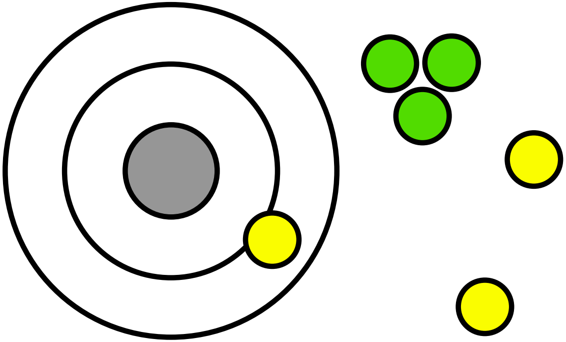
Resolution, Accuracy, Repeatability



Resolution	Accuracy	Repeatability
Low	Low	Low

Resolution, Accuracy, Repeatability



	Resolution	Accuracy	Repeatability
	Low	Low	High
	Low	Low	Low

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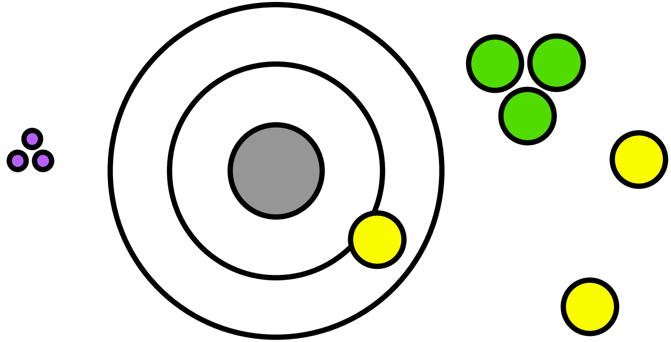
Resolution, Accuracy, Repeatability



	Resolution	Accuracy	Repeatability
	High	Low	High
	Low	Low	High
	Low	Low	Low

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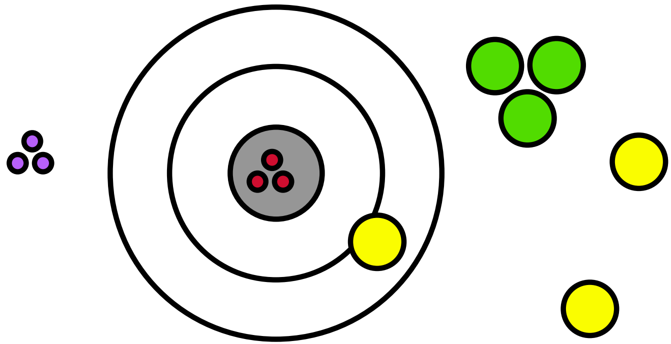
Resolution, Accuracy, Repeatability



	Resolution	Accuracy	Repeatability
	High	High	High
	High	Low	High
	Low	Low	High
	Low	Low	Low

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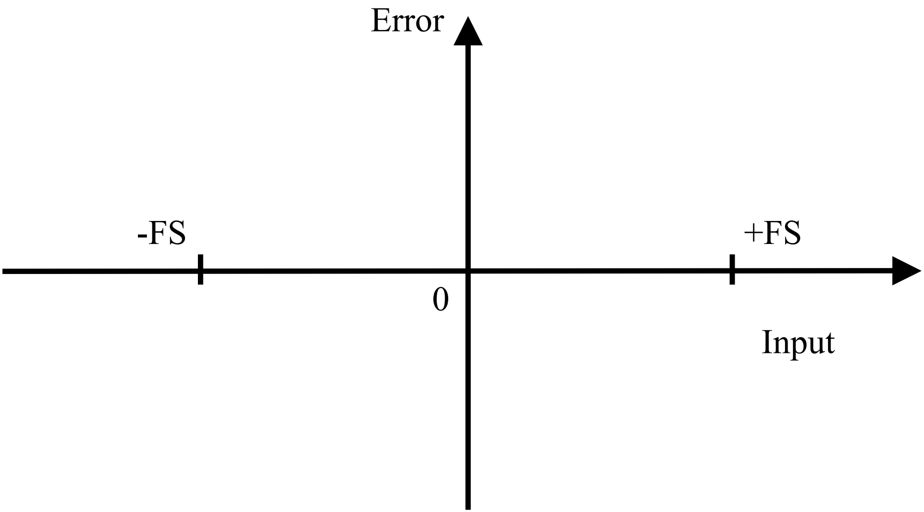
Design measurement

