# CAL LAB

## THE INTERNATIONAL JOURNAL OF METROLOGY


2020
APRIL
MAY
JUNE

**Verifying the Integrity of S-Parameter Measurements**

**Thru-Reflect-Line (TRL) Calibration**

**Redefined but Not Perfected: The On-going Saga of the Kilogram**

# PRECISION CURRENT INSTRUMENTATION AND CURRENT CALIBRATION

## DANISENSE HIGH PRECISION CURRENT TRANSDUCERS

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

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# FEATURES



# DEPARTMENTS



**ON THE COVER:** Automated accredited calibrations at NI's Calibration Services Laboratory, Debrecen, Hungary. NI is National Instruments' new corporate name

## UPCOMING CONFERENCES & MEETINGS

*Since time of printing, some of the following events may have changed. Visit the event URL provided for the latest information.*

**Aug 24, 2020 NCSL International Workshop & Symposium/ Conference on Precision Electromagnetic Measurements (CPEM).** Virtual Program. This joint conference has been rescheduled to take place in 2024. To circumvent this issue in 2020, we have added a Virtual Technical Program module. https://www.ncsli.org/aws/

**Sep 7-11, 2020 The XXX International Scientific Symposium** "Metrology and Metrology Assurance 2020." Sozopol, Bulgaria. The ISS "MMA 2020" will provide insights to the latest achievements in metrology and metrology assurance. http://www.metrology-bg.org/

**Sep 14-16, 2020 IMEKO TC-4 International Symposium.** Virtual. The main interest of Technical Committee 4 of International Measurement Confederation (IMEKO TC4) is related with theoretical and practical aspects of the measurement of electrical quantities. http://www.imeko-tc4-2020.org/

**Oct 5-7, 2020 IMEKO TC-19 International Workshop on Metrology for the Sea.** Naples, Italy. MetroSea represents an international meeting place in the world of research in the field of metrology for marine environment. http://www.metrosea.org/

**Oct 15-17, 2020 International Conference on Sensing, Measurement and Data Analytics in the era of Artificial Intelligence (ICSMD2020).** Xi'an, Shaanxi, China. Xi'an Jiaoton University will host the first ICSMD, inviting experts and scholars to meet and exchange ideas. http://icsmd2020.icrp.xjtu.edu.cn/

**Oct 20-23, 2020 3rd International Colloquium on Intelligent Grid Metrology.** Virtual Event. It is our pleasure to invite experts in precise metrology infrastructure for effective development and deployment of smart grids as well as in broad range of its accompanying applications and beyond. http://smagrimet.org/2020/

**Oct 26-29, 2020 38th North Sea Flow Measurement Workshop.** Virtual Event. The Workshop continues to deliver fantastic knowledge sharing and networking opportunities for delegates. https://www.tuvsud.com/en-gb/events/north-sea-flow-measurement-workshop

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# EDITOR'S DESK

**Loss**

Loss is the word that seems to describe what I've been feeling, when reading about the jobs and businesses lost, family separations, and overwhelmed hospitals and supply chains. There's also loss of normalcy from not being able to meet at the library for book club, shoot hoops at the park, go to the brew pub on trivia night, hang out at the mall, or see a movie. You know you'll be back, but right now, the void is very big and the grief is real. And what will normal look like, say two years from now?

Loss is only part of the journey the world is experiencing as we are forced to acknowledge tiers of civil rights in a so-called free and equitable society. Meanwhile, our planet's oceans and atmosphere are rapidly changing. How do I gracefully compose an Editor's Desk while acknowledging all the reasons we can't sleep at night? I can't, but neither can I ignore these catastrophic, human-created problems. These problems just don't hang over my head; they are knocking at the front door, so they have arrived upon this page too.

We missed our opportunity to meet up with new and familiar faces at the Measurement Science Conference Training Symposium—same with the NCSLI Workshop/CPEM that was scheduled in our home town this summer. Notice most of the Conference and Meetings for the remainder of 2020 have gone virtual. This inspired me to mix scheduled webinar training into the Calendar section to simplify things.

Speaking of webinars… NCSL International has been producing an interesting and informative series of webinars called "Metrology in Motion." As part of this series, Patrick Abbott of NIST presented "Metrology and the Updated SI," where he went through each of the base units, how they were affected by the updated SI, and how they related to their defining constants. For this issue, Mr. Abbott focuses on the kilogram in "Redefined but Not Perfected: The On-going Saga of the Kilogram." His writing delivers an intriguing and detailed "saga" that I encourage readers of all disciplines to read.

But to begin, we have two short articles handling Vector Network Analyzer calibration. First is Chris Grachanen's article on "Verifying the Integrity of S-Parameters," where he shares with us best practices for making s-parameter measurements. Then Brian Walker of Copper Mountain Technologies explains the difference between SOLT and TRL calibration of VNAs with an emphasis on understanding TRL calibration kits.

After 25 years of publishing, CAL LAB has collected a treasure trove of contributions from senior techs, engineers, and scientists. These are made freely available to everyone/anyone with access to an internet connection. Go to: **https://www.callabmag.com/article-index/**.

Happy Measuring,

Sita

P.S. If you are an industry professional and would like to publish a measurement related article, consider submitting an abstract or fully formed article for review to CAL LAB at: office@callabmag.com. **Knowledge should be shared!**

### SEMINARS: Dimensional

**Jul 29-30, 2020 Gage Calibration & Repair.** Houston, TX. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Aug 3-4, 2020 Gage Calibration & Repair.** Birmingham, AL. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Aug 4-6, 2020. Seminar 114: Gage Calibration.** Aurora (Chicago), IL. Mitutoyo Institute of Metrology. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/events/categories/educational-seminars/

**Aug 19-20, 2020 Gage Calibration & Repair.** Grand Rapids, MI. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Sep 8, 2020 Dimensional Measurement User.** Bristol, UK. INSHERE Ltd. In this training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviours. This is a EAL approved qualification. https://training.npl.co.uk/course/dimensional-measurement-user/

**Sep 15-16, 2020 Gage Calibration & Repair.** Louisville, KY. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Sep 24-25, 2020 Gage Calibration & Repair.** Bloomington, MN.

IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Sep 29, 2020 Dimensional Measurement Applier.** Bristol, UK. INSPHERE Ltd. A four day training course for those who have a good basic understanding of measurement principles gained through the Dimensional Measurement User training course. https://www.npl.co.uk/training

**Sep 30-Oct 2, 2020. Seminar 114: Gage Calibration.** Mitutoyo Institute of Metrology. Aurora (Chicago), IL. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/events/categories/educational-seminars/

**Oct 6-7, 2020 Gage Calibration & Repair.** Monroe, MI. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Oct 20, 2020 Dimensional Measurement User.** Coventry, UK. Coventry University DMU. In this training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviours. This is a EAL approved qualification. https://training.npl.co.uk/course/dimensional-measurement-user/

**Oct 20-21, 2020 Gage Calibration & Repair.** Wichita, KS. IICT Enterprises. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.calibrationtraining.com/

**Nov 3-6, 2020. Seminar 114: Gage Calibration.** Mitutoyo Institute of Metrology. Aurora (Chicago), IL. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/events/categories/educational-seminars/

# CALENDAR

**SEMINARS: Electrical**

**Sep 21-24, 2020 MET-301 Advanced Hands-On Metrology.** Everett, WA. This course introduces the student to advanced measurement concepts and math used in standards laboratories. The student will learn how to make various types of measurements using different measurement methods. We will also teach techniques for making good high precision measurements using reference standards. https://us.flukecal.com/training

**Sep 23-24, 2020 Electrical Measurement.** Lindfield NSW, Australia. NMI. This two-day course covers essential knowledge of the theory and practice of electrical measurement using digital multimeters and calibrators; special attention is given to important practical issues such as grounding, interference and thermal effects. https://www.industry.gov.au/client-services/training-and-assessment

**Oct 19-22, 2020 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. The student will be competent to make measurements after passing the final exam. https://us.flukecal.com/training

**SEMINAR: Flow**

**Sep 29-30, 2020 Flow Measurement and Calibration (in English).** Munich, Germany. TrigasFI GmbH. This seminar 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://www.trigasdm.com/en/flowhow-2/seminars/

**Oct 5-8, 2020 Gas Flow Calibration Using molbloc/molbox.** Phoenix, AZ. Fluke Calibration. A four day training course in the operation and maintenance of a Fluke Calibration molbloc/molbox system. The course's central objective is to assure optimum system use. https://us.flukecal.com/training/

**SEMINARS: General**

**Aug 6, 2020 Calibration and Measurement Fundamentals.** Brisbane QLD, Australia. NMI. This one-day fully interactive course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://www.industry.gov.au/client-services/training-and-assessment

**SEMINARS: Industry Standards**

**Aug 3-6, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories – VIRTUAL.** QC Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://qctraininginc.com/course/understanding-iso-iec-170252017-for-testing-calibration-laboratories-virtual/

**Aug 5-6, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Denver, CO. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

**Aug 5-6, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories (MS 111W).** A2LA WPT. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events/understanding-iso-iec-17025-2017-for-testing-calibration-laboratories-ms-111w

**Aug 10-13, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017 - VIRTUAL.** QC Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://qctraininginc.com/course/auditing-your-laboratory-to-iso-iec-170252017-virtual/

**Aug 10-13, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017 (AUD 102W).** A2LA WPT. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2lawpt.org/events/auditing-your-laboratory-to-iso-iec-17025-2017-102w

**Aug 17-18, 2020 Managing Risk In Your 17025 Accredited Organization – VIRTUAL.** QC Training. This course introduces the participants to risk-based thinking from an international standards perspective. The participant will learn risk concepts from ISO 31000 and ISO 9000 and become familiar with industry tools used to assess and manage risk in the ISO conformity assessment arena. https://qctraininginc.com/course/managing-risk-in-your-organization-virtual/

**Aug 27, 2020 Document Control and Record Keeping.** NIST OWM. This 2 hour webinar will introduce the fundamentals of Laboratory Management System Document Control and Record Keeping that are necessary to successfully implement ISO/IEC 17025:2017. https://www.nist.gov/news-events/events/2020/08/5613-document-control-and-record-keeping

**Aug 27-28, 2020 Introduction to ISO/IEC 17025.** St. Louis, MO. 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://anab.ansi.org/public-course-schedule

**Aug 31-Sep 3, 2020 Applied Measurement Uncertainty for Calibration Laboratories.** QC Training. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://

qctraininginc.com/course/applied-measurement-uncertainty-for-calibration-laboratories-virtual/

**Sep 14-15, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Charlotte, NC. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

**Sep 14-15, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Frederick, MD. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

**Sep 14-16, 2020 Internal Auditing to ISO/IEC 17025:2017.** Milwaukee, WI. ANAB. Attendees of this 2.5-day training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/public-course-schedule

**Sep 15-16, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Doha, Qatar. International Accreditation Service®. To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

**Sep 16-17, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017 (AUD 102W).** Webinar. A2LA WPT. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2lawpt.org/events/auditing-your-**laboratory-to-iso-iec-17025-2017-102w**

**Sep 16-17, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017.** Charlotte, NC. A2LA WPT. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2lawpt.org/events

**Sep 16-17, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Brea, CA. International Accreditation Service®.

To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

**Sep 21-22, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Chicago, IL. International Accreditation Service®. To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

**Sep 23-24, 2020 Internal Auditing for all Standards.** Chicago, IL. International Accreditation Service®. This 2-day Training Course examines auditing principles and techniques and facilitates the practice of required internal audit skills. It is based on internationally-recognized approaches to conducting conformant internal audits. https://www.iasonline.org/training/internal_audit_for_accredited_organizations/

**Sep 28-29, 2020 ISO/IEC 17025:2017 - La Nueva Norma Para La Competencia del Laboratorio (MS111S-W).** Webinar. A2LA WPT. Este curso incluye una revisión exhaustiva, así como una exposición de los principales conceptos y de los requisitos de esta Norma Internacional. https://www.a2lawpt.org/events/iso-iec-17025-2017-la-nueva-norma-para-la-competencia-del-laboratorio-ms-111s

**Sep 28-Oct 1, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories (MS 111W).** Webinar. A2LA WPT. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events/understanding-iso-iec-17025-2017-for-testing-calibration-laboratories-ms-111w

**Sep 30-Oct 1, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs.** Webinar. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

**Sep 30-Oct 1, 2020 Auditando Su Laboratorio con la Norma ISO/IEC 17025:2017 (AUD 102S-W).** Webinar. A2LA WPT. Este curso introduce a los participantes a la norma ISO/IEC 19011, directriz para la auditoría de los sistemas de gestión aplicada a la norma ISO/IEC 17025. https://www.a2lawpt.org/events/auditando-su-laboratorio-con-la-norma-iso-iec-17025-2017-aud-102s-w

# CALENDAR

**Oct 5-6, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Savannah, GA. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

**Oct 5-6, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories.** Dallas, TX. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

**Oct 7-8, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017.** Savannah, GA. A2LA WorkPlace Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2lawpt.org/events

**Oct 7-8, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017.** Dallas, TX. A2LA WorkPlace Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2lawpt.org/events

**Oct 13, 2020 Documenting Your ISO/IEC 17025 Management System.** Philadelphia, PA. A2LA WorkPlace Training. During this course, the participant will gain an understanding of the basic concepts of management system documentation structure, content, and development. https://www.a2lawpt.org/events

**Oct 14-15, 2020 ISO/IEC 17025:2017 for Cannabis Testing Laboratories.** Philadelphia, PA. A2LA WP Training. Throughout this course participants from the cannabis industry will learn how and why the new ISO/IEC 17025:2017 standard applies to them and how accreditation improves the visibility, creditability, and safety of the cannabis industry. https://www.a2lawpt.org/events

**Oct 19-23, 2020 ISO/IEC 17025:2017 Lead Assessor Training.** Austin, TX. ANAB. The 4.5-day ISO/IEC 17025:2017 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. https://anab.ansi.org/public-course-schedule

**Oct 29, 2020 Internal Auditing Best Practices.** NIST OWM. This 2 hour webinar will consider internal auditing techniques and best practices that are used by a metrology laboratory to comply with ISO/IEC 17025:2017 criteria. There are no prerequisites for this webinar. https://www.nist.gov/news-events/events/2020/10/5616-internal-auditing-best-practices

