Using Reference Multimeters for Precision Measurements

Advanced techniques for improved confidence in metrology

Teleconference:
US & Canada Toll Free Dial-In Number: 1-(866) 230-5936
International Dial-In Number:+1-720-2395774

Conference Code: 1010759559

Welcome

Greetings from –

Fluke Corporation
Everett, Washington, USA

We are very pleased to bring you this presentation on voltage ratio measurement techniques.

Welcome and Thanks!

This presentation is based on Fluke's extensive experience with:

- **Calibration Instruments**
- **Metrology Ratio Standards**
- **Our experience and understanding of the problems faced when making such measurements**

Thanks for your time, we hope you find it both valuable and useful.

Presented by

Fluke's Precision Measurement Business Unit

and Jack Somppi

Electrical Calibration Instruments
Product Line Manager
jack.somppi@fluke.com

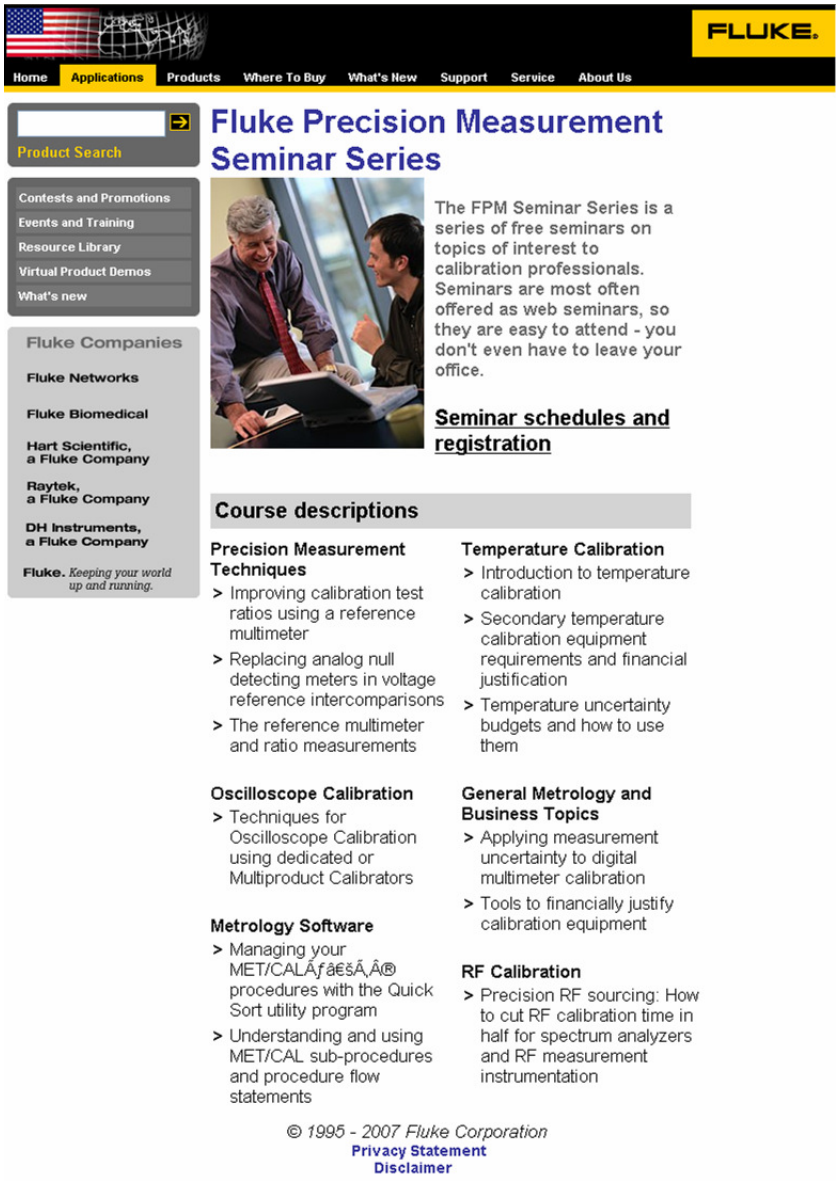
Fluke Precision Measurement Web Seminar Series

For information & reservations to attend our seminars, go to www.fluke.com, click on the sidebar "Events, Seminars & Training", and click on FPM Seminar Series selection,

or directly go to:
www.fluke.com\fpmseminars

Our Seminar Topics Include:

- Precision Measurement Techniques
- Oscilloscope Calibration
- General Metrology
- Temperature Calibration
- Metrology Software
- RF Calibration

