Modern Precision Multimeter Measurement - putting theory to the test

Steve Chapman

Fluke Precision Measurement

Abstract

- In a controlled experiment we asked five laboratory personnel to perform some basic measurements using the same precision digital multimeter and control reference sources. The results yield an unusually wide spread of readings – why?

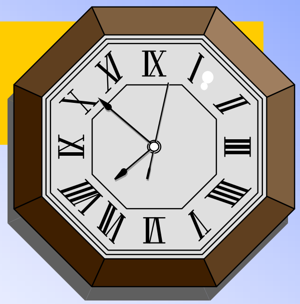
- Is the operator or the instrument to blame, or were the results within an acceptable measurement uncertainty? Modern precision multimeters have numerous measurement modes to cater to a diverse range of applications, but which mode is right? This paper unravels the confusion over choice of instrument operating modes and promotes best measurement practices to maintain consistent and repeatable measurements.

Background

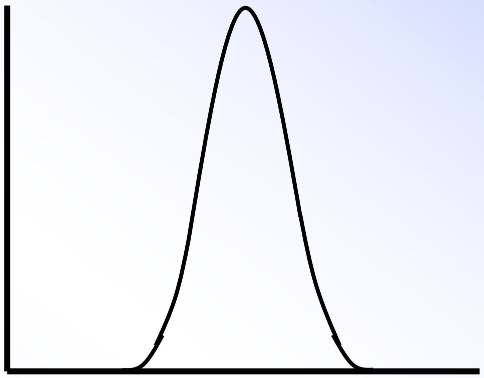
- Increased reliance on automation to improve lab efficiency -- but what’s being compromised?
- Can measuring instrumentation be improved to better support the process?
- Are existing metrology training programs sufficient for today's needs?
- Future use of the Internet as a tool for remote calibration?
- Who reads the manual anyway?

FLUKE

Complexity (Experiment 1)



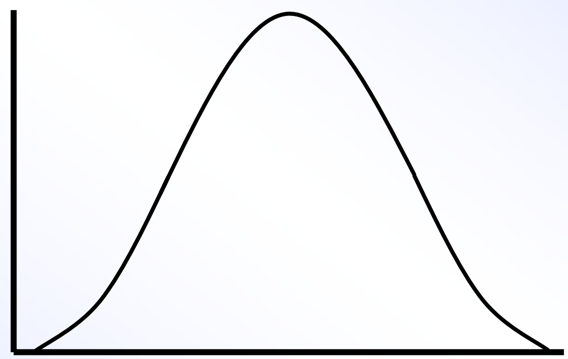
- Look at the clock at the rear of the room and record the time.
- Error contributions
  - User
    - * Ability to see the clock
    - * Ability to define time
    - * Ability to record time
  - Hardware
    - * Resolution
    - * Parallax (Analog clock)
    - * Accuracy relative to time standard (unless locked to GPS)



- The distribution of results should be small.

Complexity (Experiment 2)

- Using a Precision Multimeter measure a 10V Reference Voltage Standard and record the result. Compared with the previous exercise the process would yield a larger distribution of results.



- Determination of combined errors cause this distribution in results?

Source of Error

- Specification
  - *Uncertainty Relative to Standards*
  - *Calibration Uncertainty*
  - *Calibration Interval*
  - *Confidence Levels*
  - *Stability*
  - *Internal Corrections*
  - *Nulls/Offset compensations/ACALS*
- Environment
  - *Temperature*
  - *Humidity*
  - *Pressure*
- Cables/Connections
  - *Thermal Errors*
    - * *Seebeck, Peltier & Thomson effect*
  - *Sensing*
  - *E-M shielding*
  - *Guard*
- Measurement
  - *A/D conversion time*
  - *Load Errors*
  - *Measurement Settling times*
  - *Bias Current*
  - *Burden*
  - *Settling times*
  - *Interference*

Quantify DMM Accuracy

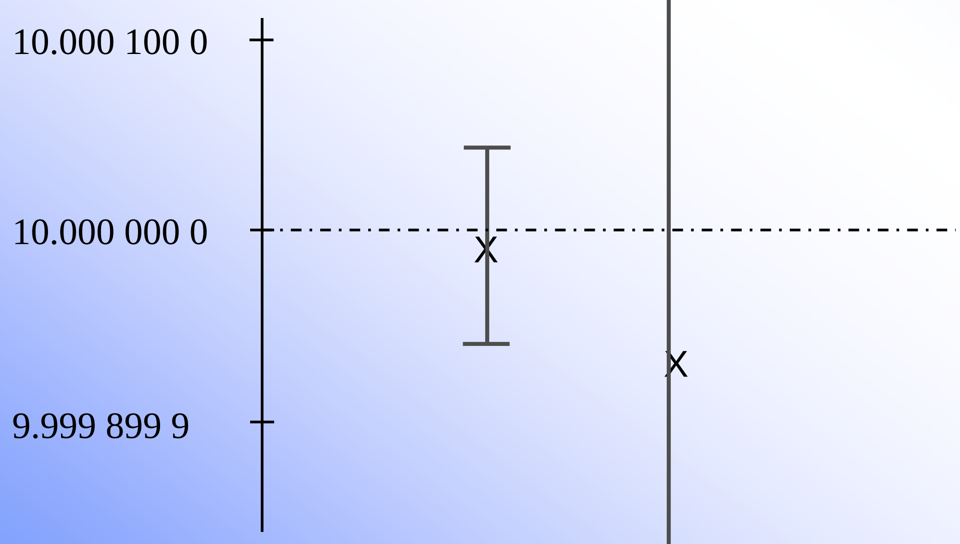
Parameter	Typical Specification Range	Error Contribution
Warm-up time	25 minutes - 4 hours	0 - 100 ppm
DC Uncertainty (Absolute)	3 - 8 ppm	3 - 8 ppm
DC Uncertainty (Cal Uncertainty)	1 - 5 ppm	1 - 5 ppm
Confidence Level 95% or 99%	1 - 1.25 multiplier	1 - 10 ppm
DC Stability	0.5 - 2 ppm	0.5 - 2 ppm
Temperature Co-efficients	0.25µV/°C - 4µV/°C	0.25 - 4ppm for 1°C change
Counts	120 - 200 million	n/a
Linearity	0.05 - 0.1ppm	0.05 - 0.1ppm
A/D Conversion Cycle	10µsec - 25 seconds	0 - 50 ppm