- Keithley's other low level seminars talk about appropriate selection of ammeters and voltmeters
- Understanding of specs of the instrumentation is key for success

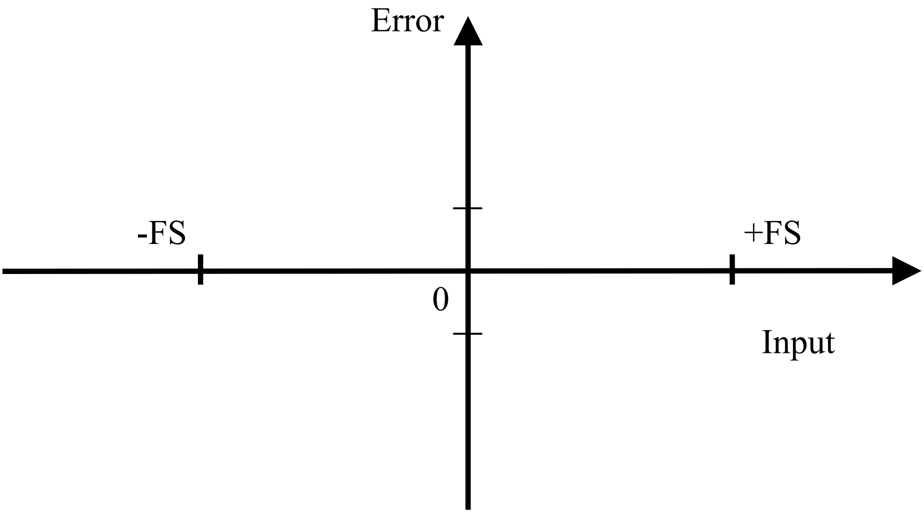
How to read specs

- Accuracy
  - Offset error vs Gain error
  - Temperature coefficient
- Sensitivity
  - Noise vs resolution
- Timing
  - Settling Time vs Rise Time