**SEMINARS: Mass**

**Oct 19-30, 2020 5615: Mass Metrology Seminar.** Gaithersburg, MD. NIST. The Mass Metrology Seminar is a two-week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the participant performs measurements by applying procedures and equations discussed in the classroom. The seminar focuses on the comprehension and application of the procedures, the equations, and calculations involved. https://www.nist.gov/news-events/events/2020/10/5615-mass-metrology-seminar

**SEMINARS: Measurement Uncertainty**

**Aug 3-4, 2020 Introduction to Measurement Uncertainty for Laboratories – VIRTUAL.** Webinar. QC Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. The participant will gain an understanding of the statistical techniques required to estimate measurement uncertainty and will practice those skills to create basic uncertainty budgets. https://qctraininginc.com/course/introduction-to-measurement-uncertainty-virtual/

**Aug 10-13, 2020 Applied Measurement Uncertainty for Testing Laboratories (EMU 201W).** Webinar. A2LA WPT. During this workshop, the participant will be introduced to several tools and techniques that can be applied in the testing laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events/applied-measurement-uncertainty-for-testing-laboratories-emu-201w

**Aug 11-13, 2020 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. https://us.flukecal.com/training/

**Aug 18-21, 2020 Applied Measurement Uncertainty for Calibration Laboratories.** Webinar. A2LA WPT. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events/applied-measurement-uncertainty-for-calibration-laboratories-emu-202-2

**Sep 13-14, 2020 Uncertainty of Measurement for Labs.** Riyadh, Saudi Arabia. IAS®. Introduction to metrology principles, examples and practical exercises. Training includes case studies and discussions, with application of statistical components in practical examples frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

**Sep 17-18, 2020 Fundamentals of Measurement Uncertainty.** Milwaukee, WI. ANAB. Attendees of the two-day Fundamentals Measurement Uncertainty training course will learn a practical approach to measurement uncertainty applications, based on fundamental practices. https://anab.ansi.org/public-course-schedule

**Sep 17-18, 2020 Uncertainty of Measurement for Labs.** Doha, Qatar. IAS®. Introduction to metrology principles, examples and practical exercises. Training includes case studies and discussions, with application of statistical components in practical examples frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

# CALENDAR

**Sep 22, 2020 Introduction to Measurement Uncertainty.** Frederick, MD. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

**Sep 22, 2020 Introduction to Measurement Uncertainty (EMU 101W).** Webinar. A2LA WPT. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

**Sep 23-24, 2020 Applied Measurement Uncertainty for Testing Laboratories (EMU 201W).** Webinar. A2LA WPT. During this workshop, the participant will be introduced to several tools and techniques that can be applied in the testing laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events/

**Sep 23-24, 2020 Applied Measurement Uncertainty for Testing Laboratories.** Frederick, MD. A2LA WP Training. During this workshop, the participant will be introduced to several tools and techniques that can be applied in the testing laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events/

**Oct 13, 2020 Introduction to Measurement Uncertainty.** Detroit, MI. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

**Oct 14-15, 2020 Applied Measurement Uncertainty for Calibration Laboratories.** Detroit, MI. A2LA WP Training. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2lawpt.org/events/

**Oct 23, 2020 Introduction to Measurement Uncertainty.** Frederick, MD. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

**SEMINARS: Photometry & Radiometry**

**Nov 17-18, 2021 Photometry and Radiometry.** Lindfield NSW, Australia. NMI. This two-day course (9 am to 5 pm) covers the broad range of equipment and techniques used to measure colour and light output, the basic operating principles involved in radiometry, working techniques, potential problems and their solutions. https://www.industry.gov.au/client-services/training-and-assessment

**SEMINARS: Pressure**

**Aug 4, 2020 Pressure Calibration Workshop.** Lower Hutt, New Zealand. MSL. This workshop is a practical one-day session dealing with all aspects of pressure gauge and transducer calibration. https://measurement.govt.nz/training/

**Sep 14-18, 2020 Principles of Pressure Calibration.** Phoenix, AZ. Fluke Calibration. A five-day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances). The class is designed to focus on the practical considerations of pressure calibrations. https://us.flukecal.com/training/

**Oct 19-23, 2020 Advanced Piston Gauge Metrology.** Phoenix, AZ. Fluke Calibration. Focus is on the theory, use and calibration of piston gauges and dead weight testers. https://us.flukecal.com/training/

**SEMINARS: RF & Microwave**

**Sep 8-10, 2020 VNA Tools Training Course.** Federal Institute of Metrology METAS. Beaverton, OR, USA. VNA Tools is a free software (www.metas.ch/vnatools) 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 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

**Oct 20-22, 2020 VNA Tools Training Course.** Federal Institute **of Metrology.** METAS. Bern-Wabern, Switzerland. VNA Tools is a free software (www.metas.ch/vnatools) 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 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

**SEMINARS: Software**

**Aug 31-Sep 4, 2020 MET/TEAM® Basic Web-Based Training.** Webinar. Fluke Calibration. 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/calibration-software-training/

**Sep 14-18, 2020 MC-207 Advanced MET/CAL® Procedure Writing.** Everett, WA. Fluke Calibration. A five-day procedure writing course for advanced users of MET/CAL® calibrations software. https://us.flukecal.com/training/

**Sep 28-Oct 2, 2020 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. https://us.flukecal.com/training

**Nov 16-20, 2020 MET/TEAM  Basic Web-Based Training.** Fluke Calibration. You will learn a systematic approach to recording the information you need to manage your lab assets routinely, consistently and completely. This course is typically held from 10:00 am to 12:00 pm (Noon) Pacific Standard Time. https://us.flukecal.com/training/calibration-software-training/

**SEMINARS: Temperature & Humidity**

**Aug 19, 2020 Infrared Radiation Thermometry Workshop.** Measurement Standards Laboratory of New Zealand. Christchurch, NZ. This is a practical course covering problems with the use and calibration of infrared radiation thermometers, including reflections, absorption, emissivity, and instrumental effects. The course builds confidence in non-contact temperature measurements in the range −50 °C to 2000 °C. https://measurement.govt.nz/training/

**Sep 14-16, 2020 Advanced Topics in Temperature Metrology.** American Fork, UT. Fluke Calibration. A three-day course on advanced topics in temperature metrology used in primary and secondary-level temperature calibration laboratories. https://us.flukecal.com/training

**Oct 7, 2020 Humidity Measurement.** Port Melbourne VIC, Australia. NMI. This one-day course provides information about the main concepts and practical techniques involved in measuring humidity in air and explains how to make such measurements accurately and consistently. https://www.industry.gov.au/client-services/training-and-assessment

**SEMINARS: Time & Frequency**

**Sep 15-17, 2020 Time and Frequency Seminar.** TBD. NIST. For NIST's 45th Time and Frequency Metrology Seminar, the Time and Frequency Division will cover clocks, oscillators, time distribution, optical atomic frequency standards, frequency precision, phase-noise and jitter measurements, network timing, and measurement accuracy and traceability standards. https://www.nist.gov/news-events/events/2020/09/2020-time-and-frequency-seminar

**Oct 20-21, 2020 Time and Frequency Measurement.** Lindfield NSW, Australia. NMI. This two-day course covers the broad range of equipment and techniques used to measure time and frequency and to calibrate time and frequency instruments. https://www.industry.gov.au/client-services/training-and-assessment

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**One-of-a-kind Building for the Measurement Standards Laboratory of New Zealand**

The simple exterior of the new building for the Measurement Standards Laboratory of New Zealand (MSL) hides a complex design and a technologically advanced laboratory.