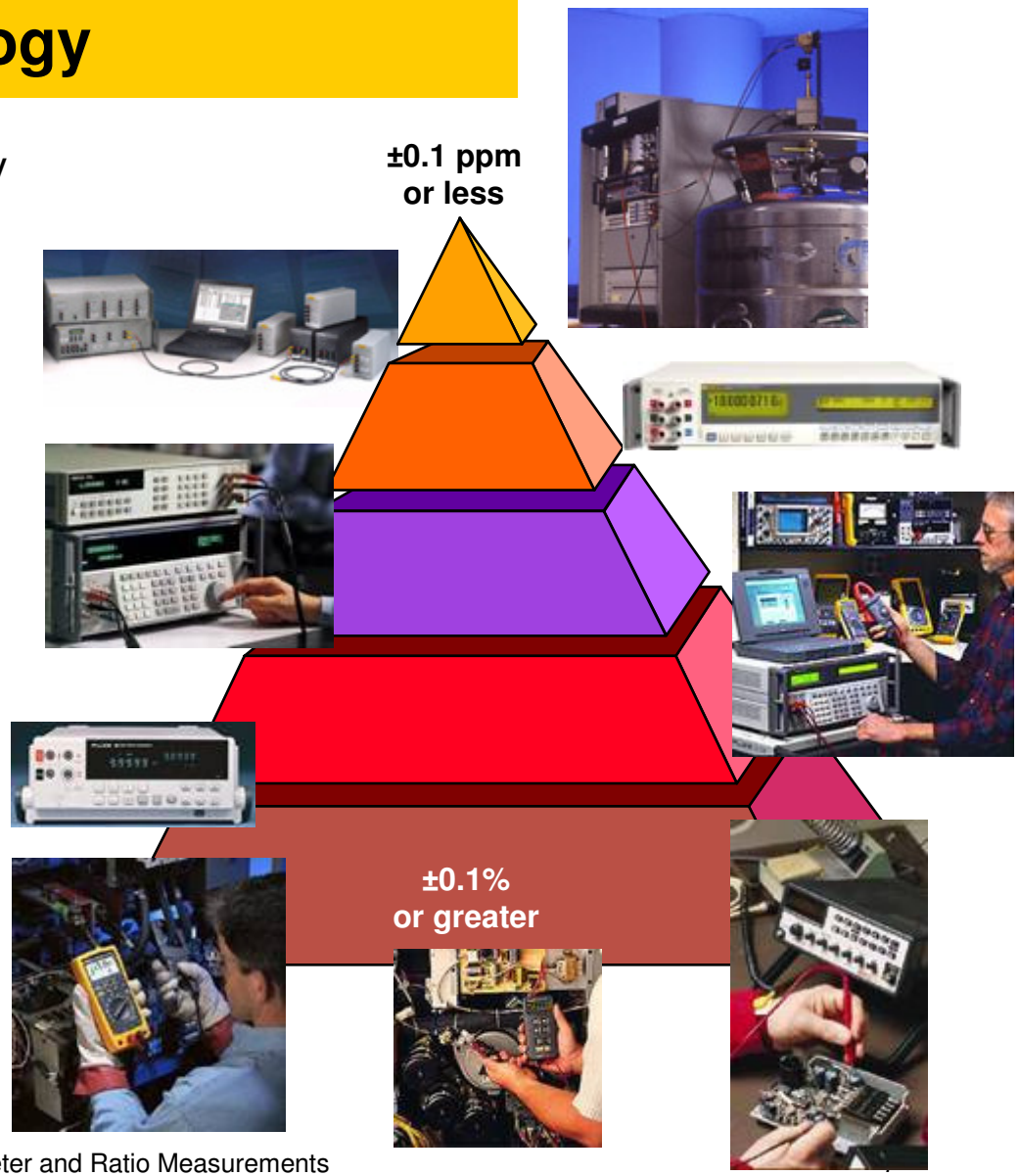


Web seminar etiquette

- Choice of Audio – VOIP or Teleconference
  - VOIP receives audio only while teleconference is two way sound
- Don’t mute your phone if you have background music enabled
- Use Q&A or chat to send me questions or request clarification
- There will be an opportunity throughout the discussion to pause and ask questions.
- You can view the material using either full screen or multi window methods

Introduction – Precision electrical metrology

- DC/low frequency ac electrical metrology can span more than five decades of uncertainties between the requirements of basic industrial testing to the highest level measurements done in primary standard's laboratories.
- Irregardless of the uncertainty, all labs require proper metrology techniques to support SI unit traceability.
- A reference multimeter can assist in a variety of tasks to support SI unit traceability.



Traceability requires proficiency in both precision measurement and precision sourcing

- Some tests require either only sourcing standards (such as calibrating meters) or only measurement standards (such as calibrating sources)
- Some tests require simultaneous use of measurement and sourcing standards (such as current shunt calibration or certain resistance calibrations)
- Laboratory measurement assurance programs use both precision measurement devices and precision sources to cross-check a standard's instrumentation between formal calibrations.
- Certain accuracy enhancement techniques use simultaneous sourcing and measurement to improve test uncertainties.

Lab capabilities are strongest when there are similar measurement and sourcing capabilities.

A reference multimeter is optimized for precision metrology

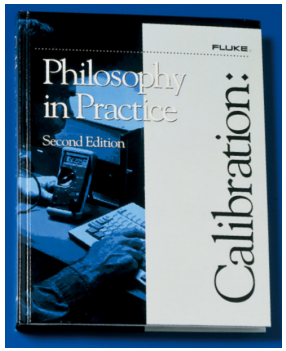
How is a reference multimeter different from a common multimeter?

- 8½ digits of measurement resolution
  - Highly linear a/d converter with 120 million to 200 million counts
  - High useable sensitivity (for example – resolves 1 nV out of 100 mV)
  - Range points set at 1.2 to 1.9 times the decade points to maximize over ranging benefits and decade point measurement accuracy
- Very good long and short term stability:
  - ±0.5 to ±1 ppm in 24 hours
  - ±3 to ±6 ppm in 1 year
- Designed with advanced ratio measurement capabilities to support the best uncertainties and best measurement practices
- Reduce measurement errors with voltage and ohms guarding

Reference multimeters are alternatives to many traditional precision instruments

- Null detectors
- Nanovoltmeters
- Kelvin-Varley dividers
- Resistance bridges
- Micro-ohmmeter
- Precision thermometers
- Electrometers/pico-ammeters
- External shunts
- Ammeters
- AC/DC transfer standards
- Multifunction transfer standards