Best Case Uncertainty ≈ 5 ppm
Worst Case Uncertainty ≈ 180 ppm

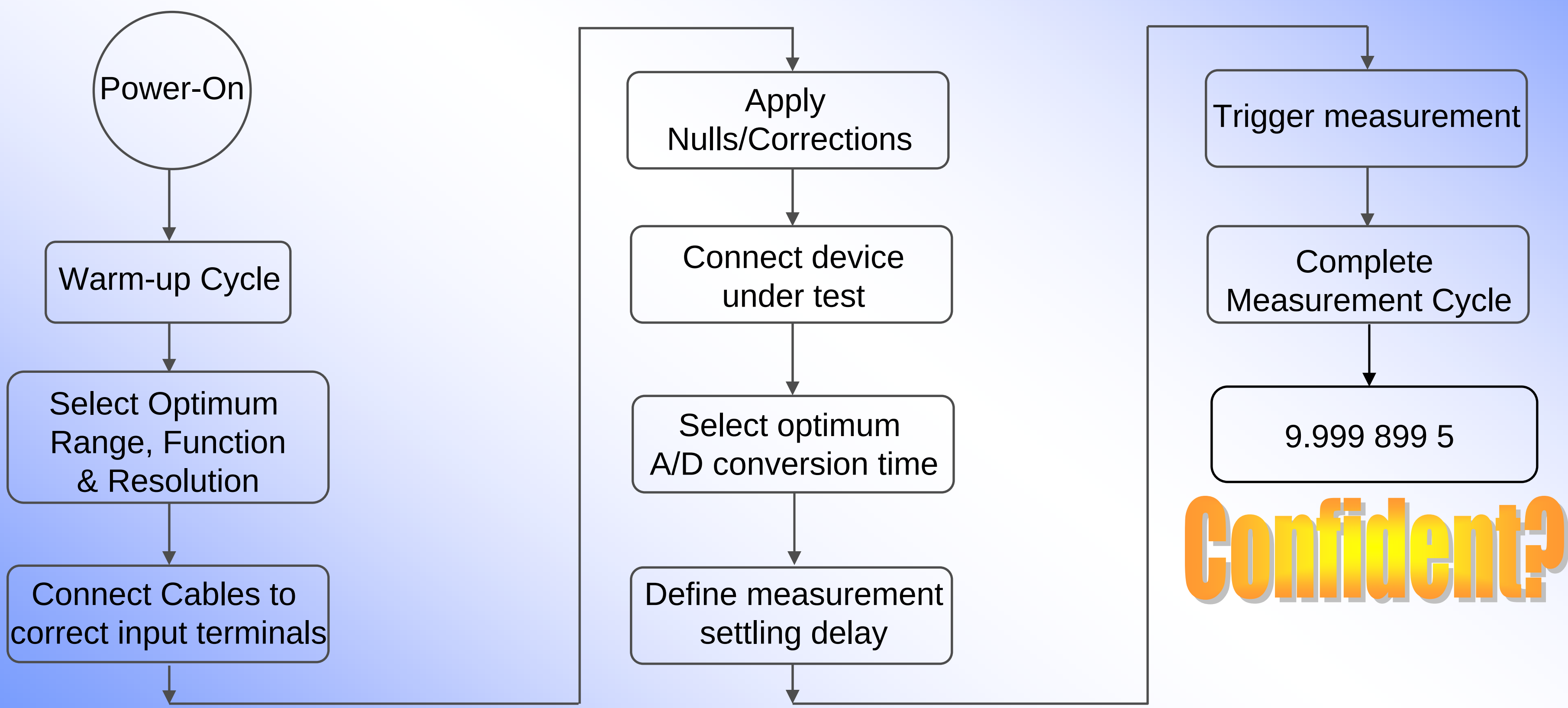
……….and that's only the published specifications!

Accurate But Not Precise

- Results maybe valid, but repeatability is poor due to increased inaccuracy or uncertainty.