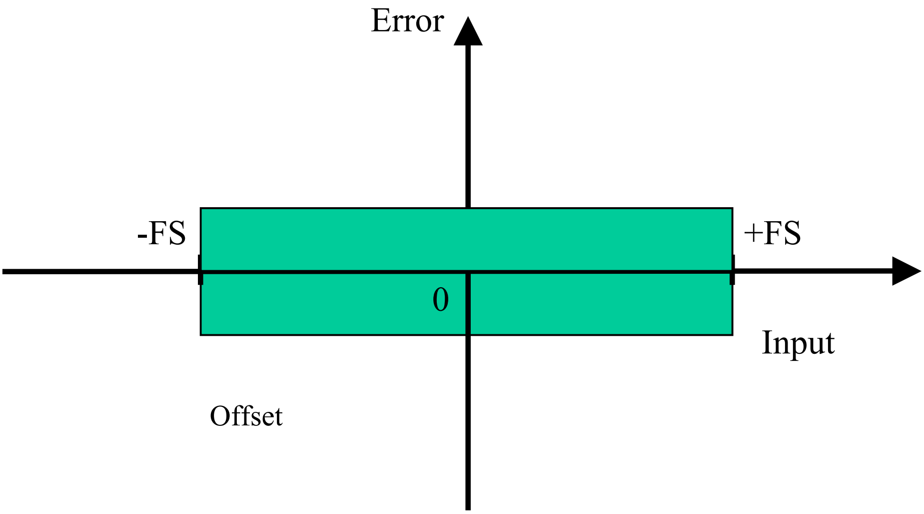
Accuracy



Accuracy



Accuracy



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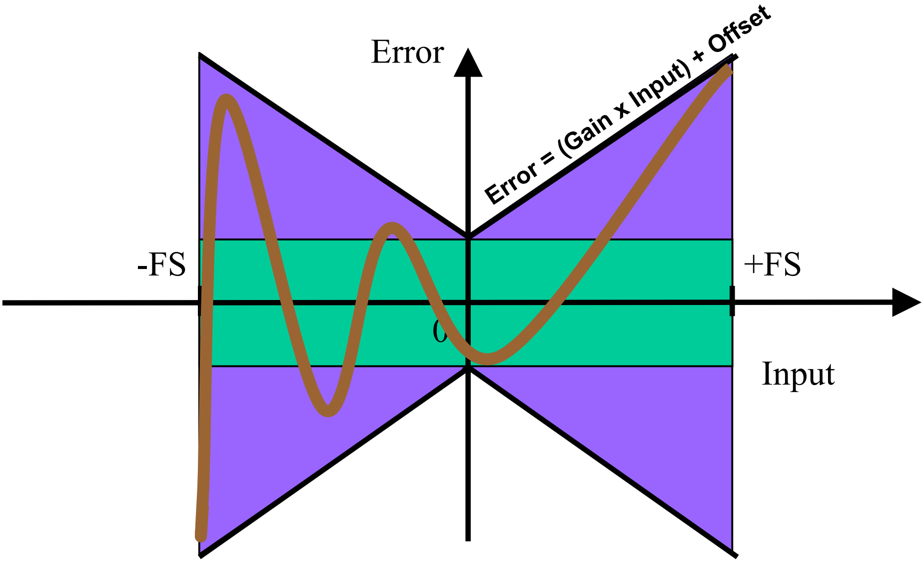
Accuracy



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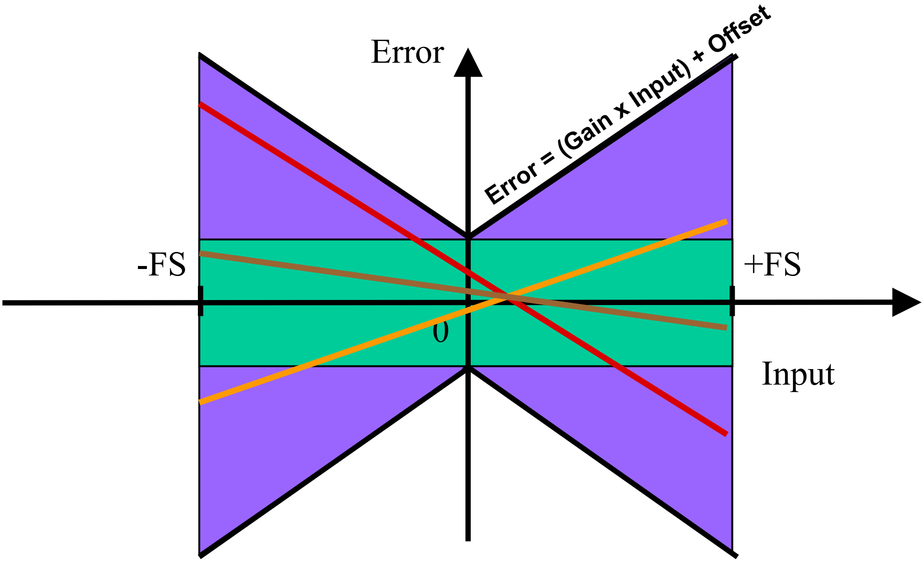
Linearity