For more information -



www.fluke.com

The Reference Multimeter and Ratio Measurements

An economical and easy-to-use alternative for Kelvin-Varley dividers

Session overview

With this session you will

- Study calibrating ratios of differing voltages at approximately a 10:1 ratio, comparing techniques using:
  - **A Kelvin-Varley divider**
  - **A ratio DMM technique**
- Use a practical application of calibrating an UUT which is 1.018 volt reference standard with a certified 10 volt reference standard
- Summarize with a comparison of ratio capabilities of Fluke's 8508A Reference Multimeter, 720A Kelvin-Varley Divider and 752A Reference Divider

Objectives & Benefits

Objective of this session-

- Understand the ratio measurement capabilities of a reference multimeter compared to a Kelvin Varley ratio measurement method

Benefits

- Understand the values offered by each technique and know how to apply the measurement methods to various metrology work

Traditional metrology ratio devices

- Voltage Ratio
  - Hamon resistor
    - SR-1010
    - 752 Reference Divider
  - **Kelvin-Varley divider**
  - Ring reference divider
  - Pulse width modulated digital- to-analog converter (PWMDAC)
  - **Linear analog-to-digital converter (ADC)**
- Resistance Ratio
  - Potentiometer methods
  - Bridges
    - Wheatstone and Kelvin bridges
    - PMWDAC Wheatstone bridge
- Current ratio
  - Direct current comparator
  - Current comparator resistance bridge

Compare voltage standards of differing values

Reference is the 732B with a +10.000 123 0 V Certified Output

UUT is the 7001 Reference's 1.018 V output

The Kelvin-Varley Divider

- Key attributes
  - Linearity (0.1 ppm)
  - Scale length (±1.099 999 X)
  - Constant input impedance (10^5 Ohms)
- Ratio
  - $V_o = V_{in}$ x Setting/$Term_{input}$
- Disadvantages
  - Operating complexity
  - Cost
  - Low output impedance can cause loading with the measurement device

Initially used to balance precision sources against standard cells with voltages of 1.018XXX volts

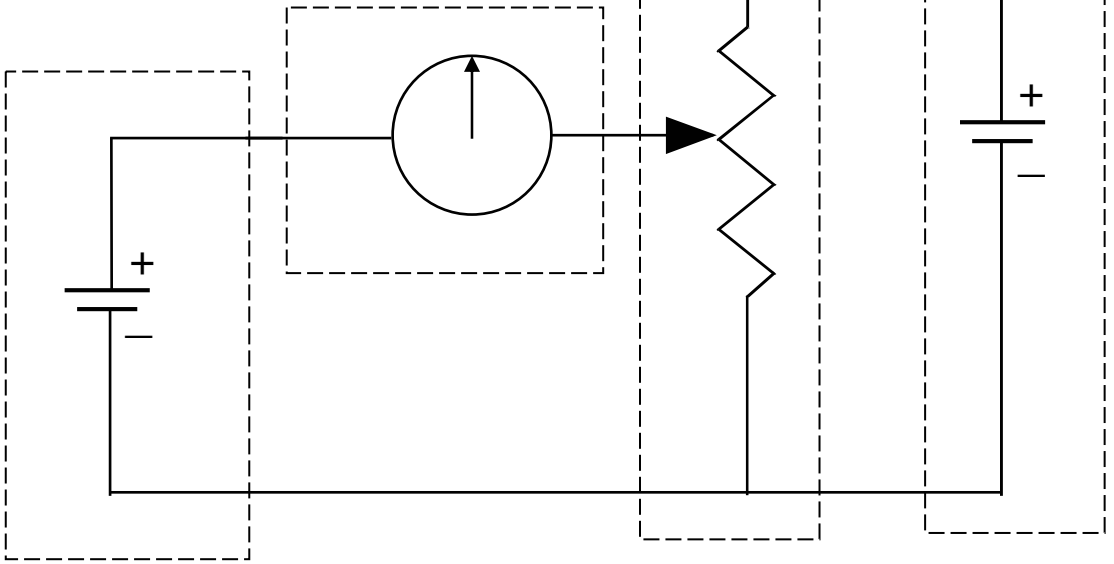
Using a K-V Divider

720A
Setting is adjusted
for null at .101 812 7

732B
Reference is
certified at
+10.000 123 V

7001
+1.018 xxx V
Reference

Null Detector



Determining the UUT value

- Ratio is calculated as:
  - **Vo = V_{in} x Setting/Terminput**
- V_{in} is the certified 10 V value on 732B at:
  +10.000 123 0
- V_{in} is applied to the 1.0 input terminals of the 720A (Terminput)
- The UUT value equals the V_o Voltage as applied to the null detector with a null condition
- In this example, at null the setting value of the 720A dial is:
  .101 812 7
- Therefore the 1.018V terminals of the 7001 are certified to be:
  - **10.000 123 V × (0.101 812 7) / (1.0)**

or **<u>+1.018 140 Volts</u>**

A simplified error summary related to instrumentation

- 732B reference uncertainty
  - ±0.3 ppm from the calibration certificate & stability spec
- 720A Kelvin Varley Divider
  - Specified at ±0.1 ppm of input equals ±1 µV or ±1 ppm of UUT value
- Null detector
  - Specified at ±0.1 µV or ±0.1 ppm of UUT value

- The combined RSS of these error values is **±1.05 µV** indicating the dominance of the 720A uncertainty