Process Flow Chart

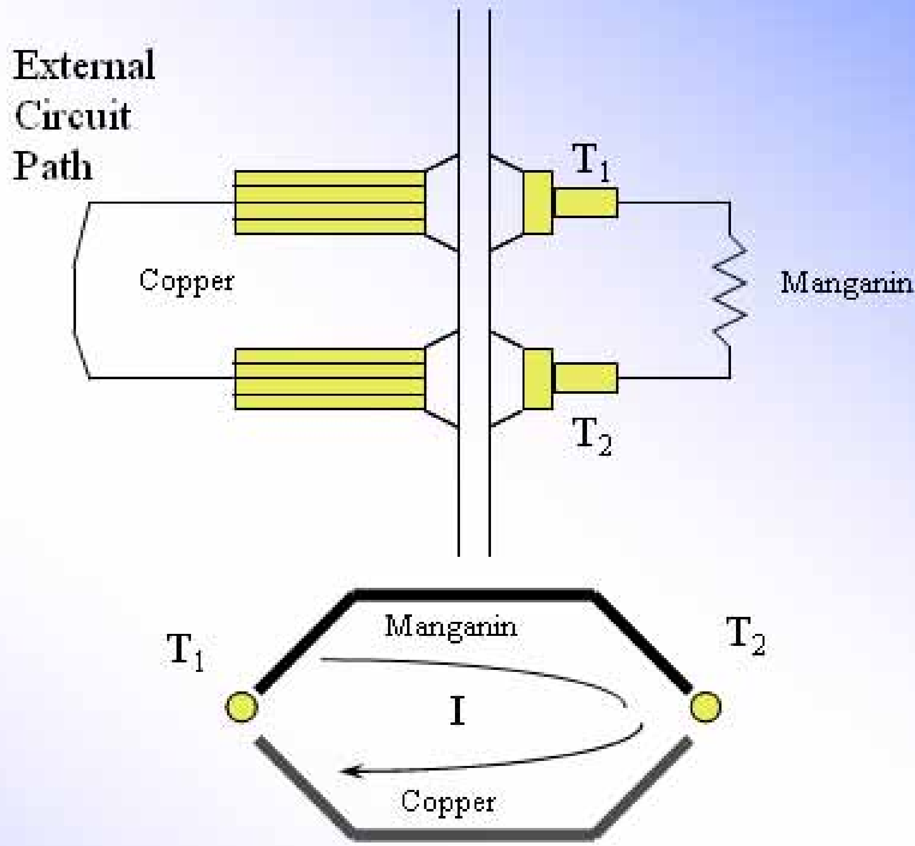


A few Common Mistakes

- Interconnection
  - Cables
  - Guarding Techniques
  - Thermal Errors
- Apply Corrections
  - When and how to apply Null/Offset correction
- Measurement conversion time
  - Resolution
  - Selectable Filters

Interconnections (1)

- Thermal Effects
  - Seebeck, Peltier & Thomson
- Consideration
  - Material of similar type
  - Shroud terminal assembly from drafts.
  - Null inputs before measurement
  - Use dynamic measurement techniques
    - * Switched current
    - * Current reversal



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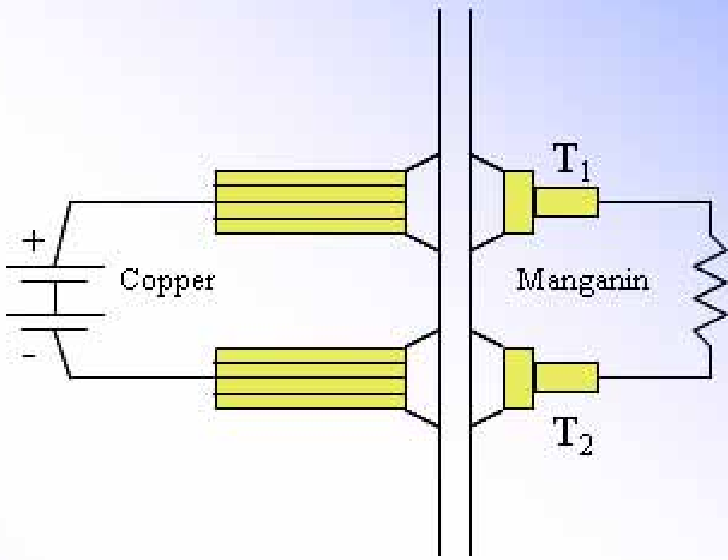

