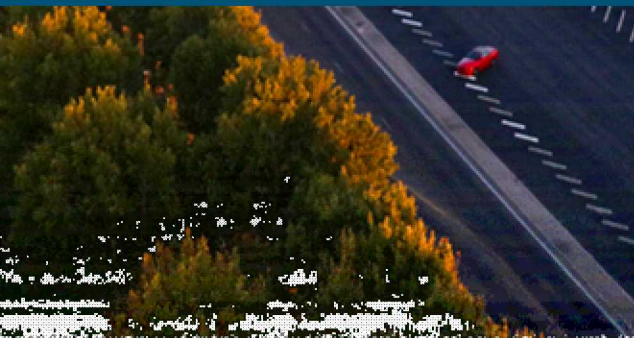




Qualification of a Calibration System for 3458A Digital Multimeters



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Outline

MMS 2300 was qualified in January 2018 to provide in-house NVLAP-accredited calibrations for 3458A digital multimeters.

1. MMS 2300 purpose and development
2. MMS 2300 system
3. Uncertainty equation and SI traceability
4. Measurements and system uncertainty
5. Future development

3458A digital multimeters



3458A digital multimeters are used throughout the Sandia PSL and DOE metrology labs to make precision electrical measurements.

- Calibrated measurement functions:
 - Resistance: $<1 \mu\Omega$ to $1 \text{ G}\Omega$
 - DC voltage: $<1 \mu\text{V}$ to 1000 V
 - DC current: $<100 \text{ pA}$ to 1 A
 - AC voltage[†]: $<10 \mu\text{V}$ to 1000 V , 1 Hz to 10 MHz
 - AC current[‡]: $<50 \mu\text{A}$ to 1 A , 1 Hz to 100 kHz
 - Frequency: 1 Hz to 10 MHz
- Manufactured by Hewlett Packard, Agilent, Keysight
- Measurements can be manual or automated (with LabView, Python, MetCal, etc.)

[†]Not all frequencies can be measured across every voltage range

[‡]Not all frequencies can be measured across every current range

MMS 2300: 3458A calibration

Goal: replicate each test point of NVLAP-accredited CCL 3458A calibration with either a 4:1 TUR or guard-banding.

CCL = “Commercial Calibration Laboratory”

MMS = “Major Measurement System”

MMS 2300 purpose:

- Provide in-house calibration of Keysight 3458A DMM's
- Replicate NVLAP-accredited 3458A calibration performed at CCL
- Eliminate risk of damage in transportation to and from CCL
- Save ~\$2k per calibration in CCL labor and shipping costs

MMS 2300 System



MMS 2300

- Physical equipment contained in one rack
- Measurements automated with MetCal procedure

Standards

- Resistors (decades from 100 m Ω to 1 G Ω)
- Zener voltage standard
- Digital multimeter
- Calibrator
- AC measurement standard
- Signal generator

Other equipment

- Reference voltage divider (self-calibrating)
- Computer running MetCal
- Low thermal scanner for resistors
- Thermometer
- Cables (4-wire, calibrator)

Expanded Uncertainty

FLUKE®

Application Note

Implementing ISO/IEC 17025 Measurement Uncertainty Requirements in MET/CAL Version 7.x

Expanded Uncertainty = (Standard Uncertainty) * K

Standard Uncertainty = $\sqrt{U1^2 + U2^2 + U3^2 + U4^2, \dots U10^2}$

U1 = Normalized system uncertainty = $\frac{\text{System uncertainty}}{\text{Confidence interval}}$