- UUT's value including these errors is:

+1.018 140 V ±1.05 µV

Using the 8508A/01 for the same ratio measurement

- The 8508A/01 has selectable rear + front input terminals
- Automatic channel switching for comparison measurements
- Ratio calculations:
  - A-B, A/B, (A-B)/B and Math y=mx+B, %, ...
- High relative accuracy
- Used for voltage and resistance ratio calibrations

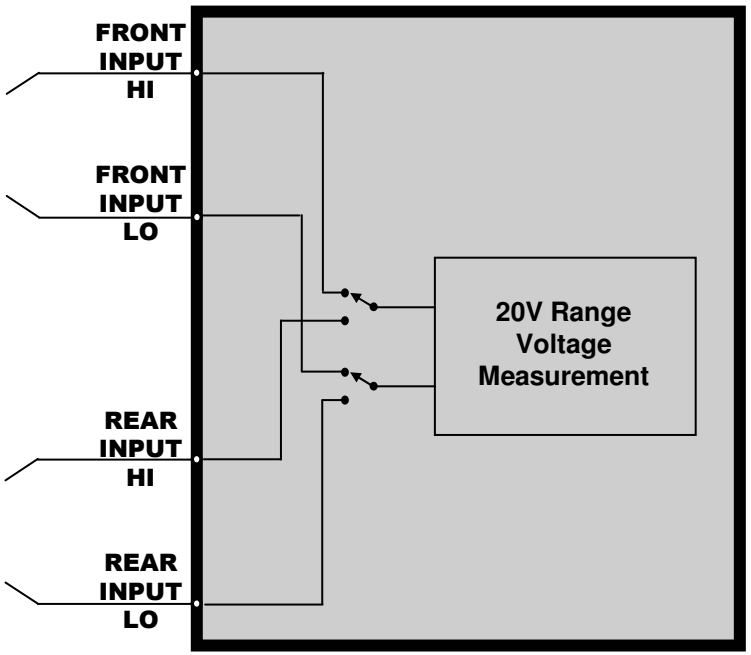
Front input terminals “A”

Rear input terminals “B”

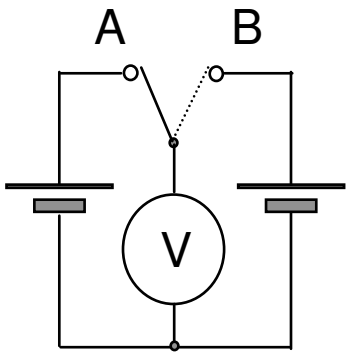
8508A/01 voltage ratio measurement diagram

UUT on Front Terminals

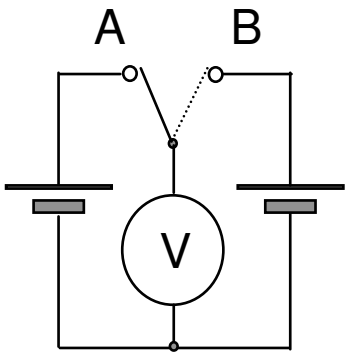
Reference On Rear Terminals



8508A/01



Example measurement



B = +10.000 430 0 V
A = + 1.018 122 6 V

Calculate & display:
A-B or A/B or (A-B)/B

Two Different Voltages References of 1.0180 V and 10 V

Rear inputs at 10V

+10.000 143 0 V
"B"

A/B=+0.101 812 8

Front inputs at 1.018 V

+1.018 xxx x V
"A"

8508A specs for voltage ratios

Key attributes for intercomparing voltage standards

- Good sensitivity (100 nV in 20 V range)
- Wide working range permitting measured ratios of up to 20:1
  (measures with ±2•10^8 displayed counts)
- Excellent transfer uncertainty for relative measurements (0.12 ppm + 2 µV)

Overall measurement considerations

- The measurements are most effectively done using the same measurement range of the dmm to minimize measurement errors.
- For “same range” measurement values, the appropriate specification to use is either the 20-minute transfer uncertainty or 24-hour specifications.
- For different range measurements, use specifications based on the absolute specifications.

DC Voltage

DC Voltage [1][2][3]

Range	Full Scale	Uncertainty Relative to Cal Stds ± (ppm Reading + ppm Range) [4]			Absolute Uncertainties ± (ppm Reading + ppm Range) [4]	
		24 hour TCal ±1 °C	90 day TCal ±1 °C	365 day TCal ±1 °C	365 day TCal ±1 °C	365 day TCal ±5 °C
95 % Confidence Level						
200 mV	199.999 999	0.7 + 0.5	1.4 + 0.5	2.7 + 0.5	4.5 + 0.5	5.0 + 0.5
2 V	1.999 999 99	0.5 + 0.2	1.4 + 0.2	2.7 + 0.2	3.0 + 0.2	3.5 + 0.2
20 V	19.999 999 9	0.5 + 0.2	1.4 + 0.2	2.7 + 0.2	3.0 + 0.2	3.5 + 0.2
200 V	199.999 999	1.0 + 0.2	2.6 + 0.2	4.0 + 0.2	4.5 + 0.2	5.5 + 0.2
1000 V	1050.000 00	1.0 + 0.5	2.6 + 0.5	4.0 + 0.5	4.5 + 0.5	5.5 + 0.5
99 % Confidence Level						
200 mV	199.999 999	0.8 + 0.6	2.0 + 0.6	3.5 + 0.6	6.0 + 0.6	6.5 + 0.6
2 V	1.999 999 99	0.6 + 0.25	1.8 + 0.25	3.5 + 0.25	4.0 + 0.25	4.5 + 0.25
20 V	19.999 999 9	0.6 + 0.25	1.8 + 0.25	3.5 + 0.25	4.0 + 0.25	4.5 + 0.25
200 V	199.999 999	1.2 + 0.25	3.5 + 0.25	5.2 + 0.25	6.0 + 0.25	7.0 + 0.25
1000 V	1050.000 00	1.2 + 0.6	3.5 + 0.6	5.2 + 0.6	6.0 + 0.6	7.0 + 0.6

