CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

A Comparison of Deadweight Testers and Digital Pressure Calibrators

More on the *t*-Interval Method and Mean-Unbiased Estimator for Measurement Uncertainty

A Risk Based Approach to Calibration Laboratory Infrastructure Modernization

2018
APRIL
MAY
JUNE

CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

Volume 25, Number 2

www.callabmag.com

FEATURES

DEPARTMENTS

ON THE COVER: Accredited pressure calibration performed at Mensor's calibration laboratory in San Marcos, Texas.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

Jul 8-13, 2018 CPEM. Paris, France. The Laboratoire national de métrologie et d'essais (LNE), in collaboration with the Centre national de recherche scientifique (CNRS) and the Observatoire de Paris, is pleased and proud to host the 2018 Conference on Precision Electromagnetic Measurements in Paris, France. http://www.cpem2018.com/

Jul 23-27, 2018 CMSC. Reno, NV. The Coordinate Metrology Society Conference is an annual event renowned for its comprehensive program of technical white papers and presentations given by industry experts from science/research laboratories and leading manufacturing industries. https://www.cmsc.org/

Aug 26-30, 2018 NCSLI Workshop & Symposium. Portland, OR. This year's Workshop & Symposium, with the theme "Measurements of Tomorrow," promises to be one of the most exciting and valuable - because tomorrow is here. http://www.ncsli.org/aws

Sep 3-6, 2018 XXII World Congress of the International Measurement Confederation (IMEKO). Belfast, Northern Ireland. Hosted by the Institute of Measurement and Control, the UK's specialist Professional Engineering Institute in the fields of measurement, automation and control, and supported by the Institute of Physics, the World Congress will cover all aspects of current research in the field of measurement and will attract some of the worlds' largest companies from the sensor, instrumentation, automation and IoT industries. http://imeko2018.org/

Sep 10-12, 2018 VII International Conference on Speckle Metrology. Janów Podlaski, Poland. The goal of the Speckle2018 conference is to gather scientists, engineers and students who work in the field of speckle metrology and related techniques. http://speckle2018poland.pl/

Nov 4-9, 2018 The 33rd Annual Meeting of the American Society for Precision Engineering (ASPE). Las Vegas, NV. The Annual Meeting is the place to discover new concepts, processes and products through people who are experts in precision technology. The network encourages the exchange of ideas with experts in the field, and ASPE is the place to develop new contacts and meaningful business relationships. http://aspe.net/technical-meetings/33rd-annual-meeting/

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Subscription fees for 1 year (4 issues)
$50 for USA, $55 Mexico/Canada,
$65 all other countries.
Visit **www.callabmag.com**
to subscribe.

Printed in the USA.

ISSN No. 1095-4791

EDITOR'S DESK

Give Back

Did you know that each issue of this publication is made possible not just because of our advertisers and paid subscribers, but because of readers like you. We get to publish because a reader contributed an article.

You have decades of knowledge holed up in your head, experiences of failure and success. Never underestimate the force of resources it took, such as time spent with colleagues, customers, mentors, educators, and employers. Share the wealth of your combined years of learning and doing by sitting down and documenting it—contribute!

Putting aside the soap box, we have a nice line-up of articles for you. For starters, Sean Nielson of Ametek provides a quick, but informative "Comparison of Deadweight Testers and Digital Pressure Calibrators."

Dr. Hening Huang contributed a meaty discussion on measurement uncertainties, "More on the *t*-Interval Method and Mean-Unbiased Estimator for Measurement Uncertainty Estimation." Dr. Huang's papers are a little different than the typical articles we publish, in that they show some of the math that happens under the covers. Our publisher often takes issue with small sample sizes and metrologists who say "All you have to do is take five measurements." I believe many of you will find value in this article.

And to round out this issue, we have a management article contributed by Kevin Abercrombie titled, "A Risk Based Approach to Calibration Laboratory Infrastructure Modernization."

If you're looking into brushing up on your skills or extending your knowledge in something else less familiar, I've included a list of Online & Independent Study courses in this issue. The list is by no means exhaustive. I encourage feedback and additions to this list, as well as any updates for educational programs/degrees we have listed on **www.callabmag.com**. Email them to office@callabmag.com.

Many thanks to our contributors! And as always…

Happy Measuring,

Sita Schwartz

Nov 12-16, 2018 International Conference on Precision Engineering (ICPE). Kamakura, Japan. The aim is to provide an international forum for experts to promote, share, and discuss various issues and developments in the field of the precision and related engineering. http://www.scoop-japan.com/kaigi/icpe2018/

Nov 13-16, 2018 General Conference on Weights and Measures. Paris, France. The kilogram, ampere, kelvin, and mole will be redefined at this meeting. It is expected that this meeting will agree the redefinition of the SI. As part of this Conference, BIPM will be organizing a number of activities, including a press conference, to mark the occasion and are looking to broadcast the event live. https://www.bipm.org/en/cgpm-2018/

SEMINARS: Dimensional

Aug 13-14, 2018 Hands-On Gage Calibration and Repair. Portland, OR. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Aug 16-17, 2018 Hands-On Gage Calibration and Repair. San Francisco, CA. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Sep 11-12, 2018 Hands-On Gage Calibration and Repair. Indianapolis, IN. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Sep 13-14, 2018 Hands-On Gage Calibration and Repair. Chicago, IL. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Oct 15-16, 2018 Hands-On Gage Calibration and Repair. Las Vegas, NV. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Oct 18-19, 2018 Hands-On Gage Calibration and Repair. Albuquerque, NM. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Nov 13-14, 2018 Hands-On Gage Calibration and Repair. Akron, OH. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Nov 15-16, 2018 Hands-On Gage Calibration and Repair. Toledo, OH. IICT. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Course includes hands on calibration and repairs and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

SEMINARS: Electrical

Sep 24-27, 2018 MET-301 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. http://us.flukecal.com/training

Oct 22-25, 2018 MET-101 Basic Hands-on Metrology. Everett, WA. Fluke Calibration. This course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. We will also teach various techniques used to make good measurements using calibration equipment. http://us.flukecal.com/training

SEMINARS: Flow / Pressure

Oct 1-3, 2018 Flow Measurement and Calibration. Munich, Germany. TrigasFI GmbH. This Training Seminar is intended for individuals with responsibility to select, calibrate and use liquid and gas flowmeters. It is designed to be an objective, independent review and evaluation of the current state of flow metering and calibration theory and technology for flowmeter users and metrologists. http://trigas.de/

Nov 12-16, 2018 Gas Flow Metrology. Delft, Netherlands. VSL Dutch Metrology Institute. http://vsl.nl/en/services/training

Electric Current Measurement

DS Series Current Transducers

DANISENSE

±300A to ±8000A, high accuracy for Power Analyzers and improved performance for Power Amplifiers

- Very high absolute amplitude and phase accuracy from dc to over 1kHz
- Low signal output noise
- Low fluxgate switching noise on the pimary
- Enhanced electrostatic shielding to increase rejection of primary dV/dt coupling
- Increased operating temperature range
- Reduced mechanical dimensions
- Options: Voltage Output Signal; Calibration Winding
- Amplitude and Phase measurement to 300kHz included with each head

DS200

DS2000

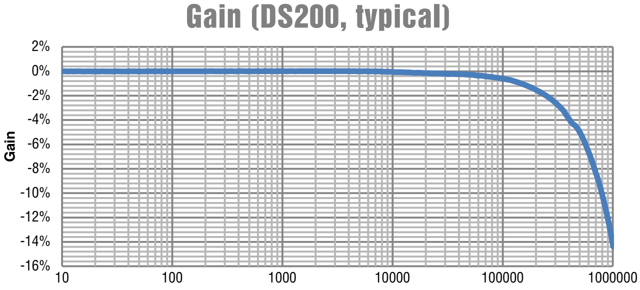
	DS200	DS600	DS2000	DS5000
Primary Current, rms	200A	600A	2000A	5000A
Primary Current, Peak	±300A	±900A	±3000A	±7000A
Turns Ratio	500:1	1500:1	1500:1	2500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†	2A/±3.2A†
Overall Accuracy	0.01%	0.01%	0.01%	
Offset	<20ppm	<10ppm	<10ppm	<5ppm
Linearity	<1ppm	<1ppm	<1ppm	<1ppm
Operating Temperature	-40 to 85˚C	-40 to 85˚C	-40 to 85˚C	0 to 55˚C
Aperature Diameter	27.6mm	27.6mm	68mm	150mm

Bandwidth Bands for Gain and Phase Error	DS200			DS600			DS2000			DS5000	
	<5kHz	<100kHz	<1MHz	<2kHz	<10kHz	<100kHz	<500Hz	<1kHz	<10kHz	<5kHz	<20kHz
Gain (sensitivity) Error	0.01%	0.5%	20%	0.01%	0.5%	3%	0.01%	0.05%	3%	0.01%	1%
Phase Error	0.2˚	4˚	30˚	0.1˚	0.5˚	3˚	0.01˚	0.1˚	1˚	0.01˚	1˚

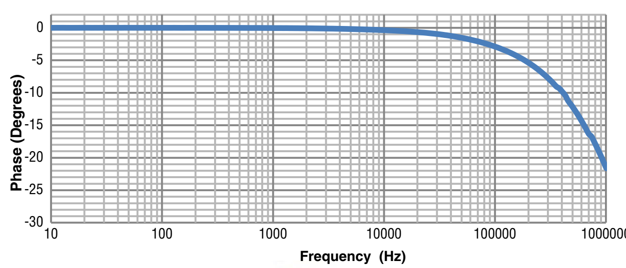
† Voltage Output options available in ±1V and ±10V

Gain / Phase

Gain (DS200, typical)



Phase (DS200, typical)



DSSIU-4 for Multi Channel Systems

4-channel Transducer Interface Unit and Power Supply improved performance for Power Amplifiers

- Power and Signal connections for up to four Current Transducer heads
- Heads may be mixed (e.g.: One DS2000 Head and three DS200 Heads)

DSSIU-4

CALENDAR

SEMINARS: General

Oct 29-Nov 2, 2018 Fundamentals of Metrology. Gaithersburg, MD. NIST. The 5 day Fundamentals of Metrology seminar introduces participants to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into a laboratory Quality Management System. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

SEMINARS: Industry Standards

Jul 24-25, 2018 Internal Auditing. San Francisco, CA. A2LA. This course introduces participants to the internationally-recognized approaches of ISO 19011 Guidelines for Auditing Management Systems for conducting effective internal audits. The course includes easy-to-implement methods for involvement of personnel, continual improvement of the audit process, as well as group exercises to apply the interpersonal skills needed to be an effective auditor. https://www.a2la.org/events/internal-auditing

Aug 15-16, 2018 Internal Auditing. Frederick, MD. A2LA. This course introduces participants to the internationally-recognized approaches of ISO 19011 Guidelines for Auditing Management Systems for conducting effective internal audits. The course includes easy-to-implement methods for involvement of personnel, continual improvement of the audit process, as well as group exercises to apply the interpersonal skills needed to be an effective auditor. https://www.a2la.org/events/internal-auditing

Aug 20-24, 2018 ISO/IEC 17025 Lead Assessor Training. Washington, DC. ANAB. The 4.5-day ISO/IEC 17025 Lead Assessor training course is designed to further develop your understanding of ISO/IEC 17025 and help you understand how to plan and lead an ISO/IEC 17025 assessment. Attendees will gain an understanding of uncertainty, traceability, and PT/ILC and how they are assessed. This course will prepare you to meet technical demands of the assessor while providing practical exercises to aid comprehension. https://www.anab.org/training/17025/lead-assessor

Sep 17-19, 2018 Internal Auditing to ISO/IEC 17025. Austin, TX. ANAB. The 2.5-day Internal Auditing to ISO/IEC 17025 training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of this course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2005 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://www.anab.org/training/17025/internal-auditing

CALENDAR

Sep 20-21, 2018 Internal Auditing. Salt Lake City, UT. A2LA. This course introduces participants to the internationally-recognized approaches of ISO 19011 Guidelines for Auditing Management Systems for conducting effective internal audits. The course includes easy-to-implement methods for involvement of personnel, continual improvement of the audit process, as well as group exercises to apply the interpersonal skills needed to be an effective auditor. https://www.a2la.org/events/internal-auditing

Oct 3-4, 2018 Internal Auditing. Frederick, MD. A2LA. This course introduces participants to the internationally-recognized approaches of ISO 19011 Guidelines for Auditing Management Systems for conducting effective internal audits. The course includes easy-to-implement methods for involvement of personnel, continual improvement of the audit process, as well as group exercises to apply the interpersonal skills needed to be an effective auditor. https://www.a2la.org/events/internal-auditing

Oct 9-10, 2018 Internal Auditing. Atlanta, GA. A2LA. This course introduces participants to the internationally-recognized approaches of ISO 19011 Guidelines for Auditing Management Systems for conducting effective internal audits. The course includes easy-to-implement methods for involvement of personnel, continual improvement of the audit process, as well as group exercises to apply the interpersonal skills needed to be an effective auditor. https://www.a2la.org/events/internal-auditing

Oct 10-11, 2018 Introduction to ISO/IEC 17025. San Antonio, TX. ANAB.The 1.5-day Introduction to ISO/IEC 17025 training course will help attendees understand and apply the requirements of ISO/IEC 17025:2017. Attendees will examine the origins of the standard and learn practical concepts such as document control, internal auditing, proficiency testing, traceability, measurement uncertainty, and method witnessing. https://www.anab.org/training/17025/intro

Nov 5-9, 2018 ISO/IEC 17025 Lead Assessor Training. San Diego, CA. ANAB. The 4.5-day ISO/IEC 17025 Lead Assessor training course is designed to further develop your understanding of ISO/IEC 17025 and help you understand how to plan and lead an ISO/IEC 17025 assessment. Attendees will gain an understanding of uncertainty, traceability, and PT/ILC and how they are assessed. This course will prepare you to meet technical demands of the assessor while providing practical exercises to aid comprehension. https://www.anab.org/training/17025/lead-assessor

SEMINARS: Management & Quality

Jul 11-12, 2018 Reducing Risk in Conformance Decisions. Minneapolis, MN. WorkPlace Training. This two-day course covers metrology's influence throughout a product's lifecycle, where it fits within a Quality Management System (QMS), such as ISO 9001, and provides the technical and mathematical details required to evaluate decision risk for measurement-based decisions. For more information, call 612-308-2202 or e-mail: info@wptraining.com. http://wptraining.com.