U2 = $\sqrt{S1^2 + S2^2}$

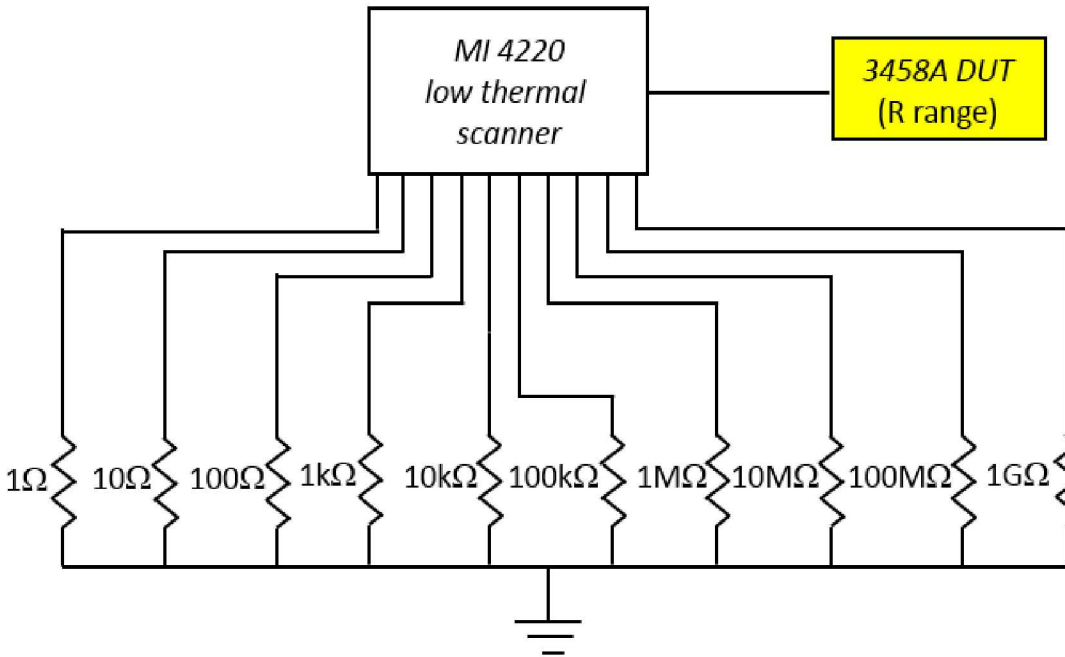
S1 = $(\text{SDEV} / \sqrt{N}) * F$

S2 = $\frac{1}{2} \text{UUT_RES} / \sqrt{3}$

$$u_{exp} = K \sqrt{\left(\frac{\text{System uncertainty}}{\text{Confidence interval}}\right)^2 + \left(\frac{F \times \text{std dev}(x)}{\sqrt{N}}\right)^2 + \left(\frac{1}{2} \frac{\text{UUT_RES}}{\sqrt{3}}\right)^2}$$

Measurement Function	Traceability to SI
Resistance	Calibrated resistors
DC Voltage	Zener voltage standard; NVLAP-accredited calibrated 3458A
DC Current	Calibrated resistors; NVLAP-accredited calibrated 3458A
AC Voltage	NVLAP-accredited calibrated Fluke 5730A calibrator & 5790B AC mmt standard
AC Current	NVLAP-accredited calibrated Fluke 5730A calibrator
Frequency	Calibrated signal generator

Resistance



Equipment Diagram of Resistance Measurement

Traceability to SI:

Resistors calibrated at PSL against L&N 4010 primary 1 ohm resistors



Calibrated at NIST against Quantized Hall Resistance (intrinsic standard)