DC Voltage (Secondary Specifications) [1][2][3]

Range	Transfer Uncertainty 20 mins ±1 °C ± (ppm Reading+ ppm Range)	Temperature Coefficient ± ppm Reading/°C	
		15 °C - 30 °C	5 °C - 15 °C 30 °C - 40 °C
200 mV	0.4 + 0.3	0.4	0.6
2 V	0.12 + 0.1	0.3	0.5
20 V	0.12 + 0.1	0.3	0.5
200 V	0.4 + 0.1	0.7	1.0
1000 V	0.4 + 0.3	0.7	1.0

Type	Multi-slope, multi-cycle A-D Converter
CMRR (1 KΩ unbalance) [5]	140 dB at DC and 1 - 60 Hz
NMRR[5]	
Filter Out	60 dB at 50/60 Hz ±0.09 %
Filter In	110 dB at 50/60 Hz ±0.09 %
Protection (All ranges)	1 kV rms
Input Impedance	
200 mV to 20 V Ranges	> 10 GΩ
200 V & 1000 V Ranges	10.1 MΩ ± 1 %
Max Input Current	50 pA
Ratio Accuracy	
Range to Range	±(Net Front Input Accuracy + Net Rear Input Accuracy)
Within Range	Apply 24 hour or 20 minute Transfer Uncertainty specifications
Settling Time (to 10 ppm step size)	
Filter Out	< 50 ms
Filter In	< 1 s

Transfer uncertainty specs versus absolute specs

Effects of measurement noise repeatability & linearity

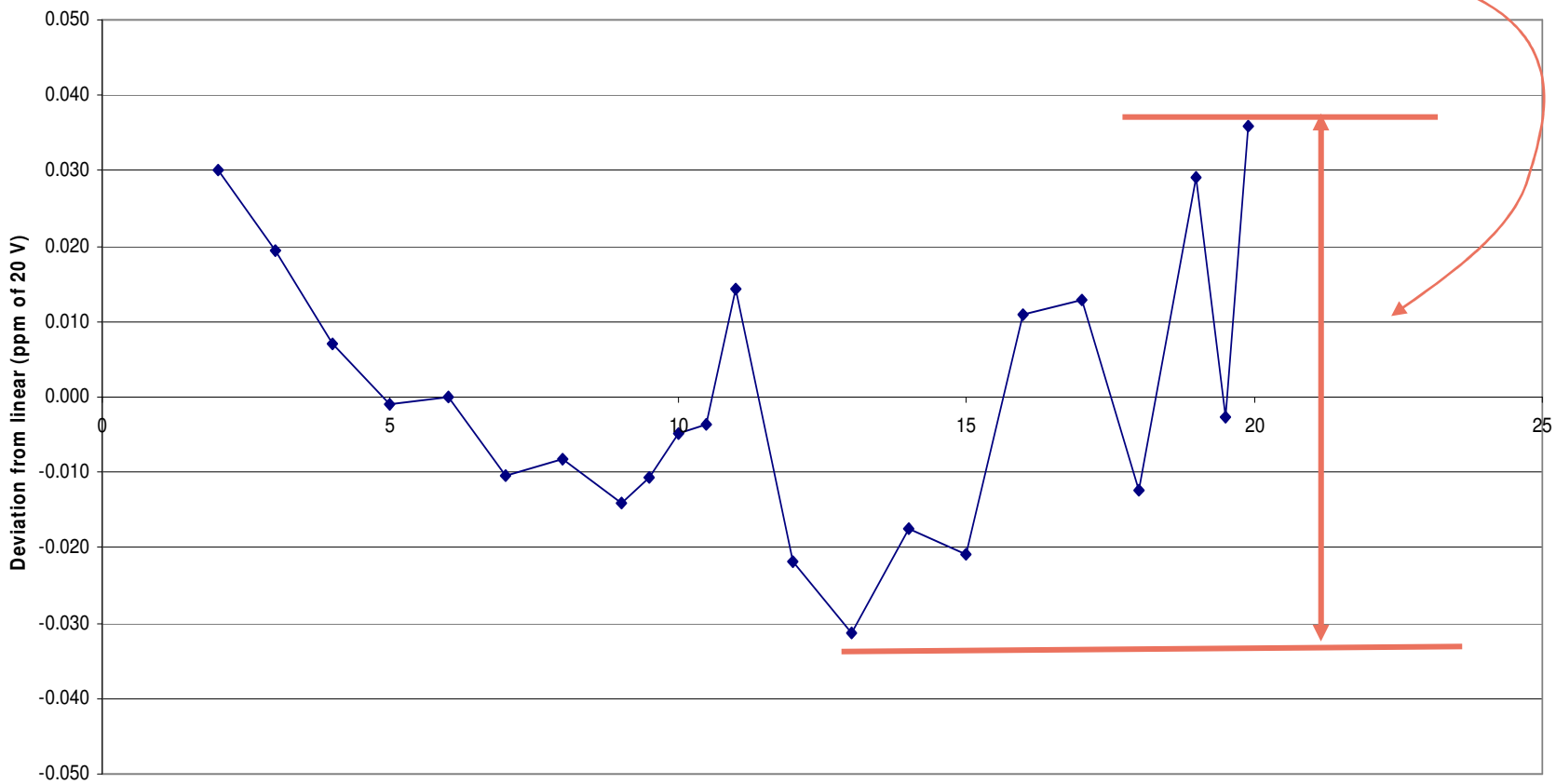
Range	Transfer Uncertainty 20 mins ±1 ºC (ppm Reading + ppm Range)	Absolute Uncertainties ±(ppm Reading + ppm Range)	
		365 day TCal ±1 ºC	365 day TCal ±5 ºC
220 mV	0.4 + 0.3	4.5 + 0.5	5.0 + 0.5
2 V	0.12 + 0.1	3.0 + 0.2	3.5 + 0.2
20 V	0.12 + 0.1	3.0 + 0.2	3.5 + 0.2
200 V	0.4 + 0.1	4.5 + 0.2	5.5 + 0.2
1000 V	0.4 + 0.3	4.5 + 0.5	5.5 + 0.5

