



Ohm's Law, how hard can it Be???

$$*R = E/I, E = IR, I=E/R ??*$$

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Ohm's Law, How hard Can it Be???

Topics Covered

1. *Resistance Metrology – A Review of*
 1. *The Physical Effects Related to Resistance*
 - Resistance is just V/I so what are the Physical Effects related to Voltage, Current and Resistance?
 2. Resistance Bridges
2. *MIL Resistance Bridges*
 1. A review of the CCC principle and the Measurements International 6010D DC Current Comparator up to 3000A (Current Ratio and traceability for resistance)
3. *DC Current Measurements to 3000A*
 1. Calibrating DC Current Transducers (Absolute Current and Traceability)
4. *DC Voltage Measurements to 1200V*
 1. Calibrating the calibrator (Voltage Ratio, Absolute voltage and traceability)
5. *Summary and Conclusions*
 1. The MI 17025 Scope



Resistance Metrology

Physical Effects Related to Resistance – A Review

Resistance is just V/I so what are the Physical Effects related to Voltage, Current and Resistance?

1. **Seebeck** effect – in a conducting loop with a temperature gradient different parts of a loop with dissimilar metals causes a thermoelectric voltage or thermal emf. This is the reason why you reverse the current through a resistor to cancel the net thermal emf.
2. **Peltier** effect – the reverse of the **Seebeck** effect, a voltage across (or current through) dissimilar metals causes a temperature difference.

This is the reason why, especially on low value resistors, the resistor and its potential and current arms are made of the same resistive material and transitions to copper terminals are well separated from the resistor body.



Resistance Metrology

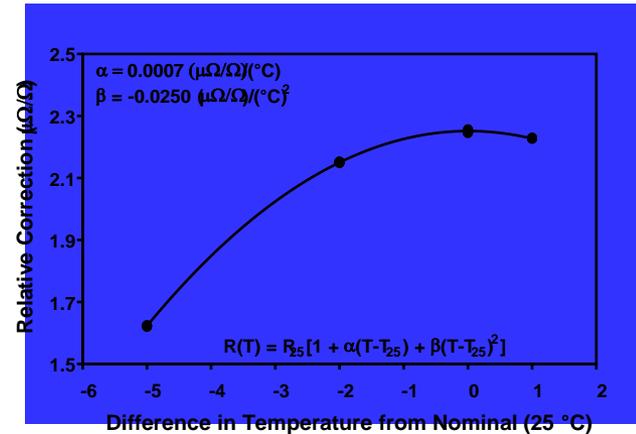
3. **Thompson effect** – current flowing in a conductor with a temperature gradient will evolve or absorb heat depending on the material, temperature difference and current direction. This is why some resistors are designed to be thermally symmetric and with a large thermal mass to equally distribute any heat flow.

The **Seebeck**, **Peltier** and **Thompson** effect are also magnetically sensitive. Current flow is usually designed to flow through twisted and shielded pairs of leads to minimize generating magnetic fields and operation in magnetic fields is cautioned.

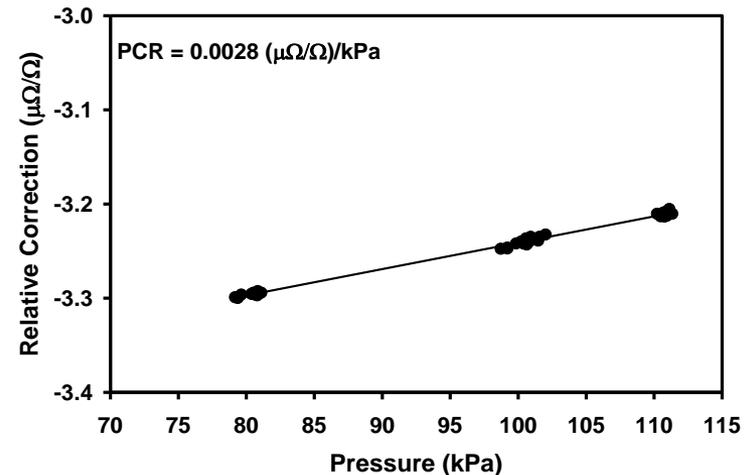


Resistance Metrology

4. **Temperature Coefficient (TC)** – the change in resistance due to a change in temperature. Typically analyzed as a second order polynomial relationship $\Delta R/R = \alpha \Delta T + \beta \Delta T^2$. In resistance measurements the Temperature Coefficient Uncertainty = $TC_{\text{RESISTOR}}/\text{Bath Stability}$



5. **Pressure Coefficient** - the change in resistance due to a change in pressure. Typically analyzed as a linear relationship $\Delta R/R = \rho \Delta P$. For example L&N Thomas type 1 ohm resistors typically have $\rho = +0.003$ ppm/kPa





Resistance Metrology

6. **Dielectric Absorption** – the change in resistance due to time delays in the redistribution of charge inside insulating parts of the resistor or its case. This is why some resistors have a variation of resistance with respect to rapid current reversal rates. Dielectric absorption can be seen in resistors as low as $1\text{k}\Omega$ resistors and higher caused by aging and/or the breakdown of the element.

7. **Voltage Coefficient** - the change in resistance due the change in measuring voltage (but not due to the power being dissipated).

This is generally associated with higher value resistors and is related to dielectric absorption and higher order interactions of other thermoelectric and physical effects.



Resistance Metrology

8. **Power Coefficient** - the change in resistance due to change in power dissipated in the resistor that is not accounted for by the temperature coefficient. This effect is most evident in low value resistors and is critically dependent on how heat is flowing from the resistor to the environment. It is further complicated by interaction of thermoelectric effects and non-uniform physical effects, such as different temperature coefficients along the resistive element interacting with current flow direction and the Thompson effect.

For example the power coefficient specification on an SR104 is $< 1\text{ppm/W}$.



Resistance Metrology

9. **Strain** - the change in resistance due to mechanical dimensional changes in the resistive element. Mechanical dimensional changes can be caused by vibration, impact or even orientation of the resistor.

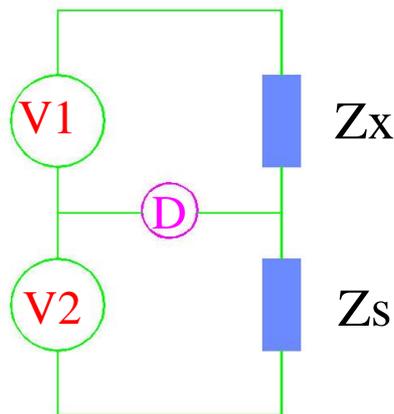
10. **Hysteresis** – the non-reversible change in resistance caused by reversible change in an influence parameter. This is a difficult effect to clearly identify. An example of a hysteric mechanism is the non-repeatable slipping along two different materials during expansion/contraction of the resistive element against its support structure.



Resistance Metrology

11. Bridge Review

$$Z_x/Z_s = V_1/V_2$$



Usually, we use a bridge to scale from a known impedance to an unknown impedance.

Bridges convert the accurate measurement of the voltage (or the current) to the ratio of two voltages, two currents or two impedances.

The bridge method has the advantages:

- A null detector (D), as opposed to a calibrated linear detector
- Low source output impedance thus lower noise...