Nov 14, 2018 Documenting Your Quality System. Frederick, MD. A2LA. During this course, the participant will gain an understanding of the basic concepts of management system documentation structure, content, and development. The participant will also practice developing processes, Standard Operation Procedures, and applying mechanisms needed to control, review, and update documents on an ongoing basis. https://www.a2la.org/events/documenting-your-quality-system

Nov 15, 2018 Management Review. Frederick, MD. A2LA. This course is designed for managers and executive management who are seeking to comply with management system requirements of international conformity assessment standards, e.g., 17025, 17034, 15189, etc., using the management review tool. The course focuses on key concepts such as: process-based approach, risk management, performance metrics and continuous improvement. Specific attention on impartiality will be discussed. https://www.a2la.org/events/management-review

SEMINARS: Mass & Weight

Jul 26, 2018 Calibration of Weights and Balances. Port Melbourne, VIC. Australian NMI. This one-day course (9 am to 5 pm) 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. http://www.measurement.gov.au/Services/Training/Pages/default.aspx#

Oct 15-26, 2018 Mass Metrology Seminar. Gaithersburg, MD. NIST. The Mass Metrology Seminar is a 2 week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the trainee performs measurements by applying procedures and equations discussed in the classroom. Successful completion of the Fundamentals of Metrology Seminar is a prerequisite for the Mass Metrology Seminar. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

SEMINARS: Measurement Uncertainty

Aug 17-18, 2018 Measurement Uncertainty per ILAC P14 Guidelines. Baltimore International Airport. WorkPlace Training. This workshop introduces basic measurement uncertainty and traceability concepts. The concepts taught are then put in practice by developing sample measurement uncertainty budgets. Call 612-308-2202 or visit: http://wptraining.com/

Aug 21-28, 2018 MET-302 Introduction to Measurement Uncertainty. Everett, WA. Fluke Calibration. This course will teach you how to develop uncertainty budgets and how to understand the necessary calibration processes and techniques to obtain repeatable results. http://us.flukecal.com/training

Sep 20-12, 2018 Fundamentals of Measurement Uncertainty. Minneapolis, MN. ANAB. Attendees of the 2-day Fundamentals Measurement Uncertainty training course will learn a practical approach to measurement uncertainty applications, based on fundamental practices. Measurement uncertainty for both testing and calibration laboratories will be discussed. Attendees will gain an understanding of the steps required, accepted practices, and types of uncertainties that need to be considered by accredited laboratories. https://www.anab.org/training/17025/fundamentals-of-measurement-uncertainty

SEMINARS: Pressure

Sep 10-14, 2018 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. http://us.flukecal.com/training

SEMINARS: Software

Jul 30-Aug 3, 2018 TWB 1051 MET/TEAM® Basic Web-Based Training. Fluke Calibration. This web-based course presents an 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 recording the information you need to manage your lab assets routinely, consistently and completely. https://us.flukecal.com/training

Aug 6-10, 2018 Metrology.NET Training. Denver Area, Colorado. Cal Lab Solutions, Inc. This 5-day training event will provide an understanding of Metrology.NET and demonstrate how you can utilize it in your lab. Participants will learn to develop drivers, test procedures, debug, and integrate uncertainty spreadsheets. Training meant for those with an understanding of the calibration lab as well as basic programming. http://www.metrology.net

Aug 6-10, 2018 TWB 1031 MET/CAL® Procedure Development Web-Based Training. Fluke Calibration. Learn to create procedures with the latest version of MET/CAL, without leaving your office. This web seminar is offered to MET/CAL users who need assistance writing procedures but have a limited travel budget. The course is designed for those who are directly involved in the operation of

MET/CAL calibration software and are required to write or modify procedures. https://us.flukecal.com/training

Aug 21-23, 2018 VNA Tools Training Course. Charlottesville, VA. Federal Institute of Metrology METAS. VNA Tools is a 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

Sep 10-14, 2018 MC-207 Advanced MET/CAL Procedure Writing. Everett, WA. This five-day in-depth workshop is for experienced MET/CAL programmers who wish to enhance their procedure writing skills. Students will focus on the use of instrument communication with the IEEE, PORT, VISA, MATH and LIB FSCs, the use of memory registers in procedures, and will create a complex procedure using live instrumentation. http://us.flukecal.com/training

Oct 1-5, 2018 TWB 1051 MET/TEAM® Basic Web-Based Training. Fluke Calibration. This web-based course presents an 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 recording the information you need to manage your lab assets routinely, consistently and completely. https://us.flukecal.com/training

Oct 8-12, 2018 TWB 1031 MET/CAL® Procedure Development Web-Based Training. Fluke Calibration. Learn to create procedures with the latest version of MET/CAL, without leaving your office. This web seminar is offered to MET/CAL users who need assistance writing procedures but have a limited travel budget. The course is designed for those who are directly involved in the operation of MET/CAL calibration software and are required to write or modify procedures. https://us.flukecal.com/training

SEMINARS: Temperature

Sep 17-19, 2018 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. http://us.flukecal.com/training

ONLINE & INDEPENDENT STUDY

CERTIFICATIONS

ASQ CCT Exam Preparation Program. Learning Measure. This program contains courses that cover all aspects of the ASQ Certified Calibration Technician exam body of knowledge. http://www.learningmeasure.com/.

Certified Calibration Technician Certification Preparation - Web-Based. ASQ. This self-paced course covers the material you will see on the CCT exam. It includes a practice test based on the CCT Body of Knowledge. https://asq.org/training/catalog

Certified Calibration Technician – Self-study Course. J&G Technology has developed a self-study course to assist you in passing the ASQ CCT exam. http://www.jg-technology.com/selfstudy.html.

Certified Calibration Technician Prep – Online. QC Training. Using the same materials used in our 3-day classroom training, students prepare for ASQ"s examination for Certified Calibration Technician. https://qctraininginc.com/

DIMENSIONAL

Basic Dimensional Measurement Tools – Self Directed Learning. QC Training. With this program, workers will master the essentials of handling, applying and reading the most common gages on today's shop floors – from steel rules to micrometers and height gages. https://qctraininginc.com/

Basic Measurement Concepts Program. Learning Measure. This program introduces basic measurement concepts, the SI system of units, and measurement uncertainty analysis. http://www.learningmeasure.com/

Precision Dimensional Measurement – Online. QC Training. Advance your career with a low-cost, online course in precision dimensional measurement, tools and techniques. https://qctraininginc.com/

ELECTRICAL

AC-DC Metrology– Self-Paced Online Training. Fluke Training. Learn the basic concepts of ac/dc metrology, including the theory and application of thermal transfer standards to measure ac voltages and currents, definition of inductance and capacitance, and the measurement of impedance, admittance and immittance. https://us.flukecal.com/training

Electrical Instrumentation for Applied Measurements – OnDemand Complete Internet Course. Technology Training, Inc. This course provides a basic understanding of electrical measurement systems, as well as the engineering concepts for the whole measurement system. https://pubs1.ttiedu.com/node_sku_269329

Precision Electrical Measurement – Self-Paced Online Training. Fluke Training. This course will increase your knowledge of terminology, concepts and procedures to help you become more proficient. https://us.flukecal.com/training

GENERAL

Introduction to Measurement and Calibration – Online Training. QC Training. An easy to access, menu driven curriculum allows the learner to concentrate on the topics specific to their job requirements. For anyone taking measurements, new hires, students or a refresher for technicians. https://qctraininginc.com/

Introduction to Measurement and Calibration – Self-Paced Online Classes. Fluke Calibration. This course instructs the user on basic concepts of measurement and calibration. https://us.flukecal.com/training

Introduction to Measurement and Calibration - Web-Based. ASQ. Satisfy the requirements for ISO 17025 and 16949, FDA,and FAA. You will learn skills including standardization, managing a metrology system, and units and instrumentation of measurements. https://asq.org/training/catalog

Introduction to Metrology - e-Learning. NPL. This course has been designed to introduce metrology, the science of measurement, and explore its value for industry, the economy, science and society. http://www.npl.co.uk/commercial-services/products-and-services/training/e-learning/

Instrumentation for Test and Measurement – OnDemand Complete Internet Course. Technology Training, Inc. (TTI). Course 163 presents basic information on selection, application, calibration and usage of modern measurement systems to measure electrical, environmental and dynamic phenomena. https://pubs1.ttiedu.com/node_sku_269309

Metrology for Cal Lab Personnel – Self-Paced Online Training. Fluke Calibration. A general overview of metrology principles and practices; designed to help calibration laboratory personnel prepare for the American Society of Quality (ASQ) Certified Calibration Technician examination. https://us.flukecal.com/training

Metrology Concepts. QUAMETEC Institute of Measurement Technology. This category contains courses designed to teach the basics that are needed for a well rounded understanding of Metrology. http://www.QIMTonline.com

Metrology Concepts – OnDemand Complete Internet Course. Technology Training, Inc. (TTI). Provides a basic understanding of the wide range of activities encompassed by personnel working in standards and calibration laboratories. https://pubs1.ttiedu.com/node_sku_269326

Safety in the Calibration Lab – Online. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/

Test Equipment Operation and Calibration – Online. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/

INDUSTRY STANDARDS

Assessment to the Requirements of ISO/IEC 17025 – Web-based. ASQ. This course is targeted toward management and what they need to be conformant to the standard. Learn about the requirements of the standard, how to prepare for the audit, how to conduct and audit of calibration suppliers. https://asq.org/training/catalog

Interval Analysis – Online. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/

ISO/IEC 17025 Compliance; Introduction for Technicians – Web-based. ASQ. Learn about the requirements of the standard, how it is applied in an accredited calibration or test laboratory, or organizations simply self-complying to the standard. https://asq.org/training/catalog

ISO 17025 Compliance: Uncertainty Management - Online. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/

Proficiency Testing - Online. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/

MASS

Basic Mass Computer-Based Training. NIST Weights and Measures Laboratory Metrology Program. Free download available in English and Spanish. https://www.nist.gov/pml/weights-and-measures/laboratory-metrology/lab-metrology-training.

MEASUREMENT UNCERTAINTIES

Measurement Uncertainty – OnDemand Complete Internet Course. Technology Training, Inc. Course 132 begins with an introduction to measurement uncertainty and to the terms associated with it. Then the accuracy and limitations of statistics are discussed, with examples of the various types of distributions encountered in statistical tests. A discussion of sources of errors and their classification into random and systematic follow, before presenting the details of using traditional versus expanded uncertainty equations. https://pubs1.ttiedu.com/node_sku_269318

Measurement Uncertainty – Self-Paced Online Training. Fluke Calibration. Learn the fundamental concepts and how to successfully determine measurement uncertainty and quality improvement techniques. https://us.flukecal.com/training

Measurement Uncertainty – Web-based. ASQ. The focus of making quality measurements is to reduce uncertainty where possible, and to increase confidence in the measurements. It doesn't matter where the measurements are made: knowing about measurement uncertainty is important in expressing measurement results in design, manufacturing, or quality in the aerospace, medical device, automotive industry or a calibration laboratory. https://asq.org/training/catalog

Measurement Uncertainty Analysis – Online Training. The QC Group. Targeted for calibration technicians, quality managers, engineers, quality technicians, and other users of uncertainty budgets. https://qctraininginc.com/

The Uncertainty Analysis Program. Learning Measure. This program covers all the courses concerning uncertainty and uncertainty analysis. http://www.learningmeasure.com/

RF MICROWAVE

Basic Antenna Measurement Program. Learning Measure. This program covers concepts associated with basic antenna measurements. http://www.learningmeasure.com/

Basic RF & Microwave Program. Learning Measure. This is an introductory program covering the RF and microwave measurement field. http://www.learningmeasure.com/

VIBRATION

Vibration and Shock Testing. Equipment Reliability Institute. Power Point text and photo slides plus animations and video clips teach you about vibration and shock basics, control, instrumentation, calibration, analysis and sine and random vibration testing, as well as ESS, HALT and HASS. http://equipment-reliability.com/training/distance-learning/

Vibration and Shock Test Fixture Design – OnDemand Complete Internet Course. Technology Training, Inc. Course 157 starts with a basic introduction to shakers and vibration testing. General considerations in fixture design are discussed next, along with an introduction to instrumentation and sinusoidal vibration testing, as they apply to the fixture design and evaluation process. https://pubs1.ttiedu.com/course_outline?tid=10

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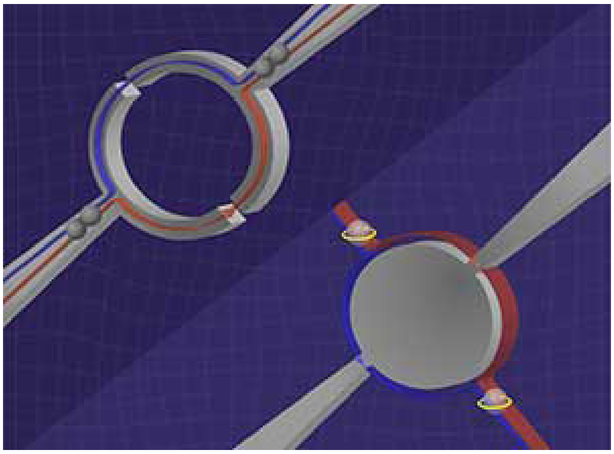


Image: Courtesy of NPL

New Quantum Device Set to Support Measurement Standards of the Electrical Current

An international collaboration, including researchers from the National Physical Laboratory (NPL) and Royal Holloway, University of London, has successfully demonstrated a quantum coherent effect in a new quantum device made out of continuous superconducting wire – the Charge Quantum Interference Device (CQUID).

April 9, 2018, NPL NEWS - This research is an important milestone towards a robust new quantum standard for the electric current, and could be capable of disseminating the new definition of the ampere, which is expected to be decided on by the global measurement community as part of the redefinition of the international system of units (SI) later this year.

As published in Nature Physics*, the device acts in the opposite way to the better-known superconducting quantum interference device (SQUID), used as an ultrasensitive sensor for magnetism. Instead of sensing a magnetic field via its influence on the current flow (moving charge) like a SQUID, the CQUID works seemingly in the opposite way, sensing charge as a result of quantum interference due to the flow of magnetic flux.

Developed throughout the last few decades, the SQUID has gone onto be commonly used in a variety of fields, from medical imaging, geological prospecting to sensors of gravitational waves. With further research, it is envisioned the CQUID will have a similar broad range of applications in the future as well.

The CQUID demonstrates, for the first time, interference of coherent quantum phase slips (CQPS) in a device made out of more than one CQPS junction. This fundamental quantum circuit element is the dual and opposite to the Josephson junction – based on the Noble Prize winning Josephson effect – and underlines the CQUID's potential.

The CQPS junction is realised in the circuit by embedding a superconducting nanowire in a very high-impedance electrical environment. The team looked to state-of-the-art nanofabrication technologies to demonstrate the device in practice. A superconducting film made from niobium nitride with a total thickness of only 3.3 nanometres was deposited one atomic layer at a time. The film was then patterned into narrow wires just a few nanometres wide.

Sebastian de Graaf, Senior Researcher at NPL and lead scientist of the study said:

"The duality between the CQUID and SQUID devices originates from the fundamental relationship between charge and phase in in quantum mechanics, made possible in these devices with superconducting materials. We can think of it as the charge and magnetic flux, or the superconductor itself and the vacuum (insulator) around it, suddenly having the opposite roles.

"This opens up the potential for a new broad range of technologies, with the interchanged roles of electrical current and voltage in a CQPS circuit compared to a Josephson junction, leading towards an equally precise and robust standard for current as the fundamental quantum standard for voltage, which today is realised by arrays of Josephson junctions."

Oleg Astafiev, Professor of Physics at Royal Holloway, University of London, and Visiting Professor at NPL, concludes:

"The results also show that the materials we are using can now be made with high enough precision and reproducibility to allow for multiple, nominally similar, CQPS junctions in the same device. This has been very challenging in the past, but with modern nanofabrication technologies this has now become possible. This is very promising for the development of sensors and metrology dual to that which already exists today based on the Josephson junction."

