# CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY



2023
OCTOBER
NOVEMBER
DECEMBER


Sidestepping the Potholes in DC Voltage Traceability

Some Perspective on Risk and Decision Rules in Calibration

# PRECISION CURRENT INSTRUMENTATION AND CURRENT CALIBRATION

## DANISENSE HIGH PRECISION CURRENT TRANSDUCERS

± 50A to ± 10000A DC/AC precision fluxgate current transducers for power measurement, battery test systems, high-stability power supplies, and current calibrations.

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CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

Volume 30, Number 4

**www.callabmag.com**

## FEATURES



## DEPARTMENTS



**ON THE COVER:** Technician David Ray is performing a Force Torque calibration at the Rothe Enterprises Inc. Metrology and Calibration Services Lab in Wallops Island, Virginia.

## UPCOMING CONFERENCES & MEETINGS

*The following event dates and delivery methods are subject to change. Visit the event URL provided for the latest information.*

**Mar 24-28, 2024 MSC Training Symposium.** Anaheim, CA. The 2024 MSC theme is: Quantum Revolution. Come explore Quantum Metrology, Quantum Engineering, and Quantum SI! The conference will offer many exceptional measurement related courses and technical sessions which will be instructed by NIST and industry experts. https://annualconf.msc-conf.com

**Apr 7-11, 2024 SPIE Photonics Europe**. Strasbourg, France. Present your research at the only cross-disciplinary event highlighting compelling optics and photonics technologies—from digital optics to quantum technologies to optical imaging, sensing, and metrology. This year, SPIE Optical Systems Design 2024 is co-located at Photonics Europe. https://spie.org/conferences-and-exhibitions/photonics-europe

**Apr 10-12, 2024 METROMEET.** Bilbao, Spain. METROMEET is a unique event and the most important annual conference in the sector of Industrial Dimensional Metrology. The conference is held in Bilbao (Spain) since 2003, with the purpose to provide information about the latest technological developments, the progress made in the sector and establishes a forum for debate on dimensional metrology in a fast-changing industry. https://metromeet.org/

**Apr 21-24, 2024 A2LA Annual Conference (ANNCON24).** Denver, CO. The A2LA Annual Conference is the ultimate opportunity for professionals to meet face-to-face, learn new skills, and collaborate on topics associated with the accreditation industry. https://a2la.org/Annual_Conference/

**May 20-23, 2024 IEEE International Instrumentation and Measurement Technology Conference (I2MTC).** Glasgow, UK. The flagship conference of the IEEE Instrumentation and Measurement Society, dedicated to advances in measurement methodologies, measurement systems, instrumentation and sensors in all areas of science and technology. https://i2mtc2024.ieee-ims.org/

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# EDITOR'S DESK

### Bringing Events Closer to Home

Each year, I'm somehow involved in behind-the-scenes at the MSC Training Symposium and NCSLI Workshop & Symposium. MSC was originally designed to be local for labs in the Southern California area. NCSLI also has roots local in Boulder, Colorado, where NBS was located (now NIST). But both conferences continue to reach as far as they can to attract attendees. Attendance at these large training events continues to dwindle, but not for want of training!

Just as industry reaches out to partner with their local community colleges, industry also has volunteers in professional associations to the benefit of their workforce. It's a recurring trend I'm becoming more aware of in the realm of measurement science. If this isn't something you've experienced, keep your ears and eyes open, or get involved by initiating an event near you!

For feature articles in this issue, we begin with a paper by David Martson with 1A CAL GmbH, "Sidestepping the Potholes in DC Voltage Traceability." Here he shares his expertise in extending support of the 3458A, with tips, workarounds, and techniques to make better measurements.

Next, James Salsbury of Mitutoyo America Corporation provides readers with "Some Perspective on Risk and Decision Rules in Calibration." He uses a clear and thoughtful approach to explore *consequences* of risk in the calculation of *level of risk*. This paper was originally presented at the 2023 NCSLI Workshop and Symposium in Orlando, Florida, and was awarded the "Dr. Allen V. Astin" award for overall best conference paper. We are very pleased for the opportunity to share it with readers.

Wrapping up this issue is another "In Days of Old" by Dan Wiswell, where he waxes philosophical with vintage volt meters.

I hope you enjoy all our features and departments for this issue and get out to participate in at least one metrology event in 2024!

Happy Measuring,

Sita P. Schwartz

# CALENDAR

**May 27-29, 2024 24th International Conference on Metrology and Properties of Surfaces.** Marrakech, Morocco. The 24th International Conference on Metrology and Properties of Surfaces (Met&Props) will contain a broad array of scientific themes including, surface characterization, measurement and instrumentation, in-process surface metrology, archaeology and anthropology and forensic science. https://metprops2024.org/

**Jun 3-5, 2024 11th International Workshop on Metrology for AeroSpace.** Lublin, Poland. MetroAeroSpace aims to gather people who work in developing instrumentation and measurement methods for aerospace. https://www.metroaerospace.org/

**Jun 12-13, 2024 CEESI Gas Ultrasonic Meter User's Conference.** Colorado Springs, CO. This conference provides a forum for ultrasonic meter manufacturers and end users to discuss measurement challenges in the hydrocarbon measurement industry. https://www.ceesi.com/

**Jun 16-21, 2024 IEEE International Microwave Symposium (IMS)**. Washington, DC. The IEEE IMS is the world's foremost conference covering the UHF, RF, wireless, microwave, millimeter-wave, terahertz, and optical frequencies. https://www.ims-ieee.org/

**Jul 6-10, 2024 NCSLI Workshop & Symposium/ Conference on Precision Electromagnetic Measurement.** Denver, CO. The theme for this joint event with CPEM and NCSLI Workshop & Symposium will be "Innovation through Measurement: A Focus on Critical and Emerging Technologies." https://ncsli.org/

**Jul 22-25, 2024 Coordinate Metrology Society Conference.** Charlotte, NC. CMS is excited to unveil the grand celebration of its 40th Year Anniversary! At this practical, user-driven metrology conference you will have the opportunity to try coordinate metrology equipment, educate yourself in metrology principles, engage in fun activities, be certified and most important, be able to implement your newfound knowledge into your workplace. https://www.cmsc.org/conference

# CALENDAR

**SEMINARS & WEBINARS: Dimensional**

**Feb 13-15, 2024 Seminar #114: Dimensional Gage Calibration.** Aurora, IL. Mitutoyo. The course combines modern calibration and quality management ideas with best practices and "how-to" calibration methods for common calibrations. The course is ideal for those operating in ISO/IEC 17025 accredited laboratories or in gage labs supporting manufacturing operations. https://www.mitutoyo.com/training-education/

**Feb 15-16, 2024 "Hands-On" Precision Gage Calibration and Repair Training**. Eau Claire, WI. IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Feb 20-22, 2024 Gage Calibration Methods Class.** Cincinnati, OH. QC Training. Our Gage Calibration Methods training is a hands-on workshop, offering specialized training in calibration and minor repair for the individual who has some knowledge of basic Metrology. https://qctraininginc.com/course/gage-calibration-methods/

**Feb 22-23, 2024 Virtual "Hands-On" Precision Gage Calibration and Repair Training**. IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Mar 4-5, 2024 "Hands-On" Precision Gage Calibration and Repair Training**. Bloomington, MN. IICT Enterprises.

This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Mar 12-14, 2024 Seminar #114: Dimensional Gage Calibration.** Aurora, IL. Mitutoyo. The course combines modern calibration and quality management ideas with best practices and "how-to" calibration methods for common calibrations. The course is ideal for those operating in ISO/IEC 17025 accredited laboratories or in gage labs supporting manufacturing operations. https://www.mitutoyo.com/training-education/

**Mar 19, 2024 EDU-V111: Introduction to Dimensional Gage Calibration.** Virtual Classroom. Mitutoyo. The course combines modern calibration and quality management ideas with best practices and "how-to" calibration methods for common calibrations of micrometers and calipers. The course is ideal for those operating in ISO/IEC 17025 accredited laboratories or in gage labs directly supporting manufacturing operations. https://www.mitutoyo.com/training-education/

**Mar 19-21, 2024 Gage Calibration Methods Class.** Cincinnati, OH. QC Training. Our Gage Calibration Methods training is a hands-on workshop, offering specialized training in calibration and minor repair for the individual who has some knowledge of basic Metrology. https://qctraininginc.com/course/gage-calibration-methods/

**Mar 20-21, 2024 Seminar #104: Intro to Dimensional Metrology Hand Tools IV.** Aurora, IL. Mitutoyo. EDU-104 is a two-day class for entry-level team members who need to learn the fundamentals of the steel rule, caliper, micrometer, pin gage, gage block, surface plate, height gage, indicator and stands, angle block, v-block, and sine bar. https://www.mitutoyo.com/training-education/

**Mar 21-22, 2024 Virtual "Hands-On" Precision Gage Calibration and Repair Training.** IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Apr 3-4, 2024 "Hands-On" Precision Gage Calibration and Repair Training.** Omaha, NE. IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Apr 10-11 Virtual "Hands-On" Precision Gage Calibration and Repair Training.** IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Apr 16-17 "Hands-On" Precision Gage Calibration and Repair Training.** Cleveland, OH. IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**Apr 16-18, 2024 Gage Calibration Methods Class.** Cincinnati, OH. QC Training. Our Gage Calibration Methods training is a hands-on workshop, offering specialized training in calibration and minor repair for the individual who has some knowledge of basic Metrology. https://qctraininginc.com/course/gage-calibration-methods/

**Apr 16-18, 2024 Seminar #114: Dimensional Gage Calibration**. Aurora, IL. Mitutoyo. The course combines modern calibration and quality management ideas with best practices and "how-to" calibration methods for common calibrations. The course is ideal for those operating in ISO/IEC 17025 accredited laboratories or in gage labs supporting manufacturing operations. https://www.mitutoyo.com/training-education/

**Apr 18-19, 2024 "Hands-On" Precision Gage Calibration and Repair Training**. Indianapolis, IN. IICT Enterprises. This 2-day online precision gage and repair training offers specialized training in calibration and repair for the

individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair, and adjustments of micrometers, calipers, indicators, height gages, etc. The course covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. https://calibrationtraining.com/

**May 1-2, 2024 Dimensional Measurement.** Port Melbourne, VIC. National Measurement Institute, Australia. This two-day course (9 am to 5 pm) presents a comprehensive overview of the fundamental principles in dimensional metrology and geometric dimensioning and tolerancing. https://shop.measurement.gov.au/collections/physical-metrology-training

**May 21-23, 2024 Gage Calibration Methods Class.** Cincinnati, OH. QC Training. Our Gage Calibration Methods training is a hands-on workshop, offering specialized training in calibration and minor repair for the individual who has some knowledge of basic Metrology. https://qctraininginc.com/course/gage-calibration-methods/

**SEMINARS & WEBINARS: Education**

**Feb 1, 2024 Metric System Education Resources.** Adobe Connect Pro. NIST. This 1.5 hour session will explore NIST Metric Program education publications and other resources that can be downloaded and freely reproduced by teachers, parents, and students. These resources are helpful to students as they become familiar with metric units, develop measurement quantity reference points, and learn more about SI basics. https://www.nist.gov/pml/owm/training

**SEMINARS & WEBINARS: Electrical**

**Mar 4-7, 2024 Basic Hands-On Metrology.** Everett, WA. Fluke Calibration. This Metrology 101 basic metrology training course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. https://us.flukecal.com/training

**Apr 8-11, 2024 Advanced Hands-On Metrology.** Everett, WA. Fluke Calibration. This course introduces the student to advanced measurement concepts and math used in standards laboratories. The student will learn how to make various types of measurements using different measurement methods. We will also teach techniques for making good high precision measurements using reference standards. https://us.flukecal.com/training

**May 22-23, 2024 Electrical Measurement.** Lindfield, NSW, Australia. NMI. This two day (9am-5pm) course covers essential knowledge of the theory and practice of electrical measurement using digital multimeters and calibrators; special attention is given to important practical issues such as grounding, interference and thermal effects. https://shop.measurement.gov.au/collections/physical-metrology-training