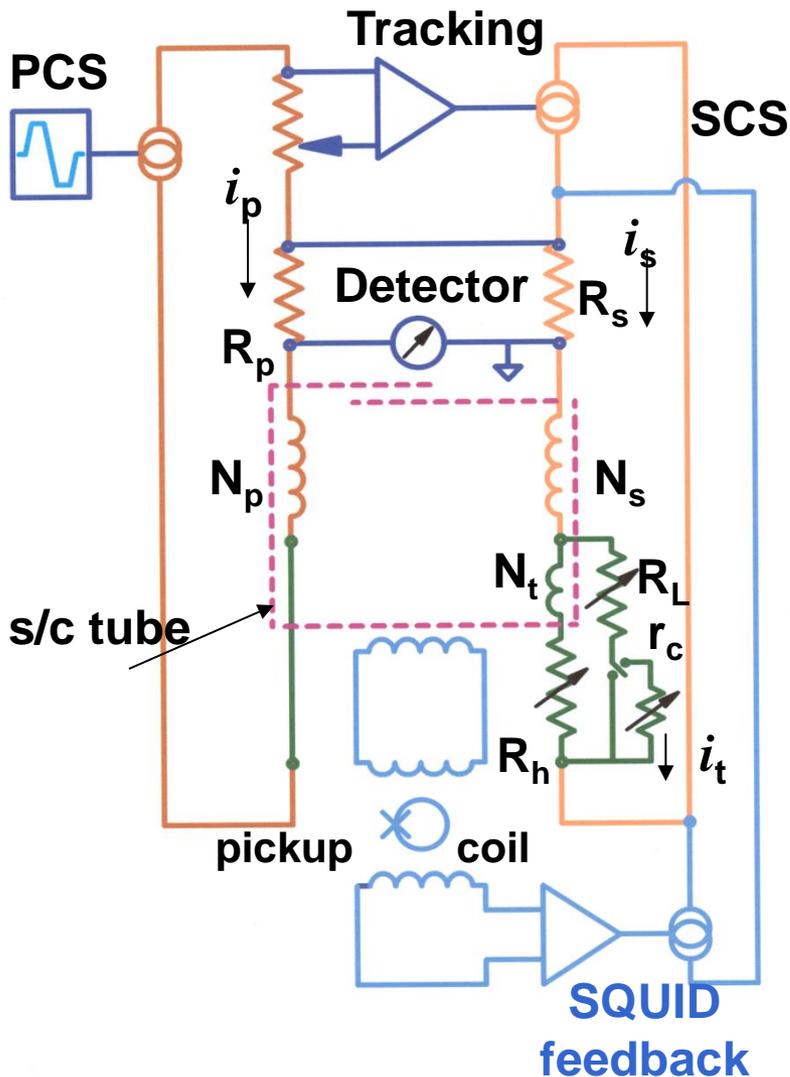
6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

1. The cryogenic current comparator Resistance Bridge

The cryogenic current comparator (CCC) resistance bridge is the most complicated of systems to be discussed especially since it operates on a principle that is not commonly understood. Yet it shares many of the design features with the dc current comparator resistance bridge:

Real Turns, Partial Turns and Ramping Current Sources.

First one needs to understand how a transformer can be made that operates at dc, has almost perfect ratio accuracy and zero leakage effects.



Cryogenic Current Comparator Bridge
Ampere Turn Device & at balance

$$i_p \times N_p = (i_s \times N_s) + (i_t \times N_t)$$

$$R_p \times i_p = R_s \times (i_s + i_t)$$

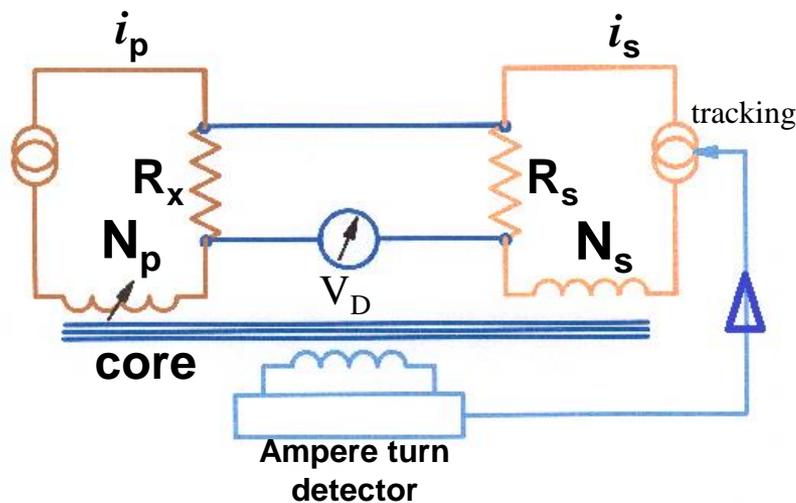
(current x turns) imbalance produces current in s/c tube; sensed by pickup coil and SQUID; drives feedback to remove imbalance.



6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE



- The tracking circuit and N_p are used to create and ampere turns balance in the comparator
- N_p is then varied to zero the difference in voltage drops across resistors (voltage detector VD)
- And hence $i_p R_x = i_s R_s = R_x / R_s = N_p / N_s$
- Excellent linearity < 0.005 ppm
- $0.001 \Omega \rightarrow 100 \text{ k}\Omega$ (Typical Range)
- Various Range Extenders extend the range and improve the accuracy down to $1 \mu\Omega$ at higher Currents
- The 6010D is a current ratio device $I_x:I_s$. As a result there is no need for current accuracy because of the master slave relationship and automatic ampere-turn balance.



Master Slave Relationship



6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

$$\text{Ratio} = N_x/N_s = R_x/R_s = I_s/I_x$$

Where N_s = fixed winding, N_p = Variable turns

$$N_p = N_{\text{real-turns}} + N_{\text{partial-turns}}$$

For a 10:1 ratio $N_{\text{real}} = N_s \times \text{ratio}$

$N_{\text{partial-turns}}$ binary weight = 1/128

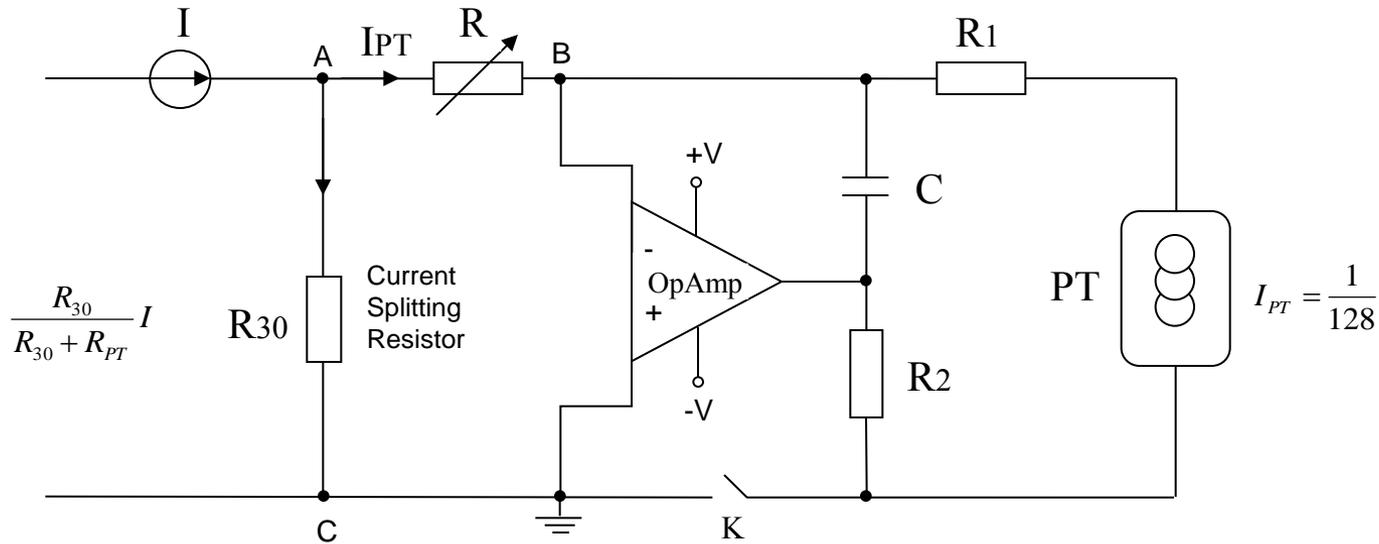
1 Real_{turn} – 128 partial_{turns}

$$V_D = ((\text{Ratio} * N_s) - N_{\text{real}}) * 128 = 1 \text{ ppm}$$

The ratio of power dissipation in the compared resistors is the inverse of the ratio of resistance (the largest power is dissipated in the smaller resistor) < 10 mW



6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

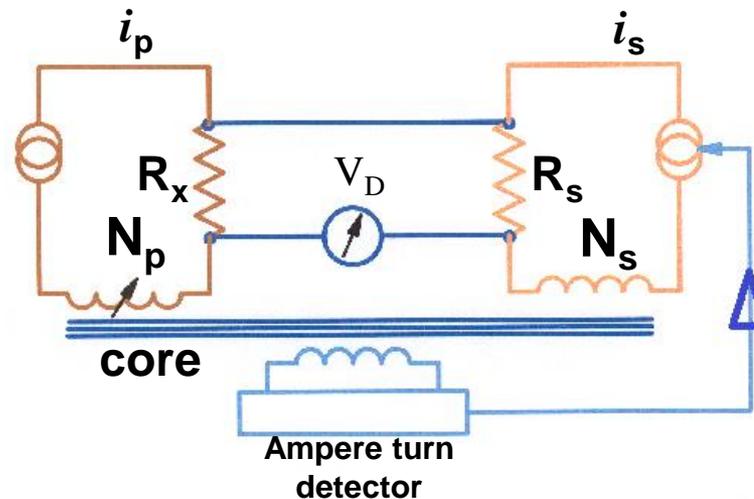


- 1) Winding resistance of the turns and the relay contact resistance from the current splitting resistor
- 2) The wire gauge of the Partial turns was increased to improve the TC of the wire and to decrease the resistance in the partial turns.