Total effects of measurement noise repeatability linearity + traceability time stability gain error offset error

- For “same range” ratio measurements, the uncertainty associated with traceability, long time drift, gain and offset errors effectively cancel and are not influencing factors.
- The calculated ratio value’s uncertainty is the RSS of the uncertainty of the two individual measurements
- $U_{total} = \sqrt{[(U_1)^2+(U_2)^2]}$

Example: measured linearity errors

- Brochure spec declares 0.1 ppm FS (which includes linearity)
- Multimeters linearity measured to be < ± 0.035 ppm FS



Determining the UUT value

- Both measurements are taken on the 20 V range for best uncertainty.
- 8508A's (rear input - "B") 10 V measurement on 732B was:
  +10.000 143 0
- 8508A's (front input - "A") 1.018 V measurement on 7001 was:
  +1.018 142 6
- The 8508A calculates and displays the "A/B" ratio as .101 812 8.
- This value is applied to scale the 732B certified value of 10.000 123 V:
  - The UUT value equals 10.000 123 V × 0.101 812 8
- The UUT is calculated to be:

+1.018 140 5 V

A simplified error summary related to instrumentation

- 732B reference uncertainty
  - ±0.3 ppm or ±3 µV from the calibration certificate & stability spec
- 8508A's (20 V range) 10 V measurement on 732B was +10.000 143 0
  - Specified at ±0.12 ppm plus 2 µV which equals ±0.32 ppm of 10 V
- 8508A's (20 V range) 1.018 V measurement on 7001 was +1.018 142 6
  - Specified at ±0.12 ppm plus 2 µV which equals ±2.12 ppm of 1.018 V

- The combined RSS of errors is ±2.16 µV dominated by the smaller measurement of the DMM
- UUT's value including these errors is:

+1.018 140 5 V ±2.16 µV

Comparing the 10:1 voltage ratio techniques

- The Kelvin-Varley approach has a better uncertainty (1 ppm vs. 2 ppm at the 10:1 volt ratio measurement)
- The 8508A can measure larger ratios with greater sensitivity & resolution
- The K-V's better uncertainty needs to be balanced with -
  - The difficulty level of Kelvin-Varley Divider measurement
  - The slower speed and self heating effects of the K-V Divider
  - The >2:1 higher cost plus upkeep expenses of a K-V Divider
  - The limited measurement uses for the K-V Divider
  - The strictly manual technique of the K-V Divider versus automation offered by the DMM
  - The Need – does 8508A/01 satisfy the required ratio uncertainty (Is 2 ppm adequate for the test?)

Digital meters versus common metrology dividers

	8508A Reference DMM	720A Kelvin Varley Divider	752A Reference Divider
Sensitivity/Range	Variable, 1 part in 200 million	Variable, 1 part in 11 million	Fixed, 10:1 & 100:1 ratios
Uncertainty of Voltage Ratio	RSS the uncertainty of each ratio value (ex: 0.32 ppm at 10 V)	0.1 ppm of **input** 1 µV for a 10 V reference plus measurement uncertainty	0.2 ppm of output at 10:1 and 0.5 ppm of output at 100:1 plus measurement uncertainty
Input Resistance	$> 10^{+10}$ Ω	110 kΩ max	380 kΩ and 2 MΩ
Output Resistance	N/A	66 kΩ max	40 kΩ
Automation	YES	NO	NO

Summary of this session

- Studied details of measurement ratios of differing voltages at approximately a 10:1 ratio, comparing techniques using:
  - A Kelvin-Varley divider making the calibration with an overall measurement uncertainty of 1 ppm
  - A Ratio DMM technique making a calibration with an overall measurement uncertainty of 2 ppm
- A comparison summary of ratio capabilities of Fluke's 8508A Reference Multimeter, 720A K-V Divider and 752A Reference Divider