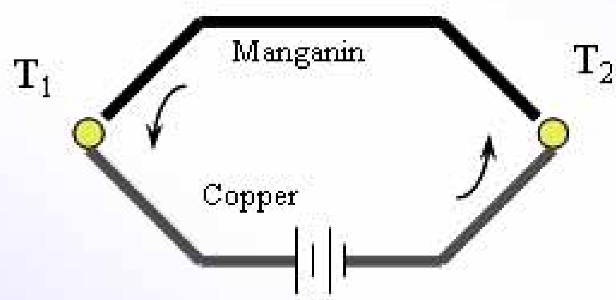

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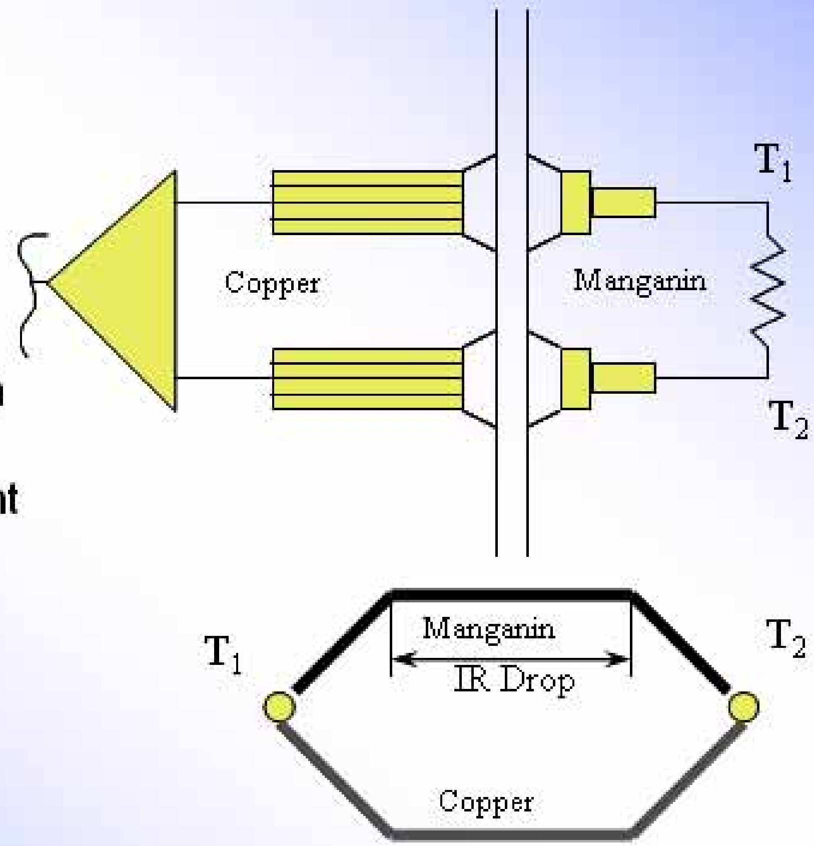
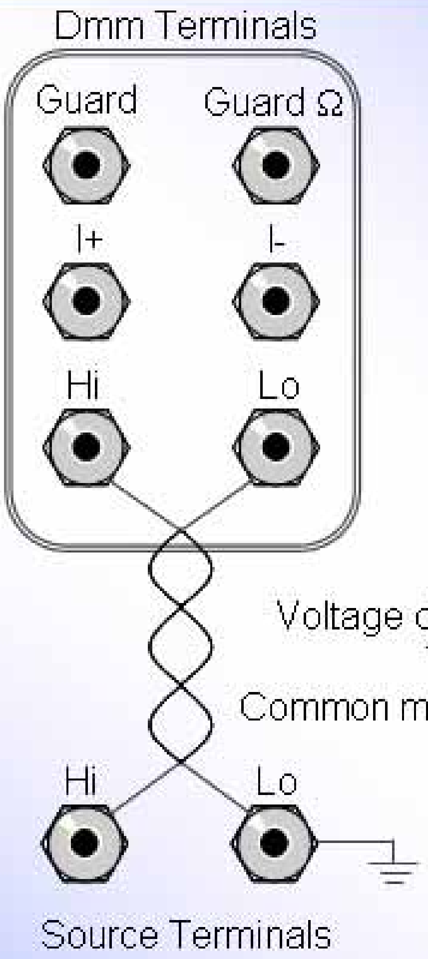


Magnitude of Thermal Emfs

Thermal EMF to Hard-Drawn Copper in Microvolts per Degree Celsius at an ambient temperature of 23°C	
Metal	Thermal EMF (µV/°C@23°C)
Evanohm	+0.20
Gold	+0.01
Annealed Silver	-0.30
Brass	-1.60
Manganin	-1.70
Tin	-2.98
Lead	-3.05
Mecury	-9.57
Constantin	~40

Interconnections (2)

- Cable type
  - Topology
    - Twisted
    - Shielded
  - Material
    - Thermals
    - Skin effect
  - Impedance
    - Length
  - Insulation/Leakage (HV)



Applications:

Voltage drop in the lead is insignificant

The E-M environment is quiet

Common mode voltages are insignificant

DCV > 100mV

ACV >100mV

F <100kHz

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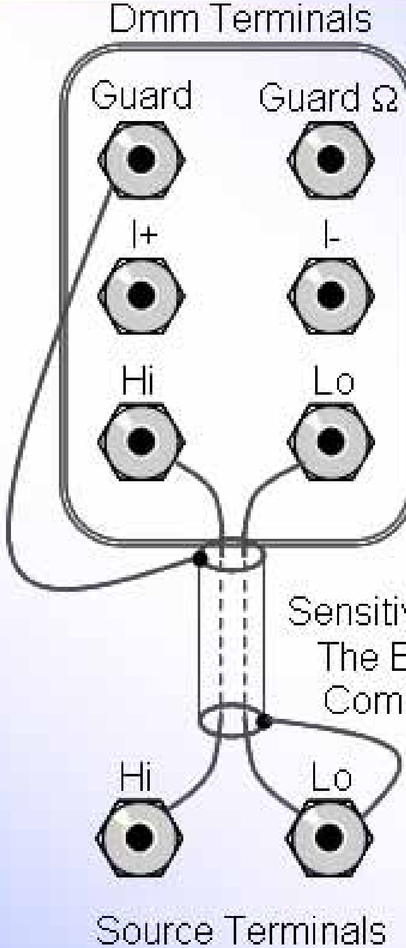