Based at Callaghan Innovation in Gracefield, Lower Hutt, scientists and technicians from MSL's Electrical and Temperature Standards teams will soon occupy the new purpose-built laboratory.

For MSL Director Fleur Francois, the building represents a significant investment in the provision of national measurement standards to New Zealand.

"The new building will deliver the incredibly precise environment we need to propel our technical capabilities forward," says Fleur. "We also received funding from the Government in 2018 that has allowed us to purchase new and replacement equipment for the new laboratory to help maintain and build the capabilities we need to help New Zealand's future competitiveness."

The new laboratory is part of a larger programme of work upgrading and future-proofing aging research facilities at Callaghan Innovation's site. It will provide a safe and fit-for-purpose working environment for MSL's teams who are currently working in a building constructed during World War II.

To ensure the building would meet its specific needs, experienced MSL staff worked closely with the in-house planning team and contractors throughout all stages of work. This enabled MSL scientists and technicians to gain an intimate understanding of how the building was constructed and how it operates. This understanding will be invaluable to the MSL scientists as they start to undertake research activities in the building where minute changes in environmental conditions or electrical interference can have big impacts on experimental results.

"The laboratory design was incredibly technical as we needed to consider building materials, equipment dependencies, air conditioning requirements and much more," says Fleur. "Within New Zealand, this physics laboratory is certainly unique."


One of the most important components is the heating, ventilation and air conditioning (HVAC) system. The environmental conditions required by a globally recognised physics laboratory are incredibly strict, particularly in MSL's Electrical Standards laboratory. The HVAC system has been built to maintain a temperature of 20.0 °C with variations of no more than 0.1 °C.

To help the system cope with those tight controls, the lab design team and MSL staff put a lot of thought into the ventilation system design so any heat-generating equipment does not impact any other adjacent equipment.

Other key aspects of the new building include ensuring the mains wiring doesn't create electrical interference, anti-static flooring, and built-in separation of the steel building frame from reinforcing bars in the concrete foundation slab to avoid creating electrical loops.

There is also a section of stainless steel reinforcing in the foundation that has been specifically placed to allow MSL's Electrical Standards team to install their Quantum Hall Resistance Standard without risking damage to the superconducting magnet that is part of this standard.

For Laurie Christian, Principal Research Scientist and one of MSL's most long-standing physicists, the new building will mean being able to make better measurements more efficiently because the laboratory environment will no longer be a limitation.

"The old laboratory began its life in the 1940s, in the time before the measurement revolution created by the transistor and microprocessor," says Laurie. "We were forced to modify the labs periodically but were always constrained by the basic structure and services. Having something purpose-built with the future in mind will be wonderful for present and future electrical and temperature metrologists."

He says that it has been a fascinating experience working with the team of architects, and electrical, structural, and mechanical engineers, to get to this point. "We all had to learn each other's way of thinking and the project managers have played a key role in enabling that."

Following almost 20 months of construction and the interior fit-out, MSL received the keys to the building in June.

Fleur said "Taking possession of the building was a significant moment for MSL, and it marked the end of a significant amount of work by the team. Most importantly, our people will be working in a safe environment, but we are also looking forward to improved business resilience to ensure we can keep delivering for our customers."

"We're also looking forward to hosting visitors in the new facility and improving collaboration with our customers, stakeholders and other institutes around the world."

The MSL team has now embarked on a move-in project that they anticipate will take the next 14 months to complete.

"The complexity of the move-in project is because we have to maintain traceability of all standards, while continuing to operate as a national metrology laboratory," says Fleur.

Before any equipment is moved into the new building, the team will take two months to gather environmental information to understand how the building environment performs and how this will impact equipment performance.

Once this baselining work is complete, a staged move of the equipment will take place over a 12-month period, with a focus on quality and safety to ensure the new set ups are stable, operating as expected, and can be used for traceable measurements.

"The new laboratory will be a significant step forward in the race to stay ahead of industry's increasing demands for accuracy in its measurements. Once up and running it will help us uphold and enhance New Zealand's reputation as providing trusted, precise measurements," says Fleur.

Whilst COVID-19 hampered plans to officially open the building on 20 May 2020, to coincide with World Metrology Day, planning is underway to welcome customers and stakeholders to the new building next year.

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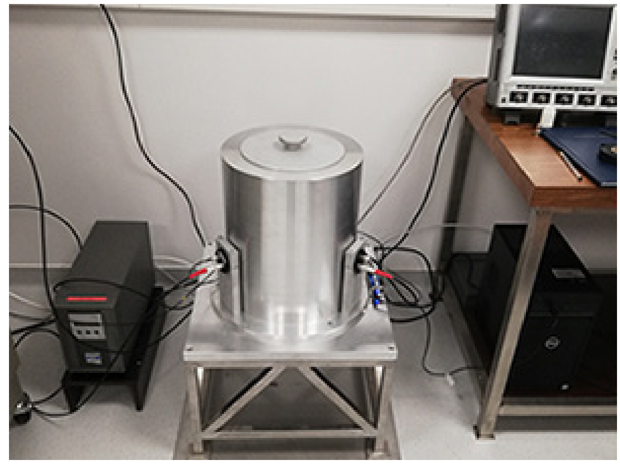
**New Instrument for Comparing Primary Standards of Pure β-Emitting Radionuclides**

The accurate measurement of radioactivity is essential for applications of ionizing radiation such as medical imaging, cancer therapy and environmental protection. To ensure that such measurements are harmonized world-wide, the BIPM operates a set of very stable and precise instruments to compare national standards of radioactivity. Up till now it has been possible to compare standards of radionuclides that emit gamma rays; setting up an equivalent instrument for radionuclides that only emit beta rays has proved to be a technical challenge.

Scientists from the BIPM have worked closely with colleagues from national metrology institutes in Germany, France, Poland, China and the UK to develop a new instrument; the device combines signals from three detectors surrounding a sample of the radioactive standard to determine an accurately reproducible parameter that is proportional to the activity (Bq) of the sample. The method was inspired by one of the techniques used to realize primary standards of radioactivity ('Triple-to-double coincidence counting'). Further details have been published in *Metrologia*.*



The new instrument for comparing primary standards of pure β-emitting radionuclides. Credit: BIPM

The new instrument, known as the ESIR, will enable metrology institutes to compare primary standards of pure beta-emitting radionuclides, reducing the need for complex and time-consuming multi-centre comparison exercises.

Visit **www.BIPM.org** for more information.

*Coulon R.M., Broda R., Cassette P., Courte S., Jerome S., Judge S., Kossert K., Liu H., Michotte C., Nonis M. The international reference system for pure β-particle emitting radionuclides: an investigation of the reproducibility of the results, Metrologia, 2020, doi.org/10.1088/1681-7575/ab7e7b

Source: https://www.bipm.org/en/news/full-stories/2020-03-beta-emitter.html (© BIPM - Reproduced with permission).

