Improving Test Ratios Using Reference Multimeters

Boosting the working accuracy of precision sources

Teleconference Phone Numbers:

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Welcome

Greetings from –

Fluke Calibration
Everett, Washington, USA

Fluke Calibration is very pleased to bring you this presentation on improving test ratios using reference multimeters

Welcome & Thanks

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

- Use and design of calibration Instruments
- Our experience and understanding of the problems faced when using calibrators in applications where their specified accuracies are less than desired

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

Welcome

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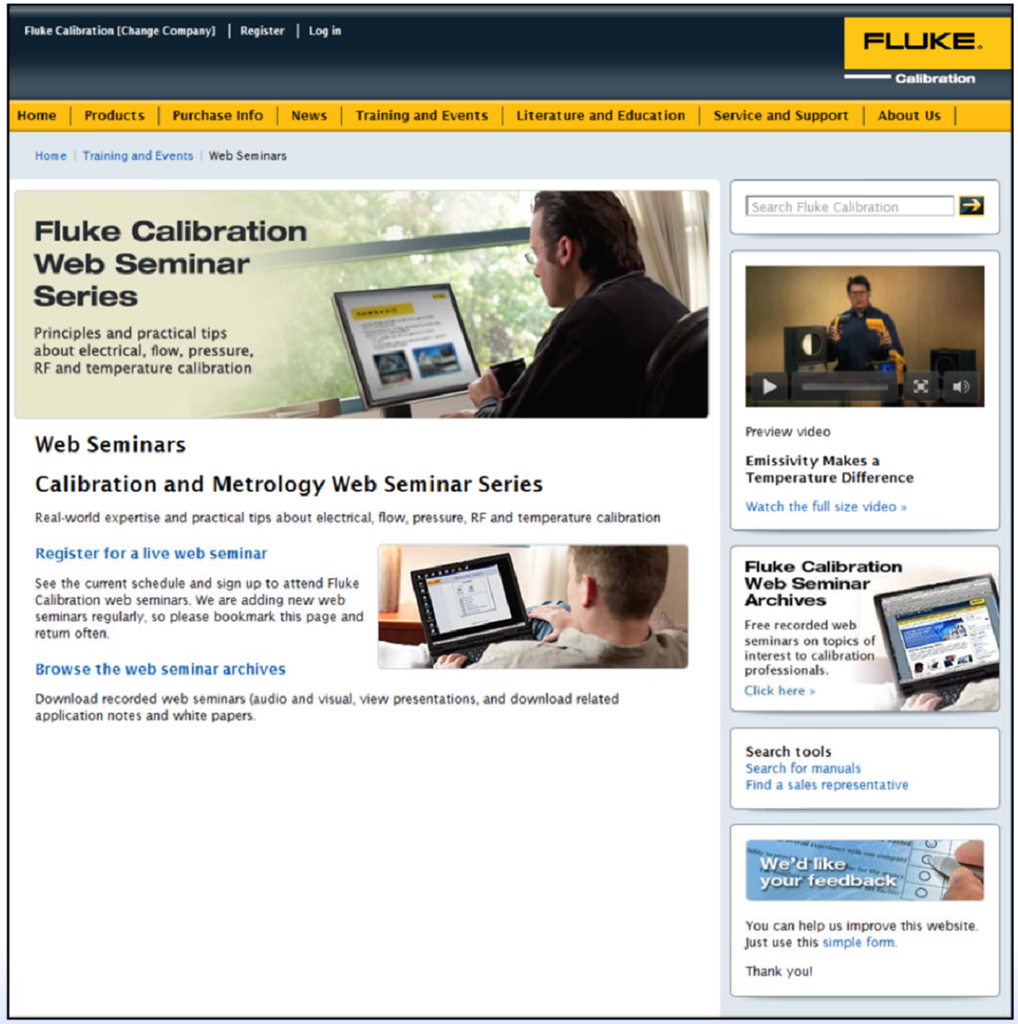
Fluke Calibration Web Seminar Series

For information & reservations to attend our seminars, go to www.flukecal.com, click on the menu selection "Training & Events", and click on the "Web Seminars" selection, and again click on the "Registration for a live web seminar" selection, then click on the "Calibration and Metrology Seminar Series"



Our Seminar Topics Include:

- **Precision Measurement Techniques**
- **Oscilloscope Calibration**
- **General Metrology**
- **Metrology Software**
- **RF Calibration**
- **Temperature Metrology**
- **Pressure/Flow Metrology**

Web seminar etiquette

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- 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.
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- Copies of the seminar materials and an audio/video recording will be made available via download through an email follow up message within 48 hours.

Improving Test Ratios Using Reference Multimeters

Boosting the working accuracy of precision sources

Using a Reference Multimeter for precision metrology

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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

Session Topic – TUR Improvement Case Studies

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- Accepted levels of test uncertainty ratios (TURs) and test specification ratios (TSRs) have been set to various levels by different quality and calibration standards, such as 10:1 or 4:1 or 3:1.
- These levels are set as acceptable limits for calibration pass or fail decisions.
  - This minimizes the risk of incorrect decisions on marginal units under test (UUTs)
- However, there will always be instrument test requirements whose TURs are less than the required levels.
  - Calibration instruments will always have test requirements where the test requirement is for better uncertainty than the instrument capabilities alone.
  - In these cases, special metrology engineering work is done to design an acceptable test technique with appropriate levels of uncertainty.
- The purpose of our session is to examine special metrology techniques to improve test ratios.