**Jun 10-13, 2024 Basic Hands-On Metrology.** Everett, WA. Fluke Calibration. This Metrology 101 basic metrology training course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. https://us.flukecal.com/training

**SEMINARS & WEBINARS: Flow**

**Mar 12-15, 2024 Gas Flow Calibration Using molbloc/molbox.** Phoenix, AZ. Fluke Calibration. Gas Flow Calibration Using molbloc/molbox is a four day training course in the operation and maintenance of a Fluke Calibration molbloc/molbox system. https://us.flukecal.com/training

**Jul 22-24, 2024 Calibration of Liquid Hydrocarbon Flow Meters.** Londonderry NSW. National Measurement Institute, Australia. This two-day course provides training on the calibration of liquid-hydrocarbon LPG and petroleum flow meters. It is aimed at manufacturers, technicians and laboratory managers involved in the calibration and use of flowmeters. https://shop.measurement.gov.au/collections/physical-metrology-training

**Sep 17-20, 2024 Gas Flow Calibration Using molbloc/molbox.** Phoenix, AZ. Fluke Calibration. Gas Flow Calibration Using molbloc/molbox is a four day training course in the operation and maintenance of a Fluke Calibration molbloc/molbox system. https://us.flukecal.com/training

# CALENDAR

### SEMINARS & WEBINARS: General

**Mar 1, 2024 Calibration and Measurement Fundamentals.** Online. National Measurement Institute, Australia. This course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://shop.measurement.gov.au/collections/physical-metrology-training

**Mar 20, 2024 Calibration and Measurement Fundamentals.** Lindfield NSW. National Measurement Institute, Australia. This course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://shop.measurement.gov.au/collections/physical-metrology-training

**Apr 1-5, 2024 Fundamentals of Metrology.** Gaithersburg, MD. NIST. The 5-day Fundamentals of Metrology seminar is an intensive course that introduces participants to the concepts of measurement systems, units, good laboratory practices, data integrity, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into a laboratory Quality Management System. https://www.nist.gov/pml/owm/training

### SEMINARS & WEBINARS: Industry Standards

**Feb 12-15, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**Feb 27-28, 2024 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017.** Live Online. ANAB. Understand requirements of ISO/IEC 17025:2017, including general, structural, resource, process, and management system requirements. Learn practical concepts, such as impartiality, documents control, ensuring validity of results and risk management. Gain an understanding of an ISO/IEC 17025:2017 laboratory management system. https://anab.ansi.org/training

**Feb 27-28, 2024 3004 Understanding ISO/IEC 17025 for Testing & Calibration Labs.** Online for the Americas. IAS. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/ias-training-schedule/

**Feb 27-29, 2024 Internal Training to ISO/IEC 17025:2017 (Non-Forensic)**. Live Online. ANAB. This training is designed for laboratory managers, technical staff, and others who want or need to learn better audit practices. https://anab.ansi.org/training

**Mar 5-6, 2024 3004 Understanding ISO/IEC 17025 for Testing & Calibration Labs.** Online for the Middle-East & South Asia. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/ias-training-schedule/

**Mar 11-14, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**Mar 18-21, 2024 Auditing Your Laboratory to ISO/IEC 17025:2017.** Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://www.a2lawpt.org/training

**Apr 16-17, 2024 3004 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Online for the Americas. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/ias-training-schedule/

**Apr 20-21, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Denver, CO. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**Apr 20-21, 2024 Auditing Your Laboratory to ISO/IEC 17025:2017.** Denver, CO. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://www.a2lawpt.org/training

**Apr 23-24, 2024 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017.** Live Online. ANAB. Understand requirements of ISO/IEC 17025:2017, including general, structural, resource, process, and management system requirements. Learn practical concepts, such as impartiality, documents control, ensuring validity of results and risk management. https://anab.ansi.org/training

**Apr 23-25, 2024 Internal Training to ISO/IEC 17025:2017 (Non-Forensic)**. Live Online. ANAB. This training is designed for laboratory managers, technical staff, and others who want or need to learn better audit practices. https://anab.ansi.org/training

**May 1-2, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**May 5-9, 2024 Auditing Your Laboratory to ISO/IEC 17025:2017.** Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://www.a2lawpt.org/training

**May 14-15, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Frederick, MD. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**May 22-23, 2024 3004 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Online for Middle-East & South Asia. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/ias-training-schedule/

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**Jun 4-5, 2024 Auditing Your Laboratory to ISO/IEC 17025:2017.** Frederick, MD. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://www.a2lawpt.org/training

**Jun 11-12, 2024 Laboratories: Understanding the Requirements and Concepts of ISO/IEC 17025:2017.** Live Online. ANAB. Understand requirements of ISO/IEC 17025:2017, including general, structural, resource, process, and management system requirements. Learn practical concepts, such as impartiality, documents control, ensuring validity of results and risk management. Gain an understanding of an ISO/IEC 17025:2017 laboratory management system. https://anab.ansi.org/training

**Jun 11-13, 2024 Internal Training to ISO/IEC 17025:2017 (Non-Forensic).** Live Online. ANAB. This training is designed for laboratory managers, technical staff, and others who want or need to learn better audit practices. https://anab.ansi.org/training

**Jun 11-14, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**Jun 25-26, 2024 3004 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Online for the Americas. This Training Course applies to testing and calibration laboratories and regulatory agencies seeking to specify 17025 within their policies and regulations. https://www.iasonline.org/training/ias-training-schedule/

**Jun 25-26, 2024 Auditing Your Laboratory to ISO/IEC 17025:2017.** Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://www.a2lawpt.org/training

# CALENDAR

**Jul 9-10, 2024 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Virtual. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/training

**Jul 22-25, 2024 Auditing Your Laboratory to ISO/IEC 17025:2017.** Virtual. A2LA WorkPlace Training. This ISO/IEC 17025 auditor training course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. https://www.a2lawpt.org/training

**SEMINARS & WEBINARS: Mass**

**Feb 26-Mar 8, 2024 Mass Metrology Seminar.** Gaithersburg, MD. The Mass Metrology Seminar is a two-week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the participant performs measurements by applying procedures and equations discussed in the classroom. https://www.nist.gov/pml/owm/training

**SEMINARS & WEBINARS: Measurement Uncertainty**

**Feb 6-7, 2024 3006 Uncertainty of Measurement for Labs.** Online for Middle-East & South Asia. IAS. 2-day online training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/ias-training-schedule/

**Feb 14&16, 2024 Introduction to Estimating Measurement Uncertainty**. Online Delivery. National Measurement Institute, Australia. This course will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. https://shop.measurement.gov.au/collections/physical-metrology-training

**Feb 21-22, 2024 Measurement Uncertainty: Practical Applications.** Live Online. ANAB. This class covers concepts and accreditation requirements associated with measurement traceability, measurement assurance, and measurement uncertainty. https://anab.ansi.org/training/

**Feb 29, 2024 5893 Basic Uncertainty Concepts.** Webinar. NIST. This 2-hour webinar provides a very basic introduction to uncertainty calculations and reporting using the 8-step process published in NIST SOP 29 (NISTIR 6969), beginning with some definitions and concepts from the Guide to the Expression of Uncertainty in Measurement (GUM) and includes some simple calculations. https://www.nist.gov/pml/owm/training

**Mar 5-7, 2024 Seminar #210: Measurement Uncertainty – Fundamentals and Applications.** Aurora, IL. Mitutoyo. This course focuses on the fundamentals and skips the more complicated math that scares away most people, and in practice, is hardly used. Most of the examples used in this course come from the dimensional metrology field, but the course contents are applicable to all types of measurements. https://www.mitutoyo.com/training-education/

**Mar 12, 2024 Measurement, Uncertainty and Calibration Workshop.** MSL. Lower Hutt, New Zealand. This course gives a broad high-level overview of measurement and calibration principles, and calculation of uncertainty. https://www.measurement.govt.nz/training/

**Mar 19, 2024 Introduction to Estimating Measurement Uncertainty.** Lindfield NSW. National Measurement Institute, Australia. This course will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. https://shop.measurement.gov.au/collections/physical-metrology-training

**Mar 19-21, 2024 3006 Uncertainty of Measurement for Labs.** Online for the Americas. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/ias-training-schedule/

**Apr 16-17, 2024 Measurement Confidence: Fundamentals.** Live Online. ANAB. This Measurement Confidence course introduces the foundational concepts of measurement traceability, measurement assurance, and measurement uncertainty and details ISO/IEC 17025 and ISO/IEC 17020 requirements. https://anab.ansi.org/training/measurement-confidence-fundamentals/

**Apr 18-19, 2024 Measurement Uncertainty: Practical Applications.** Live Online. ANAB. This class covers concepts and accreditation requirements associated with measurement traceability, measurement assurance, and measurement uncertainty. https://anab.ansi.org/training/

**Apr 20-21, 2024 Applied Measurement Uncertainty for Calibration Laboratories.** Virtual. QC Training. During this Applied Measurement Uncertainty for Calibration Laboratories course, the participant will be introduced

SINE
CALIBRATION SCHOOL

TRAINING THE INDUSTRY

# NEEDS

## We understand the situation you are in out there...

- You can't find qualified entry level technicians
- You can't find actual intermediate level technicians
- Forget about finding an advanced technician, or Metrologist
- You calibration workload is growning exponentially...

We offer training in levels, currently from 1-3. Level 1 can be taken 100% online and at-your-own-pace. This program has been very popular for a new employee's training, that can free up manager time. The online course currently offers the following courses:

**General Metrology**
**Electronics**
**Temperature**
**Pressure**
**Force**
**Torque**
**RF and Microwave**
**Dimensional**

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**Jun 3-4, 2024 3006 Uncertainty of Measurement for Labs**. Online training for Middle-East & South Asia time zone. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/ias-training-schedule/

**Jun 17-18, 2024 Measurement Confidence: Fundamentals**. Live Online. ANAB. This Measurement Confidence course introduces the foundational concepts of measurement traceability, measurement assurance, and measurement uncertainty and details ISO/IEC 17025 and ISO/IEC 17020 requirements. https://anab.ansi.org/training/measurement-confidence-fundamentals/

**Jun 19-20, 2024 Measurement Uncertainty: Practical Applications.** Live Online. ANAB. This class covers concepts and accreditation requirements associated with measurement traceability, measurement assurance, and measurement uncertainty. https://anab.ansi.org/training/

**Jul 9, 2024 Introduction to Measurement Uncertainty**. Frederick, MD. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/training

**Jul 10-11, 2024 Applied Measurement Uncertainty for Calibration Laboratories.** Denver, CO. A2LA WorkPlace Training. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/training

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**Apr 8-12, 2024 Principles of Pressure Calibration**. Phoenix, AZ. Fluke Calibration. A five-day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances).The class is designed to focus on the practical considerations of pressure calibrations. https://us.flukecal.com/training

**Jun 19-20, 2024 Pressure Measurement.** Port Melbourne, VIC. Australian NMI. This two-day course (9 am to 5 pm each day) covers essential knowledge of the calibration and use of a wide range of pressure measuring instruments, their principles of operation and potential sources of error — it incorporates extensive hands-on practical exercises. https://shop.measurement.gov.au/collections/physical-metrology-training

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Mar 11-15, 2024 Basic MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. In this five-day Basic MET/CAL Procedure Writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. https://us.flukecal.com/training

**Apr 15-19, 2024 MET/TEAM® Asset Management.** Everett, WA. Fluke Calibration. This five-day course presents a comprehensive overview of how to use MET/TEAM Test Equipment and Asset Management Software in an Internet browser to develop your asset management system. You will learn a systematic approach to collect the information you need to manage your lab assets routinely, consistently and completely. https://us.flukecal.com/training

**Apr 23-25, 2024 VNA Tools Training Course.** Beaverton, OR. Federal Institute of Metrology METAS. VNA Tools is free software developed by METAS for measurements with the Vector Network Analyzer (VNA). The software facilitates the tasks of evaluating measurement uncertainty in compliance with the ISO-GUM and vindicating metrological traceability. The software is available for download at www.metas.ch/vnatools. The three day course provides a practical and hands-on lesson with this superior and versatile software. https://www.metas.ch/metas/en/home/dl/kurse---seminare.html