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**Electrical Characterization of Graphene**

23 Mar 2020, NPL News - Scientists from NPL, in collaboration with Instituto Nazionale di Ricerca Metrologica (Italy), Graphenea SA (Spain), Das-Nano (Spain), delivered the EMPIR Grace project with the aim of developing novel metrology for electrical characterization of graphene, to enable standardization electrical measurements of future graphene-based electronics.

Graphene has become the focus of extensive research efforts to harness the potential for disruptive applications. Advances in manufacturing mean that the material can now be produced on a wafer scale up to 6''. To harness the opportunity for the development of next generation graphene-based electronic components using wafer scale materials, electrical characterization of graphene is imperative and requires the measurement of work function, sheet resistance, carrier concentration and mobility on a variety of scales (i.e. macro-, micro- and nano-scale).

The industry pull to incorporate graphene in RF electronics, integrated circuits and optoelectronics has triggered manufacturing progress for the scale up of

production. However, in this emerging industry there is a lack of standardized electrical measurements to extract useful parameters such as carrier concentration, mobility and sheet resistance, all of which are often presented as figures-of-merit of the graphene quality.

In recognition of the challenges posed, a consortium of National Metrology Institutes, universities and industries ( producing both the material and the advanced instrumentation) worked together to collaboratively deliver the EMPIR Grace project with the aim of developing novel metrology for electrical characterization of graphene, to enabling standardized electrical measurements of future graphene-based electronics.

Currently, the most widely used method for electrical characterization is slow, requiring off-line measurements. The method is not suitable for high throughput characterization and often the measured graphene is significantly altered due to contamination associated with the microfabrication processes. Commercial applications of graphene require fast and large-area mapping of electrical properties, rather than obtaining a single point value, which should be ideally achieved by a contactless measurement technique.

The consortium developed a comprehensive and metrologically accurate methodology for measurements of the electrical properties of graphene that ranges from nano- to macro- scales, while balancing the acquisition time and maintaining the robust quality control and reproducibility between contact and contactless methods. The results exhibit excellent agreement between the different techniques. A further outcome of the research is the need for standardized electrical measurements in highly controlled environmental conditions and the application of appropriate weighting functions.

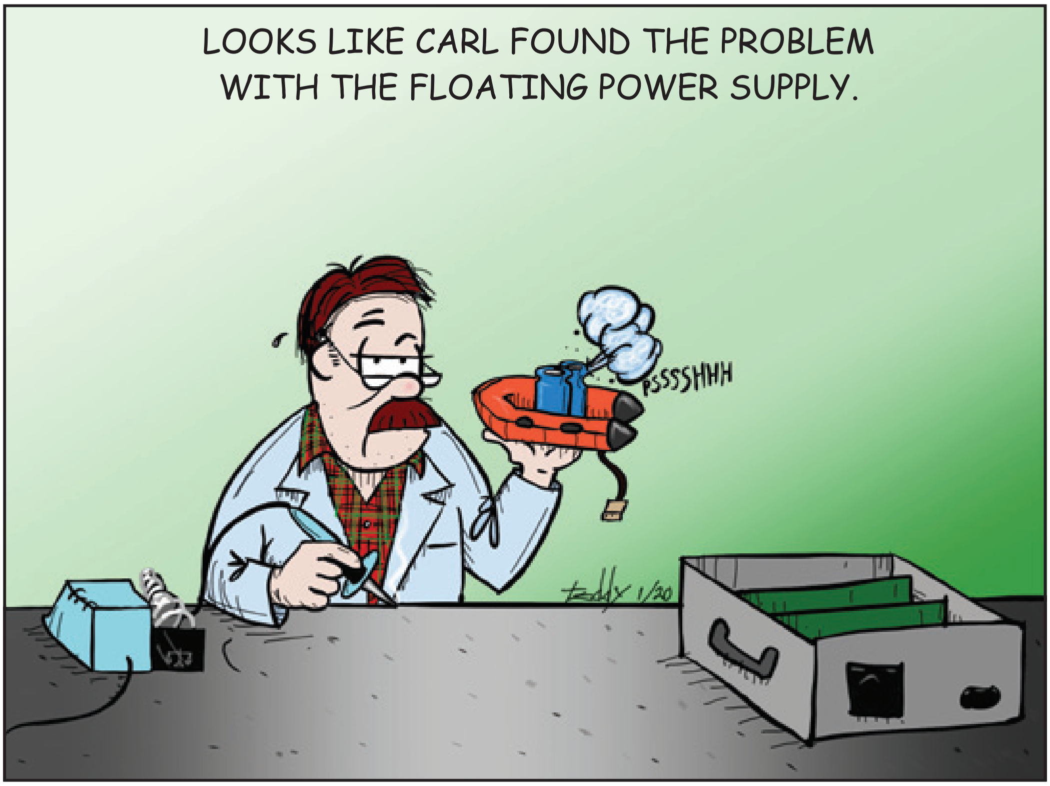
The impact of this research has been to bring together the emerging supply chain to understand the challenges for the scale up of production and trial new Quality Control instrumentation against precision laboratory measurements. This paper marks significant progress not only for the EMPIR GRACE project but also for the emerging industry. As the next step, the consortium will release two metrological best practice guides for electrical measurements of graphene.

To read the article in full, visit: https://www.nature.com/articles/s41598-020-59851-1.

To learn more about EMPIR Grace: http://empir.npl.co.uk/grace/.

Source: https://www.npl.co.uk/news/electrical-characterisation-of-graphene

CAL-TOONS by Ted Green teddytoons@icloud.com



**Atomic 'Swiss Army Knife' Precisely Measures Materials for Quantum Computers**

July 6, 2020, NIST News — It images single atoms. It maps atomic-scale hills and valleys on metal and insulating surfaces. And it records the flow of current across atom-thin materials subject to giant magnetic fields. Scientists at the National Institute of Standards and Technology (NIST) have developed a novel instrument that can make three kinds of atom-scale measurements simultaneously. Together, these measurements can uncover new knowledge about a wide range of special materials that are crucial for developing the next generation of quantum computers, communications and a host of other applications.

From smartphones to multicookers, devices that perform several functions are often more convenient and potentially less expensive than the single-purpose tools they replace, and their multiple functions often work better in concert than separately. The new three-in-one instrument is a kind of Swiss Army knife for atom-scale measurements. NIST researcher Joseph Stroscio and his colleagues, including Johannes Schwenk and Sungmin Kim, present a detailed recipe for building the device in the Review of Scientific Instruments.

"We describe a blueprint for other people to copy," Stroscio said. "They can modify the instruments they have; they don't have to buy new equipment."

By simultaneously conducting measurements on scales ranging from nanometers to millimeters, the instrument can help researchers zero in on the atomic origins of several unusual properties in materials that may prove invaluable for a new generation of computers and communication devices. These properties include the resistance-less flow of electric current, quantum jumps in electrical resistance that could serve as novel electrical switches, and new methods to design quantum bits, which could lead to solid-state-based quantum computers.

"By connecting the atomic with the large scale, we can characterize materials in a way that we couldn't before," said Stroscio.