*https://www.nature.com/articles/s41567-018-0097-9\

Source: *http://www.npl.co.uk/news/new-quantum-device-set-to-support-measurement-standards-of-the-electrical-current*

Fluke Calibration Publishes Second Annual Calibration and Metrology Compensation Survey Results

Everett, Wash., May 17, 2018 – Fluke Calibration has released the results of their second annual Calibration and Metrology Compensation Survey. Data collected in this survey shows median annual base salary information across multiple industries and disciplines in the field of metrology in the United States, and how those incomes differ between educational backgrounds, ranging from high school diploma to doctorate degree and including years of service and job roles, such as metrologist, calibration manager, calibration technician, metrology technician, or calibration engineer.

Invitations to participate in the survey were circulated via email and on social media. The survey included 17 questions about respondents' geographic location; type of organization, industry, and lab; gender; job title; education and years of experience; salary; and workload. Salary estimates listed in the report are based on median values by volume of pay ranges selected.

"We're pleased to be able to provide valuable insights for members of the calibration and metrology community for a second year," said Dave Postetter, director of marketing for Fluke Calibration. "Having multiple years of data presents us with richer insights into the compensation landscape in metrology today. It also helps us keep a pulse on issues related to how job titles or location of employees impact pay, as well as to understand relationships between compensation and workload or size of calibration facilities. We feel that measuring these variables helps metrology professionals better navigate professional development paths."

The results of the 2018 Calibration & Metrology Compensation Survey can be found at https://us.flukecal.com/metrology-compensation-survey.

NIST Team Shows Tiny Frequency Combs Are Reliable Measurement Tools

April 25, 2018, NIST News – In an advance that could shrink many measurement technologies, scientists at the National Institute of Standards and Technology (NIST) and partners have demonstrated the first miniaturized devices that can generate desired frequencies, or colors, of light precisely enough to be traced to an international measurement standard.

The researchers combined a pair of frequency combs, a tunable mini-laser, and electronics to create an optical frequency synthesizer. The advance transfers the capability to program optical frequencies from tabletop-scale instruments to three silicon chips, while retaining high accuracy and precision.

Just as radio and microwave chips powered the electronics revolution, the miniaturization of optical frequency synthesizers to make them portable and suited to high-volume fabrication should boost fields such as timekeeping, communications, trace gas monitoring and astronomy.

The prototype synthesizer is described in the journal Nature, in a paper* posted online April 25. Frequency combs are a Nobel-honored technology developed at NIST that are crucial to the latest experimental atomic clocks.

"Nobody knew how to make an optical frequency synthesizer using little chips," NIST co-author Scott Papp said. "This is the first breakthrough to show you can do this. Until now, no one's ever used a chip-scale frequency comb to do metrology that's fully traceable to an international standard."

The project was led by NIST physicists in Boulder, Colorado, with one comb chip made at California Institute of Technology (Caltech in Pasadena, California) and the second comb chip made at NIST's Center for Nanoscale Science and Technology (in Gaithersburg, Maryland). The University of California at Santa Barbara developed a programmable semiconductor laser chip.

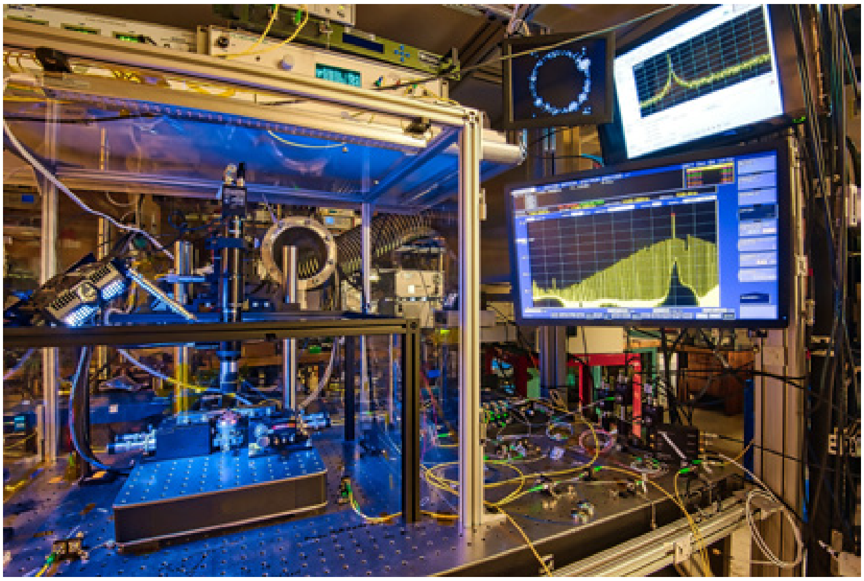
Each of the three chips is about 5 millimeters by 10 millimeters. With further advances in materials and fabrication, the chips will likely be packaged together by one of NIST's partner institutions, Papp said.

In a full-size tabletop frequency comb—typically assembled by hand from metal and glass components—laser light circulates inside an optical cavity, a specialized set of mirrors, to produce a set of equally spaced lines that looks like a hair comb in which each "tooth" is an individual color. In the chip-based versions, the cavities are flat, round racetracks that are fabricated on silicon using automated techniques similar to those used in making computer chips.

The new optical synthesizer uses only 250 milliwatts (thousandths of a watt) of on-chip optical power—much less than a classic, full-size frequency comb.

The synthesizer output is the programmable laser, whose lightwave oscillations serve as optical clock ticks traceable to the SI second, the international standard of time based on the microwave vibrations of the cesium atom. The output laser is guided by the two frequency combs, which provide synchronized links between microwave and optical frequencies.

Each comb is created from light emitted by a separate, single-color "pump" laser. The NIST comb is 40 micrometers



Composite photo of the test bed for NIST's chip-based optical frequency synthesizer. A key component, NIST's frequency comb on a chip, is mounted in the set-up on the lower left. A sample output of the programmable synthesizer, an optical frequency spectrum, is shown at middle-right. The synthesizer components provide for further integration into easily portable packages. Credit: Burrus/NIST (millionths of a meter) in diameter. This comb has wide spacing between the teeth but can calibrate itself by spanning an octave—which, as in music, refers to the interval between two notes that are half or twice the frequency of each other. This feature calibrates the synthesizer.

The racetrack is a custom waveguide made of silicon nitride, which offers special properties that broaden the spectrum of light, concentrate the light in a small area to boost intensity, can be tuned through changes in geometry, and can be made like computer chips by lithographic techniques.

The Caltech comb is physically larger, about 100 times wider and made of fused silica. But this comb's teeth are much finer and span a much narrower wavelength range—in the 1550 nanometer band used for telecommunications, the focus of the synthesizer demonstration. The spacing between the teeth is a microwave frequency that can be measured and controlled relative to the SI second. Through a digital mathematical conversion process, this fine-toothed comb identifies stable, accurate optical frequencies within the wider spacing of the calibrated NIST comb.

Thus, the two combs function as a frequency multiplier to convert the clock ticks from the microwave to the optical domain while maintaining accuracy and stability.

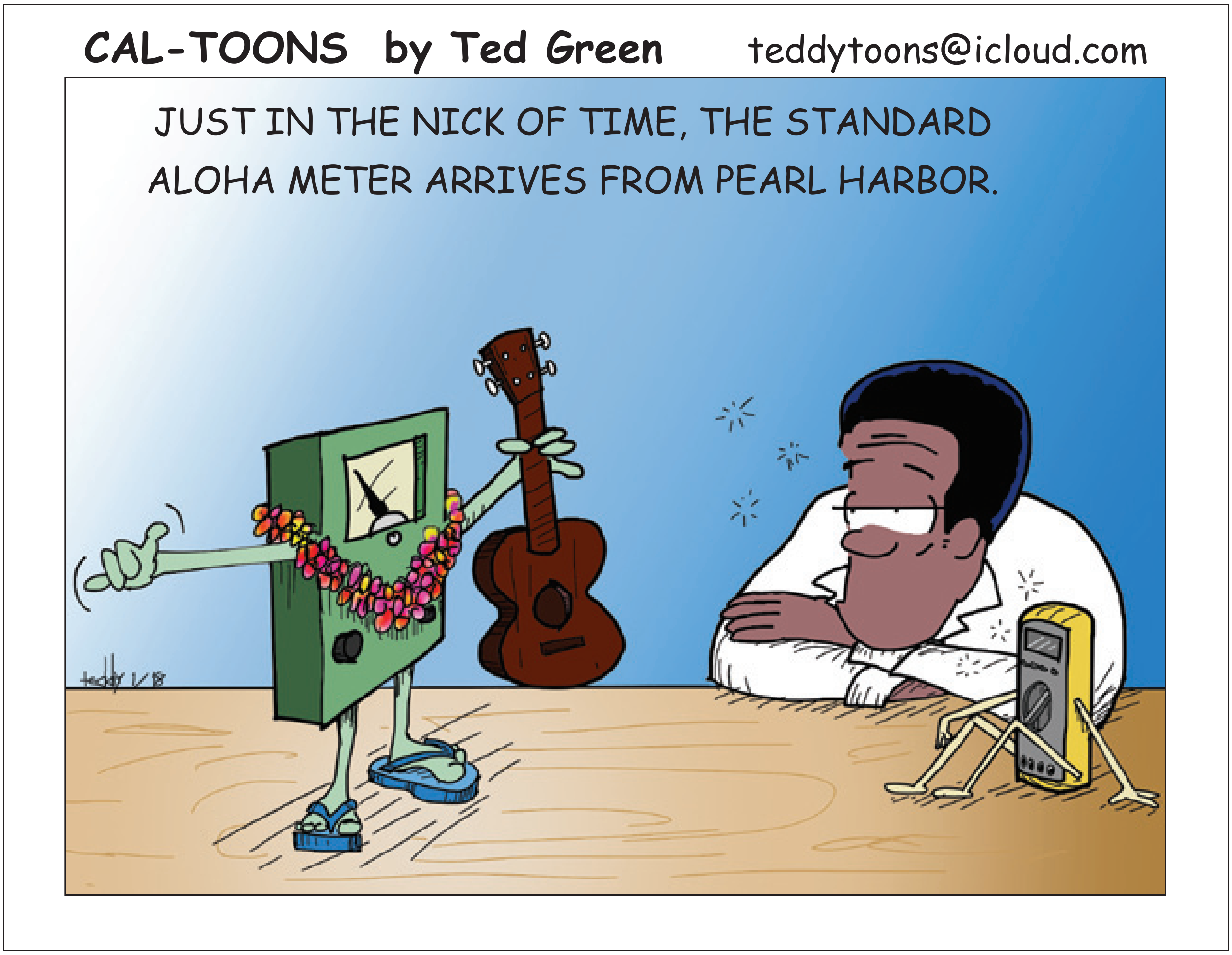
The research team demonstrated the system by synthesizing a range of optical frequencies in the telecom band and characterizing the performance with a separate frequency comb derived from the same clock. Researchers demonstrated the system architecture, verified the accuracy of the frequency synthesis, and confirmed that the synthesizer offered stable synchronization between the clock and the comb output.

The research was funded in part by the Defense Advanced Research Projects Agency. The project is also part of a broader "NIST on a Chip" effort** to make the instruments needed for NIST measurements and standards more portable, cost-efficient and suitable for mass production.

* https://www.nature.com/articles/s41586-018-0065-7

** https://www.nist.gov/pml/productsservices/nist-chip-portal

Source: *https://www.nist.gov/news-events/news/2018/04/nist-team-shows-tiny-frequency-combs-are-reliable-measurement-tools*



JofraCloud is a new way to perform remote reading and setting of Jofra temperature calibrators over an unlimited distance. The data is presented as a copy of the calibrator's display, and can be viewed at jofracloud.com. The webpage is accessible via a browser on any device — PC, laptop, tablet, or smartphone.

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A Comparison of Deadweight Testers and Digital Pressure Calibrators

Sean Nielson
AMETEK Sensor, Test & Calibration

When choosing which instrument to use when calibrating pressure, the two most popular choices are deadweight testers and digital pressure gauges/calibrators with a pressure comparator. Each has its advantages and disadvantages.

The deadweight tester has long been the standard for pressure calibration. However, advancements in technology have led to the development of digital pressure standards worthy of consideration in lieu of a deadweight tester. Understanding how to contrast the two technologies is key to selecting the appropriate solution.

Accuracy

Deadweight testers are systems that physically generate a known pressure. They may also be used as gauges to accurately measure system pressure. These devices do not require a display, as the combination of the masses is used to determine the output pressure. They operate under the simple formula that pressure is equal to force applied over a known area. Deadweight tester output is typically very accurate, even at its lower ranges. Industrial deadweights are available with accuracies to ±0.015% of reading.

By contrast, digital pressure standards must be combined with a pressure source to generate a known pressure. Without the capability of producing pressure, the digital standards are technically gauges. However, in the market, they may be called calibrators to distinguish them from the lower classes of digital indicators.

These digital devices are typically available in accuracies as a function of their full scale, such as ±0.050% of full scale (FS). However, advancements in technology have led to some instruments specified as a function of the reading, like deadweight testers. Accuracies are available as low as ±0.025% of reading.

Site Corrections

When comparing accuracy or uncertainty, an important factor to consider is site corrections. Because deadweight testers are physical standards, they are subject to effects that digital standards are not. One major effect is gravity. The force of gravity on the masses of a deadweight tester varies based on distance from the Equator and elevation. For example, a deadweight using the same exact mass will generate a different pressure at Houston, TX than Denver, CO. The effect is substantial enough that it can alter the output to a value that is outside of the tolerance of the tester.

Users have two options to correct for this. They can either have the unit calibrated to their local gravity, or to International Mean Gravity (980.665 gals) and then calculate a correction factor for the work site. Digital standards are not affected by gravity, so such correction is not necessary.

A second site factor to consider is temperature. While the temperature effect on a deadweight tester is not considerable, the additional error should be calculated and accounted for. Many digital gauges and calibrators are subject to temperature effects, which may be significant. The manufacturer's specifications should offer this information, allowing users to calculate a total error for their local conditions. Higher quality digital standards include temperature compensation so that there is no effect on the accuracy of the device.

Other Considerations

Digital devices typically will have other functions that are very beneficial in completing certain tasks. These may include the ability to measure mA in a loop, source and measure the loop, and read temperature. Firmware functions may include special modes for relief/safety valve testing, peak measurement recording, scaling, error calculations, or data logging.

In addition to the onboard functions, manufacturers may include software with these devices to allow for automated recording of test results, generation of calibration records, or review and analysis of data. Deadweight testers do not offer such additional functions so additional equipment may be necessary to complete these tasks.

Additionally, digital pressure gauges will typically offer the capability to easily change engineering units (for example: psi, bar, kPa, H2O). This is particularly useful in workshop or lab settings in which various devices using different engineering units may be tested. Because deadweight testers utilize specific masses to produce an output, those masses are dedicated to specific engineering units while other mass sets are required to produce useable values of other engineering units.

Primary vs. Secondary Standards

Deadweight testers are primary standards. That is because they are based solely upon physical parameters, and the pressure measurement is not translated into an electronic or analog signal. Since they are a physical standard, they can be made to cover wide pressure ranges using different masses and effective area components.

Conversely, these units are bulkier and much heavier than most digital standards. They are often more difficult to set up and require more training to become an efficient user than would be the case for a digital pressure calibration system. However, because of the stable, regulated output, technicians can become proficient in the use of these testers and can complete a calibration in a very reasonable time.

Digital pressure gauges are secondary standards, because the pressure is translated into an electronic signal using a transducer. They also may be considered as transfer standards, as they are used on site and then checked against a primary standard on a regular basis.