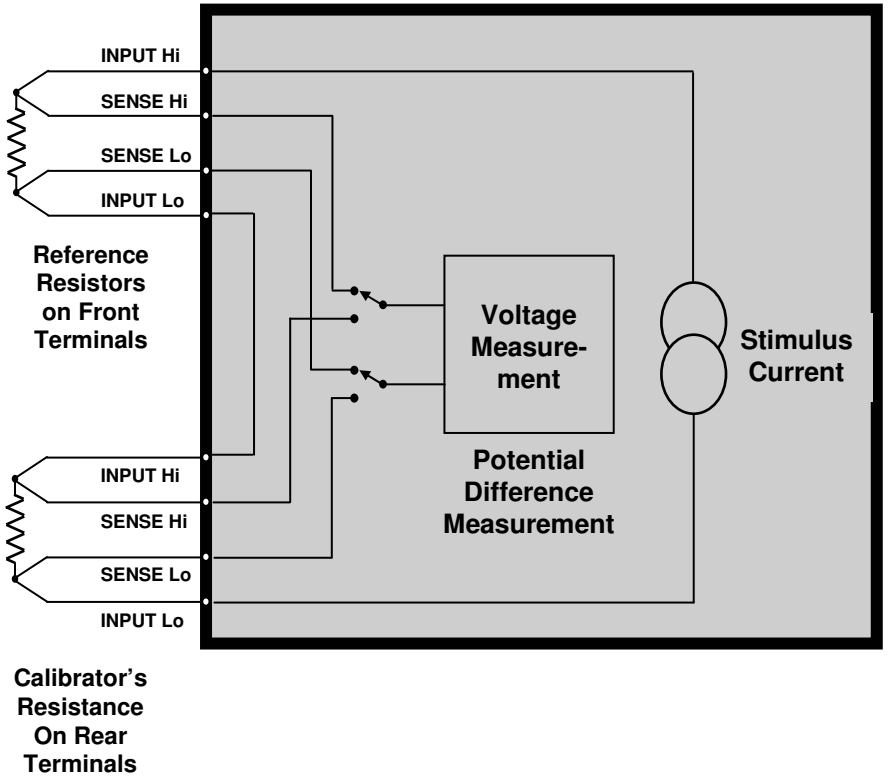
The value of ratio measurements with a reference multimeter

- For varying values of ratios, the reference multimeter is **extremely versatile, easy to operate and economical** versus traditional KV dividers.
- For many voltage measurements requiring varying ratios between 1:1 to 20:1 the **simplicity of use** and the **very good measurement uncertainty** of the ratio dmm is a very satisfactory and valuable alternative
- It can ratio both **voltages and resistances** simply, with very good ratio accuracy.
- Reference multimeters can **automate** the ratio measurement tasks to increase lab efficiencies and maintain measurement consistency.
- While **manual resistive dividers are more accurate**, they do require greater operator expertise and a larger capital investment. These **added costs** are not justified in some cases.

8508A/01 & resistance ratios

- Ratio benefits don't stop with dc voltage!
- The 8508A/01 is an econimical alternative to a resistance bridge

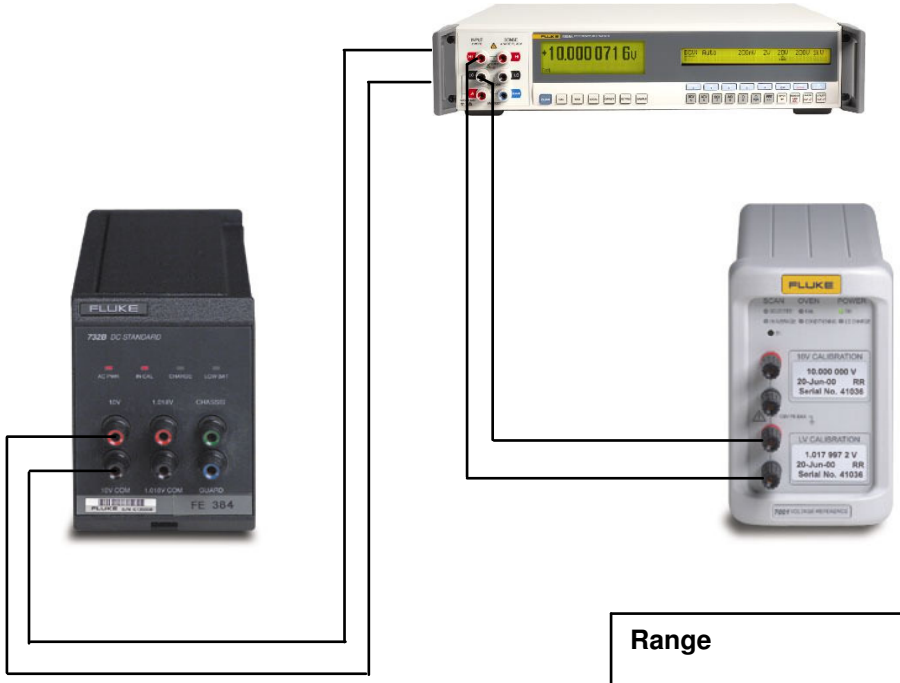
8508A in ohms ratio mode



Summary

- Long scale DMMs and reference multimeters are a very cost effective and powerful addition to calibration and labs.
- Reference multimeters replace a number of traditional standards.
- **They are easy to use and widely understood -- makes assessment easier.**
- **Multimeters are now a credible and *essential* part of the laboratory equipment.**
- They can be used to enhance the performance of other instruments.
- Characterization routines can greatly enhance performance.
- Easy to automate, especially with calibration programs like MET/CAL®.

Questions?