Case Study 1: Improving resistance calibration test ratios

Using a multi-product calibrator to calibrate a high performance resistance measuring instrument

The calibrator:
Fluke 5520A MPC

The UUT:
PRT measurement function on a Fluke 525A Temperature Calibrator

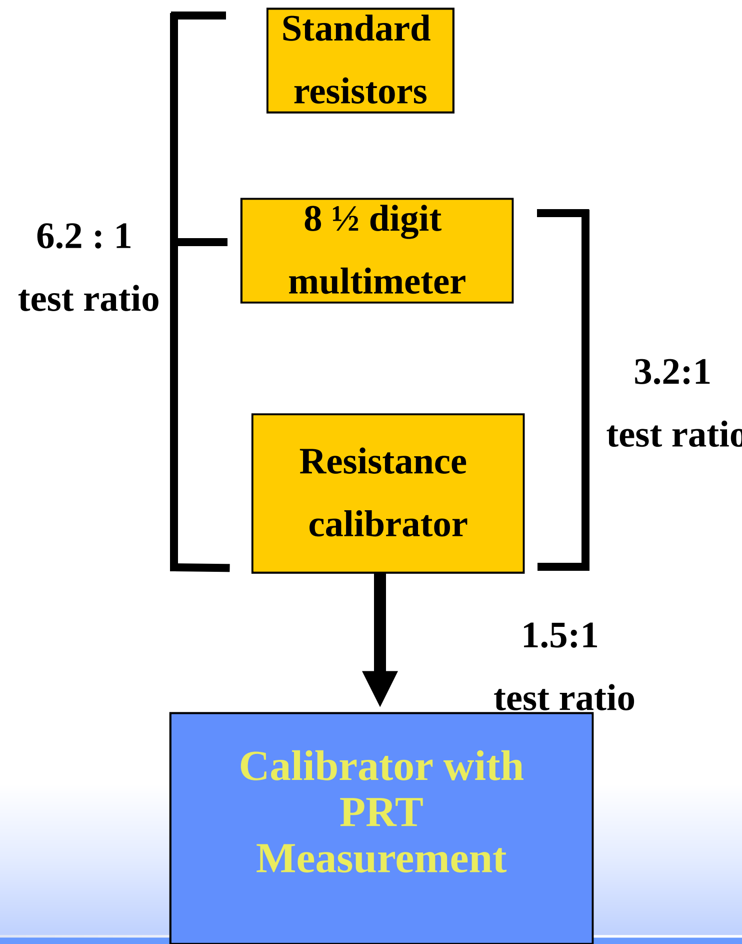
Details of the Challenge

- Fluke 525A Temperature Calibrator has precision SPRT measurement capability that must be calibrated.
- The available calibrator is a 5520A Multi-Product Calibrator.
- Calibration points of 400 ohms and 4 kohms are required.
- 525A has specification of ±40 ppm for 400 ohms and 4 kohms measurement.
- 5520A has specification of ± 27 ppm at 400 ohms and 4 kohms.
- A test uncertainty ratio (TUR) of 1.5:1 (or 40ppm / 27ppm) is not acceptable.

What enhancements can be made to improve the TUR between the calibrating standard of the 5520A and the measurement accuracy of the 525A?

TUR improvement techniques for calibrating resistance measurement

- Begin with a resistance calibrator.
  - Calibrator resistance sourcing provides a lower than desired 1.5:1 test ratio
- (1) Enhance the calibrator with an 8½ digit multimeter.
  - Measurement disciplining of the calibrator's resistance output for a 3.2:1 test ratio
- (2) Enhance TUR further by comparison with standard resistors.
  - Characterization of the calibrator resistance output by ratios with standard resistors for a 6.2:1 test ratio



Method 1: Traditional Accuracy Enhancement

Assist with a DMM because it has better resistance specs than the 5520A.

- Measure the 5520A calibrator with the precision DMM.
- Note the reading correction and then quickly make measurement of the same parameter with UUT.
- Uncertainty is based on a combination of the meter reading and calibrator stability.

Instrument Uncertainties to Consider

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Resistance

Resistance [1] [2] [3] [9]

Range	Full Scale	Mode [10]	Uncertainty Relative to Cal Stds			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
99% Confidence Level							
2 Ω	1.999 999 99	Normal	6.0 + 2.5	10 + 2.5	12 + 2.5	19 + 2.5	22 + 2.5
20 Ω	19.999 999 9	Normal	3.0 + 0.9	5.5 + 0.9	8.5 + 0.9	11.5 + 0.9	12.0 + 0.9
200 Ω	199.999 999	Normal	1.8 + 0.3	5.0 + 0.3	8.5 + 0.3	9.5 + 0.3	10 + 0.3
2 kΩ	1.999 999 99	Normal	1.2 + 0.3	4.5 + 0.3	8.5 + 0.3	9.5 + 0.3	10 + 0.3
20 kΩ	19.999 999 9	Normal	1.2 + 0.3	4.5 + 0.3	8.5 + 0.3	9.5 + 0.3	10 + 0.3
200 kΩ	199.999 999	Normal	1.2 + 0.3	4.5 + 0.3	8.5 + 0.3	9.5 + 0.3	10 + 0.3
2 MΩ	1.999 999 99	Normal	2.5 + 0.6	5.0 + 0.6	8.5 + 0.6	10.5 + 0.6	12 + 0.6
20 MΩ	19.999 999 9	Normal	4.5 + 6.0	7.5 + 6.0	12 + 6.0	20 + 6.0	25 + 6.0
200 MΩ	199.999 999	Normal	25 + 60	30 + 60	35 + 60	75 + 60	150 + 60
2 GΩ	1.999 999 99	Normal	325 + 600	450 + 600	650 + 600	675 + 600	1810 + 600

- 8508A resistance measurement:
  - 1 Year, 99 % confidence, Tcal ±5 ºC absolute spec
  - ±10 ppm of reading + 0.3 ppm of range equals at 4 kΩ to 11.5 ppm uncertainty of the reading
- Short term stability of 5520A
  - Not normally specified
  - It must be evaluated for this case

How the 5520A Short Term Stability Was Evaluated

- The specific 5520A was evaluated at both 400 ohms and at 4 kohms output settings