Although the properties of all substances have their roots in quantum mechanics — the physical laws that govern the Lilliputian realm of atoms and electrons — quantum effects can often be ignored on large scales such as the macroscopic world we experience every day. But for a highly promising class of materials known as quantum materials, which typically consist of one or more atomically thin layers, strong quantum effects between groups of electrons persist over large distances and the rules of quantum theory can dominate even on macroscopic length scales. These effects lead to remarkable properties that can be harnessed for new technologies.

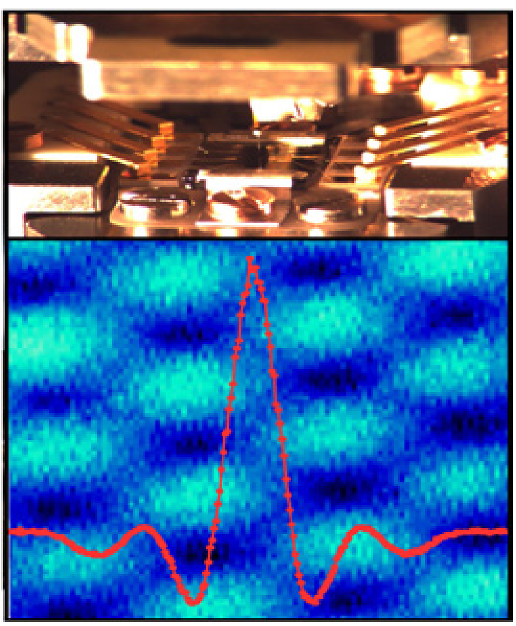
To study these properties more precisely, Stroscio and his colleagues combined in a single instrument a trio of precision measuring devices. Two of the devices, an atomic force microscope (AFM) and a scanning tunneling microscope (STM), examine microscopic properties of solids, while the third tool records the macroscopic property of magnetic transport — the flow of current in the presence of a magnetic field.

"No single type of measurement provides all the answers for understanding quantum materials," said NIST researcher Nikolai Zhitenev. "This device, with multiple measuring tools, provides a more comprehensive picture of these materials."

To build the instrument, the NIST team designed an AFM and a magnetic-transport-measuring device that were more compact and had fewer moving parts than previous versions. They then integrated the tools with an existing STM.

Both an STM and an AFM use a needle-sharp tip to examine the atomic-scale structure of surfaces. An STM maps the topography of metal surfaces by placing the tip within a fraction of a nanometer (billionth of a meter) of the material under study. By measuring the flow of electrons that tunnels out of the metal surface as the sharp tip hovers just above the material, the STM reveals the sample's atomic-scale hills and valleys.

In contrast, an AFM measures forces by changes in the frequency at which its tip oscillates as it hovers over a surface. (The tip is mounted on a miniature cantilever, which allows the probe to swing freely.) The oscillation frequency shifts as the sharp probe senses forces, such as the attraction between molecules, or the electrostatic forces with the material's surface. To measure magnetic transport, a current is applied across a surface immersed in a known magnetic field. A voltmeter records the voltage at different places on the device, revealing the electrical resistance of the material.



Top: Photo of a sample inside the scanning probe module showing the eight electrical contacts to a plate containing the sample to be studied. In the center the probe tip and its reflection in the sample can be seen.

Bottom: Atomic force image of an aluminum sample showing the arrangement of atoms measured at 0.01 Kelvin (-459.65 °F). The red curve shows the aluminum film is superconducting by having an electrical current with zero voltage. Credit: NIST

The ensemble is mounted inside a cryostat, a device that chills the system to one-hundredth of a degree above absolute zero. At that temperature, the random quantum jitter of atomic particles is minimized and large-scale quantum effects become more pronounced and easier to measure. The three-in-one device, which is shielded from external electrical noise, is also five to 10 times more sensitive than any previous set of similar instruments, approaching the fundamental quantum noise limit that can be achieved at low temperatures.

Although it's possible for three entirely independent instruments —an STM, an AFM and a magnetic transport setup—to make the same measurements, inserting and then retracting each tool can disturb the sample and diminish the accuracy of the analysis. Separate instruments can also make it difficult to replicate the exact conditions, such as the temperature and rotation angle between each ultrathin layer of the quantum material, under which previous measurements were made.

To achieve the goal of a three-in-one instrument with high sensitivity, the NIST team partnered with an international team of experts, including Franz Giessibl from the University of Regensburg, Germany, who invented a highly effective AFM known as the qPlus AFM. The team chose a compact design that increased the stiffness of the microscope and outfitted the system with a series of filters to screen out radio frequency noise. The atomically thin needle of the STM doubled as the force sensor for the AFM, which was based on a new force sensor design created by Giessibl for the three-in-one instrument.

For Stroscio, a pioneer in building ever-more-sophisticated STMs, the new device is something of a pinnacle in a more than three-decade career in scanning probe microscopy. His team, he noted, had been struggling for several years to dramatically reduce the electrical noise in its measurements. "We have now achieved the ultimate resolution given by thermal and quantum limits in this new instrument," Stroscio said.

"This feels like I've climbed the highest peak of the Rocky Mountains," he added. "It's a nice synthesis of everything I've learned over the last 30-plus years."

Paper: J. Schwenk, et al. Achieving ueV tunneling resolution in an in-operando STM, AFM, and Magnetotransport System for Quantum Materials Research. *Review of Scientific Instruments*. Published July 6, 2020. DOI: 10.1063/5.0005320

Source: https://www.nist.gov/news-events/news/2020/07/atomic-swiss-army-knife-precisely-measures-materials-quantum-computers

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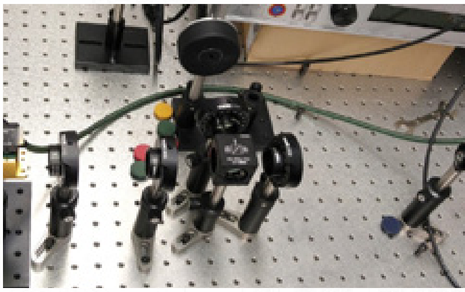

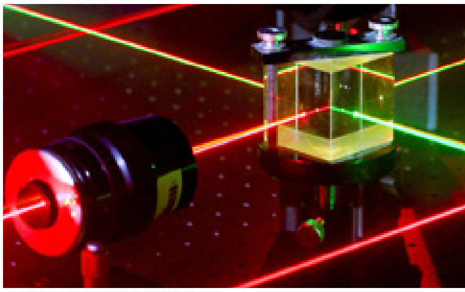

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# Verifying the Integrity of S-Parameter Measurements

Christopher L. Grachanen
National Instruments

## S-Parameters

Vector Network Analyzers (VNA) are used to measure a variety of RF parameters such as transmission loss, reflection loss, phase and group delay for a variety of passive RF devices and signal interconnections. RF devices span from attenuators and terminations to power splitters and directional couplers. Interconnections include RF cables, adapters, fixtures, probes as well as PCB signal traces. These RF devices and interconnections as measured by VNAs yields s-parameters. S-parameters describe the response of a RF device or interconnection to a stimulus (incident signal) applied to any or all of its connections (ports). S-parameters are essentially ratios comparing port stimuli to port responses to the applied stimuli.