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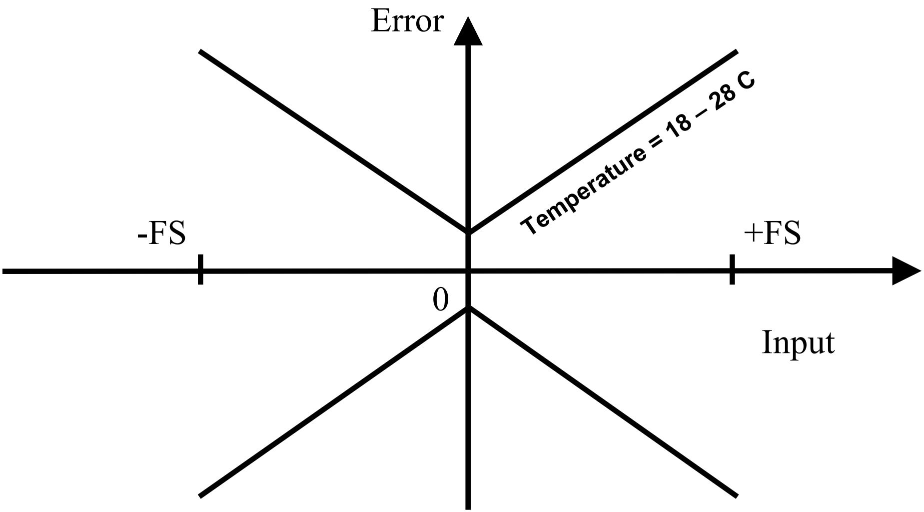
Temperature Coefficient



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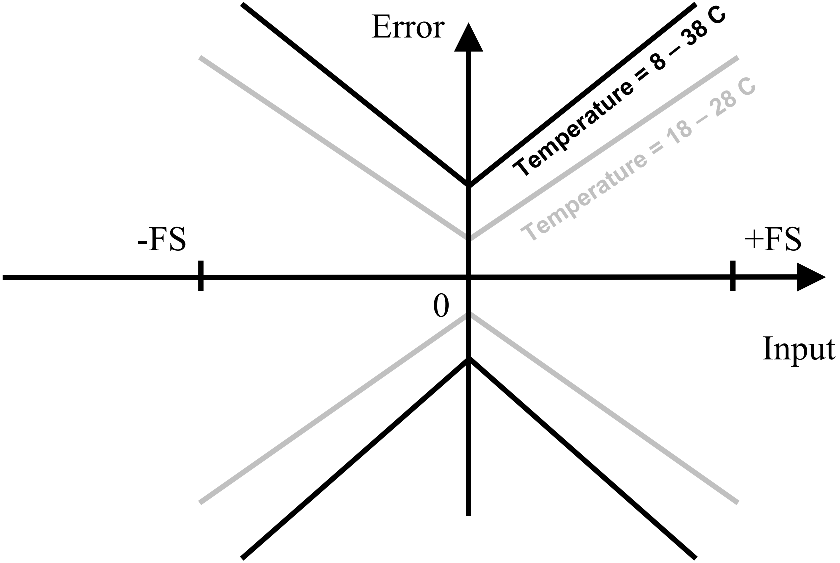
Temperature Coefficient



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Instrumentation Error

- Accuracy = ± (% reading + % range)
  = ± (gain error + offset error)
- For example, DMM 2V range:
  Accuracy = ± (0.03% of reading + 0.01% range)
- For a 0.5V input:
  Uncertainty = ± (0.03% x .5V + .01% x 2.0V)
  = ± (.00015V + .00020V)
  = ± 350 μV
- Reading = .49965 to .50035

Instrumentation Error - DMM Example

- DMM, 6 1/2 digit, 2V range (2.000000)

  Accuracy

  $= \pm$ (0.003% reading + 0.001% range)

  $= \pm$ (30 ppm readings + 10 ppm range)

  $= \pm$ (0.003% reading + 20 counts)

  Uncertainty @ .5V

  $= \pm$ (.000015 + .000020)

  $= \pm$ .000035V

  $= \pm$ 35 μV

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Instrumentation Error – Data Acquisition Board Example