**May 6-10, 2024 Basic MET/CAL® Procedure Writing**. Everett, WA. Fluke Calibration. In this five-day Basic MET/CAL Procedure Writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. https://us.flukecal.com/training

**May 28-30, 2024 VNA Tools Training Course.** Berne-Wabern, Switzerland. Federal Institute of Metrology METAS. VNA Tools is free software developed by METAS for measurements with the Vector Network Analyzer (VNA). The software facilitates the tasks of evaluating measurement uncertainty in compliance with the ISO-GUM and vindicating metrological traceability. The software is available for download at www.metas.ch/vnatools. The three day course provides a practical and hands-on lesson with this superior and versatile software. https://www.metas.ch/metas/en/home/dl/kurse---seminare.html

**Jul 15-19, 2024 Basic MET/CAL® Procedure Writing.** Everett, WA. Fluke Calibration. In this five-day Basic MET/CAL Procedure Writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. https://us.flukecal.com/training

**SEMINARS & WEBINARS:**
**Temperature & Humidity**

**Mar 7, 2024 Testing Temperature Controlled Enclosures**. Lindfield NSW. National Measurement Institute, Australia. This one day course is for people involved in routine performance testing of temperature-controlled enclosures (oven, furnace, refrigerator and fluid bath). It incorporates an extensive overview and comparison of AS2853 and IEC 60068-3-5 requirements, and it also includes an overview of the medical refrigeration equipment temperature mapping requirement to AS3864.2. https://shop.measurement.gov.au/collections/physical-metrology-training

**Mar 13, 2024 Temperature Measurement and Calibration Workshop.** MSL. Lower Hutt, New Zealand. This course covers the use, care, and calibration of liquid-in-glass, platinum resistance, thermocouple, and radiation thermometers. The course is relevant to all personnel who use or check thermometers as a part of testing, installation, or monitoring and maintenance tasks. https://www.measurement.govt.nz/training/

**Mar 18-20, 2024 Practical Temperature Calibration.** American Fork, UT. Fluke Calibration. A three-day course loaded with valuable principles and hands-on training designed to help calibration technicians and engineers get a solid base of temperature calibration fundamentals. https://us.flukecal.com/training

**Mar 21-22, 2024 Infrared Calibration.** American Fork, UT. Fluke Calibration. A two-day course with plenty of hands on experience in infrared temperature metrology. This course is for calibration technicians, engineers, metrologists, and technical experts who are beginning or sustaining an infrared temperature calibration program. https://us.flukecal.com/training

**May 6-8, 2024 Advanced Topics in Temperature Metrology.** American Fork, UT. Fluke Calibration. A three-day course for those who need to get into the details of temperature metrology. This course is for experienced calibration technicians, metrologists, engineers, and technical experts working in primary and secondary-level temperature calibration laboratories who would like to validate, refresh, or expand their understanding of advanced topics in temperature metrology. https://us.flukecal.com/training

**Aug 27-29, 2024 Temperature Measurement**. Sydney, Australia. National Measurement Institute. This three-day course (9 am to 5 pm) covers the measurement of temperature and the calibration of temperature measuring instruments. It incorporates extensive hands-on practical exercises. https://shop.measurement.gov.au/collections/physical-metrology-training

**Aug 30, 2024 Liquid-In-Glass Thermometry.** Sydney, Australia. National Measurement Institute, Australia. This one-day course will provide calibration and quality control technicians with the skills required to calibrate liquid-in-glass thermometers in accordance with NATA and 17025 requirements. https://shop.measurement.gov.au/collections/physical-metrology-training

### SEMINARS & WEBINARS: Time & Frequency

**May 8-9, 2024 Time and Frequency Measurement.** Lindfield, NSW. National Measurement Institute, Australia. This two-day course covers the broad range of equipment and techniques used to measure time and frequency and to calibrate time and frequency instruments. https://shop.measurement.gov.au/collections/physical-metrology-training

### SEMINARS & WEBINARS: Validation & Verification

**May 29, 2024 Validation and Verification of Analytical Methods**. Live Online. ANAB. This course provides an introduction to validation and verification of analytical methods and ISO/IEC 17025 & ISO/IEC 17020 requirements. https://anab.ansi.org/training-course-schedule/

### SEMINARS & WEBINARS: Volume

**Apr 8-12, 2024 Volume Metrology Seminar.** Gaithersburg, MD. NIST. The 5-day OWM Volume Metrology Seminar is designed to enable metrologists to apply fundamental measurement concepts to volume calibrations. A large percentage of time is spent on hands-on measurements, applying procedures and equations discussed in the classroom. https://www.nist.gov/pml/weights-and-measures/training

### SEMINARS & WEBINARS: Weight

**Mar 21, 2024 Calibration of Weights and Balances**. Lindfield NSW. National Measurement Institute (NMI), Australia. This course covers the theory and practice of the calibration of weights and balances. It incorporates hands-on practical exercises to demonstrate adjustment features and the effects of static, magnetism, vibration and draughts on balance performance. https://shop.measurement.gov.au/collections/physical-metrology-training

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Prototype of the new JAWS metrology system. Credit: PTB

## Flexible Josephson Metrology System

PTBnews 3.2023—Working within an industrial cooperation project, PTB has developed a novel metrology system for the quantum-based generation and measurement of voltage signals. The system is based on a pulse-driven Josephson standard, the Josephson arbitrary waveform synthesizer (JAWS), and has been designed for deployment in a wide variety of applications. This system can be used not only as a quantum-based voltage generator, but also as an ultra-accurate instrument for measuring DC voltages and AC voltage signals. A prototype has been successfully tested at PTB for signal frequencies up to 100 kHz.

Josephson voltage standards based on JAWS allow electric voltages with arbitrary and spectrally pure waveforms to be generated with "quantum accuracy." This explains their use in a large number of metrological applications. Metrology institutes such as PTB are already successfully using JAWS in a wide frequency range from a few Hz up to 1 MHz, for example as a reference for AC voltages, for setting up novel user-friendly impedance bridges, and for calibrating noise amplifiers for the "electronic kelvin."

Within the scope of a technology transfer project funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) as part of the TransMeT funding program, PTB is developing – in cooperation with two industrial partners – a novel product based on JAWS: The JAWS Source Measurement Unit (JAWS-SMU) can not only generate voltages with quantum accuracy (Source mode), but can also be used in Measurement mode as an ultra-accurate measuring instrument for DC and AC voltages (waveforms).

In Source mode, measuring instruments can be directly calibrated by applying a well-defined voltage with accuracies in the nV/V range. For example, the linearity behavior of voltmeters for DC voltages between 1 nV and 100 mV was measured, and the properties of analogue-to-digital converters were characterized by means of sine waves up to 100 kHz. As the system is also capable of generating signals with an accurately defined phase, it can also be used for the calibration of phase standards.

In Measurement mode, the voltage signal of a source is compensated by means of JAWS, and the small residual voltage is measured by a null detector. With the quantum standard as reference, relative measurement uncertainties in the range of 10 nV/V can be achieved within minutes.

As their practical advantages over conventional systems make quantum electrical standards interesting for industrial applications as well (in calibration laboratories, for example), the JAWS-SMU has also been designed for reliable operation in "harsh" environments. A prototype has already been used at PTB to demonstrate precision measurements with effective output voltages up to 100 mV.

Within the scope of on-site tests at the project partner's (esz AG) accredited calibration laboratory, the next step will consist in optimizing the prototype for practical use. It will then be developed into a completely automated, user-friendly product. Supracon AG (instrument manufacturer and project partner) will be in charge of the subsequent commercialization. Long-term planning includes an increase of the output amplitudes to 1 V.

Scientific publication: J. Herick, R. Behr, O. Kieler, L. Palafox: Development of JAWS-SMU. Conference on Precision Electromagnetic Measurements Digest (CPEM 2022), 489-490 (2022).

Source: https://www.ptb.de/cms/en/presseaktuelles/journals-magazines/ptb-news.html

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## World Metrology Day Formally Endorsed by UNESCO

The UNESCO General Conference held from 7 to 22 November 2023 adopted 20 May as a UNESCO International Day, following the proposal presented by Kazakhstan and supported by 43 additional nations, alongside the BIPM and the OIML.

The declaration of World Metrology Day by UNESCO, to be observed annually on 20 May, will significantly enhance global awareness of metrology's role in everyday life and will enhance BIPM's actions in capacity-building with developing economies.

The BIPM expresses its sincere thanks to Ambassador Gulsara Arystankulova and the Permanent Delegation of the Republic of Kazakhstan to UNESCO as the main sponsor of the World Metrology Day proposal, as well as the 43 UNESCO Member States who have given their written support following decision 41 at the 215th Executive Board meeting in 2022.

Source: https://www.bipm.org/en/-/2023-11-21-wmd-unesco-adoption


From left to right: His Excellency Ambassador Askar Abdrakhmanov (Permanent Delegation of the Republic of Kazakhstan to UNESCO in Paris), Dr Martin Milton (Director, BIPM), Ms Rahima Guliyeva (Institutional liaison and membership, BIPM). Credit: BIPM, https://creativecommons.org/licenses/by/3.0/igo/


## EMPIR Project Videos Explaining Aspects of Magnetic Calibrations and Measurements Freely Available

January 17, 2024 – EMPIR Capacity Building project Traceability Routes for Magnetic Measurements (TRaMM, 21SCP02) is a training project, where INRIM, the NMI for Italy, is transferring knowledge and expertise in the field of magnetic measurements and calibrations to CEM and NSAI, the NMIs for Spain and Ireland respectively. This will extend the European capabilities for measurements in this technical area, where currently only four NMIs have the ability to perform traceable measurements of all of the most important magnetic quantities.

Traceable magnetic measurements are important for a number of applications including: power transformers, electrical motors, cleaner transportation systems, cleaner energy sources including wind turbines, sustainable ways of improving our lifestyle, better technologies for diagnostics and therapy, and understanding exposure levels to electromagnetic fields of workers or of the general population close to specific appliances

The transfer of knowledge and expertise has taken place through a series of high-level training events, expert training material and laboratory demonstration videos, both online and in INRIM laboratories.

**Videos**

A video (https://www.tracemag.eu/) explaining the overall aims of the project is available.

The PhD course video lecture series (https://www.tracemag.eu/trainingmaterial) consists of the following modules:

- Introduction to magnetism
- Magnetostatics
- Magnetic interactions
- Electromagnetics
- Magnetization processes
- Hard magnetic materials
- Magnetoresistance

The laboratory demonstrations videos (https://www.youtube.com/@EURAMET-TRaMM/videos) cover the following topics:

- Wattmeter
- Ballistic method
- DC probe 50 mT – 1 T
- DC probes – low fields
- Hard magnetic materials IEC 404.5
- Inductive measurements theory
- Inductive measurements
- Magnetometers
- VNA measurements theory
- VNA measurements
- VNA

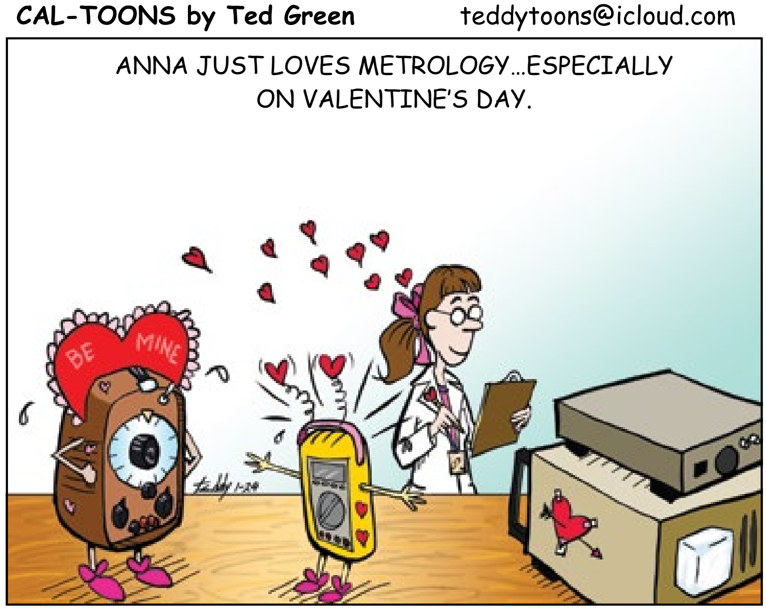
Project coordinator Marco Coisson from INRIM said "The TRaMM project has helped in our understanding that the metrological services currently offered by NMIs are extremely important, but must be updated to fit with the new needs of stakeholders, working on novel magnetic materials and sensors for the energy, automotive, health and information technology industries.