- Repeated measurements of each output setting were made during a three minute period to evaluate output stability
  - 3 minutes represents a time period representative of the time required for a calibration or verification test
  - Measured by a precision dmm at 4 readings per minute, this provided a set of 12 measurements
  - The short term stability of the precision dmm was much better than the calibrator, so the measured data variations represented the calibrator's stability

- Repeated this test 10 times to model any variation between different tests
  - Included operate-to-standby-to-operate transitions between each test series
  - Provided a data set of 120 measurements (ten sets of 12 measurements)
  - The scatter of the measurements represents the short term stability of the calibrator
  - Data is random in nature with a normal distribution

Statistical data analysis determines stability of the resistance setting

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- The stability is calculated using statistical analysis on the set of 120 resistance test measurements
- The mean (or average) value (symbolized as "$\overline{x}$"); as well as the standard deviation of the mean (symbolized as "$\boldsymbol{u}$") are calculated
- Calibrator stability is calculated to be the range of the measured resistance variation as stated with a 99% confidence level
  - 120 measurements are effectively an infinite set of data points, statistically a very good population to use for calculating the stability
  - With such a normally distributed population, use a coverage factor of 2.58 to expand u to a stated value range which has a 99% confidence level
  - The short term stability value is calculated by:
    multiplying the standard deviation x 2.58
- Let's look at our data & review the process -

Our Specific Data

- **120 measurements (10 sets of 12 measurements):**
  - 399.98684
  - 399.98711
  - 399.98718
  - 399.98729
  - … (plus all other points) ...

$$\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i = \frac{x_1 + x_2 + \cdots + x_N}{N}$$

- **The mean ($\overline{x}$) of the measurements: 399.98714 ohms**
- **The standard deviation (S) of 120 readings: ±8.49 milliohms** $s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$
- **The variance or standard deviation of the mean (u): ±0.775 milliohms or ±1.94 ppm** $u = \frac{s}{\sqrt{N}}$
- **Calculating the stability or the expanded uncertainty (U):** $U = ku$

  Our specific data:
  - u = ±1.94 ppm
  - k = 2.58
  - Therefore U, the stability, is ±5 ppm (calculated by: 5 = 2.58 x 1.94)

Instrumentation Error Analysis

- DMM ohms readout gives 11.5 ppm per spec
- Short term stability of the calibrator was measured to be 5 ppm
- Combine the errors using an RSS method results in 12.5 ppm
  (square root of [$11.5^2 + 5^2$])
- This improved TUR is:
  - (40ppm / 12.5ppm) = <u>3.2:1</u>
  - a definite improvement over 1.5:1
- But other methods can improve this still more.

Method 2 – Calibrator Characterization Using Ohms Ratio

- Take advantage of the better stability of the calibrator (vs. the DMM resistance spec) as the basis for still more improvement.
- Characterize the calibrator's resistance using a ratio to compare it's setting with standard resistors.
- Do this using a precision DMM to make a precision ratio of the calibrator to the standard resistors.
- The excellent uncertainty of the DMM's ratio measurement, along with the better uncertainty of the standard resistors, are a better alternative than a simple resistance measurement by the DMM.

Front "A" channel

Rear "B" channel

Ratio "A" to "B"

Setup for Ratio Style Characterization

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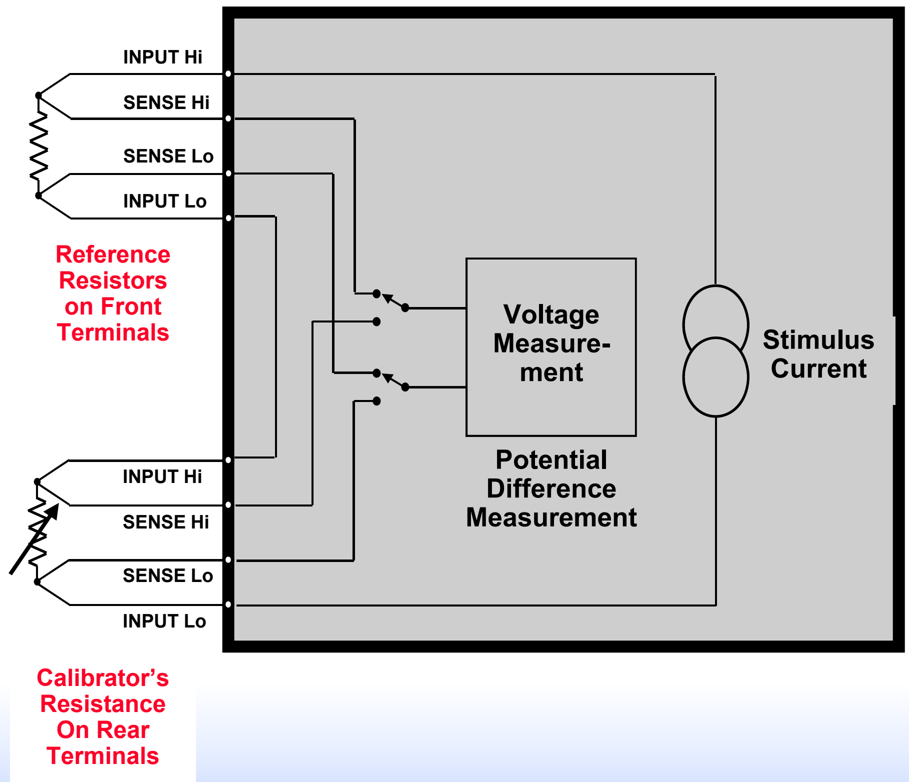
- Additional equipment required:
  - 10 kohm reference resistor
  - 1 kohm reference resistor
- Measure an ohmic ratio of approximately 2.5:1 (reference resistor ratioed to the 5520A)
  - 10 kohm to 4 kohms
  - 1 kohm to 400 ohms
- The 5520A is actually adjusted to a setting which is exactly 400 ohms and 4 kohms, as ratioed to the reference resistors.