$$R_{Hall} = \frac{h}{ne^2}$$

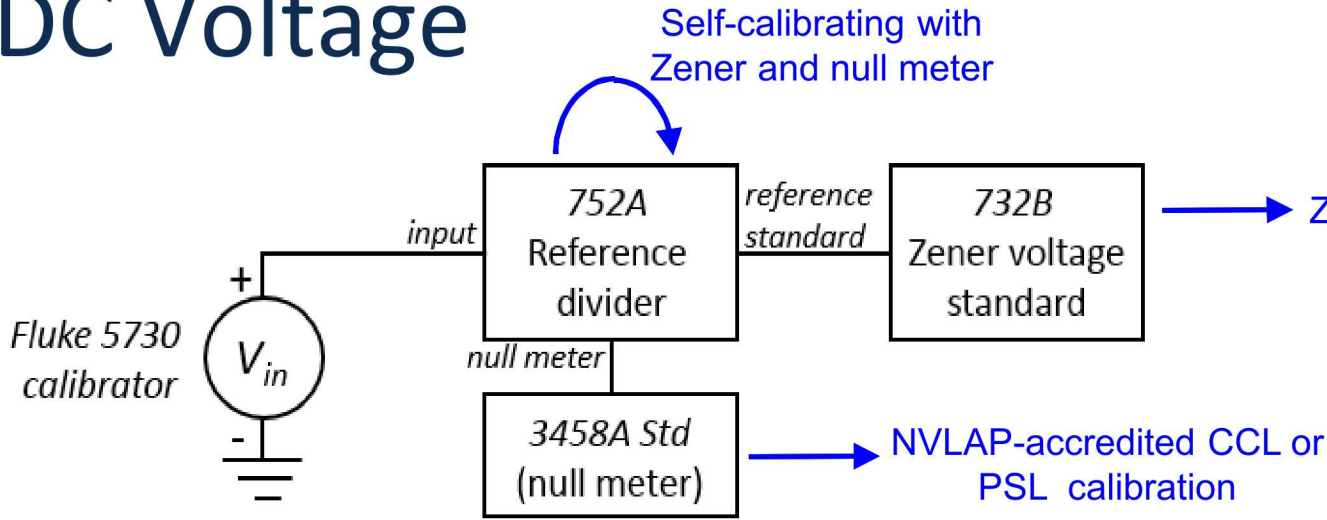
Example: 1 Ω resistance measured on 3458A's 10 Ω range:

System uncertainty: standard resistor's certified expanded uncertainty = 1.8 μΩ

MetCal uncertainty: $u_{exp} = 2\sqrt{\left(\frac{(1.8 \times 10^{-6} \Omega)}{2}\right)^2 + \left(\frac{1.14 \times (7 \times 10^{-6} \Omega)}{\sqrt{10}}\right)^2 + \left(\frac{1}{2} \frac{(1 \times 10^{-7} \Omega)}{\sqrt{3}}\right)^2} = \pm 5.3 \mu\Omega$

Manufacturer's specs: 10 ppm reading + 5 ppm range = **±65 μΩ**

DC Voltage

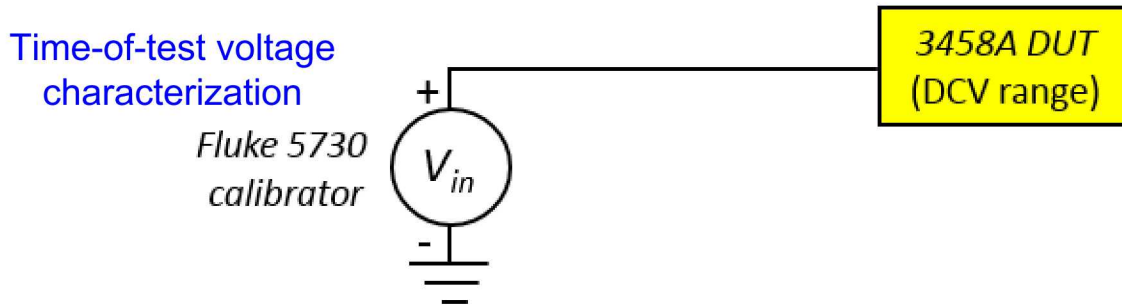


Traceability to SI:

Zener calibrated at PSL against Josephson Voltage Array (intrinsic standard)