Bringing to the industry and to the metrological level the latest techniques in the field of magnetic materials and measurements is a challenge that the metrological community will have to face in the next months and years, and the TRaMM project is building the foundations for that development to happen."

*This EMPIR project is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States.*

Source: https://www.euramet.org/publications-media-centre/news

**CAL-TOONS by Ted Green** teddytoons@icloud.com



# Sidestepping the Potholes in DC Voltage Traceability

David F. Martson*
1A CAL GmbH

The development and use of intrinsic standards, e.g., Josephson Voltage Standard or JVS, has brought the primary level of uncertainty achievable for DC voltage down to a few nV/V (ppb), while at the test bench, precision digital multimeters (DMM) routinely provide direct reading accuracy to a few µV/V (ppm). Although the references typically employed for traceability (i.e., those used to perform DMM calibrations in primary or secondary laboratories) have remained virtually unchanged, the ancillary equipment required to support their use is obsolete, in this case, the analog DC null detector. This paper discusses alternative approaches to effectively bridge the gap created by that obsolescence, while maintaining DC voltage traceability at levels of uncertainty satisfactory to support the calibration of high accuracy DMMs and associated infrastructure.

## 1. Historical Background

Prior to 1990, the primary representation of the DC volt was maintained at NMIs in groups of saturated, standard (Weston) cells at the 1.018 V level. For many years, the US NBS (National Bureau of Standards, now NIST) maintained the US volt in terms of a working group of standard cells. At the local calibration lab, the same technology was employed, with standard cell enclosures being ubiquitous fixtures in nearly every calibration laboratory, providing the link in DC traceability.

Standard cells are delicate devices and drawing current from them during measurement can significantly impact their stability, at best, or ruin them, at worst. Instrumentation commonly used for DC voltage measurements of those devices, e.g., L&N®† (Leeds & Northrup) 7553 Type K-3 Universal Potentiometer [1], having a maximum input of 1.6110 V and associated "Limits of Error" of ± (0.01 % + 20 µV), were routinely used to transfer from the local standard cell reference to a lead-acid, 2 V working cell, capable of sourcing adequate current during use without damage. Light beam galvanometers, e.g., L&N 2430-E (prior to about 1960) were primarily employed as null detectors, due to their high sensitivity, until the development of high resolution, analog meter-readout ("electronic"), null detectors subsequently replaced them in most applications. Compared to galvanometers, their replacements were robust, easy to use, had multiple ranges, and were often calibrated in terms of absolute voltage, instead of a fixed sensitivity, based on applied voltage or current, and expressed in millimeters of deflection (e.g., 0.5 µV/mm scale division) on a graduated scale.

To transfer the accuracy from the standard cell to voltages beyond the 1.6110 V range of the K-3, a Voltbox (e.g., L&N 7582) was used. The L&N Voltboxes, however, were hampered by their low input impedance, 750 Ω/volt, drawing current from the source being tested and loading its output. Since then, other, improved (i.e., high input impedance) divider models to extend the measurement range without drawing excessive current from the source have been produced by various manufacturers, for example, the ESI® 1040A Guarded Absolute Voltbox [2] (1968), similar to and perhaps the functional predecessor of the currently used reference, the Fluke® 752A Reference Divider [3], introduced in 1983. The 752A, like the 1040A, employs an internal bridge in conjunction with a null detector to align the divider resistor elements to achieve the specified accuracy. The primary difference, besides lower uncertainty, is that the 752A was designed and optimized for use with Zener (10 V) references, then coming to the fore.

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## 2. Changing Technology

In the early 1970s, NBS began development of a Josephson Junction-based Voltage Standard. The first systems consisted of a single junction, limited to producing about 10 millivolts, and requiring a special divider to transfer its accuracy to the 1.018 V output level of the standard cell references then in use. Subsequently, the junction technology was expanded to use many elements, combined in a series array consisting of 18,992 junctions, for example, increasing the output capability to approx. ± 12 V, facilitating direct DC voltage comparisons (transfers) with Zener reference devices. The first, commercial installation of a J-array system capable of producing these higher voltages was installed in the Hewlett-Packard® (now Keysight Technologies) Primary Standards Laboratory at Loveland, CO, USA, in November 1988 [4]. Although the original, multijunction array element has been replaced since then (and the lab subsequently relocated to Roseville, CA), the system remains in active use today.

NIST (and the SI) switched from using standard cells to a Josephson-based reference in 1990, necessitating a +9.264 μV/V shift in the value of the volt, now based on the Josephson constant (2 *e*/*h*). Since then, as a result of technological advancements and reduced cost, approximately 70 NMIs currently now disseminate their DC volt via the use of a Josephson Voltage Standard, with Zener-based reference sources becoming the default artifact, eliminating the use of saturated cells in their entirety as the local reference in virtually every calibration laboratory.

## 3. Technical and Usage Background

As previously stated, the Zener reference has replaced the saturated, standard cell as the principal means of disseminating DC voltage traceability, due to their stability, robustness, and proven history of operation. While a few nV/V of uncertainty are relatively easy to achieve when measuring the output using the J-array, conventional dissemination of the volt down the hierarchy between Zener reference devices (e.g., the 'transfer' of one certified, Fluke 732 device to another Zener reference) is practically limited to about 0.1 μV/V, due to noise and usable detector resolution. From there, however, the uncertainty of the certified 10 V output must be referred to via the hierarchical 'unbroken chain of comparisons' when calibrating that precision DMM used in the test bench example, mentioned at the outset, which measures from 0 V to 1100 V DC, and whose own calibration requires the use of a DC calibrator, which also must first be calibrated. As discussed above, to accomplish that task typically requires the use of a precision, fixed-ratio (reference) divider such as the 752A.

When it comes to the local dissemination of the volt, i.e., performing calibration of DC calibrators, high-performance DMMs, or other workload, the technology employed in the trenches has remained in use for over 50 years, with the use of Zener reference devices supplanting the role previously relegated to standard cells as a reference, but otherwise essentially unchanged for more than 35 of those years. In brief, a known, voltage reference is used in conjunction with a precision, fixed-ratio (reference) divider to scale from the DC reference nominal voltage (10 V) to other levels, such as 100 mV, 1 V, or 1000 V, for example. The 752A has a high output impedance (e.g., 40 kΩ), and was designed to be used with a battery-operated (line isolated) null detector whose input impedance is infinite at null, with at least $1 \times 10^{12}$ Ω isolation to minimize leakage. In the past, several manufacturers have produced instruments that satisfied the required performance criteria, e.g., the Hewlett-Packard 419A, Keithley® 155, and Fluke 845A series—now there are none. A specialty manufacturer, PPM, Inc.®, also produced a null detector for a short time, as did Tegam®, who subsequently acquired the product line from PPM, producing the AVM-2000 to fill the void, but it too, is now discontinued.

## 4. What Now?

Experiments have been performed previously using nanovoltmeters as null detectors, e.g., the Keithley 2182A [5]. While certainly having adequate sensitivity for the task, comparable with analog null detectors, the input bias currents can be > 50 pA (more on this aspect later), significant by itself, but perhaps the largest error source is the lack of adequate isolation—often a result of leakage through the transformer to power line mains. Typically, available nanovoltmeters only have isolation on the order of 10 GΩ, or about 100x less than a comparable DMM! To be fair, nanovoltmeters are intended to measure low source impedance devices, not one having as much as 40 kΩ output impedance.


Figure 1. Keysight® 3458A. Credit: Keysight Technologies

## 5. An Alternative Approach

In 2014, a paper [6] was presented at CPEM discussing the very problem mentioned above, that is, the lack of suitable null detectors, leaving a void that demanded a working solution. In the paper, the (Fluke) authors discussed the primary error sources associated with their use, and although cautious not to imply the possibility of widespread DMM use for the purpose, described general techniques and requirements for mitigating the effect on the outcome when substituting a specific model of DMM (Fluke 8508A)[7] for a null detector. Following the paper's presentation, Fluke published a specific protocol for using the 8508A as a null detector with the 752A Reference Divider that provides satisfactory results, while minimizing inherent errors associated with its use [8]. As of this date, the 8508A is no longer in production.

## 6. Will It Work?

Subsequent to the previous paper's publication, Keysight-owned analog null detectors were failing, with little chance of repair, and no suitable replacements available, yet the need to continue to provide DC calibrations remained. With few options, and the broad availability of the 3458A‡ in mind, a decision was made to evaluate the potential of that DMM model for use as a null detector, using the information from the previously published paper as a starting point. At that time, the chances for achieving success in the venture were unknown, but a cautionary statement from the previous paper stating that "not every DMM can be used as a direct substitute for the 845A" seemed somewhat ominous at the outset of the investigation.

## 7. The Investigation Begins

Beginning with a review of the information presented in the Faulkner/Gust paper, the initial thought process was to compare the required, critical specifications and characteristics of the 8508A offered in the paper with those for the 3458A [9], to determine if such a substitution was even feasible. Beginning with the input impedance of the 8508A (200 mV to 20 V ranges), it is specified as > 10 GΩ. Similarly, the 3458A input impedance (100 mV to 10 V ranges) is also specified as > 10 GΩ, so the first concern was met, or was it? In comparison, analog null detectors have a 10 MΩ input impedance, which becomes infinite at null.

As stated in the original paper, the bias current of the DMM under investigation (Fluke 8508A), although specified to be < 50 pA (it was noted that it is not uncommon for it to be ≤ 5 pA for some units), with levels exceeding 5 pA causing significant errors when placed across the high source impedance of the divider. Thus, the magnitude of the bias current must be determined prior to use as a null detector, as it is a critical value. Recalling a prior investigation on that topic, a Dutch NMI [10] paper discussing its measurement and providing experimental results was referred to. The results shown were encouraging; testing performed on two 3458A specimens from different production runs indicated that although somewhat different, the measured bias currents

‡ The 3458A was updated to be RoHS compliant in 2019, ensuring continued availability.

were ≤ 5 pA (the 3458A specification is < 20 pA at 25 °C). Subsequently undertaking the same tests internally, similar results were obtained on several, in-house 3458A units measured. With the bias current remaining below 5 pA, the deleterious effects of its presence are significantly reduced, relative to the specified performance of the 752A. It should be noted that the bias current magnitude is somewhat temperature dependent, although in most lab environments this should not be problematic, with performance of an ACAL prior to use largely alleviating its impact.

Another error source identified previously is the pumpout current commonly associated with digital multimeters. In the case of the 3458A, setting the AZERO to OFF will substantially reduce the pumpout current observed, but incurs a large penalty in its uncertainty when doing so, due to the added 5 µV/°C temperature coefficient. However, simply following the guidance in the original paper was found to be adequate. That is, connecting the DC source (calibrator) to the divider input, setting the output of the source to 0 V with its output enabled (providing a path to ground back through the source's power supply), followed by execution of a MATH NULL, once the indication has settled, proved to be adequate in the case of the 3458A as well.

Investigating what is typically the bane of the nanovoltmeter, mediocre isolation, the input isolation of the 3458A was compared with that of the 845AB null detector. The 845AB input isolation is specified as "Better than $10^{12}$ ohms at less than 50 % relative humidity and 25 °C…" In comparison, the 3458A is specified as ">$10^{12}$ Ω, Guard to Earth," which suggests the isolation of the 3458A is at least as good as the 845AB, making it a satisfactory candidate in that aspect.