- Analog input board, 12 bit, 2V range

Accuracy

$$= \pm (0.01\% \text{ reading} + 1 \text{ LSB})$$

$$= \pm (100\text{ppm} + 1 \text{ bit})$$

Uncertainty @ .5V

$$= \pm \left(.000050 + \frac{2.0}{4096}\right)$$

$$= \pm (.000050 + .000488)$$

$$= \pm .000538$$

$$= \pm 538\ \mu\text{V}$$

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Sensitivity

- The smallest observable change may be limited either by noise or by digital resolution
- Instrument Noise is often specified
  - Peak-to-peak, RMS, in some bandwidth
- If not specified, could be measured:
  - Voltmeters/Ohmeters: Shorted Input
  - Ammeters: Open (Shielded) Input

Timing

- Rise Time:
  - 10% – 90%
  - 2.2 time constants (2.2 X RC)
- Settling Time:
  - Specified as time for measurement circuitry to settle to within 1% (or .1%) of final value

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Measurement System

Instrument

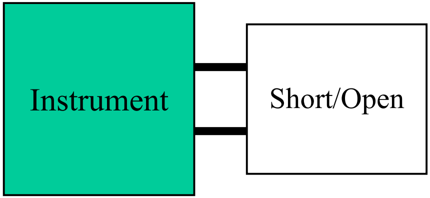
Cabling/
Interference

DUT/
Test Fixture

- We have picked appropriate equipment, cables, and fixtures
- We know the specs of the equipment
- Verify performance one step at a time

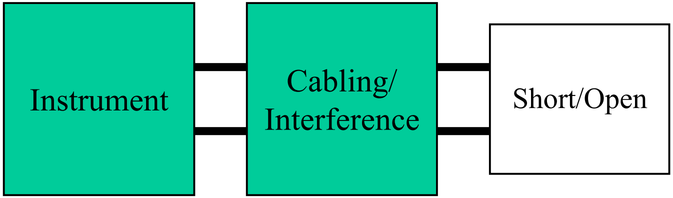
Assemble system one piece at the time

- Start with the instrument, verify noise and error:
  - Voltage measurements: Short circuit input
  - Ammeter: Open circuit input



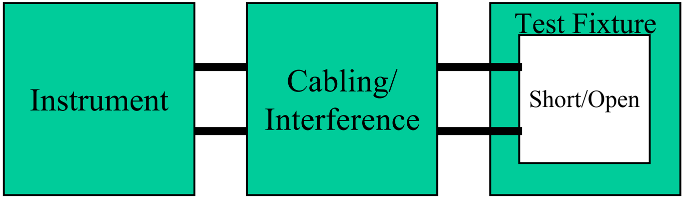
Assemble system one piece at the time

- Start with the instrument, verify noise and error:
  - Voltage measurements: Short circuit input
  - Ammeter: Open circuit input
- … Then include Cabling



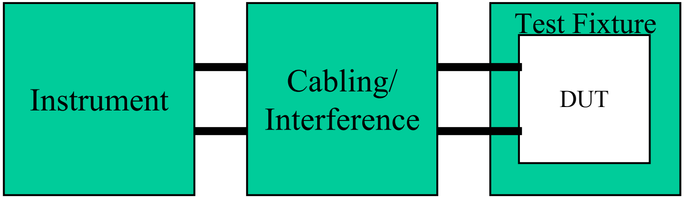
Assemble system one piece at the time

- Start with the instrument, verify noise and error:
  - Voltage measurements: Short circuit input
  - Ammeter: Open circuit input
- Include Cabling
- … Then include the Test Fixture



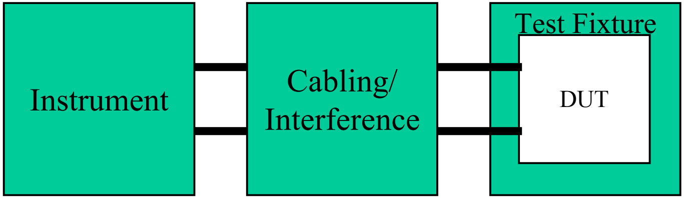
Assemble system one piece at the time

- Start with the instrument, verify noise and error:
  - Voltage measurements: Short circuit input
  - Ammeter: Open circuit input
- Include Cabling
- Then include the Test Fixture
- … Then include the DUT