Applications:

Sensitive measurements are being made

The E-M environment is relatively noisy

Common mode voltages are significant

DCV > 10μV

ACV >90μV

F <1MHz

Interconnections (2)

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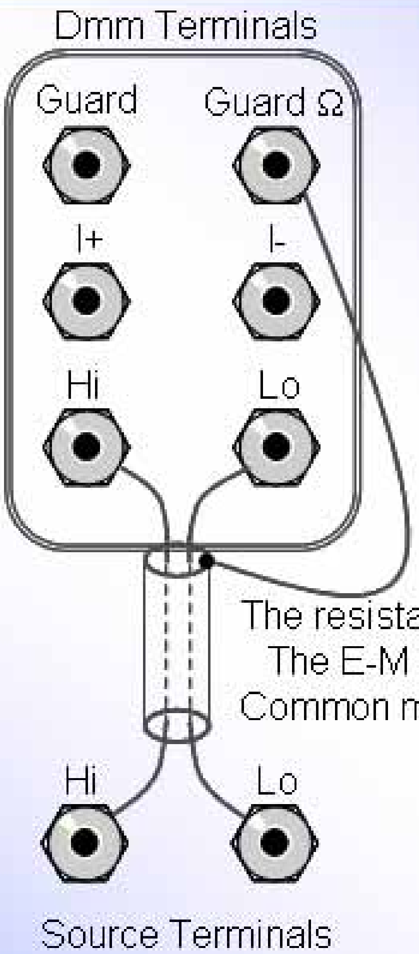

Resistance Applications:
The resistance of the lead is insignificant
The E-M environment is relatively quiet
Common mode voltages are insignificant
between 1kΩ & 1MΩ

Interconnections (2)

- Cable type
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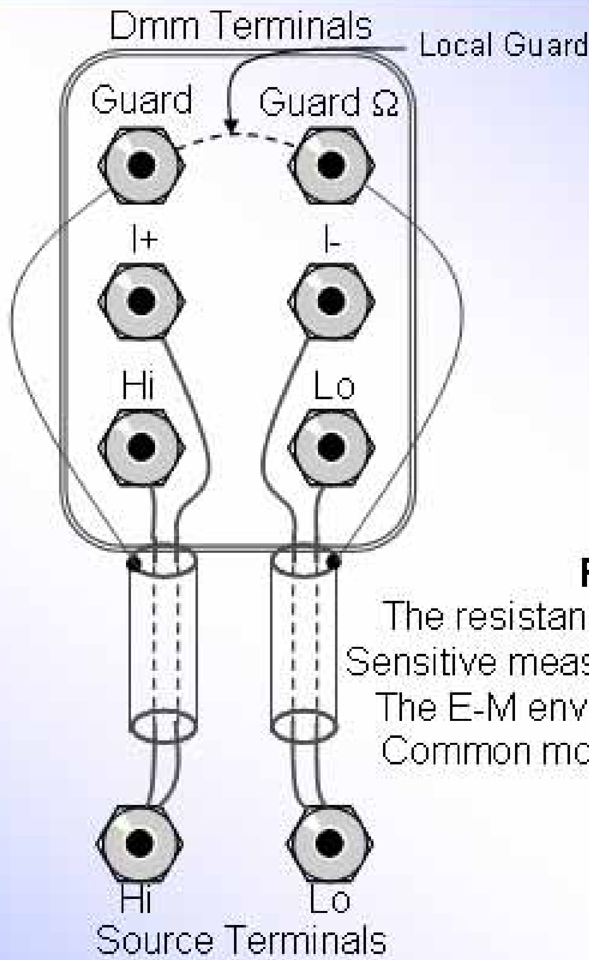
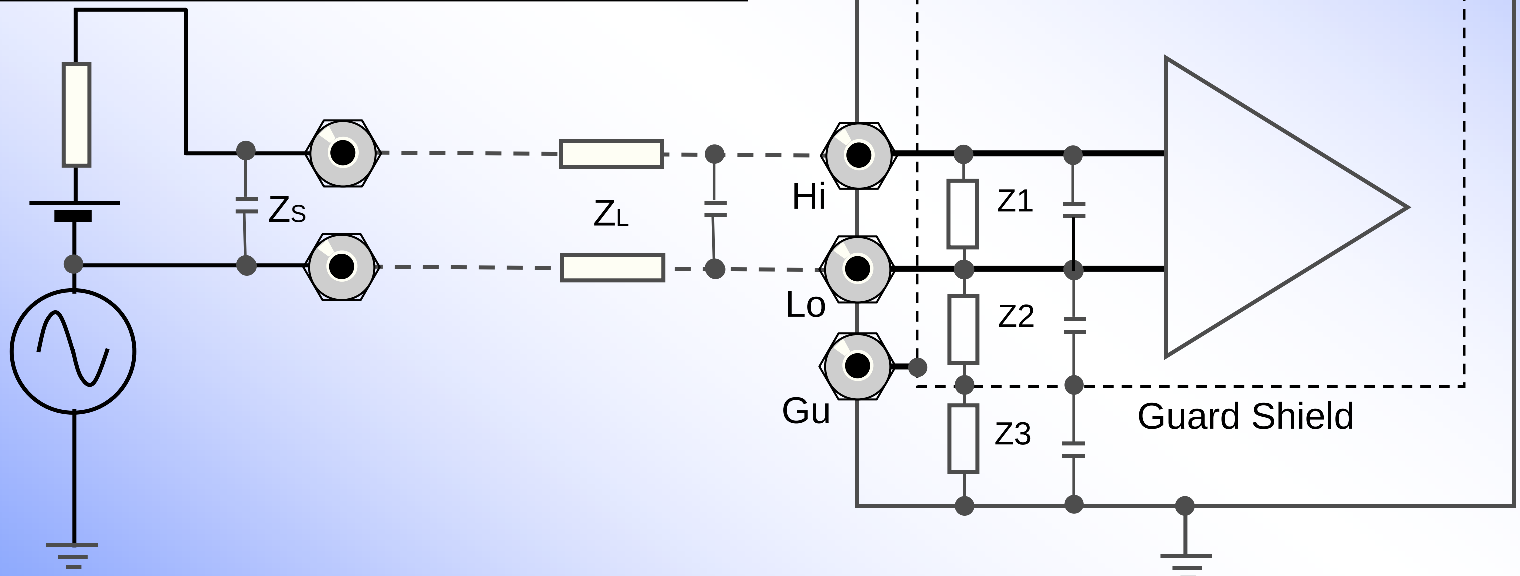