8508A in Ohms Ratio Mode



The Traditional Accuracy Enhancement Method

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Example Values for 400 Ohms

- If the 1 kohm standard resistor is certified to be 999.977 ohms, then the displayed ratio would need to be 2.4999425
 (as 999.977 / 400.000)
- Adjust the 5520A output to reach the required 8508A measured ratio of 2.4999425.
- Let's assume for this example that the 5520A has an error of +15ppm (well within it's ±27 ppm spec).
- Then the 5520A setting of 399.9940 ohms gives the desired ratio
- This 5520A setting of 399.9940 ohms is established as the best calibrator setting for a 400 ohm resistance value, and is used to calibrate the 525A test point.

Desired ratio "A/B"
2.4999425

Front "A" channel
999.977 ohms

Rear "B" channel
adjusted to
399.9940 ohms

Calibrate the UUT

Characterized 399.9940 ohms

Characterized Ωs

Verified/adjusted to be 400.000 ohms

- **Apply the characterized values of exactly 400 ohms (as determined by ratio) and 4 kohms to the resistance measurement function of the UUT.**
- **Verify and/or adjust the UUT's performance at these points.**

Calculate the 8508A's Specified Resistance Ratio Measurement Error

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- Consider the 4 kΩ test.
- Use 20 kΩ range transfer spec
  - ±0.2 ppm of reading + 0.15 ppm of range
- DMM transfer measurement of 10 kΩ standard resistor is 0.5 ppm.
- DMM transfer measurement of 4 kΩ on 5520A is 0.95 ppm.
- RSS combination of both measurement uncertainties (0.5ppm and 0.95 ppm) results in an overall ratio uncertainty specification of *1.1 ppm*.

Resistance - Normal Mode (Secondary Specifications) [1] [2] [3] [10]

Range	Measurement Current	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
2 Ω	100 mA	2.0 + 2.0	1.5	2.5
20 Ω	10 mA	0.8 + 0.7	0.6	1.0
200 Ω	10 mA	0.2 + 0.15	0.5	0.8
2 kΩ	1 mA	0.2 + 0.15	0.5	0.8
20 kΩ	100 µA	0.2 + 0.15	0.5	0.8
200 kΩ	100 µA	0.2 + 0.15	0.5	0.8
2 MΩ	10 µA	0.5 + 0.5	0.6	1.0
20 MΩ	1 µA	2.5 + 5	2	3
200 MΩ	100 nA	15 + 50	20	30
2 GΩ	10 nA	200 + 500	200	300

Instrumentation Error Analysis

- 742A 10k has 4 ppm maximum error (per the spec & cal certificate)
- An 8508A ratio measurement error of 1.1 ppm (per the specification)
- 5520A short term stability of 5 ppm
  (similarly evaluated as was the 400 ohm setting)
- These errors combined (RSS) = 6.5 ppm
- TUR = (40 ppm / 6.5 ppm) or 6.2:1
- Almost a two times improvement over traditional accuracy enhancement!

The final test ratio is very acceptable for our test & quality requirements!

Summary of Case Study 1

There are several ways a high performance meter can improve test ratios in this calibration application.

- Calibrator disciplining through direct measurement of the output improves it up to the limit of the DMM spec plus calibrator stability.

- A better technique is to take advantage of several low uncertainty measurement elements together using:
    - The excellent stability of the calibrator
    - The low uncertainty of the standard resistor
    - The low uncertainty of the same range ratio measurement of the DMM.

Case Study 2: Improving voltage and resistance uncertainties to support a new precision DMM

FLUKE Calibration

- **Verifying a high performance DMM of the 6.5 digit class as an example of a new generation of T&M instruments with superior specifications (the Fluke 8846A)**

Case Study 2: Improving voltage and resistance uncertainties to support a new precision DMM

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- Using a multi-product calibrator (the Fluke 5520A), the most frequently used medium to high accuracy calibration source in modern DC/LF AC laboratories

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- Using a multi-product calibrator (the Fluke 5520A), the most frequently used medium to high accuracy calibration source in modern DC/LF AC laboratories
- In this case, of the more than 130 test points required to verify the DMM, many have Test Specification Ratios of less than 4:1, applying….
  - 90 day specs for the DMM
  - 1 year specs for the calibrator
  - For volts (dc & ac) and ohms, 27 points of insufficient TSRs were studied for possible improvement via characterization

Table Of Test Points Having Low Test Specification Ratios

FLUKE® Calibration

Function		Nominal	Frequency	5520A 1-year specification	8846A 90-day specification	8846/5520A Ratio	Comments
4WR	Ohms	10		0.0014	0.0038	2.71	Assume zero 5520A at beginning of each day.
4WR	Ohms	100		0.0042	0.012	2.86	
2WR	Ohms	1.0E+6		34.00	90.00	2.65	5520A 4-W connection at 8846A terminals
2WR	Ohms	10.0E+6		1350.00	2100.00	1.56	
2WR	Ohms	1.0E+9		15.5E+6	1.6E+6	0.10	
DC	V	0.1		0.000003	0.000006	2.00	
DC	V	-0.1		-0.000003	-0.000006	2.00	
DC	V	1		0.000013	0.000025	1.92	
DC	V	-1		-0.000013	-0.000025	1.92	
DC	V	5		0.00008	0.000115	1.44	
DC	V	-5		-0.00008	-0.000115	1.44	
DC	V	10		0.00014	0.00023	1.64	
DC	V	-10		-0.00014	-0.00023	1.64	
DC	V	100		0.00195	0.0033	1.69	
DC	V	-100		-0.00195	-0.0033	1.69	
DC	V	1000		0.0195	0.041	2.10	
DC	V	-1000		-0.0195	-0.041	2.10	
AC	V	0.1	10	0.000038	0.00009	2.37	
AC	V	1	10	0.00035	0.0008	2.29	
AC	V	10	10	0.00365	0.008	2.19	
AC	V	100	100000	0.25	0.68	2.72	
AC	V	750	45	0.235	0.6	2.55	
AC	V	750	1000	0.1975	0.6	3.04	
AC	V	750	1200	0.1975	0.6	3.04	
AC	V	750	10000	0.235	0.6	2.55	
AC	V	1000	45	0.31	0.8	2.58	
AC	V	1000	10000	0.31	0.8	2.58	