Unlike deadweight testers, digital standards have limited ranges due to the sensors used in their construction. Multiple units may be necessary to cover large pressure ranges. Even if multiple units are needed, the overall size and weight of the digital system will typically be less than that of a deadweight tester. Because they do not generate a pressure, some consideration needs to be given to the portability of the pressure source.

If the pressure source is a handpump or jack pump, care must be taken to ensure a stable pressure is applied to the instrument under test and to the reference standard. Additionally, training is required such that the technician identifies and understands system indications such as a temperature change, adiabatic effects, and entrained air.

Cost of Ownership and Other Factors

One final matter to consider when evaluating the deadweight testers versus digital gauges is the overall cost of ownership and long-term monetary benefit. Deadweight testers typically cost more to purchase than a digital pressure system.

In addition to the initial purchase cost, the calibration cost for a deadweight tester is typically more than a digital standard. However, in general, deadweight testers will last longer than digital devices, and their higher accuracy may result in smaller errors throughout a system. These reduced errors may result in a higher monetary benefit.

When considering a change from one technology to the other, all factors should be considered, including a proper support and training program for the technicians and understanding the complete accuracy/uncertainty specifications for the units.

A digital to deadweight change would increase stability and accuracy, and cover a wider pressure range. However, corrections for gravity and temperature must be applied. A deadweight to digital change would increase portability, reduce purchasing and operating costs, add the ability to read directly in multiple pressure units, remove requirement to adjust for gravity, may be fully temperature compensated, and will include useful functions and features. However, they are not as accurate, may not last as long, and are not primary standards.

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AMETEK Sensors, Test & Calibration is among world leaders in calibration instruments for pressure, temperature, and process signals. For more information about AMETEK STC's products, please visit ametekcalibration.com.

	Deadweight Primary Standard
●	Higher accuracy (0.015%).
●	Much higher accuracy at lower pressures below 9 psi / 250 "H_2O.
●	One unit covers a wide pressure range.
●	Much better pressure stability, "regulated output."
○	Must apply corrections to achieve high accuracy.
○	Accuracy affected by ambient temperature, not specified below 0° C.
○	Slower to setup and more complex to operate.
○	Heavier.
○	More expensive to purchase and own.
●	No power required.
○	No software.
○	One pressure unit.
○	Cumbersome to set small or specific pressure values.
●	Longer lifetime.
○	Pressure only, may need other equipment for task.

Figure 1. Primary Standard: AMETEK Type T Deadweight Tester

	Digital Pressure Standards with Comparator (pump) or Systems Secondary or Transfer Standard
○	Lower accuracy (0.025% - 0.1%).
○	Much lower accuracy at lower pressures below 9 psi / 250 "H_2O.
○	Requires multiple units or unit with multiple sensors to cover a wide range.
○	Less pressure stability due to adiabatic affects.
●	No corrections required if fully temperature compensated.
●	Accuracy not affected by ambient temperature, wider temperature range, -20° C.
●	Faster to setup and easier to use.
●	Lighter, more portable.
●	Less expensive to purchase and own.
○	Requires power.
●	Software available to speed up calibration process and generate certifcates.
●	Read directly in many pressure units.
●	Easy to set small or specific pressure values.
○	Shorter lifetime.
●	Pressure, mA, V, task specific features like PSV, switch, logging.

Figure 2. Secondary Standard: AMETEK HPC40 Series Calibrator with a GaugeCalHP Pressure Comparator

More on the *t*-Interval Method and Mean-Unbiased Estimator for Measurement Uncertainty Estimation

Hening Huang
Teledyne RD Instruments

This paper further explores the *t*-interval method and the mean-unbiased estimator for uncertainty estimation with a small number of measurements. It describes the logic behind the error bound-based definition of uncertainty, which leads to the mean-unbiased estimator. To reflect the physical meaning of an interval, we suggest using the term 'degree of certainty' for the probability associated with a probability interval (e.g. the *z*-interval) and 'capture rate' for the probability associated with a confidence interval (e.g. the *t*-interval). We propose a physical law-based criterion for validating uncertainty estimation methods. Results from detailed error and uncertainty analyses for a dataset of Mississippi River discharge measurements are presented as an example to demonstrate the appropriateness of the mean-unbiased estimator and the inappropriateness of the *t*-interval method for measurement uncertainty estimation.

1. Introduction

This paper considers the problem of estimating the uncertainty of the sample mean (taken as the measured value) with n observations from a normally distributed quantity. When the population standard deviation σ is known, the true expanded uncertainty, referred to as the z-based uncertainty, is

$$U_z = z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \quad (1)$$

where $z_{\alpha/2}$ is the z-score from the standard normal distribution.

When σ is unknown and n<30, the expanded uncertainty is traditionally estimated using the t-interval method (JCGM 2008), i.e., the half-length of the t-interval, referred to as the t-based uncertainty

$$U_t = t_{\alpha/2}\frac{s}{\sqrt{n}} \quad (2)$$

where $t_{\alpha/2}$ is the t-score from the t-distribution with $n-1$ degrees of freedom; and s is the sample standard deviation $s=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-x)^2}$.

However, the use of the t-interval method for uncertainty estimation caused three paradoxes: the uncertainty paradox (Huang 2010), the Du-Yang paradox (Du and Yang 2000), and the Ballico paradox (Ballico 2000, Huang 2016a). The measurement quality control based on the t-interval method is overly conservative and misleading when the sample size is very small (Huang 2014). In 2006, the author (Huang 2006) proposed a mean-unbiased estimator of the z-based uncertainty for estimating the uncertainty of streamflow measurements made with acoustic Doppler current profilers (known as ADCP). He later (Huang 2010, 2012) discovered through an internet search that this mean-unbiased estimator is exactly the first term of a series for estimating probable error, presented by Craig in 1927 (Craig 1927). The mean-unbiased estimator, denoted by $U_{z/c4}$, is written as

$$U_{z/c4} = z_{\alpha/2}\frac{s}{c_4\sqrt{n}} \quad (3)$$

where c_4 is the bias-correction factor for s: $c_4=\sqrt{\frac{2}{n-1}}\Gamma\left(\frac{n}{2}\right)\Big/\Gamma\left(\frac{n-1}{2}\right)$; and $\Gamma(.)$ stands for Gamma function (e.g. Wadsworth 1989). The mean-unbiased estimator satisfies $\mathrm{E}(U_{z/c4}) = U_z$.

The author recently published a series of two papers in *Measurement Science and Technology* titled "Uncertainty estimation with a small number of measurements, Part I: new insights on the t-interval method and its limitations; Part II: a redefinition of uncertainty and an estimator method." Part I (Huang 2018a) introduced a concept called 'transformation distortion.' It revealed that the transformation distortion is the root cause of extremely high t-scores when the sample size is very small (<5), resulting in unrealistic estimates of uncertainty with the t-interval method. Part II (Huang 2018b) revealed that the t-interval method is an 'exact' answer to a wrong question; it is actually misused in uncertainty estimation. Part II proposed an error bound-based definition of uncertainty and a modification of the conventional approach to estimating measurement uncertainty. The proposed modification is to replace the t-interval method with an uncertainty estimator (mean or median-unbiased). The uncertainty estimator method is an approximate answer to the right question to uncertainty estimation. It provides realistic estimates of uncertainty and resolves the three paradoxes caused by the misuse of the t-interval in uncertainty estimation.

The purpose of this paper is to further explore the t-interval method and the mean-unbiased estimator, and to demonstrate the appropriateness of the mean-unbiased estimator and the inappropriateness of the t-interval method. This paper is divided into the following sections. Section 2 introduces a term 'dilation factor' that measures the artificial dilation of uncertainty due to the t-interval method. Section 3 describes the logic behind the error bound-based definition of uncertainty. Section 4 discusses the true meaning of a confidence interval (e.g. the t-interval). Section 5 presents a physical law-based criterion for validating uncertainty estimation methods. Section 6 provides a comparison between the t-interval method and the mean-unbiased estimator. Section 7 presents the results from detailed error and uncertainty analyses for a dataset of Mississippi River discharge measurements.

2. Artificial Dilation of Uncertainty Due to the *t*-Interval Method

It has been well known that the t-interval method overestimates uncertainty for small samples (e.g. D'Agostini 1998, Jenkins 2007, Huang 2010, 2012). In fact, the true uncertainty (i.e. U_z) is artificially dilated by the t-interval method. In order to measure the artificial dilation of uncertainty, we introduce a term 'dilation factor,' which is defined as the ratio between the expectation of the t-based uncertainty U_t and the z-based uncertainty U_z. That is

$$\text{Dilation Factor} = \frac{\mathrm{E}\,(U_t)}{U_z} = \frac{c_4 t_{\alpha/2}}{z_{\alpha/2}} \quad (4)$$

Figure 1 shows the dilation factor as a function of the number of observations.

It can be seen from Figure 1 that, at n=2, the dilation factor is extremely high; it is 5.17 with $1-\alpha$=95% and 19.72 with $1-\alpha$=99%. The dilation factor decreases with increasing the number of observations. At n=30, it is 1.03 with $1-\alpha$=95% and 1.06 with $1-\alpha$=99%.

The artificial dilation of uncertainty is due to the transformation distortion that is the root cause of extremely high t-scores when the sample size is very small (<5) (Huang 2018a). In statistics, transformation of variables or data is often employed to facilitate mathematical formulation. It should be emphasized that a transformation itself may be mathematically valid. However, a statistical inference performed in the transformed sample space may not be valid unless the transformed quantity has a physical meaning or the transformation reflects a physical law. The t statistic is a transformed quantity (i.e. the ratio between the sample error and standard deviation), but it is not a real-world physical quantity and so has no physical meaning at all (Huang 2018a). Therefore, although the t transformation itself is mathematically valid, the t-interval, which is a result of the inference performed in the transformed sample space $\Omega(t)$, is faulty because of the transformation distortion.

In contrast to the t-interval method, the mean-unbiased estimator does not cause any artificial dilation of uncertainty. This is because the mean-unbiased estimator is a result of inference performed in the original sample space $\Omega(\varepsilon, s)$ based on the mean-unbiased criterion.

3. Logic Behind the Error Bound-Based Definition of Uncertainty

The expanded uncertainty is redefined as the probabilistic error bound (PEB) when σ is known and an estimate of PEB when σ is unknown (Huang 2018b). The z-based uncertainty is a PEB under the assumption of normality. Accordingly, the mean-unbiased estimator of the z-based uncertainty is an estimate of PEB. The logic behind the error bound-based definition of uncertainty is described in the following.

In any measurement, we want to ask the following question: "How close is the measured value to the true value?" Since error is defined as the difference between the measured value and the true value, this question is equivalent to "What is the error of the measured value?" The smaller the error, the closer the measured value to the true value, or the more precise of the measurement (assume that only random errors are considered in our discussion).

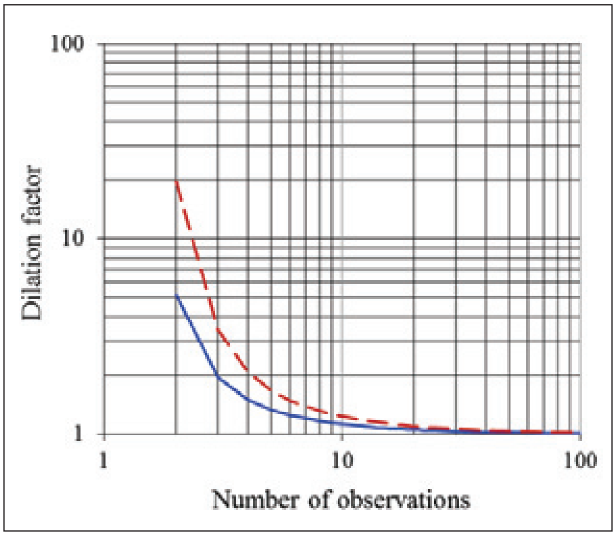

Figure 1. Dilation factor as a function of the number of observations (solid line: 1-α=95%, dashed line: 1-α=99%).

In many measurements except calibrations, however, we do not know the true value or error (otherwise, there is no need to make measurements). However, we may know the standard deviation σ, a statistical characteristic of the error, from historical data or calibration. In this situation, we can use the z-based uncertainty as a *measure* of the measurement precision. This is the so-called Type B evaluation of uncertainty according to the GUM (JCGM 2008). That is, the z-interval for the measurement error ε, $(-z_{\alpha/2}\frac{\sigma}{\sqrt{n}}, +z_{\alpha/2}\frac{\sigma}{\sqrt{n}})$, describes the measurement uncertainty. Note that the z-interval is a probability interval, i.e., a fixed interval with a random subject ε. Its physical meaning is that, if we make a large number of measurements, $1-\alpha$ percent of the measurement errors will fall into the fixed interval $(-z_{\alpha/2}\frac{\sigma}{\sqrt{n}}, +z_{\alpha/2}\frac{\sigma}{\sqrt{n}})$. In other words, for a measurement we have made, we are $1-\alpha$ percent certain that its measurement error ε is within the z-interval $(-z_{\alpha/2}\frac{\sigma}{\sqrt{n}}, +z_{\alpha/2}\frac{\sigma}{\sqrt{n}})$. In order to reflect the physical meaning of the z-interval, we designate the probability $1-\alpha$ as the degree of certainty, which is expressed as

$$\text{Degree of certainty} = \Pr\left(\varepsilon \in \left[-z_{\alpha/2}\frac{\sigma}{\sqrt{n}}, +z_{\alpha/2}\frac{\sigma}{\sqrt{n}}\right]\right) = 1-\alpha. \quad (5)$$

Note that we use the symbol $\in$ in Eq. (5). In mathematics, the symbol means "an element of." We use this notation to emphasize the physical meaning of the z-interval. Willink (2012) used the same notation $\in$ to emphasize the subject of the probability statement for a probability interval.

Equation (5) is what the Law of Probability of Errors (LPE) means. An important application of the LPE is that, when the error of a measurement is unknown but σ is known, the precision of the measurement can be characterized by the z-based uncertainty. Accordingly, the measurement quality evaluation or control based on the z-based uncertainty is equivalent to that based on the error analysis. In other words, the Type B evaluation of uncertainty is equivalent to the error analysis. An example that demonstrates this equivalence will be shown later in this paper.

Now consider the case where neither the error of a measurement nor σ is known, but we still want to approximately know the precision of the measurement. It is then straightforward to ask a question: "What is the 'best' estimate of the z-based uncertainty U_z when σ is unknown? (Huang 2018b)" This question leads to the mean-unbiased estimator. It does not lead to the t-interval method or any CI method.

4. True Meaning of a Confidence Interval

The theory of confidence intervals (CIs) was developed by Neyman in the 1930's (Neyman 1935, 1937). It is essentially the theoretical base of GUM's uncertainty framework. However, CI is one of the most confusing concepts in statistics and is often misinterpreted or misunderstood. It is a common mistake to consider a 95% CI, calculated from a sample, as the interval that contains the true value μ at the 95% probability. The confusion about CIs is not only among practitioners, but also among statisticians or experts, referring to the papers titled "Confidence intervals? More like confusion intervals" by Etz (2015), "How confidence intervals become confusion intervals" by McCormack et al. (2013), "Robust misinterpretation of confidence intervals" by Hoekstra et al. (2014), and "Continued misinterpretation of confidence intervals: response to Miller and Ulrich" by Morey et al. (2016b). In their recent paper titled "The fallacy of placing confidence in confidence intervals," Morey et al. (2016a) stated, "We have suggested that confidence intervals do not support the inferences that their advocates believe they do… we believe it should be recognized that confidence interval theory offers only the shallowest of interpretations, and is not well-suited to the needs of scientists." Deming (1982) warned, "The students should also avoid passages in books that treat confidence intervals and tests of significance, as such calculations have no application in analytic problems in science and industry." Apparently, Deming's warning has been ignored. The CI procedure has been adopted in measurement uncertainty analysis. The misuse of CIs in science and industry has been finally recognized by several statisticians and practitioners in recent years (e.g. Karlen 2002; Lewandowsky 2015; Morey et al. 2016a, Huang 2018a, b).