Resistance Applications:
The resistance of the lead is significant
Sensitive measurements are being made
The E-M environment is relatively noisy
Common mode voltages are significant
< 1MΩ

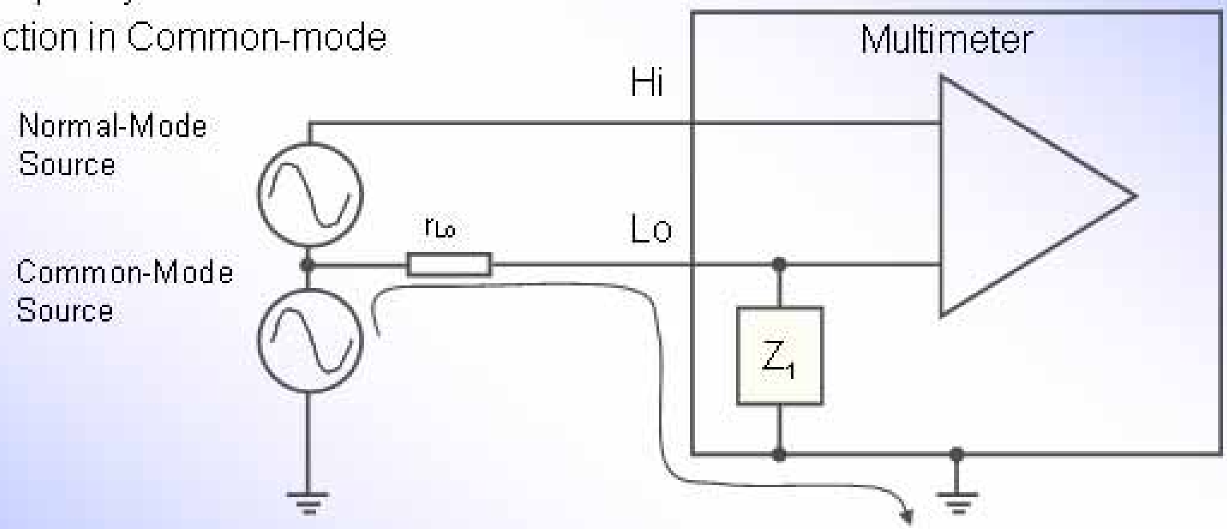
Effective Impedance

Frequency	Impedance for lead capacitance		
	4pf	65pf	160pf
100Hz	400MΩ	20MΩ	10MΩ
1kHz	40MΩ	2MΩ	1MΩ
10kHz	4MΩ	200kΩ	100kΩ
100kHz	400kΩ	20kΩ	10kΩ
1MHz	40kΩ	2kΩ	1kΩ



Interconnections (3)

- Effect use of Guarding
  - Connect Guard to Common mode source
  - Select Remote Guard
  - Effective at Line Frequency Disturbances
  - Effective 80dB rejection in Common-mode noise