Lower than desired TSRs

Possible Alternative Solutions

- Acquire a more accurate calibrator – a major investment
- Perform limited calibrations – not usually acceptable
- Use advanced metrology techniques (guard banding for example) – a viable alternative on a case by case, test by test basis
- Improve calibrator's working specs via characterization – also a viable alternative on broader basis

Characterization Method 1: Real time characterization

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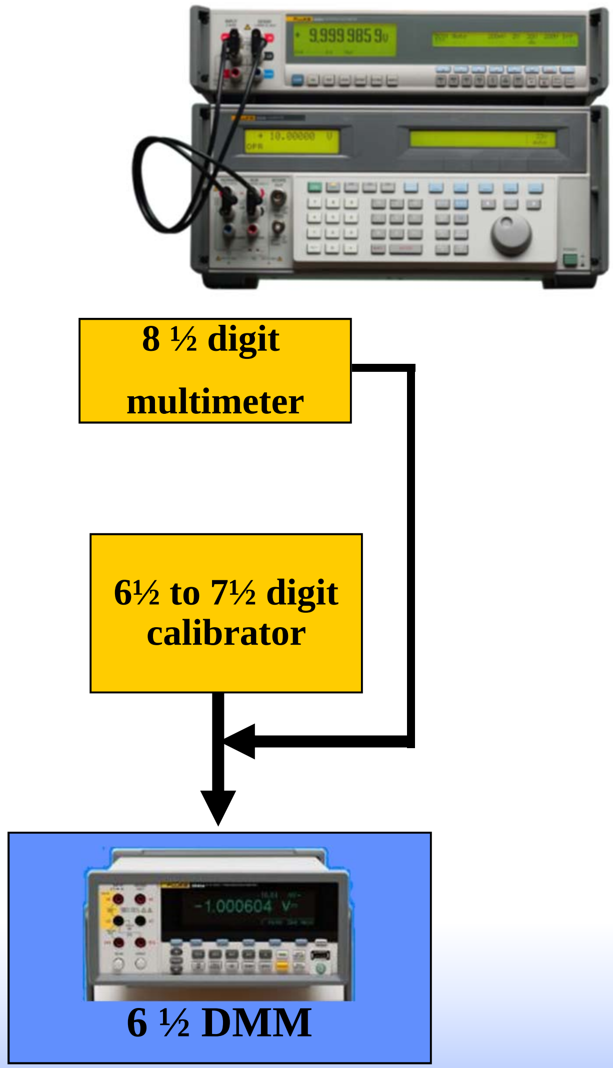
- **Using a better standard to identify the calibrator's output setting errors at the time of use**
- **For example, a high performance 8 1/2 digit DMM measures a less accurate calibrator at the time of use**

Real time characterization

- The higher accuracy 8.5 digit reference DMM is the actual traceable standard
- The calibrator performs as a stable source to the DMM as the UUT during verification
- The uncertainty for the standard is the combination of the reference DMM's measurement specification plus any stability considerations for the calibrator



Test points with test specification ratios based on the 8½ digit reference DMM as the standard

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Function		Nominal	Frequency	8508A 1-year specification	8846A 90-day specification	8846/8508 Ratio	Comment
4WR	Ohms	10		0.000109	0.0038	34.86	8508A 4W Normal I
4WR	Ohms	100		0.00085	0.012	14.12	8508A 4W Normal I
2WR	Ohms	1.0E+6		10.00	90.00	9.00	
2WR	Ohms	10.0E+6		300.00	2100.00	7.00	
2WR	*Ohms*	*1.0E+9*		*2.51E+6*	*1.6E+6*	*0.64*	Use Standard Resistor
DC	V	0.1		0.0000006	0.000006	10.00	
DC	V	-0.1		-0.0000006	-0.000006	10.00	
DC	V	1		0.0000039	0.000025	6.41	
DC	V	-1		-0.0000039	-0.000025	6.41	
DC	V	5		0.0000215	0.000115	5.35	
DC	V	-5		-0.0000215	-0.000115	5.35	
DC	V	10		0.0000397	0.00023	5.79	
DC	V	-10		-0.000039	-0.00023	5.90	
DC	V	100		0.00059	0.0033	5.59	
DC	V	-100		-0.00059	-0.0033	5.59	
DC	V	1000		0.006025	0.041	6.80	
DC	V	-1000		-0.006025	-0.041	6.80	
AC	V	0.1	10	0.000018	0.00009	5.00	
AC	V	1	10	0.000135	0.0008	5.93	
AC	V	10	10	0.00135	0.008	5.93	
AC	V	100	100000	0.077	0.68	8.83	
AC	V	750	45	0.10725	0.6	5.59	
AC	V	750	1000	0.10725	0.6	5.59	
AC	V	750	1200	0.10725	0.6	5.59	
AC	V	750	10000	0.10725	0.6	5.59	
AC	V	1000	45	0.136	0.8	5.88	
AC	V	1000	10000	0.136	0.8	5.88	

Assume +/- 5C max temperature variation

Improved TSRs

Characterization Method 2: Create a "Golden Calibrator" with improved working specs

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- A "golden calibrator" that has had its actual performance extensively measured so its short term and long term stability is known and this replaces the "generic specifications"
- Modern calibrators have generic specifications providing a greater than 99% confidence that all the population of calibrators will be within spec.
- Individual calibrators often perform well within 30% to 50% of the allowable performance errors
- Characterization of an individual calibrator usually permits using a calculated uncertainty of 2 to 4 times better than spec, or more.