## 8. Does It Work?

Following the feasibility investigation, tests were initially made internally, comparing the measured results of a Fluke 5720A calibrator, after first performing the 752A self-calibration using a Keithley 155, then again after recalibrating it using the 3458A. It can be quite frustrating trying to achieve an effective null using a digital readout, while watching seemingly innumerable digits 'rattle' on the display, confirming why analog indicating devices still have a place in the world! However, after operator tests were performed by several different calibration technicians and their inputs compiled, some fine-tuning was applied to the process, and the results improved markedly. For example, setting the NPLC to 20 initially, increasing the sample rate at the expense of noise, then increasing the NPLC to 100 as a final null is approached, reducing the noise impact, expedited the process, while minimizing operator frustration. As an 'acid test,' a Keysight facility in Penang, Malaysia participated in an internal ILC, comparing the measured DC voltage results using the 3458A vs. with those obtained using a Keithley 155, achieving successful closure ($E_n$ < 1) at all test points. The largest, observed deviation of -0.7 µV/V occurred at -100 mV, and is only about one-seventh of the OEM's reported uncertainty of 4.8 µV/V, in comparison. Since then, the testing has been extended to a UK Keysight facility, also achieving successful closure vs. use of a 155 at that location.

Based on the results achieved and ongoing testing, the 3458A will likely become the 'null detector' of choice for use in Keysight calibration labs, with virtually all facilities already equipped with the device, making its implementation easy and cost effective.

## 9. Other Null Detector Applications

### 9.1 Transfer Measurements

Besides its use when self-calibrating the 752A, a DC null detector is historically used for many, additional tasks in the calibration lab. One of those tasks where the 3458A is admirably suited, for instance, is the comparison of Zener reference standards. Perhaps one of the least known features of the 3458A operation is its ability to compare (transfer) two independent voltage sources with a very low, contributory uncertainty [11]. For example, suppose it is desired to calibrate an unknown Zener reference at 10 V via transfer from a certified one. By making two, manual measurements (see Figure 2), first of the UUT ('Signal Voltage'), recording its value, then followed by measuring the certified unit ('Reference Voltage') and recording its value, the voltages of the two can be compared with a high degree of accuracy. Assuming the uncertainty of the reference is ± 0.15 µV/V ($k$=2) and referring to the 3458A Transfer Accuracy/Linearity specifications,

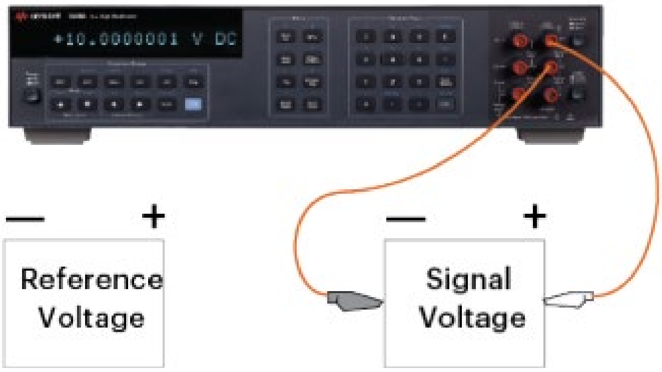


Figure 2. Keysight 3458A manual transfer measurement. Credit: Keysight Technologies

the combined uncertainty when making the cited (1:1) comparison results in an uncertainty at time of measurement of ± 0.19 µV/V (*rss*).

Having made a transfer from a reference Zener device (e.g., Fluke 732) at the 10 V level, it may be desirable to transfer the 10 V accuracy to the 1 V output as well. Using the same connections as described for a 10 V (1:1) transfer, measuring first the reference (10 V output) followed by the 1 V output of the UUT. Referring again to the 3458A Transfer Accuracy/Linearity (10 V range) specifications, the combined uncertainty when making the cited comparison results in an uncertainty at time of measurement of ± 0.65 µV/V (*rss*). That level of uncertainty is adequate to calibrate most models of currently produced DMMs with a TUR of better than 4:1.

**9.2 Ratio Measurements**

Another application where a null detector and a high resolution divider (e.g., Kelvin-Varley) have been used in the past is the potentiometric measurement of ratio. In this usage, an unknown device is measured in terms of ratio to a known source, similar to use of the 752A, except the 752A ratios are fixed; in this case, the ratio divider setting is adjusted until a null is achieved, with the ratio read directly from the divider dial settings. Alternatively, using the connections shown in Figure 3, the 3458A can be configured for 'automatic' ratio measurements, making the measurements much faster, and at lower uncertainties, in many cases.

In this configuration, the 3458A will automatically measure the two applied voltages using internal switching then calculate the resulting voltage ratio value from the two independent measurements. When used in this mode, the uncertainty is somewhat larger than when making manual, transfer measurements (previously described), and includes the 24 hour DC voltage specification contribution. Using the previous examples shown, that is, a 1:1 ratio at 10 V and a 10:1 ratio comparing 10 V with 1 V, the calculated ratio uncertainties are ± 1.38 and ± 2.63 µV/V, respectively. An instance where this method was recently employed was in the comparison of two current shunts, a reference shunt with an unknown UUT, measuring the ratio of the voltage drop across the reference and UUT shunt and computing the value of the UUT in terms of the reference based on it. Automatic ratio measurements are supported for DCV|DCV, ACV|DCV, and AC+DCV|DCV parameters.

**9.3 Other Measurements**

After the investigation to determine if the 3458A was a suitable candidate for null detector use in conjunction with the 752A was well underway, a new, fixed ratio divider, the Measurements International, Ltd.®, Model 1340A High Precision Voltage Divider [12] was introduced. Rather than being based on successful performance of a sometimes arduous, self-calibration procedure,

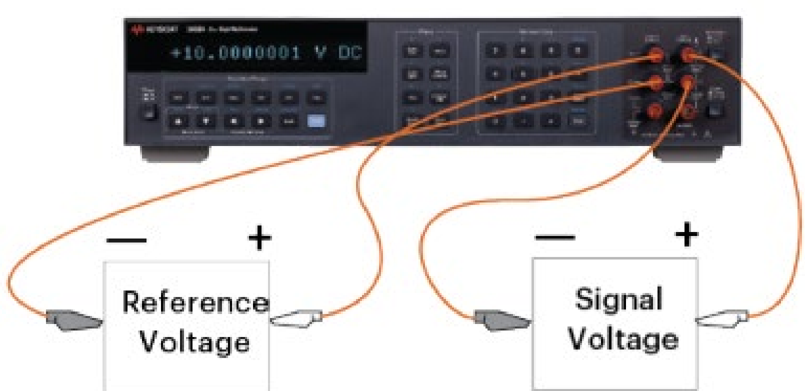


Figure 3. Keysight 3458A automatic ratio measurement. Credit: Keysight Technologies

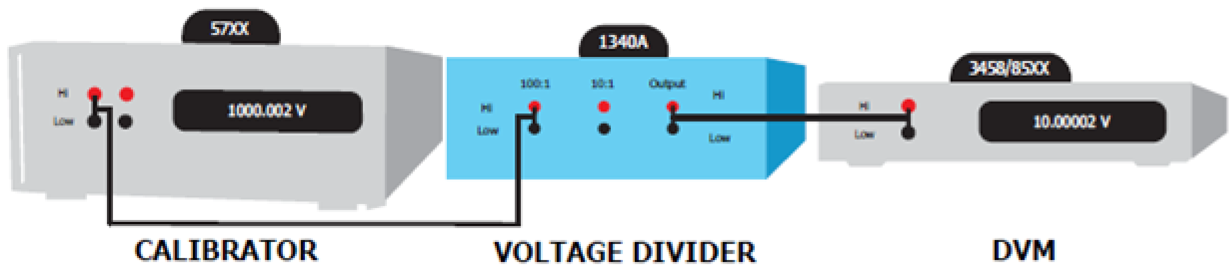


Figure 4. Typical 100:1 absolute output measurement using DVM (Keysight 3458A) [12].

the 1340A utilizes selected, high-stability resistors maintained in a tightly regulated (i.e., 5 mK, peak-to-peak, 24 hours) internal oven, providing similar uncertainties to those associated with the 752A. Furthermore, a DMM (use of the 3458A is suggested by the OEM) may be used to measure the divider output directly (see Figure 4). Alternatively, an automatic ratio measurement can be made as described in the previous section (at a slight penalty in uncertainty) but can be accomplished without using an external scanner.

Another common technique using a null detector is the comparison to a known reference using series opposition connections. Here again (shown in Figure 5), for example, the 3458A can be used, and will measure the offset (difference) voltage between the two (Divider output and 732) directly.

The determination of the ratio of the 1340A is based on the measurement of the divider resistors and the subsequent computation of the actual ratio based on those measurements, performed using a resistance bridge every 30 days. This is in contrast with the 752A requirement to self-calibrate the device every eight (8) hours, or whenever the ambient temperature changes by more than ± 1 °C from that at time of self-cal. In either use case, the 3458A can fit the bill.

## 10. Wrapping Up

The phrase “sidestepping potholes” was used in the title because that is what we are effectively doing – mitigating known error sources while cautiously navigating through the unknown ones (or as a colleague used to say, “Extending the Traceability”), maintaining traceability using alternative equipment and methods, in this case, for DC voltage. Although outside the scope of this paper, similar obsolescence has also struck other pertinent, fundamental instruments in metrology, forcing metrologists to devise alternative solutions to address those losses, as well.

## Acknowledgements

I would like to thank the following Keysight individuals who contributed to this effort to help bring it to fruition. Without their assistance this work would not have been possible: Jon Harben, Wei (Viva) Wang, Xun Zhang, and Tim Lowndes.

Thanks also to Mike Frisz and Measurements International, Ltd., for product information and background.

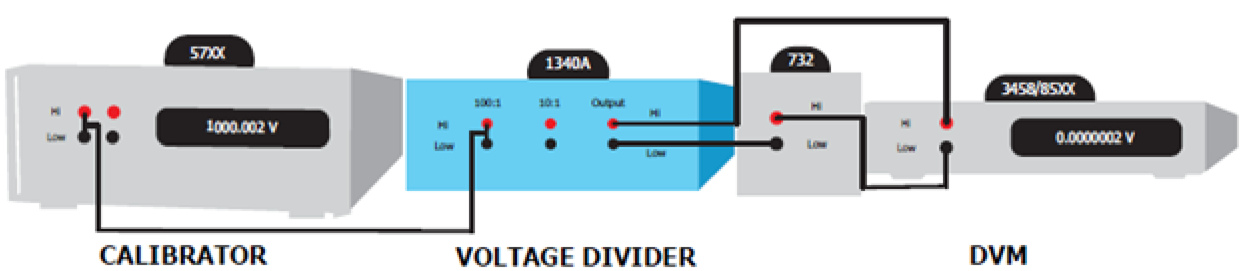


Figure 5. Typical 100:1 relative output measurement using DVM (Keysight 3458A) [12].

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# Some Perspective on Risk and Decision Rules in Calibration

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When an accredited laboratory makes a statement of conformity to a specification, ISO/IEC 17025 requires the use of a decision rule that takes into account the level of risk associated with the decision rule employed. There are numerous resources available that address the calculation of the likelihood of risks like false accept and false reject in measurement. However, *level of risk* is defined as the combination of the *likelihood* of risk along with the consequences of risk, and the *consequences* of risk in measurement decision rules is a rather unexplored area in existing literature. This paper specifically explores calibration of measuring instruments, which is a rather unique type of measurement, as calibration always supports subsequent downstream measurements made with the calibrated measuring instrument. This uniqueness provides an opportunity to explore the consequences of decision rules used in calibrations that involve statements of conformity. This paper explores the impact of risk and decision rules in calibration and shows how it is possible, and potentially more useful, to account for the level of risk associated with decision rules by managing the consequences and not necessarily the likelihood of the risk.

## 1. Introduction

I always wear a seatbelt when in a car. I don't wear one because it's the law in most places, and I don't wear one because the probability of being in a bad accident is high. In my entire five decades plus of living, I have been lucky to have never been in a car accident where a seatbelt was needed to protect me. When I get in a car, I know the likelihood of the risk of being in an accident is quite low, and so that is not what motivates me to click the seatbelt. I fear the impact of the risk. I fear my head going through the front windshield or my body being tossed around in the car. I've read enough articles about horrible car accidents where someone died, but the people wearing seatbelts survived. I've read articles from the United States National Highway Traffic Safety Administration (NHTSA) that say wearing a seatbelt can reduce risk of critical injuries or death by around 50% [1]. I don't fear the *likelihood* of the risk, but I do fear the *consequences* of the risk, and so I wear a seatbelt, always.