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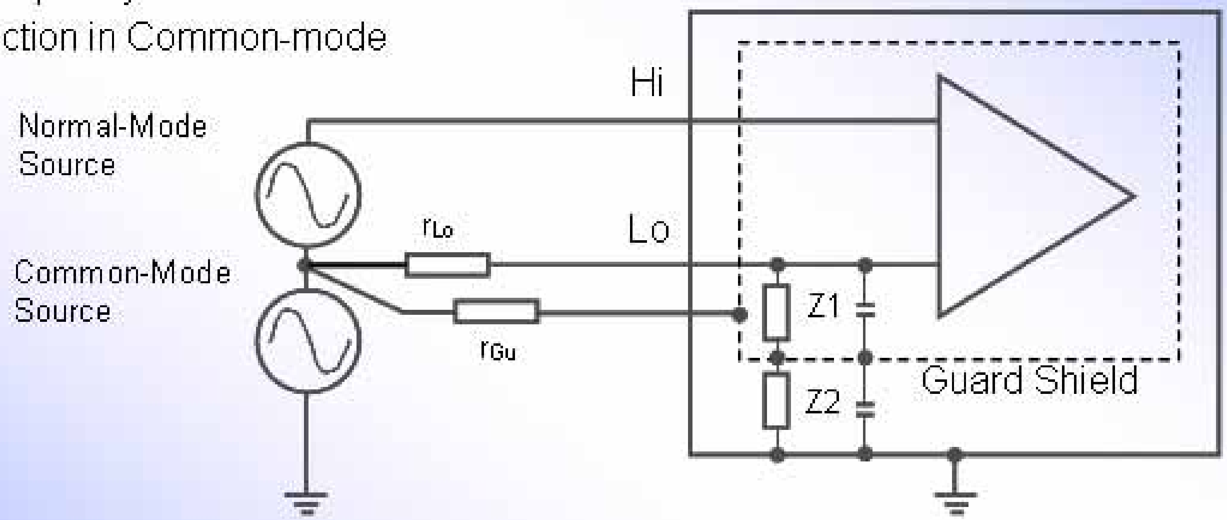
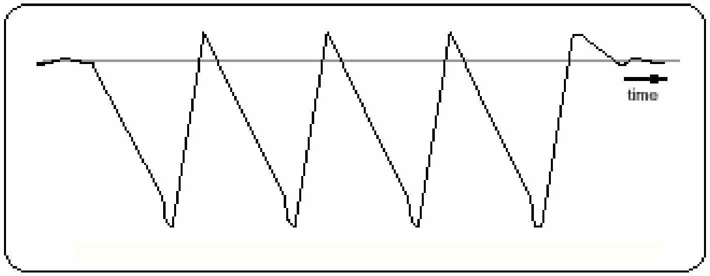


Select Remote Guard on Dmm

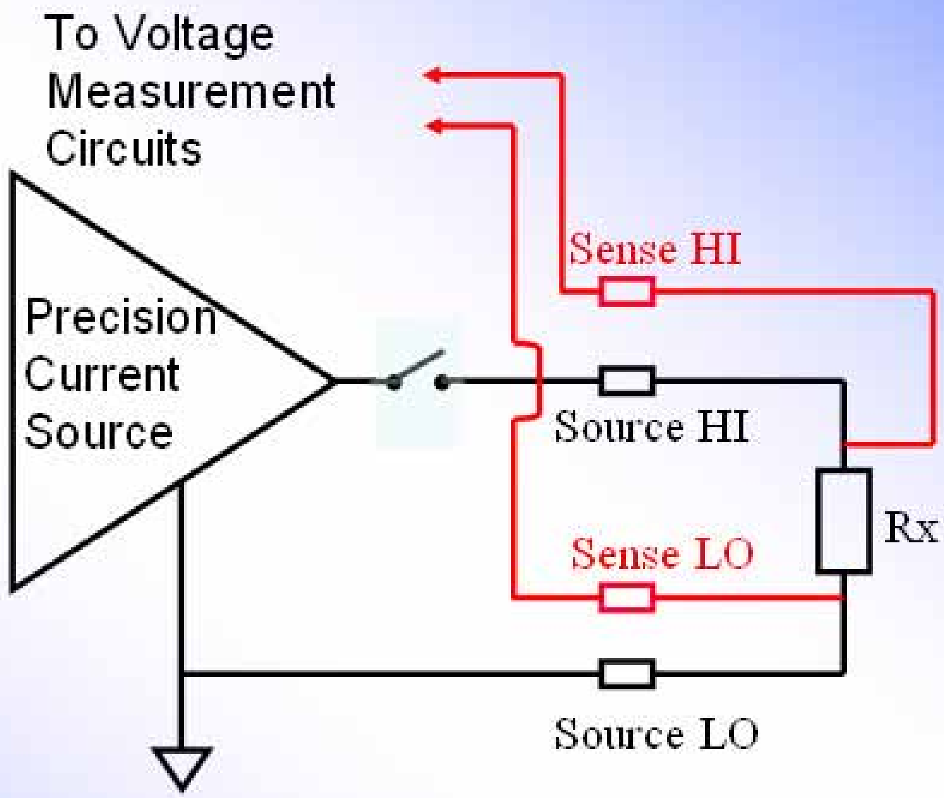
Measurement - Filters



- Selecting appropriate filter
  - Frequency selective 2/3 pole analog low pass filters
  - Effective 120dB series mode noise rejection
- Filter consideration
  - Manage the noise before it gets to the Dmm terminals
  - Select the lowest frequency filter appropriate for the measurement
- A/D conversion time.
  - User define Number of Power line Cycles (NPLC)
  - or defined by Instrument Resolution settings
- A/D consideration
  - Accuracy is compromised by speed of A/D conversion
  - Minimal integral of one line cycle

Measurement - Sense

- Thermal emfs
  - Initial
  - Dynamic
- Consideration
  - Maintain thermal equilibrium
  - Minimize excitation currents
  - Allow adequate settling delays
- Use of 4 wire
  - minimize lead resistance
- Current reversal techniques
  - Reduce errors due to self heating