The author (Huang 2018b) purposely used the word stick to describe the t-interval. This stick notion helps understand the true (physical) meaning of the t-interval or CI procedure. Let us use 'sticks' to conduct a 'physical experiment.' This physical experiment has four steps. Step 1, draw a line on the ground, denoted by L-L. This L-L line represents the true value μ. Step 2, collect a large number of wood sticks such as chopsticks to represent the realized t-intervals or CIs. Step 3, throw the wood sticks onto the L-L line; make sure that each stick is perpendicular to the L-L line and centered at the sample mean $\bar{x}$. Step 4, calculate the frequency that the wood sticks have captured the L-L line. To reflect the physical meaning of this t-interval stick procedure (or any CI procedure), we designate this frequency as 'capture rate.' The mathematical expression of the capture rate associated with the t-interval is written as

$$\text{Capture rate} = \Pr\left(\left[\bar{x}-t_{\alpha/2}\frac{s}{\sqrt{n}}, \bar{x}+t_{\alpha/2}\frac{s}{\sqrt{n}}\right] \ni \mu\right) = 1-\alpha. \quad (6)$$

Note that we use the symbol $\ni$ in Eq. (6). In mathematics, the symbol means "there exists." We use this notation to emphasize the physical meaning of the t-interval. Willink (2012) used the same notation for the probability statement of a CI procedure.

The capture rate $1-\alpha$ is known as confidence level, coverage probability, or long-run success rate in the literature. However, among these four terms, 'capture rate' most accurately reflects the physical meaning of a

CI stick procedure. Therefore, we suggest using the term 'capture rate' instead of the other three terms. Note that capture rate is a long-run property and is associated with a CI stick procedure. For a realized CI stick, the capture rate, i.e. the probability with which μ is captured by the realized CI stick, is either 0 or 1.

Therefore, Neyman's CI procedure is merely to generate a collection of CI sticks with a specified capture rate for the true value. It is not a method for inferring the measurement precision (i.e. the z-based uncertainty) from a sample at hand. Morey et al. (2016a) stated, "Claims that confidence intervals yield an index of precision, that the values within them are plausible, and that the confidence coefficient can be read as a measure of certainty that the interval contains the true value, are all fallacies and unjustified by confidence interval theory." Trafimow (2018) also stated that CI is inappropriate for measuring precision.

Morey et al. (2016a) suggested abandoning the use of CIs in science. They stated, "Abandoning the use of confidence procedures means abandoning a method that merely allows us to create intervals that include the true value with a fixed long-run probability. We suspect that if researchers understand that this is the only thing they will be losing, they will not consider it a great loss." The international journal, *Basic and Applied Social Psychology* (BASP) has officially banned CIs and the null hypothesis significance testing procedure (NHSTP) since 2015 (Trafimow and Marks 2015). Moreover, the error bound-based definition of uncertainty essentially rules out CIs (including the t-interval) from uncertainty estimation.

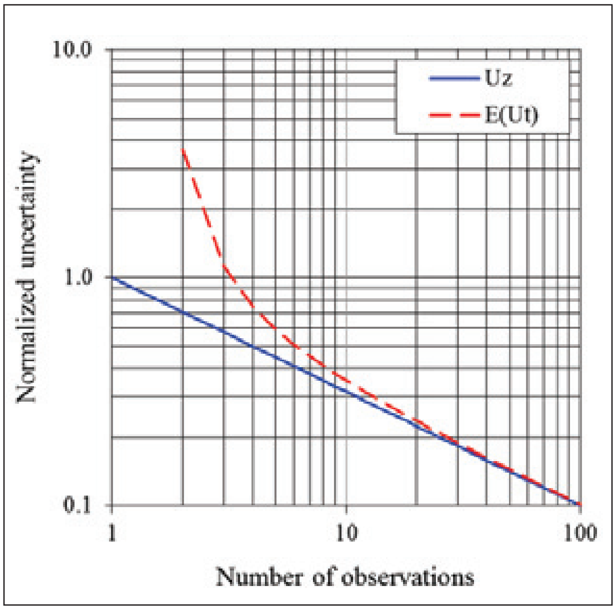

Figure 2. U_z and E(U_t) (normalized by $z_{\alpha/2}\sigma$ with 1-α=95%) on the log-log scales. Note that E(U_t) significantly deviates from the -1/2 power law, the physical law for the relationship between the measurement precision and the number of observations.

5. The *t*-Interval Method Violates the -1/2 Power Law

Recall that, when σ is known, the z-based uncertainty U_z is the true uncertainty under the assumption of normality. U_z is inversely proportional to the square root of the number of observations: $U_z \propto (n^{-1/2})$. That is, U_z exhibits a -1/2 power law on a log-log plot. Again, U_z is a measure of measurement precision. Therefore, the -1/2 power law is a physical law for the relationship between the measurement precision and the number of observations. Because it is a physical law, the -1/2 power law must be observed by the results obtained with any uncertainty estimation method. We therefore propose a physical law-based criterion for validating uncertainty estimation methods. That is, the expectation of an uncertainty estimator must comply with the -1/2 power law.

The mean-unbiased estimator meets this criterion because its expectation is exactly U_z. The expectation of the t-based uncertainty can be written as

$$E(U_t) = c_4\, t_{\alpha/2} \frac{\sigma}{\sqrt{n}} \quad n \geq 2. \tag{7}$$

Figure 2 shows U_z and E(U_t) normalized by $z_{\alpha/2}\sigma$ with 1-α=95% on the log-log scales.

It can be observed from Figure 2 that E(U_t) significantly deviates from U_z for small samples. The relationship between E(U_t) and n does not follow the -1/2 power law. E(U_t) approaches U_z only when the sample size n becomes greater than 30.

6. Comparison

Table 1 (on the next page) shows a comparison for the long-run properties between the mean-unbiased estimator and the t-interval method.

The mean-unbiased estimator $U_{z/c4}$ has two factors: $z_{\alpha/2}$ and c_4. The z-score $z_{\alpha/2}$ depends on the desired degree of certainty. The bias correction factor c_4 is due to the mean-unbiased criterion for estimating σ from the sample standard deviation s. As seen in Table 1, the expectation of the mean-unbiased estimator is the z-based uncertainty with the desired degree of certainty. Thus, the mean-unbiased estimator has correct magnitude and probability in the long run. In contrast, the t-interval method has incorrect magnitude or has a bias with respect to the z-based uncertainty in the long run.

One of the most important differences in philosophy between the mean-unbiased estimator and the t-interval method is that the former focuses on the magnitude of uncertainty, whereas the latter focuses on the associated probability (i.e. capture rate). It is important to note that magnitude is visible either at the population level

	The mean-unbiased estimator	The *t*-interval method
Degree of certainty (nominal)	$1-\alpha$	Not applicable
Capture rate (nominal)	Not applicable	$1-\alpha$
Expectation	$E(U_{z/c4}) = z_{\alpha/2}\frac{\sigma}{\sqrt{n}} = U_z$	$E(U_t) = \frac{c_4 t_{\alpha/2}}{z_{\alpha/2}} U_z$
Dilation factor	1	$\frac{c_4 t_{\alpha/2}}{z_{\alpha/2}} > 1$
Relative bias error (with respect to U_z)	zero	$\left(\frac{c_4 t_{\alpha/2}}{z_{\alpha/2}} - 1\right) > 0$
Relative precision error (with respect to U_z)	$\frac{\sqrt{1-c_4^2}}{c_4}$	$\frac{t_{\alpha/2}}{z_{\alpha/2}}\sqrt{1-c_4^2}$

Table 1. Comparison for the long-run properties between the mean-unbiased estimator and the *t*-interval method.

(or in the long run) or at the sample level, whereas the probability is visible only at the population level or in the long run and is invisible and meaningless at the sample level. The mean-unbiased estimator is inferred based on a criterion about magnitude estimation of the *z*-based uncertainty. In contrast, the *t*-interval method is inferred based on a criterion about probability. In general, however, a probability criterion does not lead to a unique interval procedure. This ambiguity, known as 'the loss of uniqueness in the result,' has been long known in statistics. Morey et al. (2016b) stated, "Fisher's critique of CI theory arose because CI theory does not afford a unique association between the probabilities and intervals." This ambiguity may be resolved, to a degree but not completely, by employing the 'shortest expected length' as an 'auxiliary' criterion for CI estimation.

The mean-unbiased estimator is based on the theory of point estimation, while the *t*-interval method is based on the theory of interval estimation (i.e. the theory of CIs). Statistics textbooks usually claim that interval estimation provides more information than point estimation. However, this claim is misleading. It is important to note that, for a given sample, its information content is *fixed* and *independent* of statistical methods. It cannot be increased or decreased by a statistical method used for inferences. Certainly, some statistical methods may be better than others according to a criterion for evaluating their performance. However, no methods can change the information context of a sample. Note that both the mean-unbiased estimator and the t-interval method rely on the underlying distribution of errors, i.e. the normal distribution with zero mean and the scale parameter σ. Thus, the most important task in uncertainty analysis is to obtain the best point estimate of σ. If we have obtained the best point estimate of σ, we will have the best estimate of the underlying distribution of errors, which certainly provides more information than any CI.

We admit that the mean-unbiased estimator and the *t*-interval method are from different school of thoughts in statistics. Then the question is, "Which method is more appropriate for uncertainty estimation?" This question may not be answered by philosophical or ideological debate because at that level of debate, people tend to persist in disagreeing based on their own perspectives. Jaynes (2003) suggested [italics in original], "*…the merits of any statistical method are determined by the results it gives when applied to specific problems.*" Jaynes (2003) also suggested using common sense to judge which method is preferable. He quoted Laplace's famous remark: "Probability theory is nothing but common sense reduced to calculation." In the example of D'Agostini (1998), the carpenter was able to tell (and laughed at), merely by common sense, the ridiculous result from the *t*-interval method. The author suspected, also by common sense, the paradoxical results from the *t*-interval method when conducting uncertainty analysis for river discharge measurements made with acoustic Doppler current profilers, which led to the discovery of the uncertainty paradox (Huang 2010).

7. Example

7.1 Data Presentation

In order to demonstrate the appropriateness of the mean-unbiased estimator and the inappropriateness of the *t*-interval method, this section presents detailed error and uncertainty analyses for a real-world dataset. An experiment study on discharge measurements using an acoustic Doppler current profiler (ADCP) was conducted on the Mississippi River in 1992 (Gordon 1992). A total of 30 observations of discharges, with flow rates in m^3/s, were

Sample	$\overline{Q}$ (m³/s)	s (m³/s)	$\frac{(\overline{Q}-Q)}{Q}$ (%)	$U_{z/c4}/Q$ (%)	U_t/Q (%)
1	14286	260.9	0.32	3.18	16.46
2	14454	22.6	1.50	0.28	1.43
3	14469	43.8	1.61	0.53	2.77
4	14375	177.5	0.94	2.16	11.20
5	14296	65.8	0.39	0.80	4.15
6	14409	94.0	1.18	1.15	5.93
7	14549	103.9	2.17	1.27	6.56
8	14592	42.4	2.47	0.52	2.68
9	14492	99.0	1.77	1.21	6.25
10	14143	394.6	-0.68	4.81	24.89
11	14164	424.3	-0.53	5.18	26.77
12	14313	213.5	0.51	2.60	13.47
13	14306	203.6	0.46	2.48	12.85
14	14199	355.7	-0.29	4.34	22.44
15	14198	354.3	-0.30	4.32	22.35
16	14162	405.2	-0.55	4.94	25.56
17	14085	297.0	-1.09	3.62	18.74
18	14059	333.8	-1.27	4.07	21.06
19	14065	342.2	-1.23	4.17	21.59
20	14153	218.5	-0.61	2.67	13.79
21	14112	161.2	-0.90	1.97	10.17
22	14192	48.1	-0.34	0.59	3.03
23	14154	6.4	-0.61	0.08	0.40
24	14214	91.2	-0.19	1.11	5.76
25	14275	4.2	0.25	0.05	0.27
26	14191	115.3	-0.35	1.41	7.27
27	14097	17.0	-1.00	0.21	1.07
28	14030	78.5	-1.48	0.96	4.95
29	14054	113.1	-1.31	1.38	7.14

Table 2. Error and uncertainty analysis results of Mississippi River discharge measurements at n=2.

made under a steady flow condition.

It should be pointed out that, ADCP streamflow measurements contain both random and bias (i.e. systematic) errors. The statistical analysis of discharge data, or the Type A evaluation of uncertainty, should account for all random error sources encountered at the measurement site, including ADCP system noise in depth and velocity measurements, pitch, roll and heading variation/errors, and ambient turbulence (Huang 2016b). The bias error in ADCP streamflow measurements includes calibration and application errors (Huang 2018c). It is usually considered separately from the random error. Our analyses in this paper consider the random sampling error only.

This large dataset (30 observations, known as transect discharges) was from an exceptional experiment that was to demonstrate the validity of ADCP technology for streamflow measurements. An ADCP streamflow measurement under a steady flow condition usually involves four transects (i.e. observations) (Oberg et al. 2005) or at least two transects (Mueller et al. 2013). A recent study (Huang 2015) suggested that two transects be sufficient for large rivers, which could lead to significant saving in labor, time, and energy. This large dataset offers an opportunity to evaluate the performance of the mean-unbiased estimator and the *t*-interval method, compared to the error analysis or the *z*-based uncertainty.

In our analyses, the average discharge, 14240 m^3/s, is assumed to be the true discharge *Q* and the experimental standard deviation with the bias corrected, 223 m^3/s, is assumed to be the true standard deviation σ_Q. We grouped the transect discharges in sequence into samples of size 2, 3, 4… and 30, obtained 29, 28, 27… and 1 samples respectively. The way that the data is grouped does not produce independent samples. However, the correlation between the samples is not a concern for the evaluation of measurement quality discussed here. This is because in practice, any sample, regardless of the sampling sequence, is valid, and the quality of a measurement (i.e. a sample) has nothing to do with the correlation between the samples.

For each sample (size n=2, 3… or 30), we calculated the sample mean $\overline{Q}$ (i.e. the measured discharge), sample standard deviation *s*, sample error $\varepsilon = \overline{Q} - Q$, mean-unbiased uncertainty ($U_{z/c4}$) at the 95% nominal degree of certainty, and *t*-based uncertainty (U_t) at the 95% nominal capture rate. The calculated errors and uncertainties are normalized by *Q*. As an example, Table 2 shows the error and uncertainty analysis results at *n*=2.