(1) Routinely measure (daily) before use

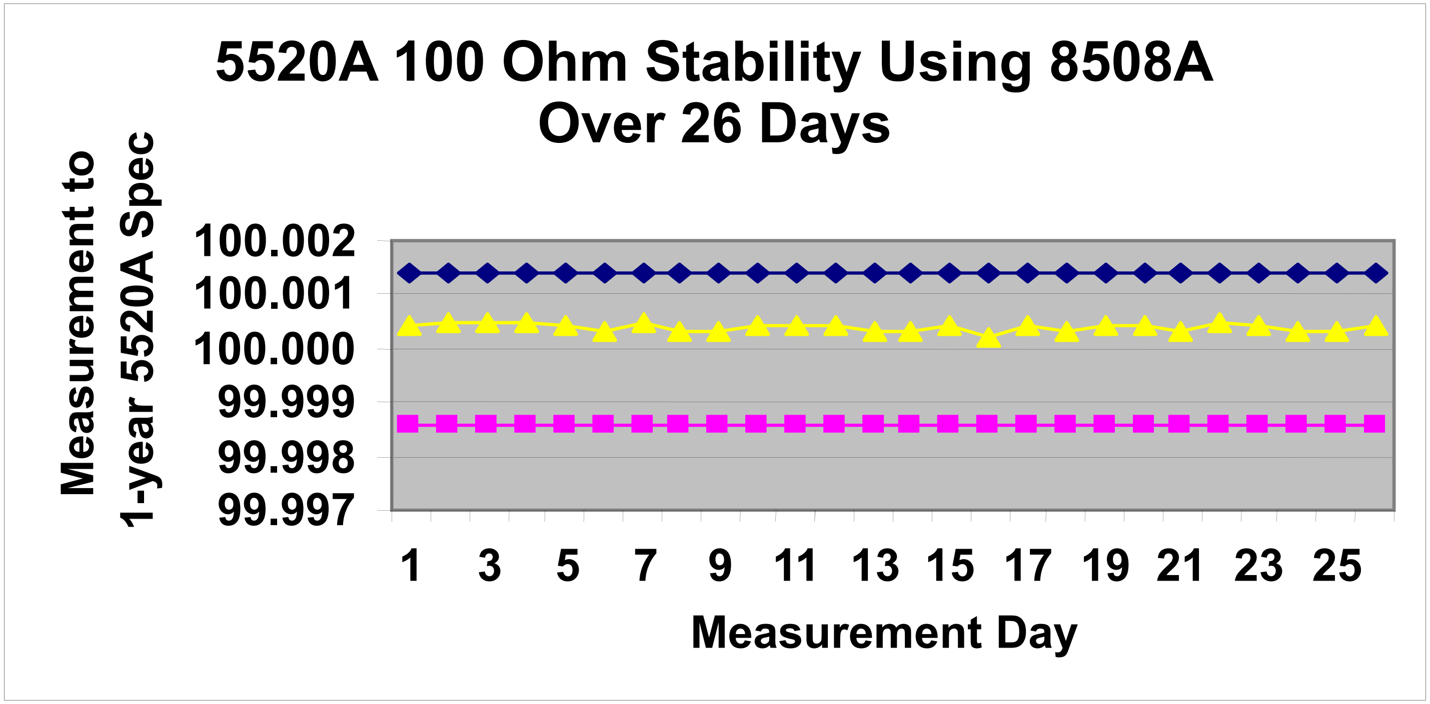
- **Measurements made using the 8508A, an 8½ digit reference multimeter**
- **Improved performance based both on dmm specs and 24 hour calibrator stability**
- **Builds history of actual calibrator performance to substantiate true performance**

(2) Study a longer term characterization alternative

Longer term testing was done by weekly testing in the Fluke Primary Standard's Lab for approximately 14 to 25 weeks