6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

- The ampere turn flux detector is a flux to voltage converter which works at dc by driving the core into saturation using ac pulse and determining the dc ampere turns imbalance as the core comes out of saturation.
- The LSB ampere turn sensitivity of the flux detector is equivalent to 0.01 ppm





6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

Using the Flux Detector the DC Current Comparator can be calibrated as follows:

Real Turn Comparison:

T 1 Error:	-0.0019	+/- 0.00130 ppm
T 2 Error:	0.0013	+/- 0.00105 ppm
T 4 Error:	-0.0018	+/- 0.00181 ppm
T 8 Error:	0.0004	+/- 0.00124 ppm
T 16 Error:	0.0042	+/- 0.00170 ppm
T 32 Error:	-0.0001	+/- 0.00108 ppm
T 64 Error:	0.0036	+/- 0.00119 ppm
T 128 Error:	0.0015	+/- 0.00130 ppm
T 256 Error:	-0.0018	+/- 0.00157 ppm
T 512 Error:	0.0019	+/- 0.00105 ppm
T 1024 Error:	-0.0005	+/- 0.00216 ppm
T 2048 Error:	0.0025	+/- 0.00102 ppm
T 1024 Error:	0.0048	+/- 0.00160 ppm
T 2048 Error:	0	+/- 0.00112 ppm

Partial Turn Comparison:

PT 1/128 Error:	0.0060	+/- 0.00130 ppm
PT 2/128 Error:	0.0004	+/- 0.00125 ppm
PT 4/128 Error:	0.0047	+/- 0.00128 ppm
PT 8/128 Error:	-0.0004	+/- 0.00128 ppm
PT 16/128 Error:	-0.0024	+/- 0.00164 ppm
PT 32/128 Error:	-0.0006	+/- 0.00146 ppm
PT 64/128 Error:	0.0007	+/- 0.00102 ppm

Normally performed once a year

No standards are required

Sensitivity $1\mu AT = 1 mV = 0.01 ppm$



6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

Verification - Intercomparison with a CCC (METAS) over 3 years

Ratio	2010 Ratio Error (10 ⁻⁹)	2013 Ratio Error (10 ⁻⁹)	Diff 10 ⁻⁹
10:1	18	9	-9
100:10	23	15	-8
1k:100	21	20	-1
10K:1K	17	16	-1
13K:1k	17	9	-8

To maintain a ratio accuracy of 0.04 ppm requires that the difference is < 0.03 ppm



Traceability

Prior to 1990 traceability was defined as Traceable to an NMI

Since 1990 the Quantum Hall is the International
Representation of the SI Ohm

Traceable through an NMI to the SI Unit

In the 6010D traceability is provided through the standard resistor
(R_s)



6010D DC CURRENT COMPARATOR RESISTANCE BRIDGE

Range Extenders and Accessories to 1050A



The 6010D bridge is extensively used in NMIs and industry for resistor maintenance and to calibrate customers resistors in the range of 1Ω to 100kΩ

NMIs: NRCC, NIST, CENAM, METAS, PTB, CMI, Singapore, NIMT, NMIJ, New Zealand, NMIA NIM, INMETRO, INTI, INTA, All the major NMI's worldwide.

Government Labs: DOE (USA) NASA, Lockheed, JEMIC, ALPHA,



R=E/I

6010D/3000A System Calibration of Resistors and Shunts





6010D/3000A System

DC Current Range Extenders Ratio and Uncertainties

Resistance Ratio	Uncertainty	Ratio
1 Ω to 0.1 Ω	0.2 ppm	10
10 Ω to 0.1 Ω	0.2 ppm	100
10 Ω to 0.01 Ω	0.2 ppm	1,000
10 Ω to 0.001 Ω	0.3 ppm	10,000
10 Ω to 0.0001 Ω	2 ppm	100,000
100 Ω to 0.0001 Ω	10 ppm	1,000,000



$$I = E/R$$

A Bi Polar DC Current Generation and Measurement System Calibration of DC Current Transducers

6010D was replaced with two DMMs

4220 scanner
10 or 20 channels

6011D Extender
Ratio 10, 100, 1000

±3000A

Current Output
I

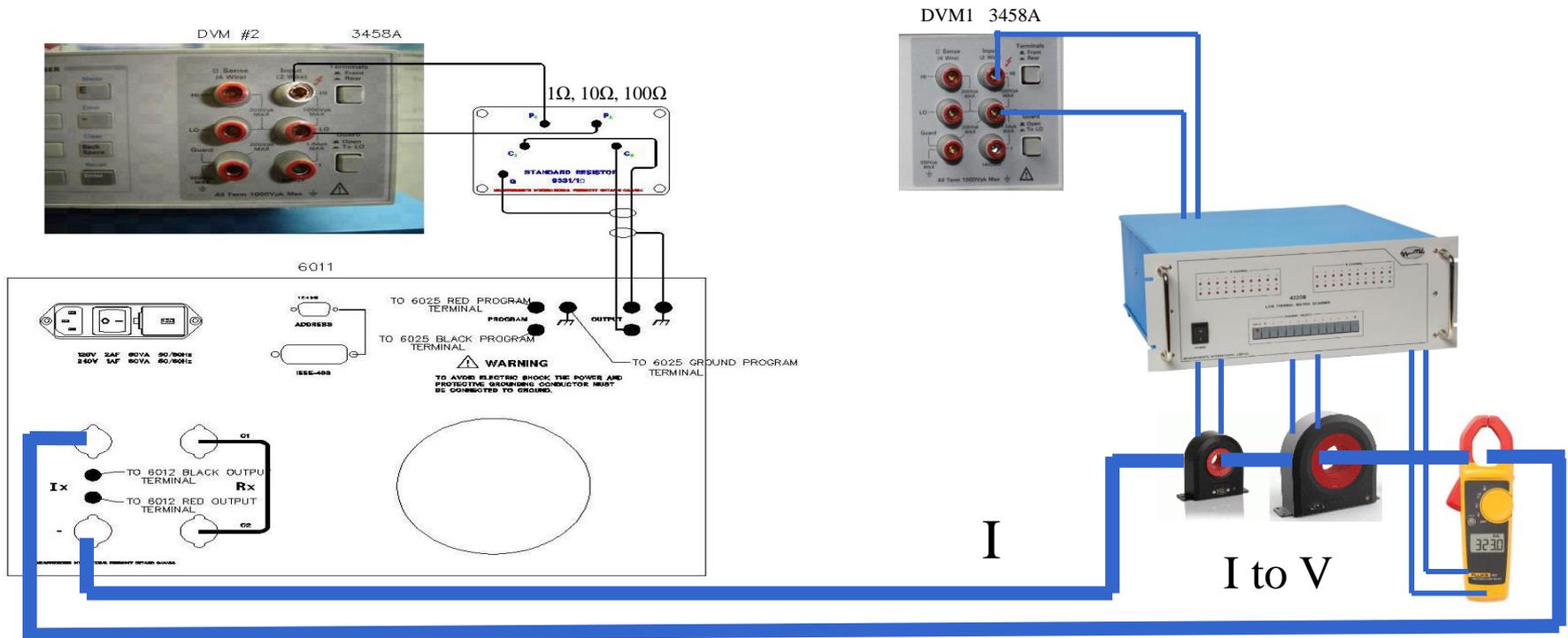
$$I_{ABS} = V_{ABS}/R_{ABS} \times \text{Range}$$