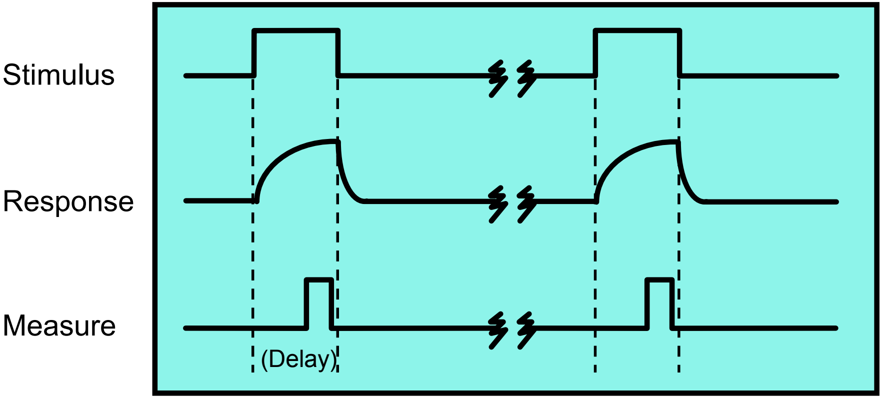


Assemble system one piece at the time

- Start with the instrument, verify noise and error:
  - Voltage measurements: Short circuit input
  - Ammeter: Open circuit input
- Include Cabling
- Then include the Test Fixture
- Then include the DUT
- Check timing, reassess measurement speed goals



Capacitance / Delay Time



Capacitance (and sometimes inductance) in the system often require that you delay measurements after a change in stimulus for a good measurement.

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Assemble system one piece at the time

- Start with the instrument, verify noise and error:
  - Voltage measurements: Short circuit input
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- Then include the DUT
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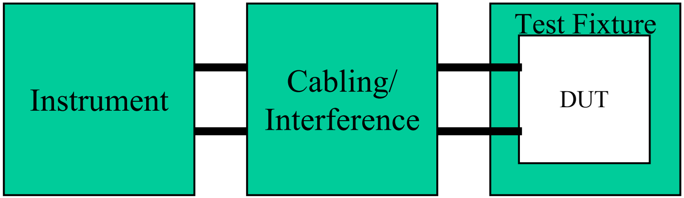