## 2. Level of Risk

As someone who works for a manufacturer of measuring instruments, and for an organization with an ISO/IEC 17025 accredited calibration laboratory, I think about measurement related risk a lot. In the measurement world, the big change found in the latest revision of ISO/IEC 17025:2017 [2] was the formal consideration of risk. This document, which provides the framework for the quality system of most commercial measurement services worldwide, contains 31 occurrences of the word *risk*. The requirements of this standard associated with risk are critical to understand for any ISO/IEC 17025 accredited calibration laboratory.

ISO/IEC 17025 specifies a number of requirements associated with risk and decision rules. Some of the key requirements and definitions include the following:

- When making statements of conformity in calibration, the use of a decision rule is required that takes into account the level of risk associated with the decision rule employed.
- A decision rule is defined as a rule that describes how measurement uncertainty is accounted for when stating conformity with a specified requirement.
- When the decision rule is prescribed by the customer, regulations or normative documents, a further consideration of the level of risk is not necessary.
- The decision rule shall be clearly defined, communicated to, and agreed with, the customer unless the decision rule is inherent in the requested specification or standard.

The term level of risk is not defined in ISO/IEC 17025 nor in any of its associated normative references. This term is defined in a number of ISO standards on risk management, and in particular ISO Guide 73:2009 [3], as the following:

> *magnitude of a risk or combination of risks, expressed in terms of the combination of consequences and their likelihood*

This definition establishes a common approach in risk analysis which involves building a risk matrix based on the level of risk as shown in Figure 1. The level of risk is assessed by separately evaluating both the likelihood and the consequence of the risk. The level of risk increases or decreases with a change in either the likelihood or consequences of the risk. In the seatbelt example used earlier, the likelihood of the risk – a serious car accident – is low, but the consequence is quite high when a seatbelt is not worn, which increases the level of risk. If a seatbelt is worn, the consequence of the risk is lowered, which lowers the associated level of risk. Wearing the seat belt does not change the likelihood of a serious car accident, but it does change the consequence and therefore the level of risk.

## 3. Level of Risk in Calibration

Let's use a simple scenario to discuss the level of risk in calibration. In this scenario, a commercial calibration lab is calibrating a gage block to its tolerance grade for a customer. Following the general recommendations of an American national standard in dimensional metrology [4] and following the recommendations of the manufacturer of the gage blocks, the calibration lab uses a simple 1:1 acceptance decision rule in accordance with ASME B89.7.3.1 [5] when making statements of conformity. The simple acceptance decision rule, which applies no guard band to specification limits when assessing conformity, does not directly evaluate the likelihood of risks, e.g. the probability of false accept (PFA). The "1:1" in simple 1:1 acceptance requires that the measurement uncertainty be equal to or smaller than the tolerance being assessed. This is equivalent to saying the Test Uncertainty Ratio, TUR [6], is greater than one.

If this calibration laboratory wanted to determine the PFA for this gage block calibration, there are a number of excellent standards and guidance documents available to help with that calculation and application (e.g. see [6-9]). Calculating the


Figure 1. Level of risk is expressed in terms of both likelihood and consequences.

PFA, or the likelihood of any risk; however, is useful in evaluating the level of risk only when the consequences of that risk are also considered. Only the customer, not the calibration lab, can know the consequences of the risk, and therefore in order for the calibration lab to properly account for the level of risk in the decision rule, as required by ISO/IEC 17025, then the customer must provide an acceptable value for the PFA. Determining the likelihood of a risk without considering the consequences will always result in insufficient understanding of the level of risk.

Let's continue this example and assume that the customer is using the gage block to calibrate a caliper. In general, the tolerances for gage blocks are about 100 times smaller than the tolerances for calipers. As such, the consequences of the risk of falsely accepting the gage block during calibration may be quite small. In this case, a larger PFA may have little impact on the level of risk. As shown in Figure 2, the same gage block calibration, with the same PFA, may have a much higher level of risk if the gage block is used instead to calibrate a micrometer, which has a tolerance approximately five times larger than the tolerance of the gage block.

## 4. Managing Consequences of Risk in Calibration

In some prior work [10], it was shown that it is possible to eliminate the impact of measurement decision risk in calibration by propagating the measurement uncertainty of the calibration into subsequent downstream measurements. That work is recast here considering the updated requirements in ISO/IEC 17015 regarding decision rules.

Let's continue with the example of a micrometer being calibrated with gage blocks. As a reference standard, gage blocks can be used in two different ways. One manner of using gage blocks is to use the calibrated value as the reference value. This approach requires tracking the value from the calibration certificate and generally will improve the measurement uncertainty when using the gage block (see Table 1). Alternatively, the nominal size of the gage block, directly marked on the gage block, can be used as the reference value. This approach provides for some simplicity in use but carries a penalty in that the measurement uncertainty must account for the tolerance of the gage block (see Table 2). In addition, the gage block calibration must include an assessment of conformity to the tolerance grade.

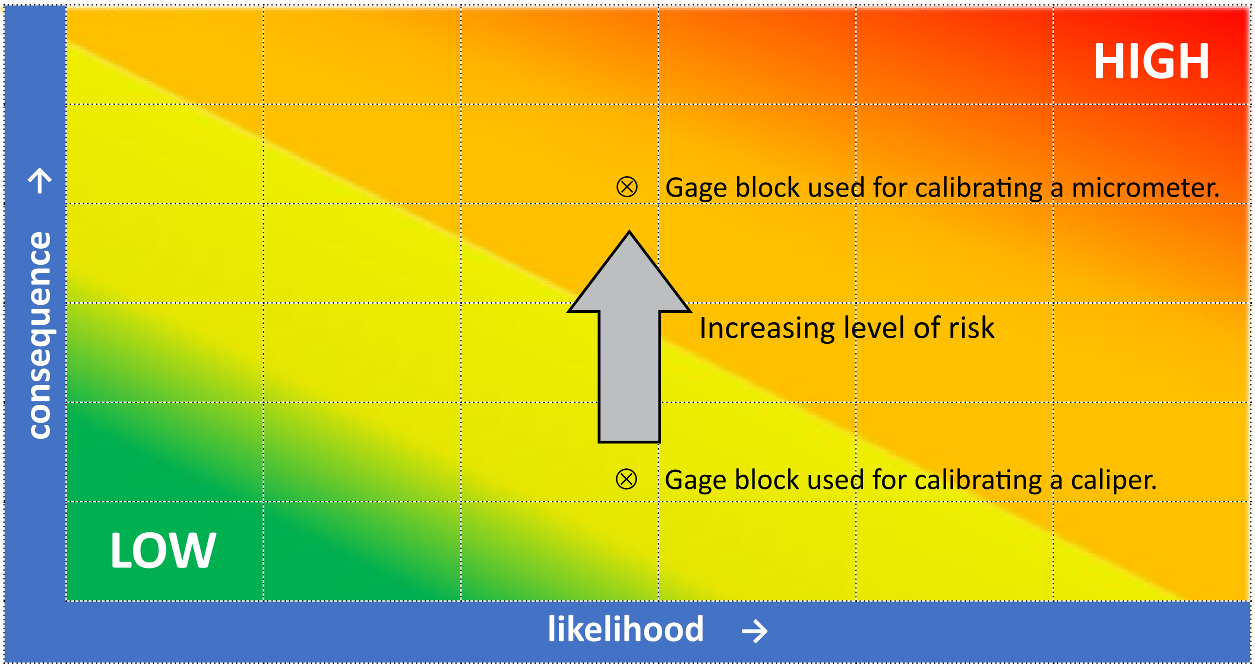


Figure 2. Evaluating the level of risk associated with false accept in the calibration of a gage block. The level of risk is impacted by the changing consequence of risk even when the likelihood (PFA) remains the same.

| Uncertainty Source | Estimated Limit | Divisor | Standard Uncertainty |
|---|---|---|---|
| Reference standard – Calibration uncertainty | 0.06 µm | 2 | 0.03 µm |
| Other contributors | 0.18 µm | 2 | 0.09 µm |

Table 1. Uncertainty budget for micrometer calibration when using the calibrated value of the gage block (values taken from example in [11]).

| Uncertainty Source | Estimated Limit | Divisor | Standard Uncertainty |
|---|---|---|---|
| Reference standard – Tolerance (grade) | 0.14 µm | $\sqrt{3}$ | 0.08 µm |
| Other contributors | 0.18 µm | 2 | 0.09 µm |

Table 2. Uncertainty budget for micrometer calibration when using the nominal value of the gage block (values taken from example in [11]).

When using the gage block nominal value, the gage block is assumed to be within tolerance. During the calibration of the gage block, and the assessment of conformity to that tolerance, a decision rule must have been used. The use of the gage block in the subsequent calibration of the micrometer is one level downstream from the gage block calibration. It is in this micrometer calibration where the consequences of the false accept risk in the gage block calibration appear. The ability to see the consequences of risk pass from one measurement to another is unique in calibration.

In order to use the gage block tolerance as an uncertainty contributor, some assumption must be made that the gage block is indeed within tolerance. The likelihood of that being correct, the PFA, may have been determined in the calibration of the gage block and accounted for in some decision rule. Since the consequences of the false accept risk in the gage block calibration can be seen in the downstream use of the gage block, this creates an opportunity to directly manage and account for the level of risk.

As shown in Table 3, the calibration uncertainty can be included, along with the gage block tolerance, in the uncertainty budget for the micrometer calibration. In this manner, the consequences of the false accept risk (of the gage block calibration) are included in the measurement uncertainty (of the micrometer calibration). This approach absorbs the impact of the false accept risk in the measurement uncertainty and eliminates the need to consider the PFA. If we look back at the risk matrix shown in Figure 1, we have lowered the consequence of the false accept risk to zero such that our level of risk will be acceptable regardless of the likelihood of the risk (the PFA).

There are some assumptions being made here regarding the distributions of the uncertainty contributors and their relative independence. This example also assumed a simple acceptance decision rule was used in the gage block calibration. This technique works particularly well mathematically

| Uncertainty Source | Estimated Limit | Divisor | Standard Uncertainty |
|---|---|---|---|
| Reference standard – Tolerance (grade) | 0.14 µm | $\sqrt{3}$ | 0.08 µm |
| Reference standard – Calibration uncertainty | 0.06 µm | 2 | 0.03 µm |
| Other contributors | 0.18 µm | 2 | 0.09 µm |

Table 3. Uncertainty budget for micrometer calibration that directly accounts for the level of false accept risk in the gage block calibration (values taken from example in [11]).

| Uncertainty Source | Estimated Limit | Divisor | Standard Uncertainty |
|---|---|---|---|
| Reference standard – Tolerance (grade) | 0.14 µm | √3 | 0.081 µm |
| Reference standard – Calibration uncertainty | 0.06 µm | 2 | 0.030 µm |
| Combined standard uncertainty from reference standard | | | 0.086 µm |

Table 4. Examining the uncertainty contribution from the reference standard only when using a simple acceptance decision.

when a simple acceptance decision rule is used due to the relative independence between the conformity assessment and the measurement uncertainty. These assumptions impact the values but do not change the general concept.

This example only considered the false accept risk, not false reject, as it is assumed that the party doing the micrometer calibration has received a calibration certificate for their gage block that shows conformity to tolerance. The risk of false reject, while important, is outside the scope of work presented in this paper.

## 5. Simple N:1 Acceptance

The simple 4:1 acceptance decision rule is the default rule found in US national standards in dimensional metrology [5]. A simple acceptance decision rule does not directly account for the probability of false accept, but as we just saw, the consequences of false accept can be directly accounted for when using simple acceptance. This approach directly controls the level of false accept risk without requiring any further details in a decision rule. In other words, there is no need to determine PFA, or TUR calculations, or guard bands. However, not everyone, and particularly not many customers of a commercial calibration lab, are interested in evaluating measurement uncertainty and propagating the calibration uncertainty downstream. Instead, the consequence of false accept risk can be used to determine useful guidelines for decision rules, particularly when using simple acceptance and establishing acceptable TUR limits.