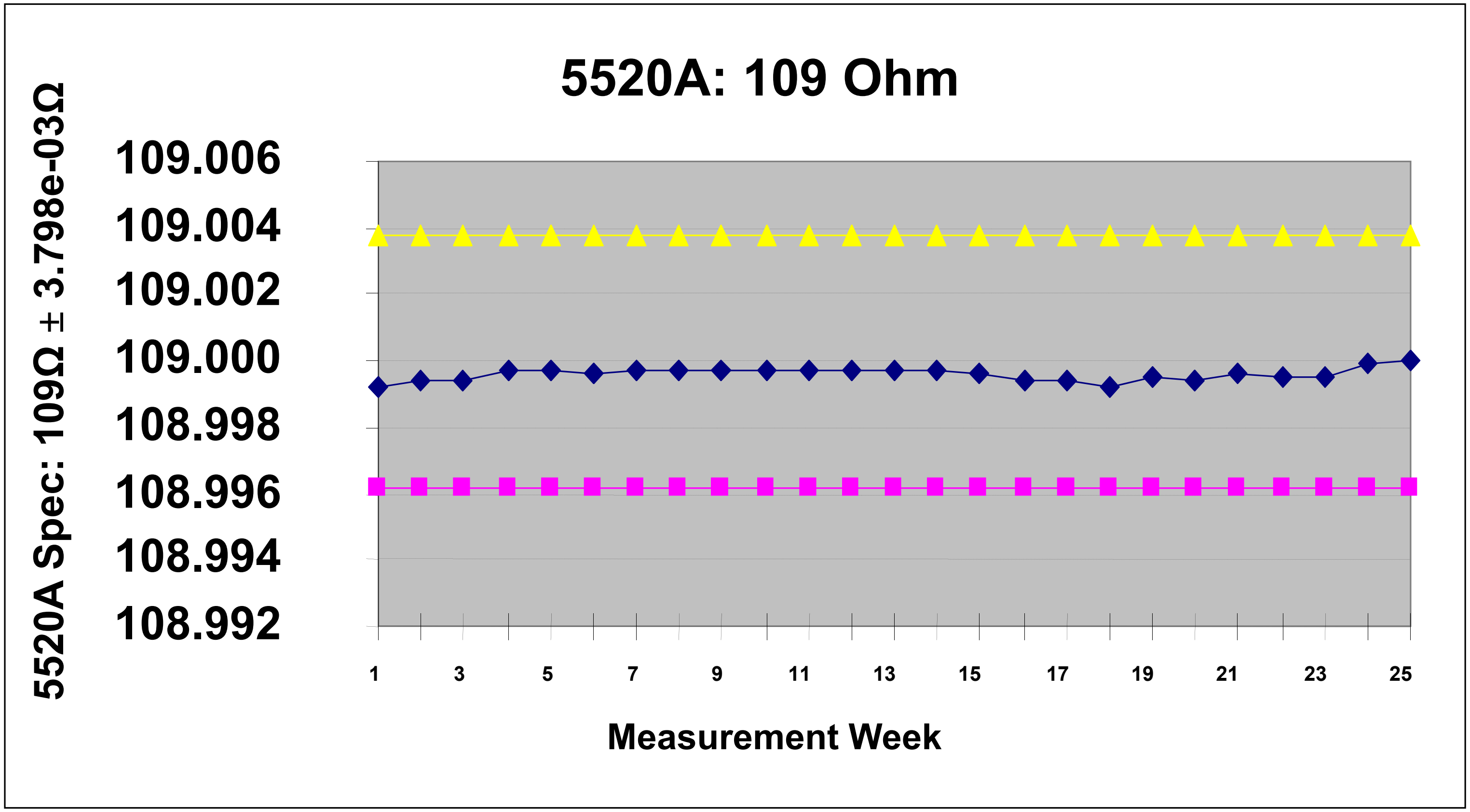
- Used to evaluate week to week variations
- This study evaluated two calibrators
- Measurements made using an automated system of primary standards, designed & used for accredited calibrations of 5520 calibrators
- Intended to proves viability of less frequent characterization (weekly or longer intervals)

Results from one month of daily testing



The Reference DMM is shown to be an excellent tool for characterizing a calibrator
(Day to day variation, and long term variation over one month shows excellent predictability.)

Results of 6 months of weekly testing



Summary of UUT test ratio improvements with characterization

Again, the final test ratios are very acceptable for our test & quality requirements!

Function		Nominal	Frequency	Measured 5520A Stability	RSS (8508A with 5520A Stability)	RSS Ratio to 8846A Spec
4WR	Ohms	10		4.00E-05	1.16E-04	32.73
4WR	Ohms	100		2.10E-04	8.76E-04	13.70
2WR	Ohms	1.0E+6		5.99E+00	1.17E+01	7.72
2WR	Ohms	10.0E+6		3.47E+02	4.59E+02	4.58
DC	V	0.1		1.92E-07	6.30E-07	9.52
DC	V	-0.1		3.20E-07	6.80E-07	8.82
DC	V	1		1.33E-06	4.12E-06	6.07
DC	V	-1		1.30E-06	4.11E-06	6.08
DC	V	5		4.60E-07	2.15E-05	5.35
DC	V	-5		9.50E-06	2.35E-05	4.89
DC	V	10		1.22E-05	4.15E-05	5.54
DC	V	-10		1.21E-05	4.08E-05	5.63
DC	V	100		1.21E-04	6.02E-04	5.48
DC	V	-100		1.33E-04	6.05E-04	5.46
DC	V	1000		1.64E-03	6.24E-03	6.57
DC	V	-1000		8.44E-04	6.08E-03	6.74
AC	V	0.1	10	4.86E-06	1.86E-05	4.83
AC	V	1	10	6.42E-05	1.49E-04	5.35
AC	V	10	10	7.00E-04	1.52E-03	5.26
AC	V	100	100000	4.03E-03	7.71E-02	8.82
AC	V	750	45	1.48E-02	1.08E-01	5.54
AC	V	750	1000	9.64E-03	1.08E-01	5.57
AC	V	750	1200	8.85E-03	1.08E-01	5.58
AC	V	750	10000	8.39E-03	1.08E-01	5.58
AC	V	1000	45	2.65E-02	1.39E-01	5.77
AC	V	1000	10000	1.27E-02	1.37E-01	5.86

Improved TSRs

Conclusion: calibrator characterization by a reference DMM

- Daily testing by a reference DMM confirms the DMM is a suitable tool to analyze and characterize a calibrator
- Long term testing by primary standards confirm the suitability of calibrators to be characterized to a better uncertainty.
- When characterizing with a DMM, the overall calibrator uncertainty is a combination of the measured stability of the calibrator and the uncertainty of the reference multimeter

Summary of both Accuracy Enhancement Methods

FLUKE Calibration

Table 6: Example Improvements In Calibrator Specifications Using Characterization.						
Calibration Test Value	UUT Test Specification	non characterized calibrator spec	Calibrator's TSR	Example spec with long term characterization with DMM	Example spec using real time characterization by DMM	Best TSR
10 volts	±23 ppm	±14 ppm	1.6:1	±4.9 ppm	±3.9 ppm	> 6:1
100 ohms	±120 ppm	±42 ppm	2.86:1	±12.3 ppm	±8.5 ppm	> 11:1
10 volts 10 Hz	±800 ppm	±365 ppm	2.2:1	±195 ppm	±135 ppm	> 6:1

In either case, the final test ratios are very acceptable for our test & quality requirements!

Accuracy Enhancement Summary

We have demonstrated that there are several ways a high performance meter can improve a calibrator's performance.