VNAs are configured with one or more ports depending on its intended purpose i.e. making single-end measurements (one or two ports), making differential measurements (four ports) and making multiple aggressor/victim crosstalk measurements (greater than four ports). S-parameter naming nomenclature is port based denoting stimuli port and response port. For a two-port s-parameter, the naming nomenclature starts with an 'S' followed by the response port and then stimuli port:

S11 = Stimuli on Port 1, Response on Port 1 (Reflection)

S12 = Stimuli on Port 2, Response on Port 1 (Transmission)

S21 = Stimuli on Port 1, Response on Port 2 (Transmission)

S22 = Stimuli on Port 2, Response on Port 2 (Reflection)

## VNA Calibration

Prior to making s-parameter measurements, the VNA should be within its calibration interval if measurements need to be traceable, a prerequisite for accredited based measurements, and allowed sufficient warmup time.

VNA calibrations are typically performed annually and should not be confused with VNA S-parameter Vector Cal (SVC) performed prior to making s-parameter measurements which are also often referred to as VNA calibrations. VNA SVC is used to remove error components from within the VNA measurement ensemble i.e. VNA, cables and adapters and fixtures if used, to within acceptable limits. For transmission measurements these errors components are associated with measurement port isolation, load matching and the frequency response of transmission tracking. For reflection measurements, these error components are associated with measurement port directivity, source matching and the frequency response of reflection tracking.

VNA SVC is performed using RF standards with known characteristics and/or known relationships. These standards are characteristically grouped together into a kit commonly referred to as a 'VNA Cal Kit' depending on the type of VNA SVC being performed. One of the most popular VNA SVC types is called SOLT (Short-Open-Load-Thru). A SOLT VNA Cal Kit with have RF standards with characteristics of a shorted transmission line, an open transmission line, a termination (typically 50 ohms) as well as an adapter (thru) for connecting measurement ports together (not needed for a single port SVC). Another popular VNA SVC type is the LRL (Line-


Maury Microwave Type N, VNA Calibration Kit, model 8850CK40. Photo courtesy of Maury Microwave.

Reflect-Line), also called TRL (Thru-Reflect-Line). VNA Cal Kits are made with different RF connectors to support specific frequency ranges such a N-Type (typically DC to 18GHz) and APC 3.5mm (typically DC to 26.5GHz). VNA Cal Kits usually include a calibrated torque wrench to insure proper torqueing of coaxial connections.

S-parameter measurements may be further enhanced after performing VNA SVC using techniques to reduce measurement uncertainties associated with VNA drift and cable flex. Additionally, de-embedding techniques may be used to reduce the effects of adapters, fixtures and probes which are required to connect to an RF device or interconnection.

## Tests For S-Parameter Measurement Integrity

After performing VNA SVC and employing the aforementioned measurement enhancement techniques as applicable one could reasonably presume that derived s-parameter measurements are accurate and correct. But what if the VNA SVC and/or enhancement technique was performed in error and/or a VNA Cal Kit standards used to perform SVC was out of specification due to its coaxial connector being worn or damaged? What if during the course of performing a VNA SVC one of the cable connections becomes loose or intermittent due to cable flexing? An easy way to flag possible VNA SVC problems is to measure a check standard and compare its s-parameter values to previous measurements. A check standard such as an attenuator does not need to be accurate but should possess stable attributes over time in order to assess measurement repeatability. It must be noted that using a check standard gives insight into measurement repeatability but will not identify a systematic error common to all measurements. Again, after measuring a check standard and determining good repeatability one could reasonably presume derived s-parameter measurements are both accurate and correct. But what if the physical connection to one of the ports of a RF device or interconnection under test is less than optimal and/or a cable becomes loose due to flexing prior to or during the measurement? The following are tests that can be performed on captured s-parameter measurements from passive RF devices and interconnections to ensure measurement integrity:

**Passivity** – A passive device such as an attenuator does not generate energy such that there should be no gain or amplification i.e. no amplitudes greater than the applied stimuli such that transmission s-parameter need to be ≤ 1.

**Reciprocity** – The losses and delays are the same between any pair of ports regardless of direction of stimuli propagation. For a two port VNA ensemble S12 losses and delays equals S21 losses and delays.

**Causality** – A passive system only produces a response after it has received a stimulus and not before i.e. an output must occur after an input and not prior to that input being applied. The frequency spacing of the s-parameter data as well as the maximum frequency of the s-parameter data can affect the apparent causality of the measurement data. One must be sure that there are sufficient frequency points across a span. The ability to determine if a calibrated VNA meets causality requirements can be impaired if the frequency spacing between measurement points is too large.

Some signal integrity-based software programs have the means for assessing s-parameter passivity, reciprocity and causality as well as providing the means for enforcing compliance. Additionally, MatLab scripts can be created to perform these tests on captured s-parameters. A 2012 DesignCon white paper titled, "Fast and Optimal Algorithms for Enforcing Reciprocity, Passivity and Causality in S-parameters"[1] is a good starting point for understanding testing algorithms. An excerpt from this paper describes its content:

> These errors in S-parameters may manifest themselves as violation of certain physical laws. Besides leading to incorrect conclusions, such violations present significant difficulties while using such S-parameters in system simulations like generating and analyzing eye patterns, or equalization of the modeled channels etc. This paper focuses on rectifying the violation of three such properties of S-parameters – causality, passivity and reciprocity.

## Conclusion

Despite all s-parameter measurement preparations i.e. VNA annual calibration, VNA sufficient warmup time, VNA SVC, measurement uncertainty enhancements, de-embedding and check standard repeatability, derived s-parameter measurement can be seriously flawed due to passivity and reciprocity non-compliance and/or excessive causality influence. Best practice for ensuring the integrity of s-parameter measurements is to run tests for assessing passivity, reciprocity and causality. It should be noted that s-parameters may be transformed from the frequency domain into the time domain providing additional insight into s-parameter integrity not addressed in this paper.

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1 http://cdn.teledynelecroy.com/files/whitepapers/14-wp6paper_doshi.pdf

# Thru-Reflect-Line (TRL) Calibration

Brian Walker
Copper Mountain Technologies

## Introduction

Calibration methodology for Vector Network Analysis has evolved over the years. The first calibrations were simple normalizations. Later, with a better understanding of the systematic errors a calibration methodology involving the measurements of three known artifacts was developed to solve for these errors and mostly eliminate them from the measurement. The three calibration artifacts are normally a characterized Open, Short and Load. Theoretically, any three artifacts with reflection coefficients widely separated on the Smith Chart could be used but these three are common.

Later, as measurements were made at higher frequencies on wafer probe stations a new method, TRL was developed which was more suitable for the application and this article will describe the advantages.

## SOLT Calibration

Thru-Reflect-Line (TRL) calibration has a number of advantages over the Short-Open-Load-Thru (SOLT) method often used in VNA calibration. For SOLT calibration, the standards must be accurately characterized. The opens and shorts might be characterized by electromagnetic simulation of the physical design or they might have associated one-port "data-base" files obtained by highly precise measurement.