In Table 4 we look at the measurement uncertainty associated with only the gage block as it propagates into the measurement uncertainty of the micrometer calibration. In a theoretical case of the gage block being calibrated with zero uncertainty (or a practical case where the TUR quite high, e.g. 10), the standard uncertainty associated with the reference standard is 0.081 µm. When the calibration uncertainty is combined in, as shown in Table 4, the impact to the combined standard uncertainty coming exclusively from the reference standard is increased to 0.086 µm, an increase of approximately 6.2 %.

The increase in the combined standard uncertainty associated with only the reference standard is a function of the TUR in the calibration of the reference standard. In this case, the TUR of the gage block calibration can be calculated as:

$$\text{TUR} = \frac{\text{Tolerance}}{\text{Uncertainty}} = \frac{0.14}{0.06} = 2.3$$

The consequence associated with false accept risk in the gage block calibration, where the TUR = 2.3, is a 6.2% increase in the measurement uncertainty associated with the use of the gage block in subsequent measurements. This analysis is expanded to other TUR values as shown in Table 5. Analysis like this can be used to select an appropriate TUR value when using simple acceptance. For example, a TUR = 2.7 means that the increase in uncertainty is less than 5 %, which is often considered insignificant [12]. As mentioned earlier, this analysis is limited to false accept risk for the scope of this paper. In addition, different uncertainty assumptions would change the values in Table 5, but not the general concept.

Managing the consequences of false accept risk may be more useful to some measurement professionals compared to managing the likelihood of the risk. It may as well be easier to talk with customers about the impact of measurement decision risk and not probabilities.

| TUR | Increase in Uncertainty Contribution Associated with the Reference Standard (%) |
|---|---|
| 4 | 2.3 |
| 3 | 4.1 |
| 2.7 | 5.0 |
| 2 | 9.0 |
| 1.9 | 10.0 |
| 1.5 | 15.5 |
| 1.15 | 25.0 |
| 1 | 32.3 |
| 0.78 | 50.0 |
| 0.5 | 100.0 |

Table 5. Impact of TUR in calibration (using a simple acceptance decision rule) on the eventual uncertainty associated with using the calibrated reference standard.

## 6. Conclusion

Decision rules associated with conformity assessment have received more attention since the release of ISO/IEC 17025:2017. Most of the available publications on measurement decision risk focus solely on the likelihood of risk. Understanding the level of risk requires considering both the likelihood and the consequence of risk, and in this paper, it is demonstrated how the consequences of false accept risk in calibration can be used to directly account for the level of risk. It is hoped that the work presented in the paper might encourage others to explore the consequences of measurement decision risk or bring forth other new or different decision rule ideas. This area is fertile for further research and development.

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# Pushing on the Observer Effect

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We've all heard people speak of accuracies and tolerances in more colorful language than what would be expected in a metrology lab. "Plus-or-minus a hand grenade" or, "Close enough for government work" are a few. Some gentlemen that I have worked with in the past often used anatomical references to describe the electrical or mechanical specifications of a device or process, but that only goes so far. When you just eyeball something (whether your observation is accurate or not) by considering what you behold, you exert an influence on its relationship with the universe.  As we have created ever more accurate instruments, we have done so to push past the technological status quo because of a particular need, and then refine them as the state-of-the-art progresses. When electrical instruments were first created, people working with them in the late nineteenth and early twentieth centuries rarely expected high-precision measurements like those that we are used to making now. Laboratory-grade instruments that measured DC voltages at tolerances better than +/-.25% of reading were ahead of the curve back then. The influence of those measuring devices on the parameter that was being observed could be dramatically different depending on the observer, and/or the instrument being used.


A replacement meter movement for a 20,000 ohm-per-volt Simpson VOM.

As a student learning about electricity, I saw an old military documentary about the proper use of a Volt, Ohm, Amp Meter. Back then they were called VOMs. The instructor said that one of the specifications of the VOM he was speaking about was "twenty-thousand ohms-per-volt on DC Voltage ranges." I remember not understanding why this was important, but I tucked that thought away until the day I could make some sense of it.

In the first calibration lab I worked in, we had a set of standard cells like those pictured below.


Model 100 Standard Cells manufactured by The Eppley Laboratory Inc., Newport, RI.

We used them as our voltage standards for the laboratory. They both provided a voltage source of 1.018xx volts DC that was measured by a very high-impedance voltmeter. We had two so that one could be sent out for calibration while we used the other in its absence. Once, an older gentleman in the lab had me observe the high-impedance voltmeter as he used a VOM to measure the standard cell at the same time. The moment his test probes made contact, the readings that I was observing began to steadily decrease, and then recover as he removed his probes. He asked me if I understood what had just happened, and then explained how the VOM had loaded down the standard cell by drawing the current required to get the indication it produced. In those days, the most accurate and sophisticated voltmeters in our lab were VTVMs, or Vacuum Tube Volt Meters. These instruments had very high input impedances and when they were connected to our standard cells, they barely disturbed their quiescent voltages.

Which brings us back to the days of old. Look at this Weston Model 540 DC Volt-Ammeter built in 1895.


A Weston Model 540 DC Volt-Ammeter, circa 1895.

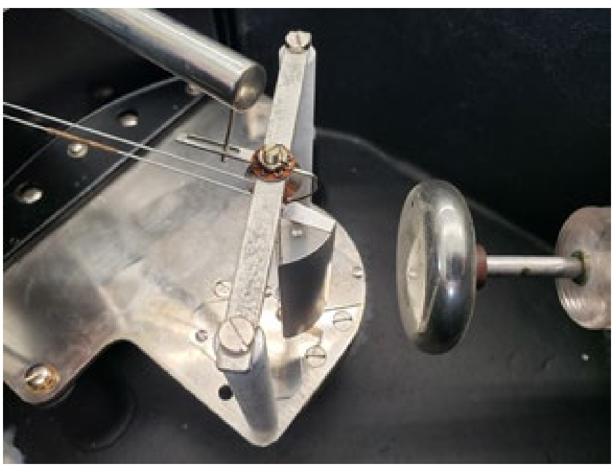
At 100 ohms per volt, this meter would have loaded a circuit down two hundred times more than the VOM my instructor was demonstrating. Ohm's law would say that if it's indicating one volt, it must be drawing ten milliamps. That's not only enough to create a spark, but it would also be quite a burden as compared to the typical digital handheld voltmeters of today that have ten megohm input impedances. Meters currently used for the same measurement would shunt off ten nano amps during the same test. It's no wonder why the laboratory sets depicted in old Frankenstein movies were arcing and sparking, that was probably caused by the kilovoltmeter connections to the circuit!

It takes careful consideration when designing instruments that are not only sensitive but are also innocuous to the circuit being tested. Of the three Ohm's law parameters, current measurement was the earliest and most studied electrical property. Beginning with direct current measurement, instruments were designed with meter movements and shunts that could provide accurate readings from microamps to many thousands of amperes. Direct-current meters are connected in series directly into the path of current flow and so can be construed as being part of the original, pristine circuit path. A voltmeter, when connected to the circuit, creates a path of its own that parallels the "primary" circuit. This creates a circuit with its own budgets, the properties of which may become too outsized to manage directly. High-voltage measurements are an example of this condition. Stresses not present in lower voltage situations can make direct, physical-contact measurement dangerous or impractical in high voltage circuits. The effects of corona and partial discharge can cause leakage currents to flow in the circuit creating carbon paths and other degradations of the circuit. In these scenarios, electrostatic measurements offer an elegant solution.

The instrument pictured below is a Model ESH made by the Sensitive Research Company. It is a three-range, thirty-thousand-volt electro-static voltmeter.

A Sensitive Research Model ESH with high and low ranges selected and meter movement detail.

Its ranges are selected by changing the orientation of a movable electrode that protrudes from the turret at the back of the instrument. On the lowest range the adjustable electrode is positioned at its closest proximity to a moving vane on the meter movement. The higher the measured voltage, the farther the high-voltage electrode is spaced in relation to the movement. Apart from the adjustable electrode, the entire rest of the circuit is connected to ground. This style of electro-static voltmeter made by the Sensitive Research Company was very expensive to manufacture as they were machined from a single block of aluminum. This created an instrument with very small "islands of potential" in its overall design. The top cover of the instrument was gasketed to minimize the ingress of foreign material.



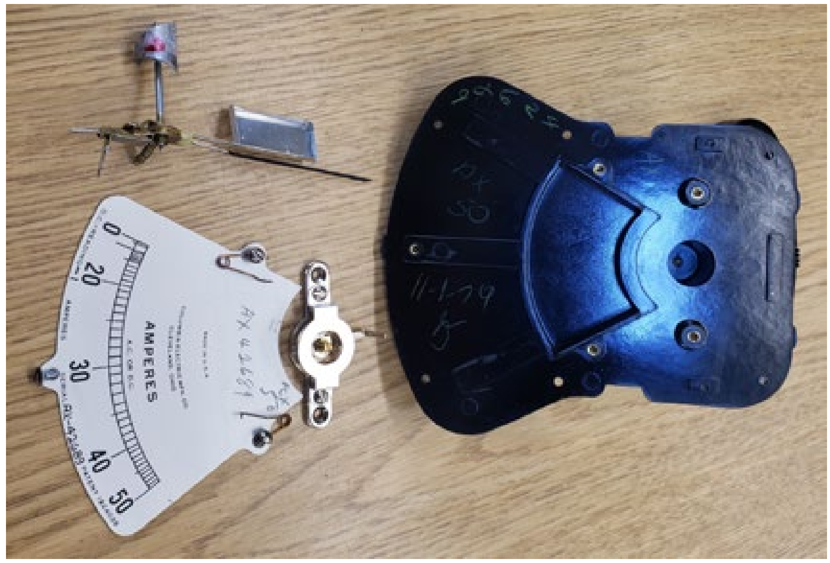
A close-up image showing the electro-static meter movement detail.

The measured input impedance of a perfect electro-static meter movement should be infinite, if that was possible. These meter movements are deflected by static attraction or repulsion. This effect will yield non-linear readings across its arc of measurement. This is due to the relatively weak field-strength of the applied electrical signal at lower voltages. To compensate for this, manufacturers would hand-point each individual meter's scale to achieve the best degree of accuracy for a given meter movement. At higher voltages, the elevated field strength becomes an advantage in the application of this technology. Electro-static meter movements have an added advantage of also being able to measure high-voltage AC test signals as well and do so over a broad range of low frequencies and crest factors. When using these high-voltage instruments, it is very important to allow them to electrically discharge after a measurement is made and to ground all parts of the case and high voltage terminals before directly encountering the de-energized circuit. By virtue of their design, electro-static voltmeters behave like a high-voltage capacitor which requires special safety consideration and good testing practices. While we are on this specific subject, let's pivot a moment and look at another field effect type of meter movement.

Elevated field strengths were also a useful engineering consideration when creating meter movements designed to measure AC current. The instrument below is a clamp-on current meter. It is called a Tong-Test, Model AX made by the Columbia Electric Manufacturing Company. This product was often sold with multiple sets of instrument heads, each with a specific current range that were connected to the base unit depending on the measurement range that was required.

By breaking down the meter movement, we can see that under the scale it uses a damping vane to stabilize

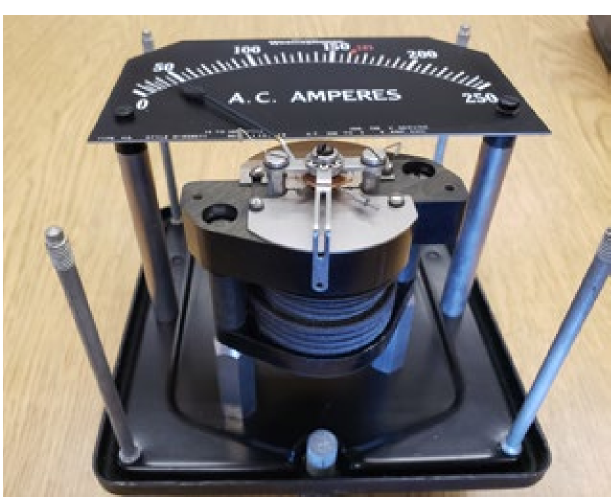
An example of a Columbia Tong Test, Model AX Clamp-on AC/DC Current Meter.