- Calibrator disciplining through direct measurement at time of use improves it up to the limit of the DMM spec
  - However it requires a dedicated DMM to augment the calibrator during the test and a more complex test process.
- An alternative technique is to independently characterize the calibrator using regular measurement to quantify the output errors.
  - Uses normal calibrator/UUT test processes, but applies a better specification
  - Requires routine metrology to support characterization improvements

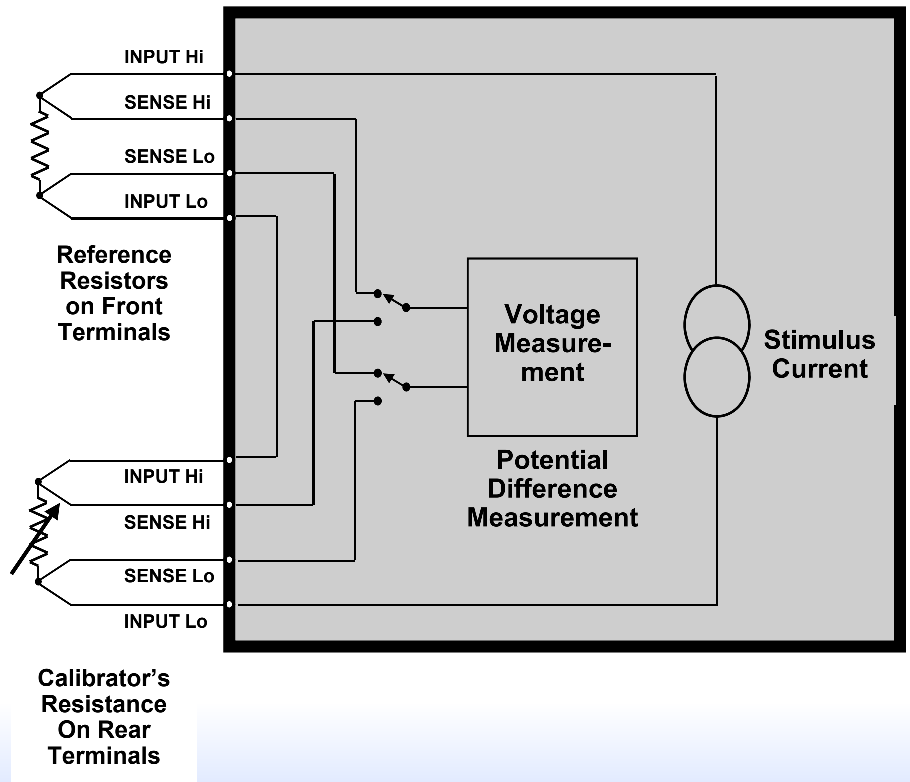
The Value of Accuracy Enhancement

- Inadequate measurement accuracy ratios is a common situation in many labs. This can have a costly impact on test quality when incorrect “pass” decisions are made.

- A precision reference multimeter is a versatile cal lab tool that can effectively improve accuracy ratios in metrology applications where an existing precision source’s specifications fall short of the required uncertainties.

- The costs of higher accuracy sources and standards are often significantly large when merely improving existing sourcing uncertainties compared to the versatility that precision measurement offers as an addition to precision sourcing.

8508A in ohms ratio mode

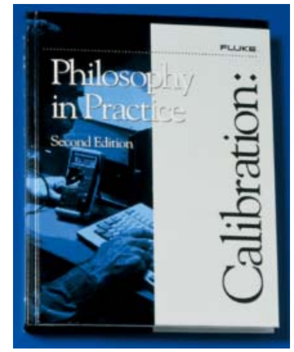


Reference multimeters are alternatives to many traditional precision instruments

FLUKE® Calibration

- 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 -



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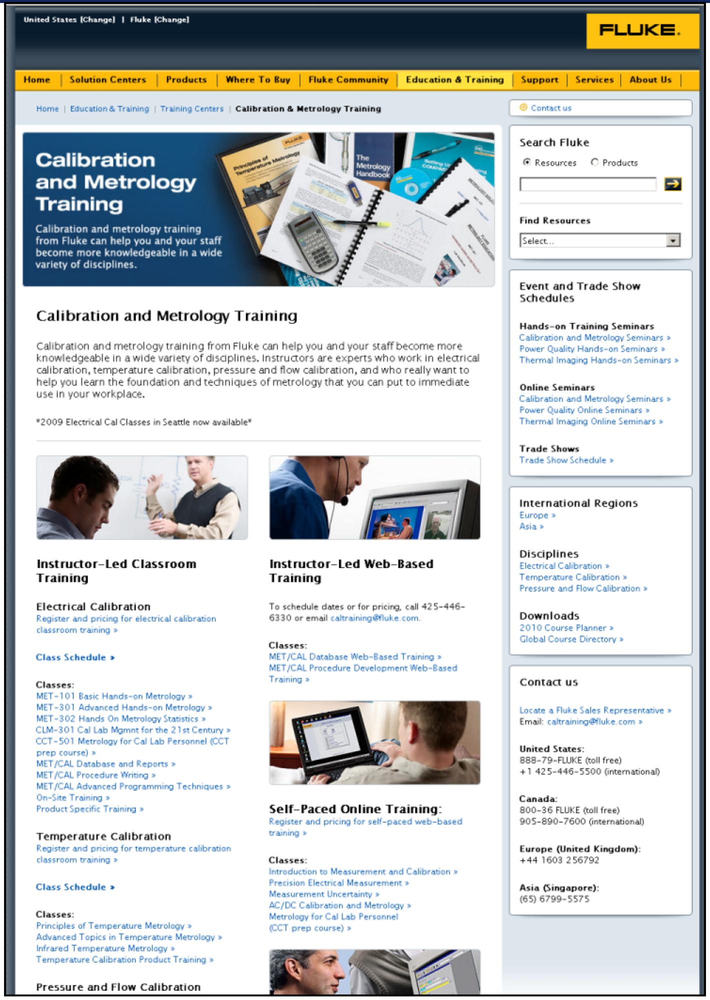

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THANK YOU !

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