6014M Extender
Ratio 1000





DC Current Calibration for 100A, 300A, 400A, 1000A and 3000A Systems.



$$I = \frac{V}{R} + \frac{-V}{R} * \text{Ratio (where ratio = 10 to 1,000,000)}$$

$$U = (DMM1_{UNC}^2 + DMM2_{UNC}^2 + R_{UNC}^2 + EXT1_{UNC}^2 + EXT2_{UNC}^2 + STD_{DEC}^2)^{1/2}$$



Operating Software

System & Rack Settings

Settings File: [] Load File: [] Save File: [] GPIB Mode: Demo Display: []

Extenders & Power Supplies | Voltmeters |

Range Extender

Expanded Unc. (95%) [0] ppm HP 6632A x 3 6100A
 Unc. Degrees of Freedom [Infinite]
 Serial Number [12345010] Serial Number [6789021] 1000A
 GPIB Address [4] GPIB Address [5] [6] [7]

Test Current Adjustment Window [10] %
 Power Supply Setting Protection Window [5] %

6012M / 6013M / 6014M

In System Expanded Unc. (95%) [1] ppm Reversing Switch
 Unc. Degrees of Freedom [Infinite] Serial Number [6023]
 Serial Number [6025] [67890]
 Serial Number [12345] 6027

Main Menu

Start Measurement System & Rack Settings Resistor ID Listings UUT ID Listings Program Selection Measurement Options File & Directory Setup History Information Diagnostic Check

DC Transformer Ratio Measurements

Print Graph

Transimpedance Mean: 1.99763E-3 Ohm Uncert. (95%) [%]: 0.16 Max [%]: 0.32 Min [%]: -0.32

UUT Current (A)	UUT Output Voltage (V)
299.049	597.477E-3
299.793	599.452E-3
300.129	600.936E-3
300.422	601.412E-3
300.541	601.043E-3
300.095	598.467E-3
299.805	599.232E-3
299.381	599.978E-3
299.759	597.935E-3
0.299.998	597.551E-3
1.000.796	600.748E-3

Rs and UUT Information Operation Information Measurement Information

Rs: sR2 Serial # 123450 Value (Ohm) 9.99674 Max. Current (A) 101.0E-3 Test Current (A) 30.00E-3

UUT: T1 Serial # 345210 Transimpedance (Ohm) 2.0000E-3 Max. Current (A) 505.0 Test Current (A) 300.0

Task: T1 Element: M1 Transimpedance Error Mean: -0.12 % Std Dev: 7.6E-2 % Uncertainty (95%): 0.16 %

Main Screen

System & Rack Settings

Settings File: 6300 Load File: [] Save File: [] GPIB Mode: Demo Display: []

Extenders & Power Supplies | Voltmeters |

DMM#1 (HP3458A) UUT Voltage

Expanded Unc. (95%) [5] ppm
 Serial Number [12345]
 GPIB Address [22]

DMM#2 (HP3458A) Rs Voltage

Expanded Unc. (95%) [5] ppm
 Serial Number [67890]
 GPIB Address [23]

Setup Function: [NPLC 10,LFREQ LINE]

System Setup files and UUT Files

History Information

UUT History (%) HF98532

Print Graph

YScale: [0.1] [1] [10] [100] [1000]

Origin: 1997-04-03

Date	Transimpedance (Ohm)	Std Dev	Uncert
1 1997-04-03	1.00084	36.52E-3	37.34E-3
2 1997-07-01	1.00088	13.84E-3	28.34E-3
3 1998-01-05	1.00090	27.36E-3	37.55E-3
4 1998-03-02	1.00090	43.35E-3	49.85E-3
5 1998-07-01	1.00092	81.34E-3	181.3E-3
6 1998-11-02	1.00092	34.34E-3	48.94E-3
7 1999-04-02	1.00094	28.47E-3	53.37E-3
8 1999-07-03	1.00095	13.46E-3	43.46E-3
9 2000-03-04	1.00096	40.83E-3	68.99E-3
10 2000-07-01	1.00096	39.55E-3	57.34E-3

Projection Value: 1.00115681

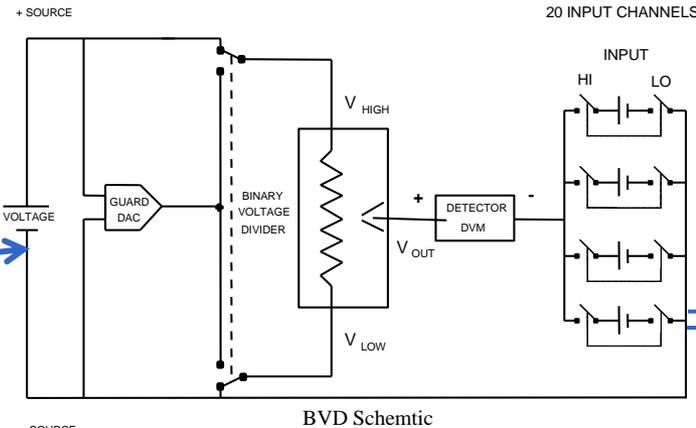
Load History File

Open Saved History File In WordPad

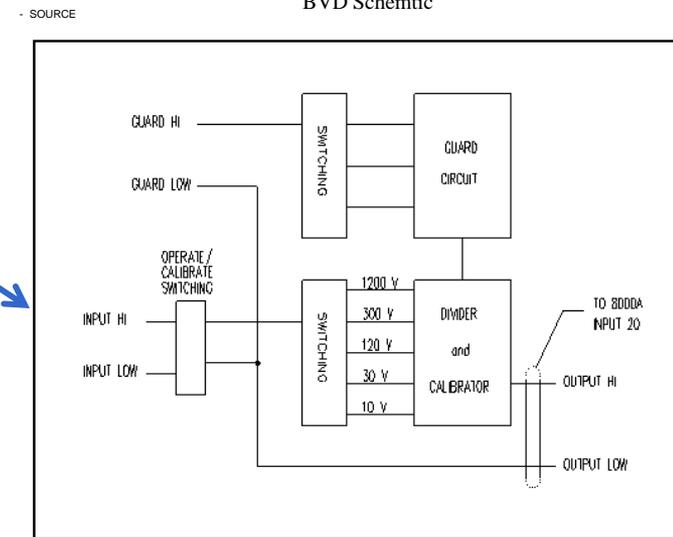
History file



DC Voltage Calibration System



BVD or Binary Voltage
Resistive Divider
Input Impedance of 40k
10V
1.018V
Self Calibration
Standardization
Measurement
With verification features

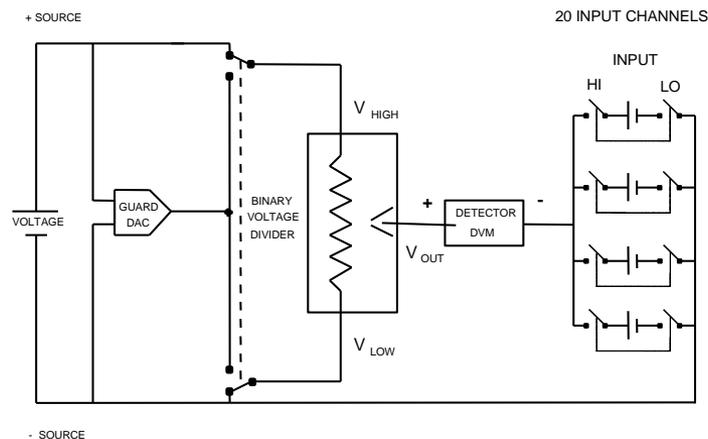


Resistive Divider
With Ranges of
10V
30V
120V
300V
1200V
Self calibration using
the BV