Model AX, meter movement detail.

the pointer when a measurement is being made. Notice that the meter movement itself also has a small, curved triangular vane that occupies the space between the upper and lower pivot and jewel assemblies of the movement. This vane is lowered into the "throat" of the electromagnetic field created by the current transformer on the clamp-on assembly when the meter is connected around a current carrying conductor. The meter is calibrated by bending the small triangular vane in such a way that the entire mechanism creates the best possible deflection for all points in the measurement range. The artistry of creating such movements is similar to that employed in custom muffler shops that auto enthusiasts go to when they want a particular pitch to the sound of their classic cars.

This principle is also the specific reason that most current transformers used in electrical power and distribution circuits are expressed as having ratios of something-to-five. That is because typical AC current meters that are used to measure the output of instrument current transformers utilize meter movements that have a five-amp field coil. AC current meters with five-amp field coils used in the electrical industry have been around for decades, as shown in the picture below. This Westinghouse Type HA AC current meter is like other instruments that have been around for more than one hundred years. When these instruments are connected in circuit, they exhibit an extremely low burden relative to other devices and loads connected in the same circuit.



Westinghouse Type HA AC current meter.

In these last few examples, the observer effect mentioned earlier is of less significance to the testing scenario being observed. On the other end of the spectrum, things like destructive high-potential testing, or scanning-electron microscopy most certainly change the state of the test subject. It seems to be true that as time marches forward our observations are becoming less invasive in the energy spent making them and the ways in which they influence the test specimen.

It may be that devices, like the variety of deep-space telescopes that are now deployed, exhibit the least effect on the portions of the universe they observe as they allow us to witness events at times and places unimaginably far from our point of reference. Thinking of such things has always made me wonder, if some future type of observatory missed seeing something like an alien tree falling on a planet in some far-flung portion of the universe, would it have made a sound?

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### Mecmesin Expands Range Of Torque Testers

Renowned global leader in force, materials, and torque testing equipment, Mecmesin, proudly announces the expansion of its range of software-controlled torque testers. The latest additions to the lineup, the VortexPro and the HelixaPro, allow torque testing up to a capacity of 30 N.m. These compact models feature a precision motor that drives the tester to a specified angle while gradually applying torque to the specimen, measured by a highly accurate ETS torque sensor. With their small footprint, the VortexPro and HelixaPro are perfect for laboratory or production environments where benchtop space is limited.

In line with the new modern Mecmesin branding, the Vortex and Helixa range has received a refreshed look, creating a uniform and cohesive visual identity across the entire product family.

Neil Pryke, U.K. Managing Director, commented, "Innovative engineering and a deep understanding of our customers' needs have come together to create a range of torque testers that not only incorporate the latest technological advancements in VectorPro, our easy-to-use and intelligent test analysis software, but also look great in any laboratory or QC environment. Our products prioritize powerful functionality, intuitive operation, and touchscreen friendliness, ensuring faster, smarter testing with accurate, reliable, and reproducible results."

Designed to meet the most demanding torque measurement applications across a wide spectrum of industries, the Mecmesin range of software-controlled torque testers caters to the diverse needs of both Research and Development laboratories and Quality Assurance environments.

The HelixaPro features a counterbalance mechanism and allows for fine adjustment of the alignment between gripping fixtures. This ensures that torque is applied precisely in-axis, making the HelixaPro the ideal choice for challenging applications where very light torque is being measured. The HelixaPro is ideally suited for measuring the mechanical properties of various small components and assemblies used in medical devices, watches, cosmetics applicators, and bearings to ensure they meet strict quality criteria.

The VortexPro is an all-round torque tester designed to accommodate larger test specimens than the HelixaPro. It excels, for example, when evaluating the closure removal torque of a wide range of specimens such as bottles and containers. Like the HelixaPro, the VortexPro delivers quantitative results with a high degree of repeatability, crucial for effective quality control.

The HelixaPro and VortexPro models incorporate state-of-the-art electronics and a range of high-resolution precision Enhanced Torque Sensors (ETS). With an impressive reading accuracy of 0.5% and a resolution of 1:50,000, these machines enable a broader range of tests to be performed without the need to switch torque sensors. This advancement in technology ensures exceptional torque measurement accuracy, setting a new industry standard.

Both cutting-edge torque testers offer a user-friendly front panel, live torque and angle readings, and precise manual positioning of the rotary table using the multifunction controller. With colored LEDs providing visual cues to indicate the machine's status during testing, these models ensure a seamless testing experience.

Customers also have the possibility to choose the HelixaPro or VortexPro with an optional Touchscreen Controller, designed as a convenient alternative to a desktop or laptop PC. The Touchscreen Controller operates with Microsoft Windows and comes pre-installed with Mecmesin's VectorPro® software, making it ready for immediate use with both models. This seamless integration allows users to streamline their testing process and enhance productivity.

Key Features of VectorPro software:

- Real-time graph plotting
- Immediate display of results
- Full data export
- Customized report generation
- Drag and drop interface
- Personalized workspace
- Secure user accounts
- Batch testing
- Full traceability for FDA 21 CFR Part 11
- Cloud-based sharing of programs & test results

"The new HelixaPro and VortexPro models perfectly complement VectorPro, which many already consider the most intuitive and feature-rich testing software on the market. Solving customer problems is in the Mecmesin DNA, and we are now uniquely positioned to offer a range of torque testing solutions at an affordable price. For the torque market especially, we feel the CFR Part 11 compliance module now available in VectorPro will resonate strongly with many of our medical device and pharmaceutical customers," said John Page, PPT Group Managing Director.

For more information visit www.mecmesin.com.

# NEW PRODUCTS AND SERVICES

## Fairview Microwave Unveils Premium Waveguide Calibration Kits

*New Kits Elevate Precision and Availability in Waveguide Technology*

IRVINE, Calif. – Fairview Microwave, an Infinite Electronics brand and a leading provider of on-demand RF, microwave and millimeter-wave components, introduces its newest lineup of waveguide calibration kits. Designed to calibrate and test microwave devices and systems, these kits are tailored specifically for the waveguide sizes WR-90, WR-75, WR-62, WR-34, WR-28, and WR-22.

Each calibration kit includes two waveguide-to-coax adapters, a waveguide-matched termination, two waveguide short plates, and precision waveguide sections of 1/4λ, 1/8λ, and 3/8λ. The kits offer frequency-range options of 8.2 to 12.5 GHz, 9.84 to 15 GHz, 11.9 to 18 GHz and 17.6 to 26.7 GHz.

In addition, for professionals with specific needs, Fairview has made optional waveguide straight sections available for individual purchase. They are built for long-term reliability, made of either aluminum or brass, depending on the waveguide size.

Unlike other suppliers, Fairview maintains an extensive in-stock range of waveguide calibration kits, eliminating the usual wait time. Despite the superior quality and unparalleled availability, the pricing remains competitive, offering customers exceptional value for their investment.

“These new waveguide calibration kits and straight sections are a testament not only to our dedication to innovation but also to our promise of ensuring product availability and affordability,” said Product Line Manager Kevin Hietpas.

Fairview’s new waveguide calibration kits (https://www.fairviewmicrowave.com/t-waveguide-calibration-kits.aspx) are in stock and available for same-day shipping. For inquiries, please call +1 (949) 261-1920.

## Save Time and Frustration with Ralston Quick-test™

Ralston Quick-test™ is a complete connection system of low volume, high pressure hoses and corresponding fittings and adapters that connect to all standard pressure connections and devices.

Quick-test hoses have a smaller inner diameter than most, which makes them ideal for transmitting high pressure without wasting large amounts of compressed gas or fluid. And because they’re made with a polyamide-reinforced inner core, they can twist and bend without losing volume across the hose. Ralston Quick-test™ adapters are a perfect complement to the hoses, allowing direct connection to male or female NPT, BSPP, Tube Fittings, Metric, AN 37° Flare and CGA 580 fillings without any additional tools or thread sealant.

They can also safely vent pressure while still connected, preventing hose whipping, and because they eliminate the need for wrenching, the threads don’t wear out. No other quick connects offer the level of speed, safety, and compatibility as Ralston Quick-test™.

The Ralston Quick-test™ Connection System is engineered to facilitate fast, leak-free connections for pressure testing, calibration, and leak testing. Standard Quick-test hoses handle up to 6,900 psi of working pressure, while Quick-test XT high pressure hoses can handle up to 10,000 psi. They’re available in pre-packaged kits designed for common applications and standards, or you can create your own solution based on your application. Cut set-up time in half with Ralston Quick-test™.

https://www.ralstoninst.com/ralston-quick-test-system

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# Moving Away from Waterfall Metrology

Michael L. Schwartz
Cal Lab Solutions, Inc.

Over the years, I have had one foot in the metrology/test and measurement world and the other foot in software and software architecture. With two different perspectives, I tend to look at things from multiple angles, which causes me to question everything – even those things we have been doing the same way for hundreds of years.

In the software world, we have the term "waterfall development." Typically, a waterfall development process is very long because it does everything in one giant step. It starts with gathering requirements and then documenting the software specifications. Those specifications are passed on to the development team, who write the application. When it meets the specifications, they call the software done.

Most of the calibration labs I have seen use a waterfall approach to calibration. When an instrument comes into the calibration lab, we assign the work to one technician. The technician looks up the procedure and follows the steps until the unit either passes calibration or is returned out-of-tolerance.

What makes this a waterfall method is the singular approach. One technician works on one instrument until it is finished, then moves on to the next item in the queue. In larger labs, the next item in the technician's queue is usually similar to the previous instrument.

One major exception to this process is in the temperature lab, where the technician typically performs several calibrations simultaneously. It can seem a little crazy at first, but temperature techs have several timers running in their heads as they track all the probes they have in different baths.

This got me thinking, "We need to move away from waterfall metrology, " just like the software industry moved from waterfall to an iterative development model. In this move, we can change some additional things along the way.

First, is the idea that a single technician needs to calibrate 100% of the instrument. In the past, when calibrations were shorter, we could have one technician calibrate everything. Today, many calibrations are hours upon hours of work, and we have computers and databases. We can track who performed what test and when; we can pass the calibration task from one technician to the next in the chain.

We can also include the Henry Ford factory approach to calibration, where a technician performs the same part(s) of a calibration then passes the instrument to the next technician/test station.

Next, is test station configuration. Today, most labs have a rack of equipment meant to do the whole calibration. But if you watch the technician work, he will use 1-3 of the 15 instruments in the rack. With automation and better test station management, the same 15 instruments could be testing 10 or more instruments. This is how the temperature technicians can be so productive. They are running multiple calibrations in parallel.

Finally, automation and why this is part of the automation corner. In the calibration lab, we still think about automation from the waterfall perspective, the all-or-nothing point of view. This is our biggest obstacle and what is preventing metrology production from moving forward at a faster pace.

It is a bold idea for a developer to think, "I don't have to automate all of it!" I can automate just some of it. Focus on automating the longer, time-consuming tasks. If you take a 20-hour calibration and automate just a 4-hour section, decreasing the time from 4 hours down to just 1 hour is still a 75% improvement.

Think about it for a second, using the 80/20 rule. If 20% of test points in a procedure will take 80% of the time to automate in a waterfall environment, it's not very efficient.

By unlocking the automation requirements tied to automating the entire procedure, to a more modular approach of automating what takes the most time, flips the 80/20 rule. Now, those test points that take 80% of the manual calibration time become the focus for automation. They have the biggest cost savings, not just in the calibration time but also in the time it takes to create and test the automation. Plus, those longer tests are usually long on similar instruments, saving even more time as the technique is applied to more and more similar instruments.

In conclusion, by breaking down this monolith of calibration into smaller parts, we can increase efficiency, as we put the pieces back together. We don't always have to think of calibration as a waterfall process. By mixing and matching technicians, lab standards, and automation, process efficiencies can increase exponentially.

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