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
Greetings from –
Fluke Corporation
   Everett, Washington, USA

We are very pleased to bring you this presentation on replacing analog null detector meters with digital multimeters in voltage reference intercomparisons

This presentation is based on Fluke’s extensive experience with:
- Calibration Instruments
- Standards Lab Metrology
- 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.
Fluke’s Precision Measurement Business Unit

and Jack Somppi
Electrical Calibration Instruments
Product Line Manager
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Fluke Precision Measurement Web Seminar Series

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Our Seminar Topics Include:
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• 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
Replacing Analog Null Detecting Meters in Voltage Reference Intercomparisons

The DMM’s role as an modern digital “null detector”
Objective of this session-

- Study
  - How a digital multimeter, versus the older/obsolete analog null detectors, can be used to compare and calibrate 10 volt reference standards
  - Investigate the measurement techniques required for good metrology.

Benefits

- Understand and implement modern and automatable measurement techniques to improve reference standard metrology in your labs.
Session Overview

Topics Covered in this session

• The analog null detector and comparing voltage standards
• Reference comparisons using a DMM
• Best measurement practices
• Measurement details
• Working with multiple standards
• Digital meters vs. analog null detectors
The Analog Null Detector

- The null detector instrument was commonly used to measure small differences in different dc voltages.
- It is often used to intercompare similar voltage references for tracking changes.
- A similar application is using a null detector to certify one standard against another known standard or set of standards.

Fluke’s 845AB Null Detector
Reference Comparisons Using a Null Detector

Comparing two similar voltages by measuring the voltage difference between one 10 V standard and another 10 V standard.
Today’s Situation

- Few analog null detectors continue to be made, so there is limited availability of such instruments.
- Existing Fluke 845 Series instruments are no longer serviceable.
- Often, precision DMMs can be used in many null detector applications.

Let’s examine this application more closely, using dmm techniques.
An Example—Comparing Voltage Standards

Reference is the 732B’s 10 V output which is certified at +10.000 123 0 V

UUT is the 7001 Reference’s 10 V output
Similar Voltage Reference Measurement Applications

- Fluke’s Direct Voltage Maintenance Program Care Plan
  - Measure your standard in your lab, and Fluke can certify the measurement.
  - Compares your standard to a Fluke owned and certified standard.
  - Accredited certificates to ±0.1 ppm uncertainty
  - Available as: 732B-200 and 732B-201 services
- Self-maintain and track your own 10 volt references.
Reference Comparisons Using a DMM

The DMM replaces the null detector to measure the difference.

DMM’s displayed value

The DMM replaces the null detector to measure the difference.
Applying the DMM’s Specs

• Key attributes for intercomparing voltage standards
  - Good resolution (1 nV)
  - Short term stability (0.5 ppm in 200 mV or 0.1 µV)
  - High input impedance (>10^{10} Ohm for up to 20 V)
  - Excellent CMRR (140 dB at DC)
  - Measurement isolation (>10^{10} Ohms lo to ground)
  - Low noise (typically < 50 nV)

• Overall measurement considerations
  - Use absolute specifications.
  - The measured difference value (from near zero to tens or hundreds of microvolts) is accurate to within ± 0.1 µV.
  - The certified uncertainty on the reference standard is larger — often ± 1 µV to ± 3 µV — the dominant factor in the measurement uncertainty.
Best Measurement Practices (1)

- Eliminate errors due to various offset effects by making repeated measurements and reversing the test leads.
- A simple reversal technique on a single reference used to correct for thermal emf errors is shown. \[ V_{\text{Ref}} = (+ \text{Forward} - \text{Reverse})/2 \]
- More thorough lead reversal methods can correct for other errors, including voltage offsets, common mode signal errors, etc.
- In practice, Fluke switches at both the DMM terminals (forward and reverse) and at the UUT (positive and negative polarity), with several measurements taken in each configuration.
Best Measurement Practices (2)

Improve measurement uncertainty by statistically averaging measurements to eliminate random errors.

- The measured value is the **average** of the multiple repeated measurements.
- Measurement uncertainty is based on the **standard deviation** of the values.
- In practice, the Fluke Voltage Maintenance Program makes three or more sets of multiple measurements.
- Each set of measurements consists of a combination of four different lead configurations - Forward/reverse and positive/negative polarity measurements -- sequenced through twice (provides eight measurements per set).
Best Measurement Practices (3)

• Zero the DMM before the measurements are performed.
  − Use a zero ohm shorting bar with *small* thermal mass.
• Use low thermal emf leads for test connections.
  − Crimp copper sleeves or lugs on copper wires.
  − Use low thermal solder (Cadmium-Tin).
  − Clean connections and remove oxides (0.2 uV vs. 1000 uV!).
  − If non-oxidized, clean copper isn’t practical, then use gold-flashed copper terminals on the cables.
Measurement Details: a Simplified Configuration

The DMM replaces the null detector to measure the difference.