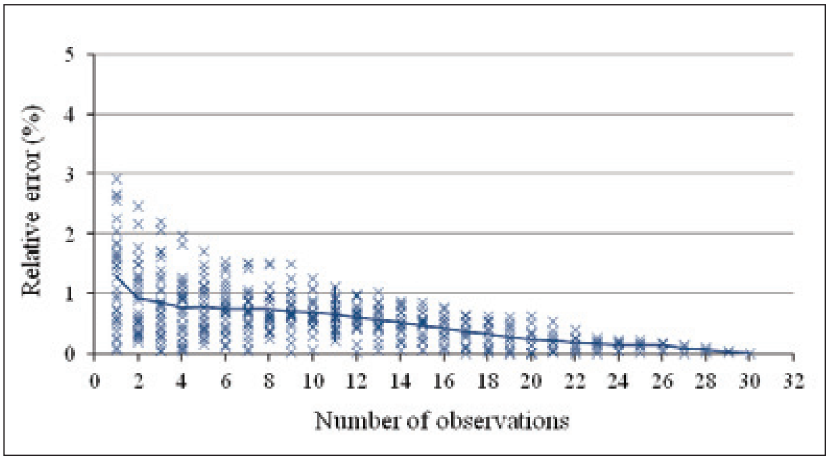

Figure 3. The absolute errors of the measured discharges as a function of the number of observations (×: data; solid line: sample means). Any measured discharge, regardless of the number of observations, is acceptable according to the error-based quality control criterion, Eq. (8).

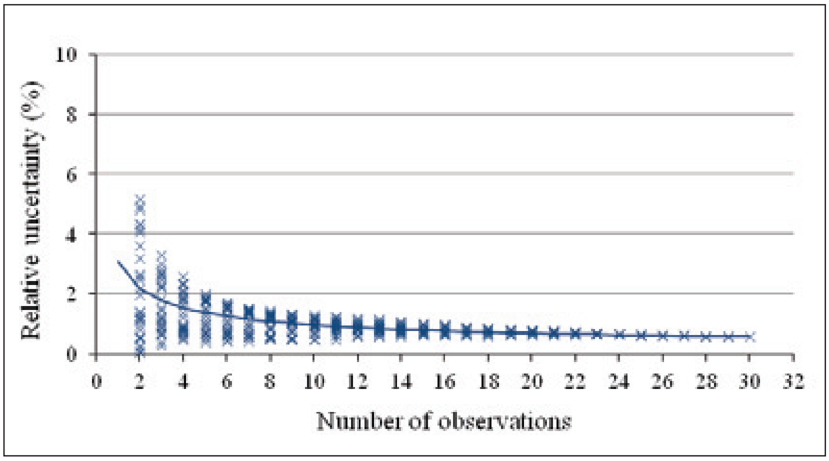

Figure 4. The mean-unbiased uncertainties of the measured discharges as a function of the number of observations (×: data; solid line: the z-based uncertainty). Any measured discharge, regardless of the number of observations, is acceptable according to the uncertainty-based quality control criterion, Eq. (9). However, four measured discharges at *n*=2 are falsely rejected according to Eq. (10).

Figures 3, 4, and 5 show the data for the measurement errors (absolute values), mean-unbiased uncertainties, and *t*-based uncertainties of the measured discharges, respectively, as a function of the number of observations. The mean of the errors of all samples at each sample size *n* and the *z*-based uncertainty are also shown in Figures 3 and 4 respectively. Both the *z*-based uncertainty and the expectation of the t-based uncertainty are shown in Figure 5.

It can be observed from Figure 5 that the *t*-based uncertainties are very large for small samples, as large as 27% at *n*=2 and 6.5% at *n*=3. Such high uncertainties are unrealistic. Note that the true uncertainty (i.e. the *z*-based uncertainty) is only 2.2% at *n*=2 and 1.8% at *n*=3. Apparently, the true uncertainty is artificially dilated by the *t*-interval method due to its inherent shortcoming (i.e. the transformation distortion).

Another important observation of Figure 5 is that, the expectation of the *t*-based uncertainty or the estimated uncertainties on average significantly deviate from the -1/2 power law for small samples. Recall that the -1/2 power law is a physical law for the relationship between the measurement precision and the number of observations. Thus, this deviation invalidates the *t*-interval method for uncertainty estimation according to the proposed physical law-based criterion. In contrast, it can be seen from Figure 4 that, the expectation of the mean-unbiased estimator or the estimated uncertainties on average complies with the -1/2 power law. This compliance validates the mean-unbiased estimator for uncertainty estimation.

7.2. Error and Uncertainty Analyses for Quality Control

In practice, the purpose of error or uncertainty analysis of discharge data is to evaluate or control the quality of the measured discharges. A measured discharge can be a single transect discharge (n=1) or the sample mean of multiple transect discharges ($n \geq 2$). For a measured discharge to be accepted (or considered to be valid), either of two quality control criteria applies. One is the error-based criterion (Oberg and Mueller 2007)

$$\text{Relative error} = \frac{|\epsilon|}{Q} < \text{MPRE} = 5\% \quad n \geq 1 \qquad (8)$$

where MPRE stands for maximum permissible relative error. Note that this error-based criterion has the degree of certainty 100%.

The other quality control criterion is based on the expanded uncertainty at the degree of certainty 95% (Huang 2015):

$$\text{Relative unc} = \frac{U_z}{Q} = 1.96\frac{\sigma}{Q\sqrt{n}} < \text{MPRU} = 4.09\% \quad n \geq 1 \qquad (9)$$

where MPRU stands for maximum permissible relative uncertainty.

In most ADCP discharge measurements, however, neither the error ε nor σ is known. In this situation, neither criterion, Eq. (8) nor Eq. (9), can be used for the quality control. We have to use a Type A uncertainty $\hat{U}$, calculated from a sample consisting of multiple observations, as an estimate of U_z. Accordingly, the uncertainty-based quality control criterion becomes (Huang 2015)

$$\text{Relative unc} \approx \frac{\hat{U}}{Q} < \text{MPRU} = 4.09\% \quad n \geq 2. \qquad (10)$$

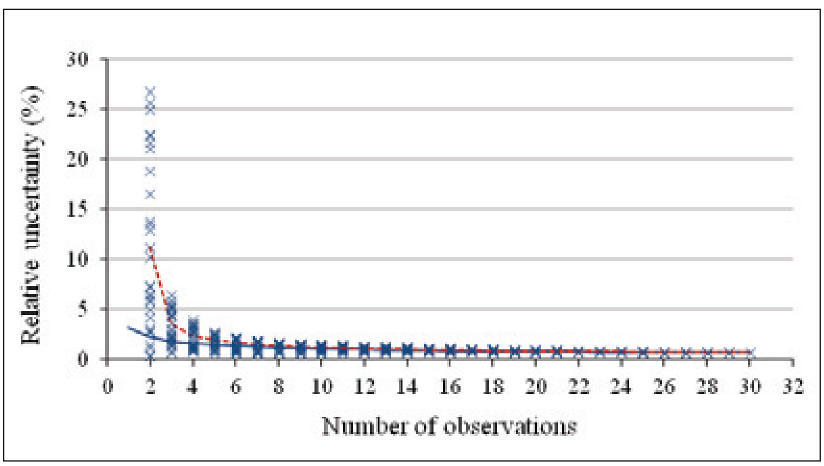

Figure 5. The *t*-based uncertainties of the measured discharges as a function of the number of observations (×: data; solid line: the *z*-based uncertainty; dashed line: E(U_t)). The *t*-interval method artificially dilates the true uncertainty when the sample size is small. Consequently, twenty-two measured discharges at n=2 and ten at n=3 are falsely rejected according to Eq. (10).

It should be emphasized again that, in any measurement, what we really want to know is how close the measured value to the true value or what is the measurement error. In this example, we have assumed that the true discharge is known. Thus, the calculated errors shown in Figure 2 indicate the quality of the measured discharges as a function of the number of observations. Notice that the error deceases or the measurement quality increases with increasing the number of observations. The maximum relative error is about 3% for the measured discharges at n=1. Thus, according to the error-based quality control criterion, Eq. (8), any measured discharge, regardless of the number of observations, is acceptable.

On the other hand, for this example the z-based uncertainty U_z at each n can be calculated using the true standard deviation 223 m^3/s. Accordingly, the true relative expanded uncertainty at the 95% degree of certainty is 3.07% at n=1, 2.17% at n=2… ; it decreases with increasing the number of observations as shown in Figure 3. Then, according to the uncertainty-based quality control criterion, Eq. (9), any measured discharge, regardless of the number of observations, is acceptable. Thus, the results of the quality control based on the z-based uncertainty are the same as those based on the error analysis.

Now, pretend that we do not know either the errors of the measured discharges or the true standard deviation σ_Q. In this situation, we have to use the sample-based criterion, Eq. (10), for the quality control. Note that a minimum sample size of 2 is required for this analysis. We understand that the Type A uncertainty $\hat{U}$ or sample standard error $s/\sqrt{n}$ of small samples will be noisy. That is, the Type A uncertainty has uncertainty due to limited sampling as the GUM stated (JCGM 2008). Therefore, we do not expect the results of the quality control based on Eq. (10) be the same as those based on Eq. (8) or Eq. (9). However, we do expect the results are compatible. In fact, the compatibility in the quality control based on an uncertainty estimation method with that based on the error analysis or the z-based uncertainty is another criterion for validating the uncertainty estimation method.

It can be seen from Table 2 that, at n=2 there are four measured discharges whose $U_{z/c4}/Q$ values are greater than MPRU=4.09 %, resulting in four false rejections. Then, it can be seen from Figure 4 that the $U_{z/c4}/Q$ values for all measured discharges at n>2 are smaller than MPRU=4.09%. Therefore, the quality control based on the mean-unbiased estimator is in general compatible with that based on the error analysis or the z-based uncertainty, and is conservative. This result validates the mean-unbiased estimator.

On the other hand, it can be seen from Table 2 that, at n=2 there are twenty-two measured discharges whose U_t/Q values are greater than MPRU=4.09%, resulting in twenty-two false rejections. At n=3, there are ten measured discharges whose U_t/Q values are greater than MPRU =4.09%, resulting in ten false rejections. Then, it can be seen from Figure 5 that the U_t/Q values for all measured discharges at n>3 are smaller than MPRU=4.09%. Therefore, using the t-based uncertainty for the quality control is overly conservative and, in fact, misleading because it results in many false rejections for small samples. This result essentially invalidates the t-interval method.

7.3. Small Samples are Still Useful

This example also demonstrates that a small sample (the size is as small as n=2) is still useful, although the small sample may have a large Type A uncertainty. It is a misconception that a small sample, say n<4, is unreliable or untrustable. It is important to note that, the Type A uncertainty, or standard error $s/\sqrt{n}$, is independent of the measurement error ε. That is, there is no correlation between the Type A uncertainty and the sample error. For samples drawn from the same population, a sample having a larger Type A uncertainty is not necessarily less accurate than a sample having smaller Type A uncertainty. Indeed, as this example has shown, the Type A uncertainty (or standard error) of a small sample may be large, but the measurement error ε, or the precision of the measured value, may not be as large as the Type A uncertainty (or standard error) suggests. Deming (1961) stated,

> The standard error of a result does not measure the usefulness thereof. The standard error, however helpful in the use of data from samples, only gives us a measure of the variation between repeated samples… It is possible for a result to be useful and still to possess a wide standard error. A result obtained by definitions and techniques that have been drawn up with care, and carried out by excellent interviewing and supervision may have a wide standard error because the sample was small; yet such a result might be preferable to one obtained with a bigger sample, with a small standard error, but whose definitions, techniques, and interviewing were out of line with the best practice and knowledge of the subject matter.

In other words, the noise in the Type A uncertainty, due to limited sampling, does not invalidate small samples. In many cases, a single measurement from a well-calibrated measuring instrument or sensor is valid because, under normal application conditions, the measurement error must not exceed the maximum permissible error, i.e. the manufacturer's specification, with the 100% degree of certainty. According to the -1/2 power law, the true uncertainty of multiple measurements will be definitely smaller than the true uncertainty of a single measurement. In practice, therefore, there should be no lower limit for sample sizes, although more observations are preferred whenever measurement conditions or costs allow.

8. Conclusion

The t-interval method is inappropriate for uncertainty estimation because of four reasons. First, the t-interval is a result from an inference performed in the distorted sample space $\Omega(t)$. The transformation from the original sample space $\Omega(\varepsilon, s)$ to $\Omega(t)$ is mathematically valid, but the statistical inference performed in $\Omega(t)$ is invalid because of the transformation distortion. The true uncertainty is artificially dilated by the t-interval method due to its inherent shortcoming, i.e. the transformation distortion. Second, the t-interval is a CI stick procedure that merely generates a collection of CI sticks with a specified capture rate. It is not a method for inferring the measurement precision (i.e. the z-based uncertainty) from a sample at hand. Third, the t-interval method violates the -1/2 power law, the physical law for the relationship between the measurement precision and the number of observations. Fourth, the quality control based on the t-interval method is not compatible with that based on the error analysis or the z-based uncertainty; it is overly conservative and misleading when the sample size is small.

The mean-unbiased estimator is appropriate for uncertainty estimation also because of four reasons. First, the mean-unbiased estimator is a result from an inference performed in the original, un-distorted sample space $\Omega(\varepsilon, s)$. Second, the mean-unbiased estimator is a method for inferring the measurement precision (i.e. the z-based uncertainty) based on a sample at hand. Third, the mean-unbiased estimator complies with the -1/2 power law. Fourth, the quality control based on the mean-unbiased estimator is compatible with that based on the error analysis or the z-based uncertainty, and is conservative.

The logic behind the error bound-based definition of uncertainty can be summarized as follows. We want to know how close is the measured value to the true value, i.e. what is the error of the measured value. Since the error cannot be known, we want to know the probabilistic error bound, i.e. the z-based uncertainty, as an alternative, which can be known when σ is known. When σ is unknown, we have to use an estimator of σ based on a sample, which leads to the mean-unbiased estimator.

The true (physical) meaning of confidence intervals (e.g. the t-interval) has been explored by conducting a physical experiment with 'sticks.' The probability associated with a CI stick procedure should be called 'capture rate' to reflect the physical meaning of the CI stick procedure. A confidence interval does not describe measurement uncertainty. In contrast, the z-interval is a probability interval. The probability associated with the z-interval should be called 'degree of certainty' to reflect the physical meaning of the probability interval. The *z*-interval describes measurement uncertainty under the assumption of normality. The concept of probability interval and the associated 'degree of certainty' can also be used to describe the uncertainty of the calibration of a measuring instrument. That is, the calibration error must not exceed the maximum permissible error with the 100% degree of certainty.

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A Risk Based Approach to Calibration Laboratory Infrastructure Modernization

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Laboratories are often faced with budget constraints that limit the amount measurement system infrastructure upgrades can be accomplished in any fiscal year. This paper describes a risk based approach to dealing with resource limitations that improves decision making.

Introduction

Measurement capability is an ever evolving activity. Advancements in computing, electronics, and material science have led to the development of Measuring and Test Equipment (M&TE), Test and Monitoring Systems (TAMs), and other consumer products with technical capabilities and measurement accuracies that once only existed at the highest level of calibration laboratories. This has driven a need to continually modernize calibration laboratory capability in order to keep pace with technologies being fielded for use in everyday activities.

Keeping pace with these advancements is a challenge for the calibration industry. Procurement of new calibration systems and/or upgrade of existing calibration systems often times require substantial capital investments. And to complicate matters, often times the technological advantage gained by these investments is short lived, on the order of 2 to 3 years before the state of art catches up or surpasses what is available within the calibration laboratory. This has led to a need to continually review and choose which systems to modernize.