FIGURE 1...8001A SYSTEM SCHEMATIC



An Accurate Self Calibrating Binary Voltage Resistive Divider System



13 Bit Binary Voltage Divider
 $10V/2^{13} = 1.2 \text{ mV}$
DMM only sees voltages
below 1.2mV

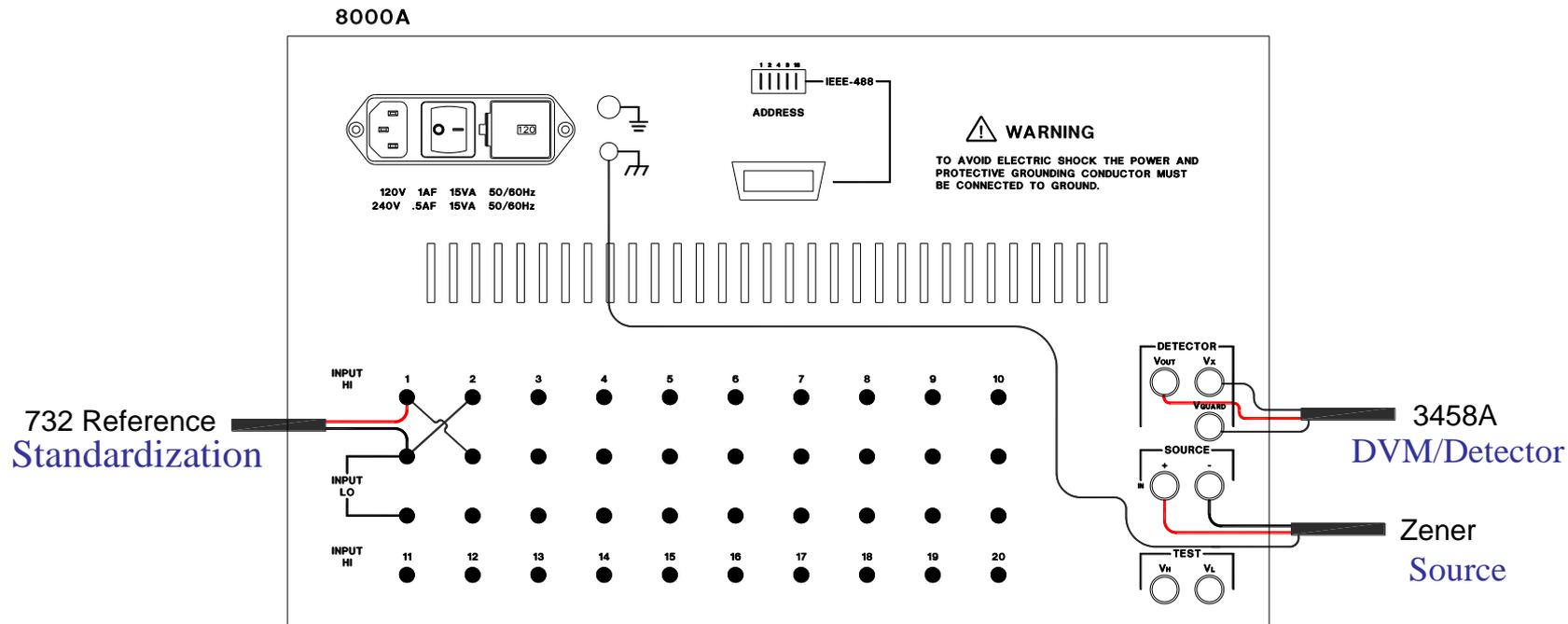
System consists of the BVD, A 3458A Detector, a stable 10V Voltage Source Voltage and a stable 10V Zener Reference

The sources of error have been critically examined, carefully controlled and accounted for. The system features various methods to verify the ratios from 1mV to 1200V with traceability to the 10V Zener Reference. This makes the system ideal for calibrating both DC References and DC

Voltage Calibrators.



BVD Connection Diagram



Source, DVM/Detector & Reference
Reference: Known 10V (JJ)
Source: Stable 10V Zener



System Configuration

Source & Reference

8000 System & Rack Settings

8000

Source switching capability required.

Serial Number: 80008000

GIPIB Address: 2

GIPIB Mode: Demo Display Commands

Settings File: sample1

Source & Reference | **DVM & Extender** | **Calibrators & DVM Under Test**

Source

Model Number: Fluke 732A
Serial Number: 732-111
Output Voltage: 10.000178
Uncertainty: 0.2 ppm
Deg. of Freedom: 50
Distribution: T (student's)

Variance = (Uncertainty)²

Standard Reference

Different Channel For Negative Polarity

Model Number: Fluke 732A
Serial Number: 732-222
Output Voltage: 10.000122
Uncertainty: 0.2 ppm
Deg. of Freedom: 50
8000 Channel: Channel 1
Distribution: T (student's)

Calibration / Standardization on Positive Polarity Only
Negative Polarity 8000 Channel: Channel 2

DVM/Detector & Extender

8000A System & Rack Settings

8000A

Source switching capability required.

Serial Number: 80008000

GIPIB Address: 2

GIPIB Mode: Demo-NoRnd Display Commands

Settings File: sample

Source & Reference | **DVM & Extender** | **Calibrators & DVM Under Test**

DVM

HP 3458A
 Keithley 2000
 Other:

Serial Number: 34588543
GIPIB Address: 16

Microvolt Range: R 0
Auto Range: RAUTO

Termination Character:
Reading Trigger:
Reading Rate:

Setup Function: NPLC 50.LFREQ LINE

8001A

In System

Serial Number:
GIPIB Address: 3

The output channel of the 8001 must be connected to channel 20 of the 8000.

Calibrator & DVM (UUT)

8000A System & Rack Settings

8000A

Source switching capability required.

Serial Number: 80008000

GIPIB Address: 2

GIPIB Mode: Demo-NoRnd Display Commands

Settings File: sample

DVM & Extender | **Calibrators & DVM Under Test** | **Scanner**

Calibrator

In System Fluke 57X0A
 Datron 4X0X

Serial Number:
GIPIB Address: 14

External Sense On

Protect from setting voltages above: 1000.00 V
(maximal voltage: +/- 1100 V)

DVM Under Test

In System

Serial Number: 85088058
GIPIB Address: 7

HP 3458A
 Keithley 2000
 Other:

Range (Auto): RAUTO
Termination Character:
Reading Trigger:
Reading Rate:

Setup Function: DCV AUTO, NPLC 50.LFREQ LINE



Measurement Process

1. Calibrate the 13 bits of the BVD
2. System Standardization – remove the DC thermals and offsets in the BVD and Detector to make it direct reading.
3. Verification – re-measure the source that you just standardized against.



BVD Stage Calibration $\pm 10V$

8000A Calibration And IEEE Operations

Save Results
Files' Name: test_5mar
File Extensions: *.cal, *.std, *.cle

Calibrate 8000A
 Standardize Source
 Calibrate 8001A

Start Calibration

8000A Calibration **Source Standardization** **80001A Calibration**

8000A S / N: 80008000 Temperature: _____ °C
Source Voltage: 10.000139200 Start Date: 2014-06-13 Pressure: _____ kPa
Cal. Personnel: A. W. Start Time: 13:32:41 Humidity: _____ %RH

Positive Source Polarity Negative Source Polarity

	Factor (x 10 ⁶)	Sqrt(Var.)(x 10 ⁶)	Change (x 10 ⁶)		Factor (x 10 ⁶)	Sqrt(Var.)(x 10 ⁶)	Change (x 10 ⁶)
1	0.005	0.012	0.000	1	-0.003	0.012	0.000
2	-0.003	0.011	0.000	2	0.004	0.010	0.000
3	-0.011	0.013	0.000	3	-0.018	0.014	0.000
4	0.012	0.012	0.000	4	0.013	0.012	0.000
5	-0.016	0.013	0.000	5	-0.022	0.011	0.000
6	0.001	0.013	0.000	6	0.000	0.011	0.000
7	-0.097	0.010	0.000	7	-0.089	0.011	0.000
8	-0.039	0.012	0.000	8	-0.036	0.011	0.000
9	-0.091	0.010	0.000	9	-0.091	0.013	0.000
10	-0.323	0.012	0.000	10	-0.335	0.012	0.000
11	1.150	0.011	0.000	11	1.156	0.012	0.000
12	-1.699	0.014	0.000	12	-1.696	0.011	0.000
13	1.110	0.011	0.000	13	1.115	0.011	0.000

