Automated Resistance Measurement Systems w/ Sub-PPM Accuracies

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Measurements International
E(Volts) = \textcolor{red}{R(Ohms)} \times I(Amps)
- Resistance
- Temperature

- 961.78°C Freezing Point of Silver
- 660.323°C Freezing Point of Aluminum
- 419.527°C Freezing Point of Zinc
- 231.928°C Freezing Point of Tin
- 156.5985°C Freezing Point of Indium
- 29.7646°C Melting Point of Gallium
- 0.01°C Triple Point of Water
- -38.8344°C Triple Point of Mercury
- -189.3442°C Triple Point of Argon
Measuring Resistance Ratios:

Passing a current through two or more resistors in series and measuring the ratio of voltages developed across the resistors

Passing known ratios of current through each pair of resistors until the voltage drop across each resistor is equal
Voltage Ratios:

\[ I_s = \frac{E_s}{R_s} \quad R_x = \frac{E_x}{I_s} \]

**Diagram:**
- **Emeas**
- **DVM**
- **Rs**
- **Rx**
- Constant Current \((I_s)\)

**Equations:**
- \( I_s = \frac{E_s}{R_s} \)
- \( R_x = \frac{E_x}{I_s} \)
\[ R_x = \frac{N_x}{N_s} \times R_s \]

Current Ratios:

\[ I_s R_s = I_x R_x \]
\[ I_s N_s = I_x N_x \]
< .1 ppm

DC Reversal
4 Wire

Ratio Measurement Device
Resistor Ratio Measurement

\[ \text{Ratio} = \frac{R_x}{R_s} \]
Ratio = $\frac{Rx}{Rs}$
Two New Technologies:

< .1 PPM Measurement Systems

High Resistance: 1000 Ohm - 1G Ohm
Binary Voltage Divider Technology

Low Resistance: .001 Ohm - 10K Ohm
Binary Wound Direct Current Comparator Technology
Binary Voltage Divider:

- History
- Limitations
- Advantages
- Applications
- Block Diagram
Binary Voltage Divider:

1-100V DC

Guard
DAC

Binary Voltage Divider

DMM

Detector

V1

V2

V3

V4

Rx

Rs
Ratio Measurement Calculation:

\[ R = \frac{V_1 - V_2}{V_3 - V_4} \]

\[ R = \frac{V_{1/E} - V_{2/E}}{V_{3/E} - V_{4/E}} \]

\[ R = \frac{r_1 - r_2}{r_3 - r_4} \]

\[ Rx = Rs \times \text{Ratio} \]
Binary Voltage Divider:

1K to 10M Ohm: <0.1 ppm
10M to 100M Ohm: <0.5 ppm
100M to 1G Ohm: <5 ppm

All Four Wire Measurements @ 1-100 Volts DC

Range: 1K to 1G Ohms
Resolution: DVM / Detector Dependant
Ratio: 1:1, 10:1, 100:1, 1000:1
Linearity: Self Calibration to ±0.01 ppm
Binary Voltage Divider:

• Source Voltage: 1 to 100 Volts

• 4 - Four Terminal Inputs via Rear Panel

• All Communication over IEEE488

• Windows Operating Software

• Self Calibrating - *stored corrections*
Binary Voltage Divider:

- Primary Std. for 10K to 1G Build Up
- Automatically Assigns Values and Calculates Uncertainties
- Voltage Coefficients of High Value Air Resistors
- Automated Potentiometer - *Voltage Maintenance*
Direct Current Comparator:  

- History
- Limitations
- Advantages
- Applications
- Block Diagram
Current Ratios:

\[ \text{Es} = \text{Ex} \]
\[ \text{IsRs} = \text{IxRx} \]
\[ \text{IsNs} = \text{IxNx} \]
\[ \text{Rx} = \frac{\text{Nx}}{\text{Ns}} \times \text{Rs} \]
Direct Current Comparator:  

**Binary Wound**

- **1u to 1.0u Ohm:** <10 ppm 100 to 2000 Amps
- **1.0u to 1.0m Ohm:** <1.0 ppm 100 to 2000 Amps
- **1.0m to 100m Ohm:** <0.2 ppm 1 to 100 Amps
- **100m to 10K Ohm:** <0.1 ppm 10mA to 10 Amps
- **1.0 to 10K Ohm:** <0.1 ppm 10uA to 150mA
- **10K to 10K:** <0.2 ppm 10uA to 2mA

Range: 0.001 to 10K Ohms  Resolution: ±0.001 ppm of Full Scale

Ratio: 0 to 13  Linearity: Self Calibration to ±0.01 ppm
Direct Current Comparator:  

* Binary Wound

- Low Current & Voltage Noise
- Range Extenders to 20,000 Amps
  - Measurement Speed
- Verifiable Throughout Range
- Manual or IEEE488 Interface
- Windows Operating Software
- Self Calibration - *no stored corrections*
Direct Current Comparator: *Binary Wound*

- Primary Resistance Intercomparison < 10K Ohms
- Automated DC Thermometry Bridge
- Automated Current Shunt System
- 13:1 Ratio - QHE Applications
Scanner

Range Extender w/ Source

Bridge

Automated Current Shunt Calibration System
Multiple Channel Automation

Automated Resistance Thermometry Bridge

Scanner

Multiple Channel Automation
Automated Temperature Calibration

Scanner

Bridge

Ratio 13:1
Automated QHE Resistance System

Quant $\Omega$

Scanner

Bridge

0.01 ppm

Automated QHE Resistance System
Automation Requirements:

- Multiple Channels
- Windows Interface
- Task Programmable
- Mathematics Capabilities
- System Verification
- Document Generation
- Customization
- Turn Key System
- No Manual Intervention
Laboratory Issues:

$\quad$ Speed
$\quad$ Accuracy
$\quad$ Measurement Range
$\quad$ Reliability
$\quad$ Complete Automation
$\quad$ Verifiable
The Facts:

- Multiple System Advantage
- Speed and Accuracy
- Turn-Key System
- Proven Technology