To address this problem, the Naval Air (NAVAIR) Systems Command (SYSCOM) Metrology and Calibration (METCAL) program has developed a Risk based approach to modernizing calibration laboratory infrastructure. This approach is being implemented at the Navy Primary Standards Laboratory (NPSL) and follows the DoD 5000 Acquisition Time Line to implement a disciplined Systems Engineering solution to this problem and is depicted in Figure 1.

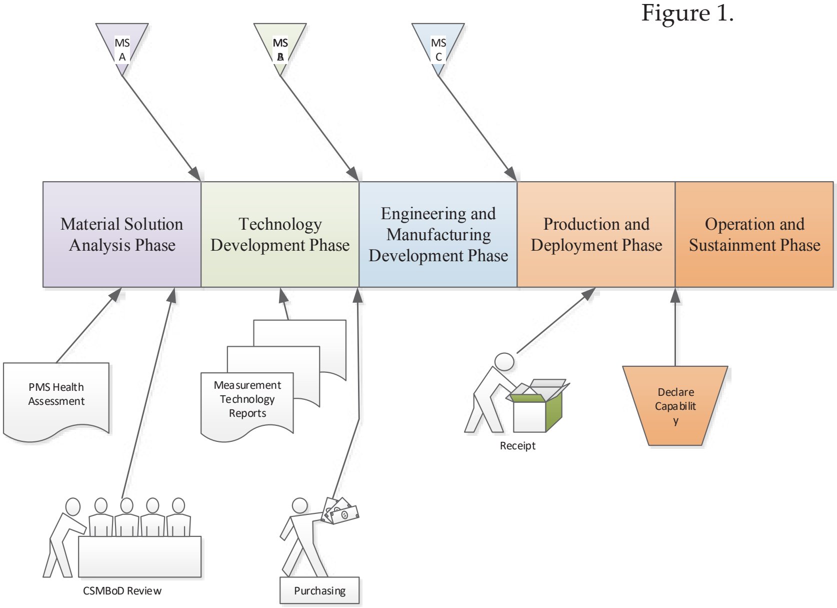


Figure 1. Risk Based CALSTD Modernization Process

The DOD5000 Acquisition process has 5 major phases, these are: Material Solution Analysis Phase, the Technology Development Phase, Engineering and Manufacturing Development Phase, Production and Deployment Phase, and Operation and Support Phase. This paper deals with the activities in the Material Solution Analysis Phase, which ends with a Milestone 'A' decision to initiate a modernization project.

Transition from one phase to another is event driven and involves several technical reviews commonly referred to as the Systems Engineering Technical Review (SETR) process. This ensures the project's transition when the technical requirements for each phase have been completed and the project is ready to move forward.

Using this disciplined engineering process ensures the process captures and identifies all of the requirements that need to be supported, while fulfilling cost schedule and legal requirements associated with government procurements. Another advantage to this process is it ensures the systems undergo scheduled evaluations which allow early detection of issues, potential problems, and new requirements in a timely manner.

Since this paper is concerned with the process of analyzing system risk to decide where to make infrastructure investments, the following paragraphs will describe this process in detail. The other phases of the project execution are outside of the scope for this paper, but closely follow the DoD 5000 processes.

Modernization Process

Material Solution Phase

NAVAIR METCAL has tailored the SETR process for this effort. Within the Material Solution Analysis Phase, the modernization process begins with an assessment of the condition the measurement systems within NPSL which we call the Primary Measurement System (PMS) Health Assessment. This is a yearly assessment on all of the PMSs used by NPSL to calibrate workload in support of Navy requirements.

During the PMS Health Assessment Phase, the laboratory measurement systems are evaluated to determine the level of Risk they represent. There are four risk factors that are evaluated, they are:

- **Traceability:** The calibration system ability to perform calibrations with sufficiently small uncertainties to meet customer requirements.
- **Supportability:** The condition of the calibration system including frequency and cost of repairs, and obsolescence issues.
- **Capacity:** The ability of the calibration system to produce the required amount of workload to meet customer schedule requirements and its impact on customer equipment availability.
- **Efficiency:** The amount of effort required to perform calibrations and the calibration system ease of use.

Each of the four risk factors is evaluated for their impact on cost, schedule, and technical performance which is documented on a RISK Cube (see Figure 2). Each factor then receives a risk score which is then aggregated to develop an overall risk score for the system. Systems are then sorted by their risk score to determine which systems will be modernized.

These risk assessments are performed by the measurement area Senior Metrology Engineer (SME). Risk assessment by nature is a subjective process based on education, experience, and personal bias, so in order to ensure consistency between the assessments performed by different SMEs, guidelines and examples are provided as to how to score the Risk Factors.

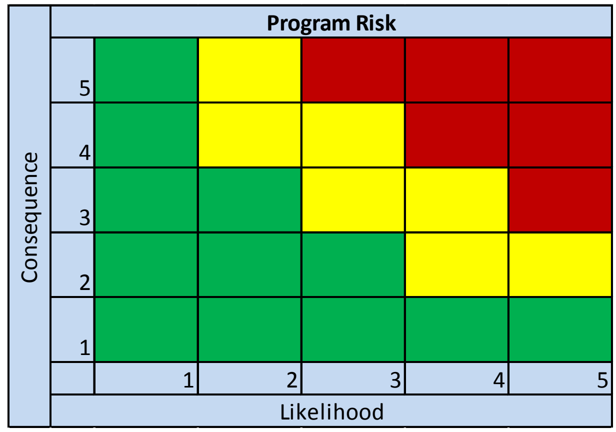
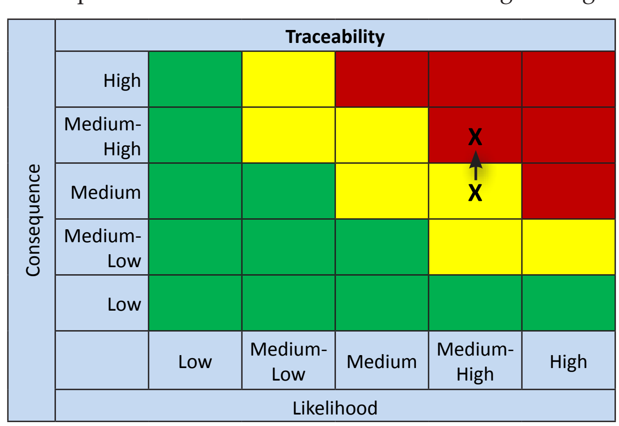


Figure 2. Sample RISK Cube

Traceability: Traceability is the ability of the system to perform calibrations with sufficiently low uncertainties as to meet your customer requirements.

Ranking	Consequence	Likelihood
Low	TUR ≥ 4	<10 %
Medium-Low	3 ≥ TUR < 4	10% to 30%
Medium	2 ≥ TUR < 3	30% to 60%
Medium-High	1 > TUR < 2	60% to 85%
High	TUR ≤ 1	>85%

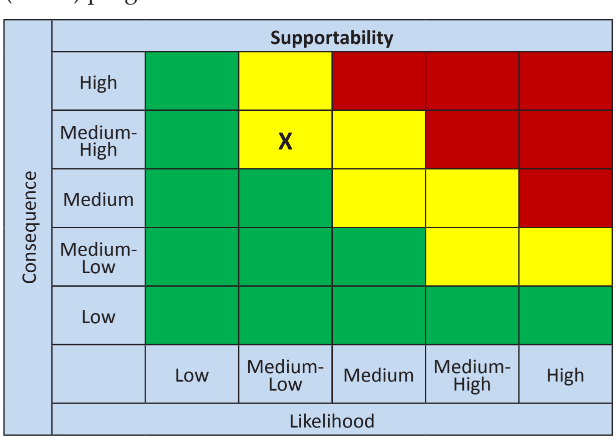
Example: The Test Uncertainty Ratio (TUR) for a PMS is 2.5:1 for some workload produced on the system and the workload affected by this low TUR accounts for 70% of the work produced on the system, so the Consequence is Medium and the Likelihood is Medium High. An adjustment could be made to this assessment based on knowledge of the future workload. If, for instance, the 30% workload that system adequately supports is being phased out, the Consequence would increase into the Medium High or High.



Supportability: The condition of the calibration system including frequency and cost of repairs, and obsolescence issues.

Ranking	Consequence	Likelihood
Low	• System is in good working condition and there are no obsolescence issues	<10 %
Medium-Low	• System occasionally exhibits problems but can be maintained using readily available replacement components. • Some Components are at or near the end of OEM support.	10% to 30%
Medium	• System exhibits problems that cannot be mitigated with available replacement components. • More than half of the system components are obsolete or no longer supported by the OEM.	30% to 60%
Medium High	• System is routinely unavailable due to maintenance problems. • The majority of components are obsolete and there is no OEM support for these components.	60% to 85%
High	• System is nonfunctional. • System is completely obsolete with no OEM support.	>85%

Example: A system has been in service for 10 years. It has failed and been unavailable to support calibration workload 3 times during the past 2 years. Each time it failed it was down for 4 weeks while replacement components were acquired or repaired. Some system components are still sold by the Original Equipment Manufacturer (OEM) and repair services are available. The system is considered critical to NPSL operations in that it supports the Operation Inter-lab (OI)[1] program supporting both Navy Calibration Laboratories and the Common Automated Support System (CASS) program.



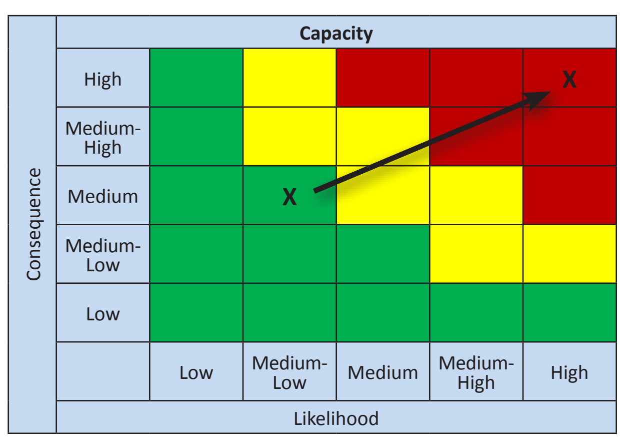
1 Operation Inter-lab is a program that provides critical calibration standards using a Just-In-Time supply philosophy.

Since the system components are available and the OEM still supports the components, the consequence is Medium-Low; however the criticality of having this system available elevates the consequence to Medium-High. The system has been unavailable for 12 weeks during the past 2 years which equates to 12% of the time the system was unavailable, therefore the likelihood of a failure is also Medium-Low.

Capacity: The ability of the calibration system to produce the required amount of workload to meet customer schedule requirements and its impact on customer equipment availability.

Ranking	Consequence	Likelihood
Low	• System Capacity exceeds demand requirement. • No impact to Support Equipment (SE) and CALSTD availability.	<10 %
Medium-Low	• System Capacity meets current demand. Any increase in demand may stress the system.	10% to 30%
Medium	• System Capacity occasionally fails to keep up with demand. Some impact on SE and CALSTD availability.	30% to 60%
Medium High	• System demand exceeds System Capacity. • Some SE and CALSTDs are not available forcing intervention or Customer Complaints.	60% to 85%
High	• System Capacity cannot meet the fleet and depot demand signals. • Fleet deploys without full CALSTD and/or SE availability. • Customers request relief from NPSL services.	>85%

Example: The System a capacity of 4 calibrations per week. This is normally adequate to meet the workload schedule, however, there are one or two months out of the year that the demand goes to 6 calibrations per week, plus there is a planned expansion of the workload for this system sometime in the next three years which will result in the



demand exceeding the capacity ten months out of the year.

Based on the current state of the system, the Consequence is Medium, and the likelihood is Medium Low because the system only fails to meet the demand 17% of the time. With the planned workload increase, the System will fail to meet the demand 83% of the time, and the capacity is no longer considered adequate; the depot and fleet laboratories may not have a critical standard available thereby affecting downstream availability of fleet SE. These factors change the Capacity Risk to Consequence: High, Likelihood: High, for future workload.

Efficiency: The amount of effort required to perform calibrations and the calibration system ease of use.

Ranking	Consequence	Likelihood
Low	• System requires minimal effort to operate.	<10 %
Medium-Low	• System requires some effort but the effort is not taxing.	10% to 30%
Medium	• System requires constant attention and interaction with the metrologist.	30% to 60%
Medium High	• System is difficult to operate. • Some measurements have to be repeated to validate the calibration results.	60% to 85%
High	• System is tedious to operate and perform a calibration. • All measurements made on this system are impacted by the effort required.	>85%

Example: The PMS is partially automated and therefore requires a technician to constantly monitor the computer to perform manual functions such as inputting data and changing switch positions on the TI and/or PMS instruments. As a result, 65% of the technician's time is spent waiting for the next computer prompt to take action and the technician is not available to perform other work during this time.

Efficiency

Consequence					
High					
Medium-High					
Medium					X
Medium-Low					
Low					
	Low	Medium-Low	Medium	Medium-High	High
	Likelihood				

The Consequence in this case is Medium in that the system requires constant attention, however, it requires this attention 100% of the time; therefore, the likelihood is High.

Risk Scoring

Once the Risk Assessment is complete for the four risk factors, a score is computed to aid in prioritizing the future modernization projects. The Risk score is computed by multiplying the Consequence by the Likelihood where the scale is from 1 (Low) to 5 (High). The by-cell scoring is shown in the following Risk Cube.

Title

Consequence					
High	5	10	15	20	25
Medium-High	4	8	12	16	20
Medium	3	6	9	12	15
Medium-Low	2	4	6	8	10
Low	1	2	3	4	5
	Low	Medium-Low	Medium	Medium-High	High
	Likelihood				

The Risk Score for a PMS is documented on a PMS Health Assessment Sheet (see Figure 3). The total risk score is then calculated by adding the individual scores for each risk area. High risk scores must be justified and a mitigation strategy put in place to reduce the impact from the high risk.

The individual Health Assessment sheets are then summarized in a summary page that shows each PMS ranking. This information then feeds a report that is reviewed by the NAVAIR METCAL Program management and used to identify funding requirements for the modernization budget.

After the health assessments are complete and the report generated, a review board comprised of the NAVAIR METCAL Chief Engineer, Calibration Standards (CALSTDs) Manager, In-Service Engineering Team Lead, and the Director of NPSL meet to discuss the rankings and to select the next set of projects to begin working on. In a typical year, it is expected that 6 to 8 new projects will be undertaken depending upon the availability of funding and resources.

Conclusion

In today's world of shrinking budgets and increased technical demands, calibration laboratory managers face difficult financial decisions when it comes to

Figure 3. Health Assessment Sheet

sustaining, improving, or establishing new capability. A risk based analysis provides these managers with information they need to make infrastructure investment decisions. The process described in this paper is one example of a Risk Based process that has been successfully used to modernize Primary Measurement Systems at the Navy Primary Standards Laboratory. The process accomplishes three things: first it provides a consistent method of assessing the health of the laboratory infrastructure, second it provides a means for ranking projects based on standardized grading criteria, and third it includes a workload evaluation to ensure that the system continues to meet your customers' current and future workload requirements.