$$V = \frac{nhf}{2e}$$

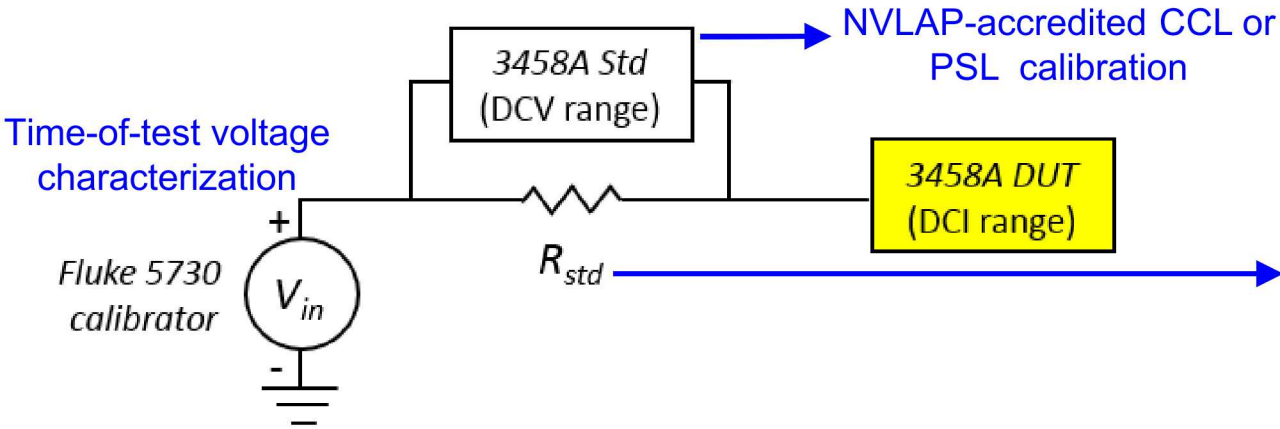
Equipment Diagram of Calibrator Output Voltage Characterization.



Equipment Diagram of DC Voltage Measurement.

System uncertainty: uncertainty of characterized DC voltage output from calibrator RSS (Zener's certified u_{exp} , reference divider's worst-case accuracy specs)

DC Current



Equipment Diagram of DC Current Measurement

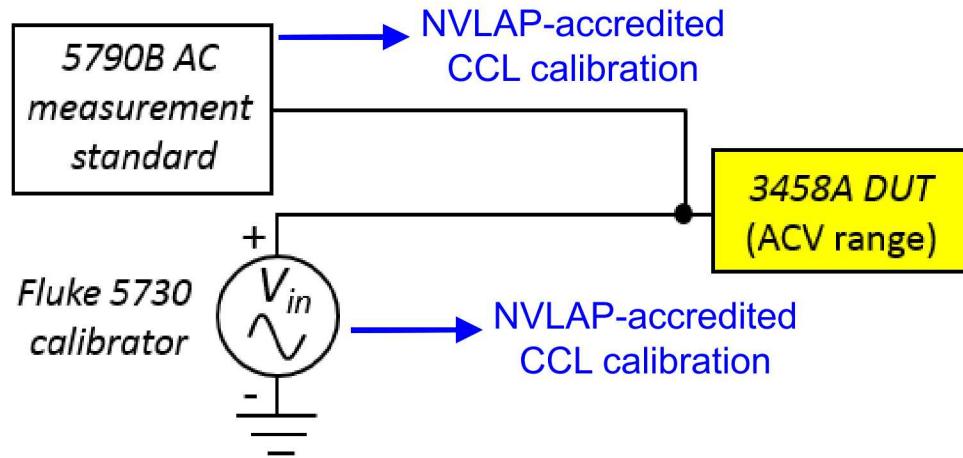


↓
Calibrated at NIST against Quantized Hall Resistance (intrinsic standard)

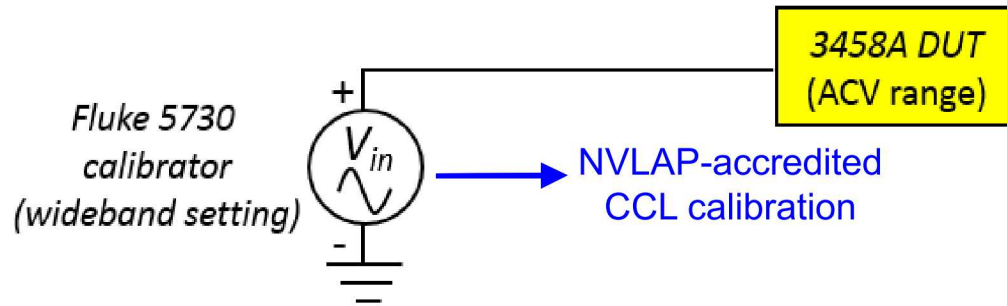
$$R_{Hall} = \frac{h}{ne^2}$$

System uncertainty: 1-yr specs for standard 3458A measuring voltage drop across standard resistor R_{SS} (Resistor's certified u_{exp} , 3458A's 1-year specs for voltage and range used (100 mV or 1 V))