Display Correction Factors

8000A Test Menu Open Saved Calibration File In WordPad Done

BVD has a reversing switch built in for reversing the source
Self Calibration removes the long term drift of the system



BVD Standardization

8000A Calibration And IEEE Operations

Save Results Calibrate 8000A
 Files' Name: test_5mar Standardize Source
 File Extensions: *.cal, *.std, *.cle Calibrate 8001A

Start Calibration

8000A Calibration		Source Standardization		80001A Calibration	
Source S / N	732-111	Ref. Voltage	10	Temperature	°C
Source Voltage	10.000140300	Start Date	2014-06-13	Pressure	kPa
Cal. Personnel	A. W.	Start Time	13:45:01	Humidity	%RH

Display Standardization Information

	Vgnd (uV)	Sqrt(Var.)(uV)		Vgnd (uV)	Sqrt(Var.)(uV)
1	3.733	0.004	1	-3.911	0.006
2	3.729	0.005	2	-3.904	0.006
3	3.725	0.003	3	-3.902	0.004
4	3.730	0.004	4	-3.899	0.004
5	3.732	0.004	5	-3.906	0.003
6	3.726	0.004	6	-3.897	0.004
7	3.721	0.004	7	-3.900	0.004

	Voltage (V)	Sqrt(Var.)(uV)		Voltage (V)	Sqrt(Var.)(uV)
1	10.000124117	0.267	1	-10.000128781	0.399
2	10.000124283	0.265	2	-10.000128867	0.399
3	10.000124230	0.274	3	-10.000129110	0.399

Mean Vgnd: (3.728 ± 0.001) uV, N = 109, p = 95.45% (-3.903 ± 0.002) uV, N = 93, p = 95.45%
 Standardized Voltage: 10.000016090 V ± 0.205 ppm, N = 50, p = 95.45% -10.000015780 V ± 0.205 ppm, N = 50, p = 95.45%

8000A Test Menu Open Saved Calibration File In WordPad Done

The BVD is a ratio device, it measures the ratio of two voltages. Standardization makes the 8000 direct reading in terms of Absolute



Standardization Verification Process

Reference Voltage = 10.0000122 UNC = 0.02 ppm
732B calibrated using Josephson Array
Connected to Channel 1 and 2

Measure Channel 1

Voltage Measurement = 10.00001220 ± 0.01 ppm

The screenshot shows a software window titled "Standard Reference". It contains the following fields and options:

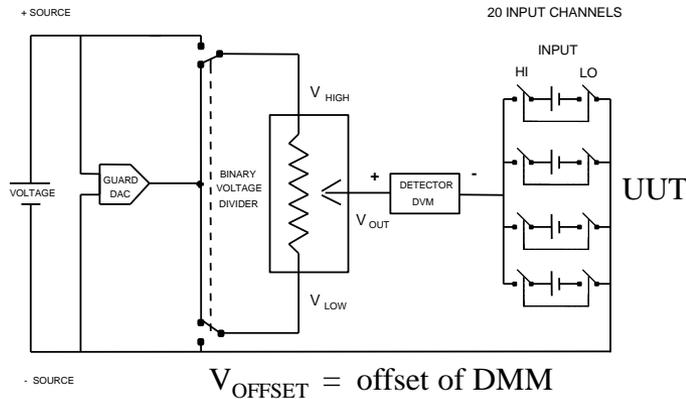
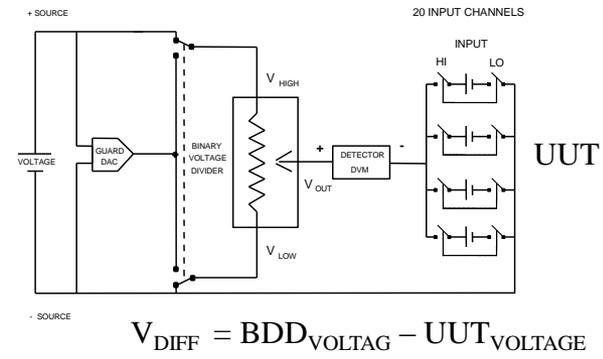
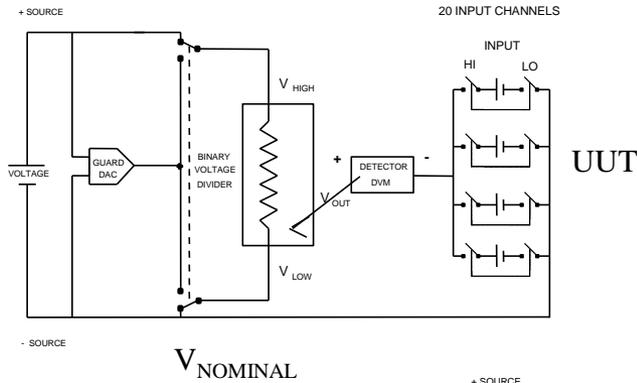
- Different Channel For Negative Polarity (with a "What does it mean?" button)
- Model Number: Fluke 732A
- Serial Number: 732-222
- Output Voltage: 10.000122
- Uncertainty: 0.2 ppm
- Deg. of Freedom: 50 (with a "8000 Channel" label) and Channel 1 (dropdown)
- Distribution: T (student's) (with a normal distribution curve icon)
- Calibration / Standardization on Positive Polarity Only
- Negative Polarity 8000 Channel: Channel 2 (dropdown)

Alternatively you could measure two calibrated 732's and record the difference in the value as the error. The 732's would require calibration on the JJ

Ref 1 – Ref 2 < uncertainty of the two references



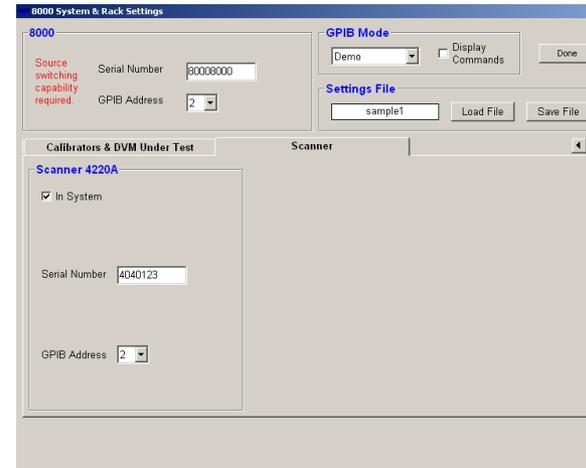
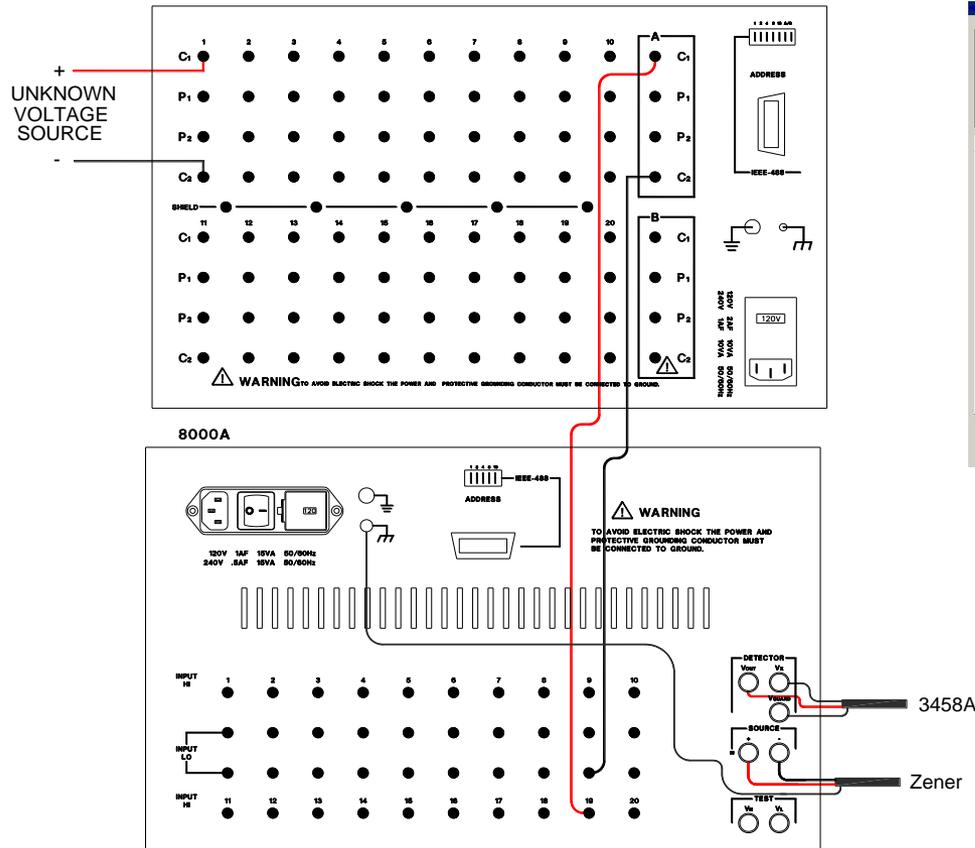
Voltage Measurement