Kevin R. Abercrombie (kevin.abercrombie@navy.mil), NAVAIR METCAL Chief Engineer, AIR 4.1.12.

NPSL Primary Measurement System Health Assessment Tool

10/10/2017

System	Date	Traceability	Supportability	Capacity	Efficiency	Overall	Risk Score
JVS	10/11/2017	Low	High	High	Medium	Medium	39
PRIMARY FLOW	10/11/2017	Low	Low	Low	Low	Low	10
ACCELERATION	11/28/2017	Low	Medium	Low	Medium	Medium	28
MICRO-WAVE-NOISE	11/28/2017	High	Medium	Medium	High	High	57

Figure 4. PMS Health Assessment Dashboard

Fluke Calibration PM500 Pressure Measurement Modules

Everett, Wash., April 24, 2018 – Fluke Calibration expands its line of pressure modules with the new PM500 Pressure Measurement Modules, a set of 46 modules ranging from low differential pressures up to 20 MPa (3000 psi). Designed for use with the Fluke Calibration 6270A Modular Pressure Controller/Calibrator and the 2271A Industrial Pressure Calibrator, the PM500 modules bridge the gap between the PM200 and PM600 Pressure Modules to provide calibration solutions across a wide range of applications.

The Fluke Calibration PM500 features a highly characterized and linearized silicon pressure sensor that provides an economical way of making accurate pressure measurements. The modules have a 0.01% reading measurement uncertainty from 50% - 100% for most ranges, allowing for a diverse workload coverage.

The PM500 modules broaden the pressure calibration capabilities of:

The 2271A Industrial Pressure Calibrator provides a complete, automated pressure testing solution for calibrating a wide variety of pressure gauges and sensors. Combined with the PM500 modules, the 2271A has even more speed and flexibility to test or calibrate higher accuracy transmitters and digital gauges.

The Fluke Calibration 6270A Pressure Controller/Calibrator is a robust, reliable solution that significantly simplifies the task of pneumatic pressure calibration. With the PM500 modules, the 6270A is even more accurate, allowing technicians to cover larger workloads.

To learn more about the Fluke Calibration PM500 Pressure Measurement Modules visit http://us.flukecal.com/pm500.

Starrett Digital Force Testers for High Volume Production Testing

ATHOL, MA U.S.A. (April 11, 2018) - The L.S. Starrett Company (www.starrett.com) has introduced a series of Motorized Digital Test Frames for performing a wide range of basic, high volume in-situ lean manufacturing force testing applications including tension, compression, flexural cyclic, shear and friction. The Starrett FMM Digital Force Testers are part of the new Starrett L1 Line of entry level computer-based force measurement solutions. Optimized for production and quality control testing, the versatile, innovative architecture of the L1 system is designed for fast, easy-to-use, reliable and repeatable operation. To view a video and request a brochure visit (http://starrett.co/2FvliDf).

What makes Starrett FMM Force Testers exceptionally unique is their ability to be used with either Starrett L1 software for computer-controlled testing, or with a Starrett DFC Digital Force Gage. The DFC gage lets users control the speed and travel of the FMM Series, providing a single operator interface for control and testing. Using the DFC Series on an FMM test frame, load, distance and break limit testing can be performed simply at an economical price and with excellent accuracy of better than 0.1%

The Starrett L1 software offers simple, fill-in-the-blank templates that let users create, perform, measure and analyze their test in seconds and perform limit testing, break testing, constant hold testing, cycle testing and more. Touch screen control simplifies operation and the high resolution display shows results in tabular and graphical formats. Tolerances can be applied for immediate pass/ fail indication. Raw data can be exported to Excel for reporting and statistical analysis.

Starrett FMM Series Test Frames are available in three force capacities: 110lbf, 330lbf and 550lbf (500N, 1500N and 2500N), and are furnished in a standard travel length (20-inches/ 508mm) or an extended travel length (30-inches/ 760mm). FMM test frames feature a small footprint for small work spaces. The frames are just 11 inches wide by 16 inches deep. All frames have a speed range from 0.02 to 40 inches per minute (1 to 1000 mm/ min). Position accuracy on the FMM test frames is better than 20 microns and speed accuracy is better than 0.1% at full load and at maximum speed. Jog keys and an LED display aide manual operation. Adjustable travel limits may be used to prevent over-travel conditions.

The FMM test frames also feature an adjustable base plate made of cast aluminum for exceptional rigidity and durability. Inspectors may use metric or imperial threaded test fixtures and clevis adapters. The base plate is adjustable so that sample alignment can be performed in seconds without special tools.

The Starrett FMM Testers' mechanical design incorporates a preloaded, grounded ball screw with a linear rail for precise, repeatable travel. Frames are capable of performing hold tests as well as cyclic testing for up to 27 hour durations. Bench clips are supplied if users want to permanently secure the frame to their work bench.

The FMM test frames are CE compliant and have USB and RS-232 communication. Plus, the frames have configurable I/O for use with annunciators or other external devices.

When more sophisticated and complex testing is required, Starrett also offers a range of force solutions via its L2, S2, L2 Plus and L3 Systems. Starrett force measuring equipment is manufactured in the U.S.A. and is available to order now in several configurations including Handheld Force Gages and digital and manual Force Testing frames.

For more information on Starrett FMM Force Testers, visit (http://starrett.co/2FvliDf) or contact The L.S. Starrett Company, 121 Crescent Street, Athol, MA 01331 U.S.A. Telephone: (978) 249-3551, Fax: (978) 249-8495, email: general@starrett.com, internet: www.starrett.com

Additel's New 875 Dry Well Calibrator Series

Brea, Calif., March 26, 2018–Additel Corporation introduces their new ADT875 Dry Well Calibrator series which consist of three temperature ranges from –40°C to 660°C. There are three ranges to choose from: low temperature –40C° to 155°C (ADT875-155), mid-temperature 33°C to 350°C (ADT875-350), and high temperature 33°C to 660°C (ADT875-660). Each unit has performance specifications related to the guidelines published in Euramet cg-13 specifying stability, radial and axial uniformity, loading, and hysteresis.

Each unit has a process calibrator option which combines many features found in a HART documenting process calibrator with the temperature dry well. This option includes the ability to measure a reference PRT and two device under test channels which can measure, mA, voltage, switch, RTD or thermocouple. In addition to these measurement functions, this calibrator has documenting capability of creating tasks, saving as found and as left results, and HART communication.

Product Availability

The Additel 875 Series are now available for order. For more information, please visit www.additel.com. For information on Additel products and applications, or to find the location of your nearest distributor, contact Additel corporation, 2900 Saturn Drive, #B, Brea, CA 92821, call 1-714-998-6899, Fax 714-998-6999, email sales@additel.com or visit the Additel website at www.additel.com

Pasternack 4-in-1 Calibration Kits with 26.5 GHz Calibration Capability

IRVINE, Calif. – Pasternack, a leading provider of RF, microwave and millimeter wave products, has released a new line of 4-in-1 3.5mm calibration kits for test and measurement, field testing, antenna measurement and cable verification applications.

Pasternack's new series of calibration kits consists of two models, both with a compact, lightweight, 4-in-1 design package. These short-open-load-through (SOLT) calibration kits have a 26.5 GHz calibration capability. They feature gold-plated 3.5mm connectors and a handy lanyard. Plus, they are available off-the-shelf and can be shipped immediately.

These SOLT calibration kits have an impedance level of 50 Ohms nominal. They also have a phase deviation of +/-2 degrees maximum and return loss of 30 dB minimum. They are ideal for telecommunications, military electronics, automotive, medical, aerospace and consumer electronics industries.

Pasternack's new 4-in-1 calibration kits are in stock and ready for immediate shipment with no minimum order quantity. For detailed information on these products, please visit https://www.pasternack.com/pages/rf-microwave-and-millimeter-wave-products/4-in-1-calibration-26.5-ghz.html.

For inquiries, Pasternack can be contacted at +1-949-261-1920.

Automatic Calibration Alert Added to Crystal Engineering XP2i Digital Pressure Gauge

Crystal Engineering, a unit of AMETEK Sensors, Test & Calibration (www.ametekcalibration.com), has added an automatic calibration reminder system to its widely used XP2i pressure gauge. The new system greatly reduces the possibility of using gauges after their calibration dates and potentially incurring regulatory fines.

Manual record-keeping and notifications are replaced by customizable on-screen alerts prior to the due date, warning alerts on and after the due date, and an optional capability to lock the gauge from use after its calibration due date. Dates, reminders and message types are set by supervisors through free software.

Because they measure critical performance metrics of a wide range of equipment, properly calibrated pressure gauges can be important factors in worker safety, pollution control and/or product quality.

Applications: Oil & gas • Power generation • Food & beverage • Plastics • Process industries • Chemical • Petrochemical • Pharmaceuticals • Industrial safety • Quality assurance

The rugged, intrinsically safe XP2i gauge offers high-accuracy pressure recording in the harshest environments, from offshore to desert to the Arctic. Key features include an IP-67 rated, marine-grade enclosure, a fast pressure safety valve (PSV) mode, custom engineering units, and a leak-free pressure fitting connection.

Active Digital Temperature Compensation corrects the sensor for changes in temperature. It is guaranteed to 0.1% of reading accuracy from -10 to 50° C. Every XP2i comes with an ISO 17025 calibration report – NIST-traceable, A2LA accredited, internationally recognized by ILAC–with test data at 5 temperatures.

Its high contract liquid crystal display is readable in all conditions from bright sunlight to dark (with included backlight).

Crystal Engineering produces highly accurate, field-grade testing and calibration equipment for measurement applications in oil and natural gas, power generation, waste water, water supply, manufacturing, aerospace, and aircraft maintenance. It is a unit of AMETEK Test & Calibration Instruments, a division of AMETEK, Inc., a leading global manufacturer of electronic instruments and electromechanical devices with annualized sales of more than US$4.3 billion.

Screen display on Crystal Engineering XP2i digital pressure gauge (right) automatically informs operator when calibration is required. Notification options are set in free software (left).

Measurements International

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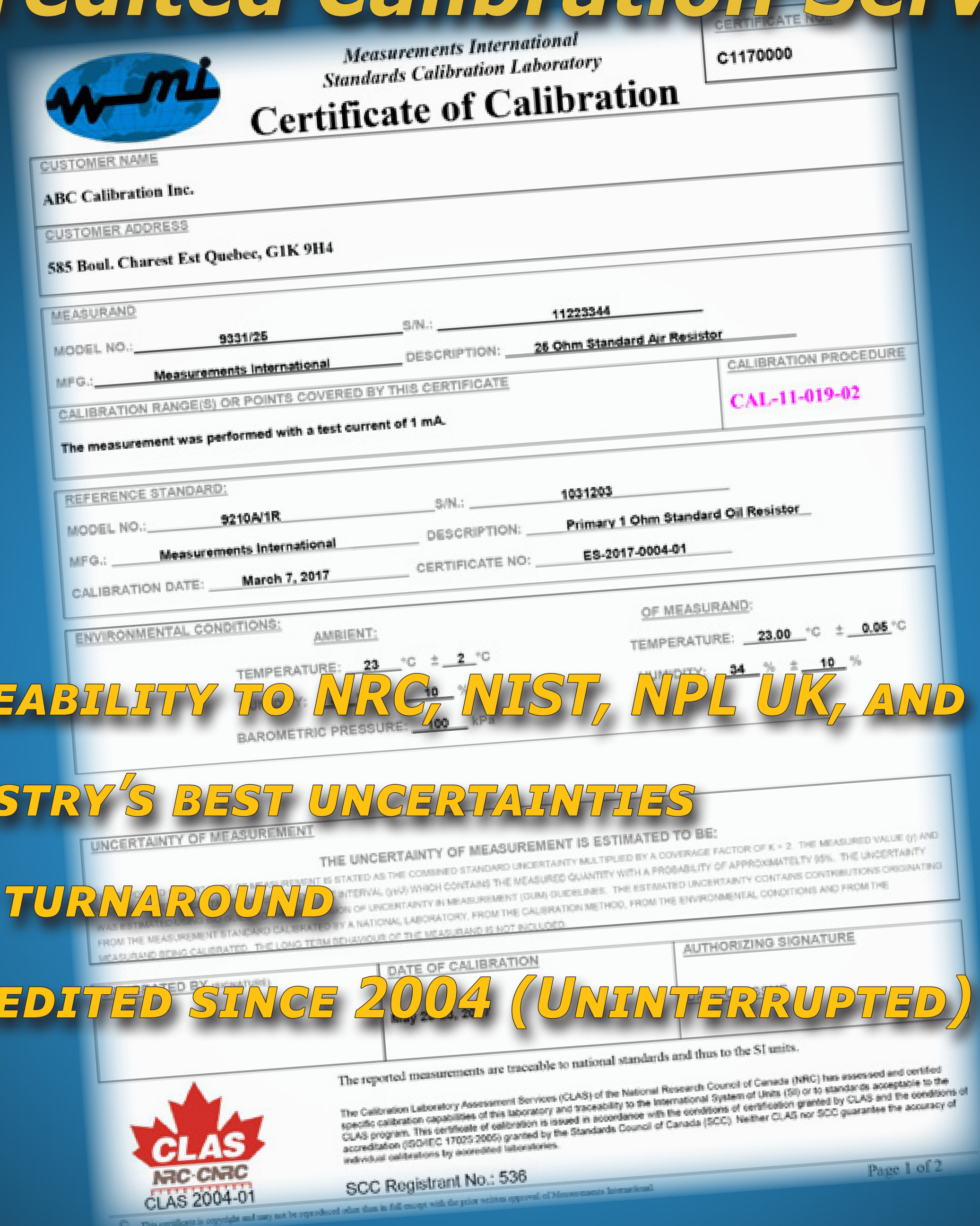

Measurements International
Standards Calibration Laboratory

Certificate of Calibration

CERTIFICATE NO.: C1170000

CUSTOMER NAME: ABC Calibration Inc.

CUSTOMER ADDRESS: 585 Boul. Charest Est Quebec, G1K 9H4

MEASURAND

MODEL NO.: 9331/25 S/N.: 11223344

MFG.: Measurements International DESCRIPTION: 25 Ohm Standard Air Resistor

CALIBRATION RANGE(S) OR POINTS COVERED BY THIS CERTIFICATE: The measurement was performed with a test current of 1 mA.

CALIBRATION PROCEDURE: CAL-11-019-02

REFERENCE STANDARD:

MODEL NO.: 9210A/1R S/N.: 1031203

MFG.: Measurements International DESCRIPTION: Primary 1 Ohm Standard Oil Resistor

CALIBRATION DATE: March 7, 2017 CERTIFICATE NO: ES-2017-0004-01

ENVIRONMENTAL CONDITIONS: AMBIENT: TEMPERATURE: 23 °C ± 2 °C; BAROMETRIC PRESSURE: 100 kPa

OF MEASURAND: TEMPERATURE: 23.00 °C ± 0.05 °C; HUMIDITY: 34 % ± 10 %

UNCERTAINTY OF MEASUREMENT

THE UNCERTAINTY OF MEASUREMENT IS ESTIMATED TO BE:

DATE OF CALIBRATION

AUTHORIZING SIGNATURE

The reported measurements are traceable to national standards and thus to the SI units.

CLAS NRC·CNRC CLAS 2004-01

SCC Registrant No.: 536

Page 1 of 2

- **Traceability to NRC, NIST, NPL UK, and METAS**
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Celebrating 1987 30 Years 2017

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