AC Voltage



Equipment Diagram of AC Voltage Measurement: 20 Hz to 1 MHz

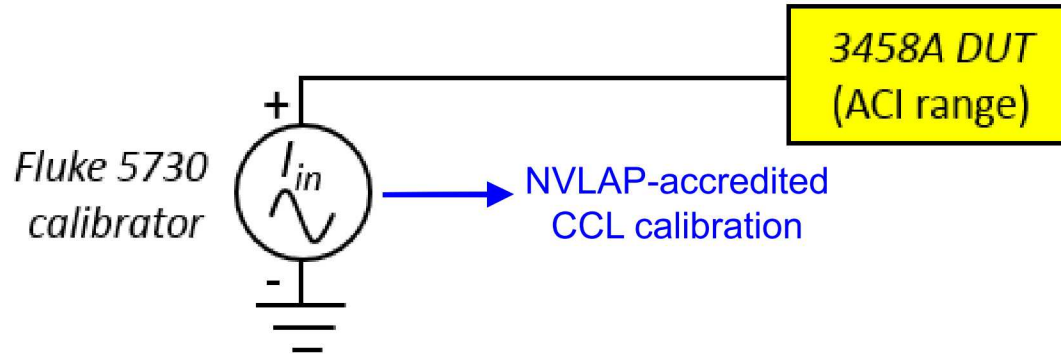


Equipment Diagram of AC Voltage Measurement: >1 MHz to 10 MHz

System uncertainty: 5790B measurement standard specs OR 5730 calibrator's wideband specs

- Up to 1 MHz: 5790B's 1-year specs for ppm of reading + floor
- Over 1 MHz: 5730A's 1-year specs for ppm of voltage output + floor

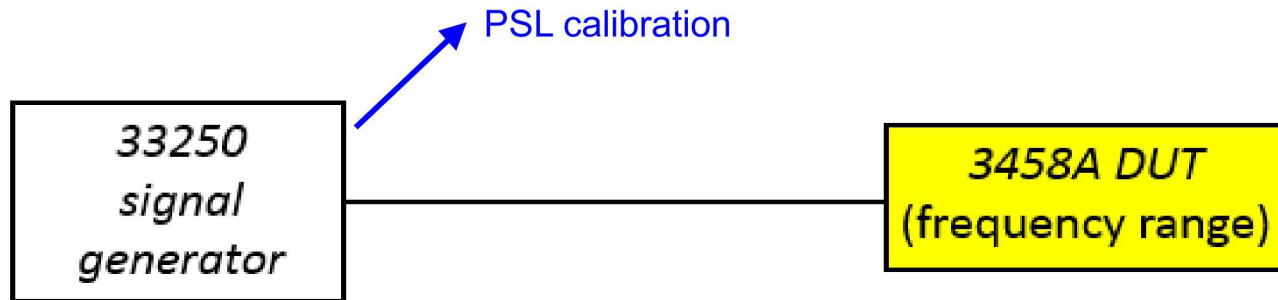
AC Current



Equipment Diagram of AC Current Measurement

System uncertainty: 5730 calibrator's specs
1-year specs ppm of current output + floor

Frequency



Equipment Diagram of Frequency Measurement

System uncertainty: Signal generator's specs
% of frequency output

Future Development

MMS 2300 has been used to calibrate DC Lab's 3458A's. The DC Lab will begin to calibrate 3458A's belonging to other PSL Labs and the wider DOE complex.

FY18 – FY20: MMS 2300 will be expanded to calibrate

- Fluke 8508A multimeters
- Fluke 5700, 5720, 5730 calibrators
- Fluke 5725 amplifiers

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- Gary Smith and Jim Novak in DC Lab (design, development, software)
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Thank you. Questions?