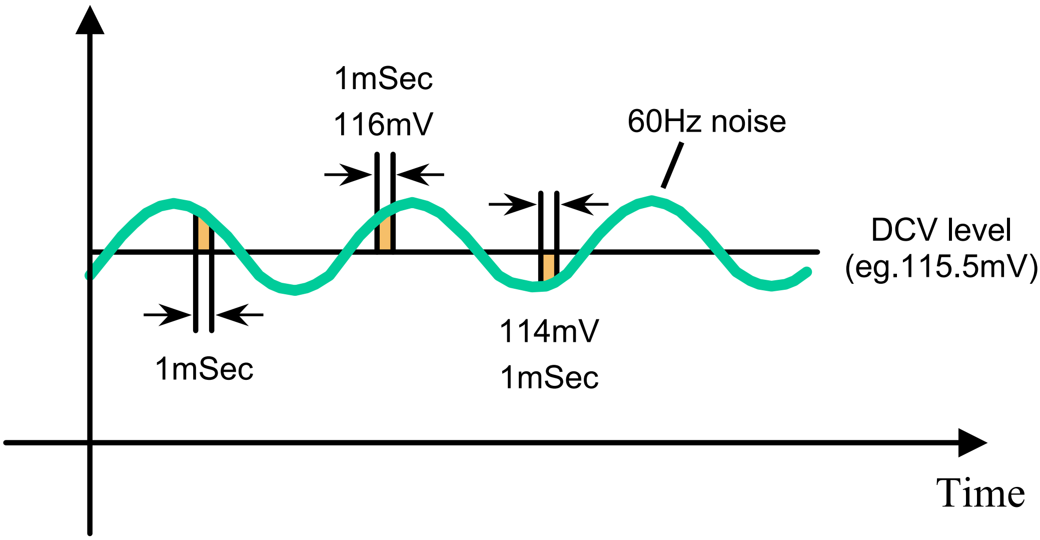
If unacceptable errors or noise

- The step-at-a-time approach allows us to identify the location of the problem
- Previous seminars talk about measurement techniques:
  - Low voltage measurements: Thermal EMFs, Magnetic interference, Ground loops, ..
  - Low current measurement: Cable noise, Contamination effects, Shielding, Guarding, ..
  - Resistance measurements: Delta mode, Alternating Voltage Mode, ..

Reducing interference

- Interference introduces AC *and* DC errors in the measured signal.
  - The source of interference is often at the power line frequency, 50 or 60 Hz
- Remedy for these types of errors
  - Integration
  - Filtering

External Noise “Pick-up”



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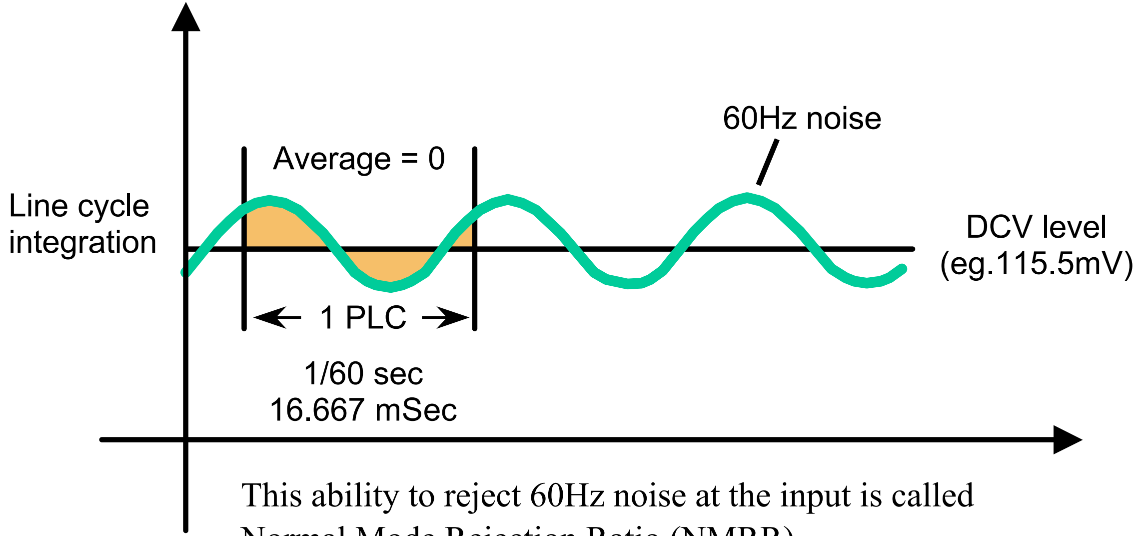
Line-Cycle Integration



This ability to reject 60Hz noise at the input is called Normal Mode Rejection Ratio (NMRR).
1Vpp noise @ 60dB NMRR = 1mV error.

Theoretical Limits of Measurement

The DUT resistance provides a fundamental limit to how well Vs or Is can be resolved:

$$V_n = \sqrt{4kTBR_{DUT}} \qquad I_n = \sqrt{4kTB/R_{DUT}}$$

K - Boltzmann's constant
T - Absolute temperature of the source
B - Noise bandwidth in hertz
R - Resistance of the source in Ohms

How to reduce Vn and In

- Reduce temperature
- Reduce the bandwidth:
  - Increasing response time of the instrument
    - Integration
  - Noise speed trade off

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Use system to gather desired information

- On a regular basis, reassess system performance
- For how long can I trust my instrument's specs
  - Specified accuracy changes with time
- Calibration - adjustment of a device to within a specified percent of a known standard (NIST)
- Component drift determines a manufacturers accuracy specs

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