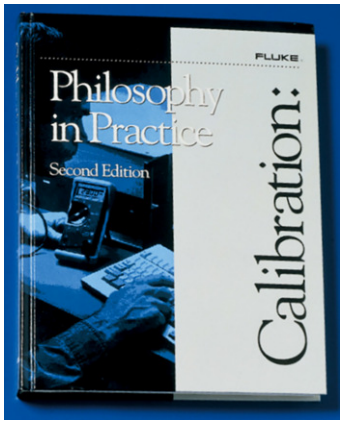


Range	Transfer Uncertainty 20 mins ±1 ºC (ppm Reading + ppm Range)	Absolute Uncertainties ±(ppm Reading + ppm Range)	
		365 day TCal ±1 ºC	365 day TCal ±5 ºC
220 mV	0.4 + 0.3	4.5 + 0.5	5.0 + 0.5
2 V	0.12 + 0.1	3.0 + 0.2	3.5 + 0.2
20 V	0.12 + 0.1	3.0 + 0.2	3.5 + 0.2
200 V	0.4 + 0.1	4.5 + 0.2	5.5 + 0.2
1000 V	0.4 + 0.3	4.5 + 0.5	5.5 + 0.5

For more information -

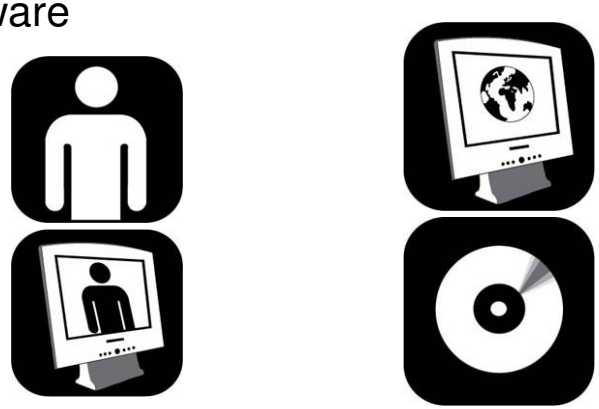
- Download your copy of the Application Note on Migrating from dc voltage dividers from the fluke web site
- Attend Fluke's Training Course – The Principles of Metrology
- Refer to Chapter 9 on DC Ratio in the text book: ***Calibration: Philosophy in Practice***
- Various other reference material at Fluke's web site:

  www.fluke.com



Fluke's calibration and metrology training offering

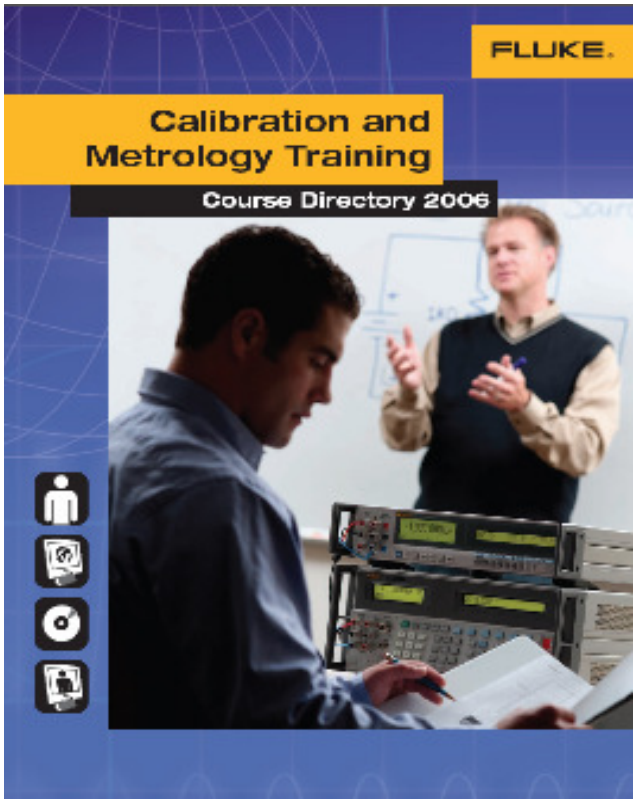
- Fluke calibration and metrology training helps you get the most from your investment in calibration instruments and software
- Multiple ways to learn:
  - **Instructor-led classroom sessions**
  - **Instructor-led web-based courses**
  - **Self-paced web-based training**
  - **Self-paced CD-ROM training**
- Multiple locations
  - **United States and Canada**
  - **Europe**
  - **Singapore**



Members of the MET/SUPPORT Gold and Priority Gold CarePlan support programs receive a 20 % discount off any Fluke calibration training course

Calibration and metrology training

- **Instructor-Led Classroom Training**
  - MET-101 Basic Hands-on Metrology (new in 2007)
  - MET-301 Advanced Hands-on Metrology (new in 2007)
  - Cal Lab Management for the 21st Century
  - Metrology for Cal Lab Personnel (A CCT prep course)
  - MET/CAL Database and Reports
  - MET/CAL Procedure Writing
  - MET/CAL Advanced Programming Techniques
  - On-Site Training
  - Product Specific Training
- **Instructor-Led Web-Based Training**
  - MET/CAL Database Web-Based Training
  - MET/CAL Procedure Development Web-Based Training
- **Self-Paced Web-Based Training**
  - Introduction to Measurement and Calibration
  - Precision Electrical Measurement
  - Measurement Uncertainty
  - AC/DC Calibration and Metrology
  - Metrology for Cal Lab Personnel (A CCT prep course)
- **Self-Paced Training Tools**
  - MET/CAL-CBT7 Computer Based Training
  - MET/CAL-CBT/PW Computer-Based Training (new in 2007)
  - Cal-Book: Philosophy in Practice textbook



More information:
www.fluke.com/fluketraining

THANK YOU !

For material related to this session, visit our web site:

http://www.fluke.com

For any questions email me at:

fpmseminars@fluke.com