DMM’s displayed value

- 000.018 850 mV

The DMM replaces the null detector to measure the difference.

+10.000 123 0 V
Determining the UUT Value

- In this example, the DMM measurements on the difference was determined to be:
  -000.018 850 mV
- This value is subtracted from the 732B certified value of 10.000 123 0 V:
  The UUT value equals
  10.000 123 0 V minus -0.000 018 850 V
- The UUT is calculated to be:
  +10.000 141 9 V
Simplified Error Analysis (1) – The Reference Standard Traceability

- Traceable uncertainties for the calibrating standard are a combination of the initial calibration uncertainty plus its stability.

- Stability depends both upon the number of references instruments combined to form the reference value and the time between periodic recertifications. Here are several alternatives to consider:
  - A single reference has a stability of ±0.7 ppm (or ±7 µV) per 90 days and ±1.6 ppm (or ±16 µV) per year. This is combined with the initial calibration uncertainty of about ±0.1 ppm.
  - Maintaining a group of four references to obtain an average reference value improves the stability to ±1.2 ppm/year.
  - Four references, certified every 90 days, with historical data, improve the stability to a certified value that is predictable to ±0.2 ppm/year.

- Another alternative is importing traceability using a service to provide a well know, traceable and characterized standard
  - Traceability of ±0.1 ppm (or ±1 µV) from a standard supplied by Fluke’s with the DVMP Care Program.
Simplified Error Analysis (2) – Adding the Measurement Uncertainty

- The DMM measurement process
  - ±0.1 µV taken from the 1-year absolute specification
- The combined RSS of errors is dominated by the reference uncertainties that range between ±1 µV to ±16 µV
  - The DMM measurement uncertainties are on the order of ±.1 µV or less and are inconsequential.
- As an example, if the calibration was performed using traceability with a Fluke 732B-200 reference standard supplied through Fluke’s DVMP Care Plan, then the UUT is certified to be:

  +10.000 141 9 V ±1 µV
Questions?
Extending this application – Working with Multiple Standards

- Adding a PC, scanner and software permits automation of standards maintenance.
- Such a system assists in intercomparison, trending and certification work.
- Fluke has used such a system (as shown here) for many years to support both customers and internal requirements.

Fluke’s system for intercomparing voltage references
Standards Maintenance Can Provide Control Charted Trends

- Four reference standards can each be intercompared and tracked over time.
- The reference value can be considered as the average of all four reference standards.
- An unusual drift in one reference can easily be detected (as seen in the example with reference C).

<table>
<thead>
<tr>
<th>DATA</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>-1.0</td>
<td>-1.2</td>
<td>-1.1</td>
<td>-0.9</td>
<td>-1.0</td>
</tr>
<tr>
<td>B-C</td>
<td>-1.6</td>
<td>-1.7</td>
<td>-1.7</td>
<td>-1.8</td>
<td>-0.7</td>
</tr>
<tr>
<td>C-D</td>
<td>+2.0</td>
<td>+2.1</td>
<td>+2.1</td>
<td>+2.2</td>
<td>+1.1</td>
</tr>
<tr>
<td>D-A</td>
<td>+0.6</td>
<td>+0.8</td>
<td>+0.7</td>
<td>+0.5</td>
<td>+0.6</td>
</tr>
<tr>
<td>A-C</td>
<td>-26</td>
<td>+2.9</td>
<td>-2.8</td>
<td>-2.7</td>
<td>-1.7</td>
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</table>
## Digital Meters versus Analog Null Detectors

<table>
<thead>
<tr>
<th></th>
<th>8508A Reference DMM</th>
<th>845AB Analog Null Detector</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy at null</strong></td>
<td>0.1 µV</td>
<td>0.1 µV</td>
<td>Similar performance</td>
</tr>
<tr>
<td><strong>Sensitivity/Range</strong></td>
<td>0.001 µV out of 200 mV</td>
<td>0.02 µV out of 1 µV</td>
<td>DMM measures larger differences with better sensitivity</td>
</tr>
<tr>
<td><strong>Input Isolation</strong></td>
<td>$10^{+10}$ Ω (or 10 GΩ)</td>
<td>$10^{+12}$ Ω (or 1000 GΩ)</td>
<td>A battery powered ND has best isolation for critical measurements</td>
</tr>
<tr>
<td><strong>Input Resistance</strong></td>
<td>&gt; $10^{+10}$ Ω (or &gt; 10 G Ω)</td>
<td>$10^{+8}$ Ω but infinite at null</td>
<td>FET inputs vs. chopper amplifier</td>
</tr>
<tr>
<td><strong>Bias current</strong></td>
<td>&lt; 50 pA (10 pA Typical)</td>
<td>&lt; 1 pA</td>
<td>Effects measurements with high source resistance, but is often correctable with an offset measurement</td>
</tr>
<tr>
<td><strong>Noise</strong></td>
<td>0.05 µV</td>
<td>0.2 µV&lt;sub&gt;p-p&lt;/sub&gt;</td>
<td>DMMs permit averaging of digital values</td>
</tr>
<tr>
<td><strong>Automation</strong></td>
<td>YES</td>
<td>NO</td>
<td></td>
</tr>
</tbody>
</table>
Other Null Detector Applications Suitable for DMM Measurements