$$UUT_{VOLTAGE} = BVD_{VOLTAGE} + (V_{DIFF} - V_{OFFSET})$$



Channel Extension



Software Configuration for the Scanner

Connecting a 20 Channel Scanner



8000 Verification Box



RATIO VERIFICATION: Where external resistors are used to verify the ratios of the 8000.

If you don't have a JJ

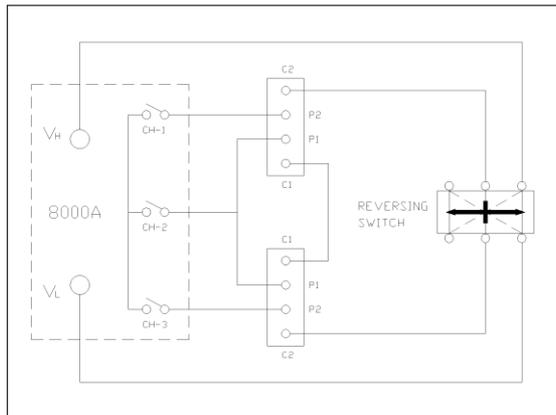
Included in the box is a pair of standard Resistors.

Good Short Term Stability

eg: for 1:1 ratio, two 10 K standard resistors.

eg: for 10:1 ratio, 1 K and 10 K standard resistors.

A low thermal reversing switch (R).



Either one of these two techniques can verify the BVD Ratio to < 0.02 ppm

Built into the software where input channels are specified



8001B 1200V Divider

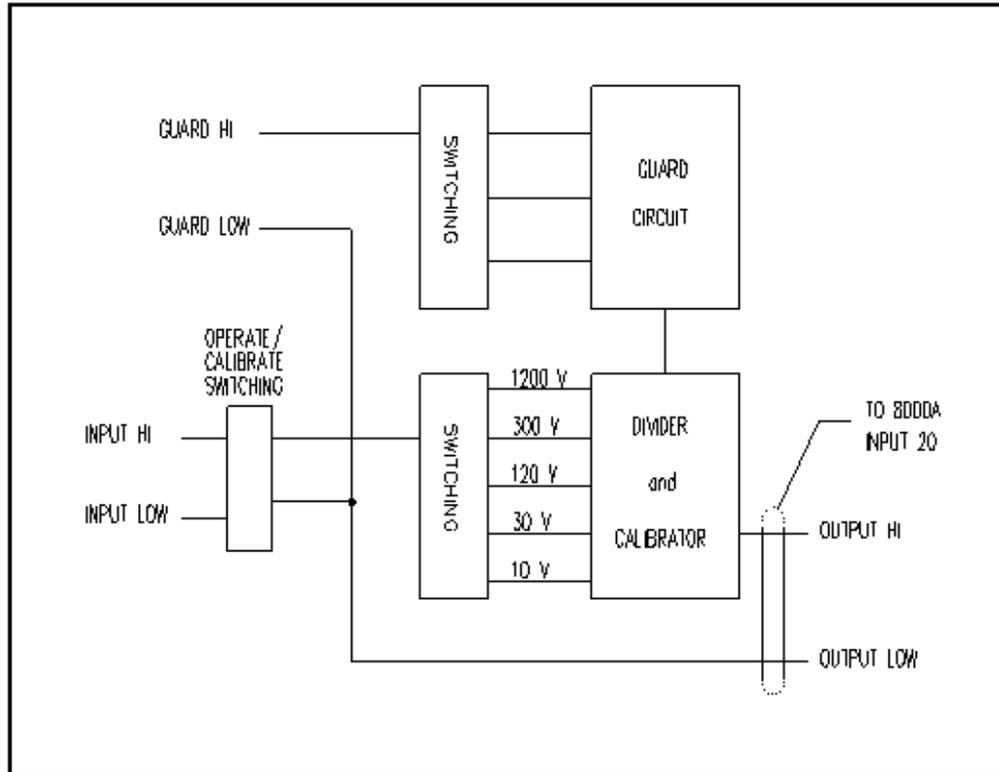
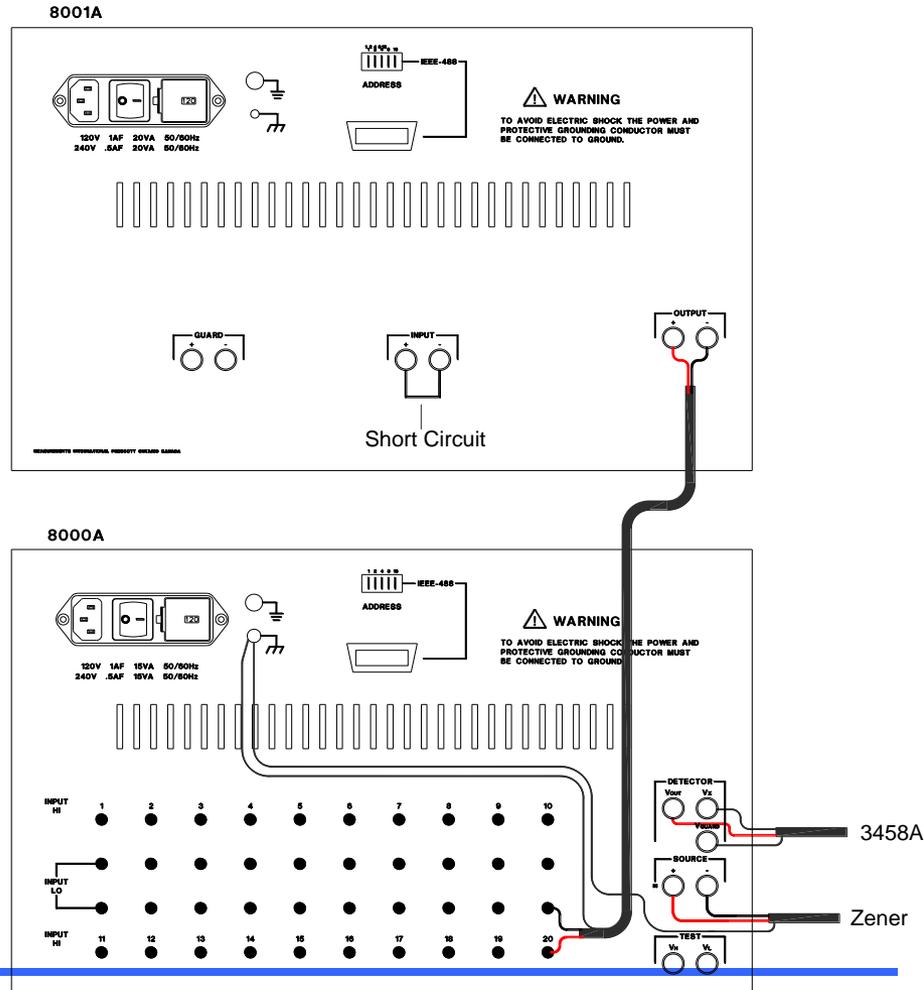


FIGURE 1...8001A SYSTEM SCHEMATIC

The Ext is also a resistive divider and maintains excellent short term drift and is self calibrating using the BVD after standardization is complete. Application for the BVD & Ext include the calibration and verification of the linearity and absolute voltage measurements of both calibrators and DMM's up to 1200V.