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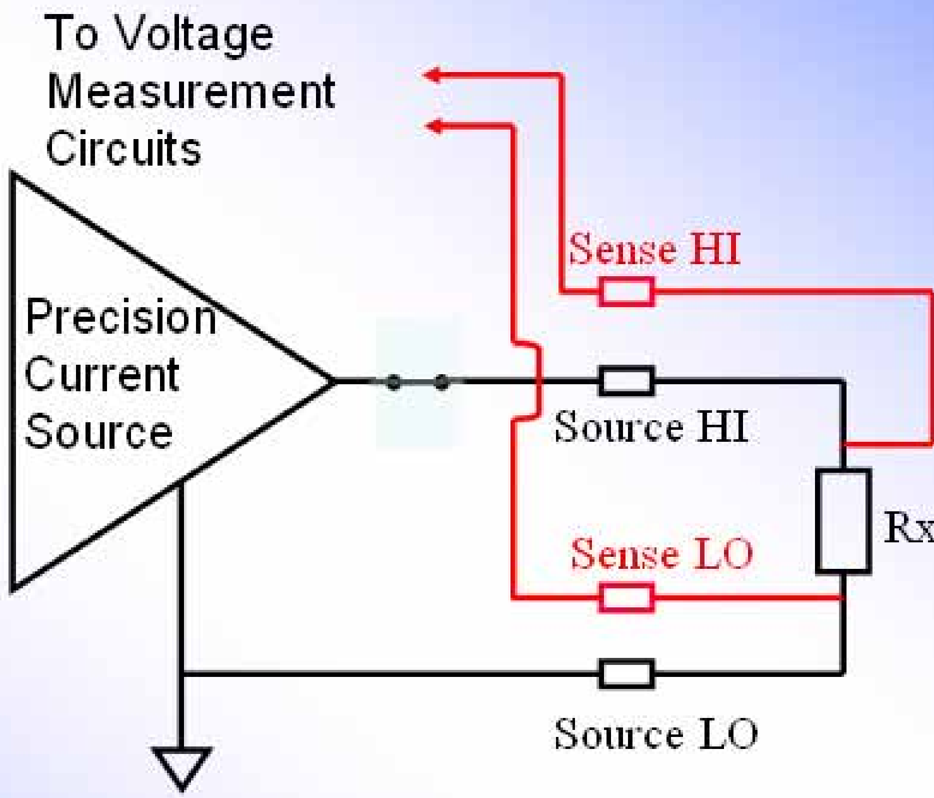
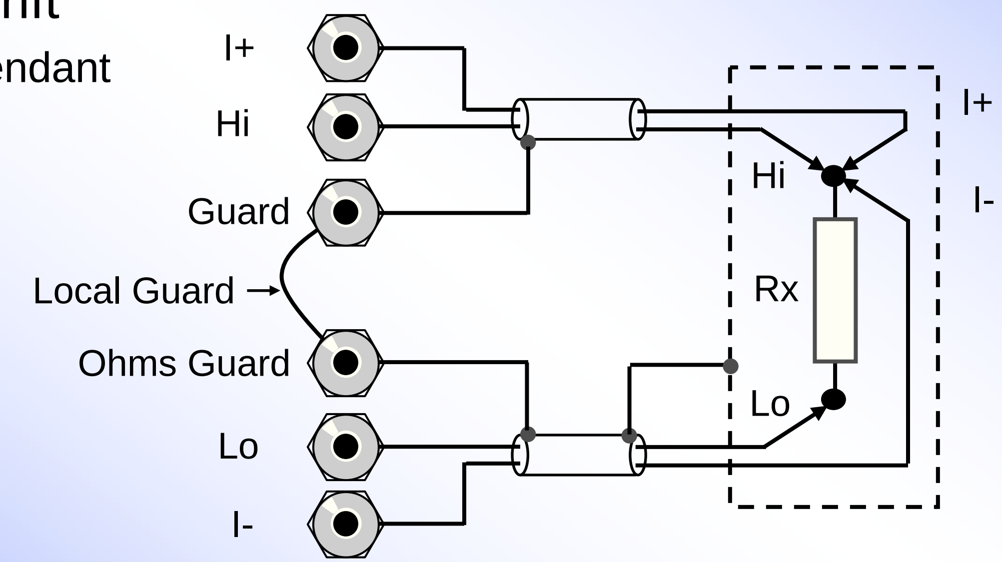


Measurement Corrections

- Offsets/Nulls
  - User defined mathematical errors stored within DMM memory
  - Additional input channels may have separate Null stores
- Correcting for short term drift
  - Time and Temperature dependant
  - Design cost compromise
  - Automatic User notification



Concluding words

- Increased reliance on automation to improve lab efficiency but what's being compromised?
  - Measurement process is more than just hitting the Enter key
  - Consider manual procedures outside the software procedures
- Can measuring instrumentation be improved to better support the process?
  - Review connectivity, default modes and measurement techniques
- Are existing metrology training programs sufficient for today's needs?
  - Review personnel training records
  - Continually update training material using latest techniques
- Future use of the Internet as a tool for remote calibration?
  - Places greater responsibility on remote experts
  - Video links help minimize errors in the process