- In labs with a reference standard and a calibrator, the output drift trends of both instruments can be tracked with regular comparisons of the calibrator’s 10 V output setting versus the 10 Volt Standard.

- Two arms of a Wheatstone Bridge can be balanced with a null detector style measurement.

- Balancing divider resistances (for example the Fluke 752A Reference Divider)

- The outputs of two separate voltage dividers powered by two independent sources can be compared or balanced with a null detector style measurement.

- A modern DMM assists to automate such measurements. Fluke has an example MET/CAL® procedure to compare two 10 volt reference standards.
The Value of Precision Multimeters When Used as Null Detectors

• Traditional analog null detectors are no longer readily available, and existing units cannot be maintained economically.
• Precision multimeters are very versatile, easily automated, and can satisfy most metrology dc/lf ac null measurement applications.
• Coupled with other applications needing precision multimeters, they are the most useful measurement device in an electrical calibration or standard’s lab.
Session Summary

- The analog null detector and comparing voltage standards
- Reference comparisons using a DMM
- Best measurement practices
- Measurement details
- Working with multiple standards
- Digital meters vs. analog null detectors
More Information

- For more information on voltage reference comparison techniques, refer to:
  - Technical material on maintaining 10 voltage references at [www.fluke.com](http://www.fluke.com), specifically the paper:
    “Maintaining 10 VDC at 0.3 PPM or Better in Your Laboratory”
  - Fluke’s *Calibration: Philosophy in Practice*, sections on
    - Primary and Secondary Standards
    - Metrology Statistics
  - Material taught in the classes on the *Principles of Metrology*, as well as Fluke’s other web-based training courses
  - Fluke Direct Voltage Maintenance Program Care Plan
Calibration and metrology training from Fluke

• 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

MET-302
Hands-On Metrology Statistics

A powerful three-day “how to” workshop that describes and demonstrates measurement uncertainty concepts and techniques.

This three-day course will introduce the student to basic measurement uncertainty concepts in the fields of electrical, temperature, pressure, and flow measurements. From the hands-on exercises and examples given in the course, attendees will learn about the uncertainty budgeting process. The course material is based on the ISO“ ‘The ISO Guide to the Expression of Uncertainty in Measurement’ and ANSI/ASME B89.3.1-2008. The MET-302 course was established and real-world measurements are used, giving the student the ability to see the practical application of uncertainty calculations. A discussion is also included on common notches, notches and production files (data rejection) as referenced in ANSI/ASME B89.3.1-2008, and the effects of data handling.

Who should take this course
This course is designed for engineers, laboratory managers and technicians who need to understand how to develop uncertainty budgets. Attendees of this course will find the information essential to understand necessary calibration procedures and techniques for obtaining repeatable results.

Course prerequisites
It is recommended that attendees have a high school education and a basic understanding of math, algebra, physics, and science. Some hands-on experience in the field is also beneficial.

Course outline
- What is Uncertainty in a Measurement?
- Introduction to Basic Metrology Statistics
- Instrument Specifications
- Statistical Distributions
- Calculating Measurement Uncertainty
- Using the Student’s t Distribution and the Welch-Satterthwaite Equation
- Creating a Basic Uncertainty Budget
- Statistical Techniques in Metrology
- Graphing and Error Analysis
- Uncertainty in Temperature Measurement
- Uncertainty in Pressure Measurement
- Uncertainty in Flow Measurement
- Course Exam

Course materials
Register online at www.calibration.com. Select Events and Training then Register and Paying. You will be prompted for your credit card information, the course date and location. Please submit to send your request to the training coordinator for processing. You will receive instructions about how to finalize your registration.

MET-302 Hands-On Metrology Statistics
Course Number: TRC 1302
3 days / Starts Tuesdays

March 18-20, 2008
Seattle, WA

June 3-5, 2008
Seattle, WA

August 12-14, 2008
Seattle, WA

October 14-16, 2008
Seattle, WA

More information:
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http://www.fluke.com

For any questions or copies of this presentation:

email inquiries to: jack.somppi@fluke.com