BVD/EXT Connection Drawing





EXT Setup & Calibration

8000 System & Rack Settings

8000

Source switching capability required.

Serial Number: 80008000

GPIO Address: 2

GPIO Mode

Demo Display Commands Done

Settings File

sample Load File Save File

Source & Reference **DVM & Extender** **Calibrators & DVM Under Test**

DVM

HP 3458A Serial Number: 34588543

Keithley 2000 GPIO Address: 16

Other:

Microvolt Range: R 0

Auto Range: R AUTO

Termination Character:

Reading Trigger:

Reading Rate:

Setup Function: NPLC 50,LFREQ LINE

8001

In System

Serial Number:

GPIO Address: 3

The output channel of the 8001 must be connected to channel 20 of the 8000.

Extender Calibration using the calibrated BVD

8000 Calibration And IEEE Operations

Save Results Calibrate 8000

Files' Name: SAMPLE1141024 Standardize Source

File Extensions: *.cal, *.std, *.cle, *.vfe Calibrate 8001 Verify 8001

8001 Calibration Connect Reference Standard to 8001 INPUT

Ranges Input Channel Start Calibration

8000 Calibration | **Source Standardization** | **8001 Calibration** | **8001 Verification**

8001 S / N: PLANT Temperature: °C

Source Voltage: 10.000178000 Start Date: 2014-10-27 Pressure: kPa

Cal. Personnel: Start Time: 11:01:08 Humidity: %RH

Input	Offset (uV)	Sqrt(Var.) (uV)
10 V	0.06	0.03
30 V	0.24	0.01
120 V	0.20	0.03
300 V	0.17	0.05
1200 V	0.16	0.03
1200/1200	-0.01	0.04
300/120	0.16	0.02
1200/120	0.15	0.17
1200/120	1.76	0.22

Voltage (V)	Sqrt(Var.) (ppm)
10 V	10.000007643
30 V	3.333480057
120 V	0.833383153
300 V	4.000010092
1200 V	0.999999134

Ratio	Sqrt(Var.) (ppm)
30:10	2.999870358
120:10	11.999294000
300:10	29.998182637
1200:10	119.993343559

Output Channel Correction:
(0.17 ± 0.04) uV, N=16, p=95.45%

8000 Test Menu Open Saved Calibration File In WordPad Done

Ext Software Configuration



EXT Verification

8000 Calibration And IEEE Operations

Save Results Calibrate 8000
 Standardize Source

Files Name: [SAMPLE1141024] Calibrate 8001 Verify 8001

File Extensions: *.cal, *.std, *.cle, *.vfe Calibrate 8001 Verify 8001

8000 Calibration | **Source Standardization** | **8001 Calibration** | **8001 Verification**

8001 S / N: [PLANT] Temperature: [] °C
Source Voltage: [10.00007970] Start Date: [2014-10-26] Pressure: [] kPa
Cal. Personnel: [] Start Time: [10:39:03] Humidity: [] %RH

Input (V)	8001 Range	Measured (V)	Uncert. (ppm)	Error (ppm)
10 V	10 V	10.00000676	0.20	-0.12
10 V	30 V	10.00001025	0.21	0.23
30 V	30 V	30.0003058	0.21	xxx
30 V	120 V	30.0003419	0.29	1.20
120 V	120 V	120.001177	0.29	xxx
120 V	300 V	120.001259	0.31	0.68
300 V	300 V	299.999572	0.31	xxx
300 V	1200 V	299.99982	0.89	-2.38
1000 V	1200 V	999.993938	0.89	xxx

Input (V)	8001 Range	Mesured (V)	Uncert (ppm)	Error (ppm)	Input
10V	10V	10.00000676	0.2	-0.12	10V Reference
10V	30V	10.0000103	0.21	0.23	10V Reference
30V	30V	30.0003058	0.21	XXX	Calibrator 30V
30V	120V	30.0003419	0.29	1.2	Calibrator 30V
120V	120V	120.001177	0.29	XXX	Calibrator 120V
120V	300V	120.001259	0.31	0.68	Calibrator 120V
300V	300V	299.999572	0.31	XXX	Calibrator 300V
300V	1200V	299.99982	0.89	-0.83	Calibrator 300V
1000V	1200V	999.993938	0.89	XXX	Calibrator 1000V



Summary: Resistance Metrology MIL 17025 Scope

Resistance Range

1 $\mu\Omega$ to 10 $\mu\Omega$	500 to 20 ppm
10 $\mu\Omega$ to 100 $\mu\Omega$	20 to 2 ppm
100 $\mu\Omega$ to 1 m Ω	2 to 0.9 ppm
1 m Ω to 10 m Ω	0.9 to 0.22 ppm
10 m Ω to 100 m Ω	0.22 to 0.17 ppm
100 m Ω to 1 Ω	0.17 to 0.16 ppm
1 Ω to 10 Ω	0.1 to 0.19 ppm
10 Ω to 100 Ω	0.19 to 0.22 ppm
100 Ω to 1k Ω	0.22 to 0.25 ppm
1k Ω to 10 k Ω	0.25 to 0.1 ppm
13 k Ω	0.2 ppm

10:1 Resistance Ratio

0.1 Ω to 1 Ω	0.05 ppm
1 Ω to 10 Ω	0.05 ppm
10 Ω to 100 Ω	0.05 ppm
100 Ω to 1k Ω	0.05 ppm
1 k Ω to 10 k Ω	0.05 ppm
1 k Ω to 13 k Ω	0.05 ppm
10 k Ω to 100 k Ω	0.08 ppm
100 k Ω to 1M Ω	0.1 ppm
1 M Ω TO 10M Ω	0.15 ppm
10 M Ω TO 100 M Ω	1.5 ppm

1:1 Resistance Ratios

1 Ω to 1 Ω	0.03 ppm
10 Ω to 10 Ω	0.03 ppm
100 Ω to 100 Ω	0.03 ppm
1 k Ω to 1 k Ω	0.03 ppm
10 k Ω to 10 k Ω	0.03 ppm
100 k Ω to 100 k Ω	0.10 ppm
1 M Ω TO 1 M Ω	0.12 ppm
10 M Ω TO 10 M Ω	0.15 ppm
100 M Ω TO 100M Ω	1.5 ppm

1000V 2 ppm

Full MI Scope NRCC Website



Summary

1) Ohms Law, how hard can it be???

Understanding the physical effects related to measuring a resistor to improve the measurement uncertainty. A resistor has a personality and it is only through experimentation and data collection that you can begin to understand it.

2) Importance of understanding and removing DC Offsets in all measurements to improve uncertainties

3) DC Voltage measurements

The importance of verifying the self calibration techniques for making accurate measurements to insure the best uncertainties when calibrating DC voltage calibrators that use (artifact calibration) and DMMS.

4) Why all this work?

Way to improve the Technologies for the improvement of measurement uncertainties worldwide for improving the quality of Life..



References and Related Documents and Websites

1. R. Cutkowsky, “A New Switching Technique for Binary Resistive Dividers”, IEEE I&M Trans, 1978
2. H. Tsao, “A 25-Bit Resistive Voltage Divider”, IEEE I&M Trans, 1987
3. Measurements from $10\mu\Omega$ to $1T\Omega$ with Traceability from the Quant Ω , 13:00-17:00 August 6, 2006 Nashville TN, Duane Brown & Barry Wood
4. A. F. Dunn "Measurement of Resistance Ratios in the Range to 100 Megohms" IEE Transactions on Instrumentation and Measurement, Vol 40. NO. 2 April 1991.