If data-base files are not available, the Open and Short will be specified by a short delay value followed by a parasitic capacitance or inductance to ground. The parasitic capacitance of the Open or parasitic inductance of the Short is specified by a third order polynomial over frequency. The "Thru" is usually assumed to be lossless with perfect characteristic impedance and its delay is usually specified. If the delay of the Thru isn't known, it can be calculated by the VNA. Unless a data-base file is provided for the load, it is assumed to be perfect. Creating a "perfect" broad-band load is exceedingly difficult and in SOLT calibration, the accuracy of the load is a large contributor to the final uncertainty of the measurement.

Clearly, using a data-based SOLT calibration kit is highly desirable, but to be useful, each kit must be precisely measured with unique characterization files provided for each kit which adds significant cost. Calibration kits characterized with polynomials are more affordable since every kit with the same mechanical design will share the same polynomial set.

## TRL Calibration

By contrast, TRL calibration is made up of a Thru Line, a Reflect standard and another Line. In true TRL, the Thru standard is zero length and the Line is 90 degrees long at the center frequency where the calibration is to be performed. The Reflect can be anything with a reflection magnitude of 1; that is, Short, open, or anything else along the circumference of the Smith Chart and does not need to be characterized. No load is needed. The delay of the Line does not need to be known with precision. Clearly, it is much easier to create calibration standards like these for very high frequencies. One important requirement though is that the characteristic impedance of the Line must be very precise and must not vary with frequency. Precision air lines are often employed for this purpose.

## Error Terms

In order to understand the calibration process, it's important to understand the error model. Figure 1 shows an S-Parameter Flow Diagram for a Device Under Test (DUT) in the forward direction with Error vectors on each side that correspond to the systematic errors which must be removed by the calibration process. On the left are Directivity, Source Match and Reflection Tracking errors. On the right are Load Match and Transmission Tracking errors. The port to port isolation is the error at the top. This last error is usually below thermal noise in the measurement bandwidth and can be safely ignored. For measurement in the reverse direction, a mirror image of Figure 1 would depict those errors.

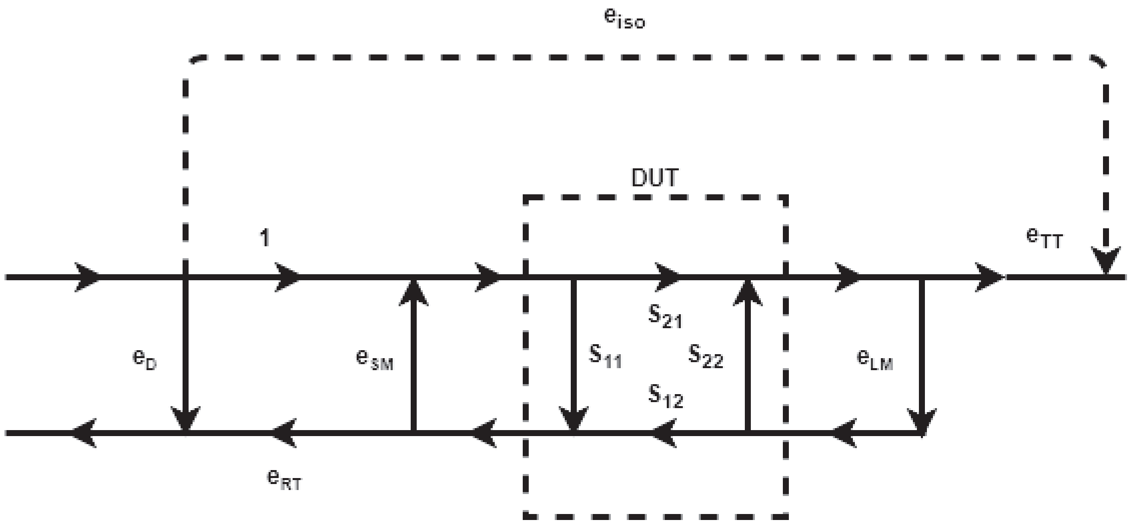


Figure 1. Forward Error Model

## The TRL Model Is Different

The model in Figure 1 makes physical sense and the various errors can be ascribed to unique features of a vector network analyzer. But another error model is one utilizing "Cascade" or "Transfer" parameters. If the actual S-Parameters for the DUT are represented by a transfer matrix "$S_a$" and matrices "X" and "Y" represent the input and output error contributions respectively then the measurement is:

$$S_m = X * S_a * Y$$

where $S_m$ are the measured Transfer Parameters and $S_a$ is the actual Transfer Matrix of the Device under Test without errors.

This model is beneficial for understanding TRL calibration. Measurement of three calibration standards in the place of $S_a$ above results in twelve independent equations.

This simple matrix equation may be solved by finding X and Y experimentally and then inverting these matrices to find $S_a$.

$$X^{-1} * S_m * Y^{-1} = S_a$$

Solving this problem clearly requires the calculation of eight (total) unknowns in the X and Y matrices but since S-Parameters are ratio-metric, one unknown can be normalized to "1," leaving seven. With twelve equations and seven unknowns, the problem is overdetermined. With that extra information the seven values for the X and Y matrices can be calculated along with five other characteristics of the calibration standards which then needn't be specified. The "Thru" for TRL is fully specified and usually zero length. (A non-zero length "Thru" is technically LRL). It has four known characteristics so only three more characteristics are needed from the other calibration standards.

The "Line" must have an excellent match to the characteristic impedance of the system or its characteristic impedance must be completely known. S12 and S21 of the Line are unnecessary. It provides two more of the needed characteristics.

The "Reflect" can be a short or an open or anything else on the circumference of the Smith chart. This provides the last of the seven needed characteristics. The same "Reflect" must be measured by each port of the VNA.

Finally, with the X and Y matrices determined, they may be inverted to enable calculation of actual S-Parameters ($S_a$) from the measured values ($S_m$).

## TRL Has Greater Accuracy

The relaxed requirements for the "Reflect" is very helpful. As previously mentioned, characterization of a reflect, either Open or Short is usually given by a delay and a third order polynomial of fringing capacitance of the open and spurious inductance of the short; a definition which is constant for every calibration kit of a certain manufacture. Clearly there will be some variation from piece to piece. TRL makes this characterization

| | Standard | | Frequency | | Offset | | | |
|---|---|---|---|---|---|---|---|---|
| **N** | Type | Label | F min | F max | Delay | Z0 | Loss | Media |
| **1** | Thru/Delay | Thru | 0 Hz | 999 GHz | 132 pS | 50 Ω | 0 Ω/s | Coax |
| **2** | Thru/Delay | Line 1 (Shortest) | 562 MHz | 4.5 GHz | 235.7 pS | 50 Ω | 0 Ω/s | Coax |
| **3** | Thru/Delay | Line 2 | 261 MHz | 2.086 GHz | 345 pS | 50 Ω | 0 Ω/s | Coax |
| **4** | Thru/Delay | Line 3 | 58 Mhz | 400 MHz | 1.12 nS | 50 Ω | 0 Ω/s | Coax |
| **5** | Open | Open | 0 Hz | 999 GHz | 0 S | 50 Ω | 0 Ω/s | Coax |

Figure 2.

superfluous and thereby results in greater accuracy.

Additionally, in SOLT calibration the uncertainty of the Calibration Load mostly determines the residual Directivity error and the Directivity error sets the "floor" for reflection measurements. A good load may have 46 dB Return Loss over a broad band which means the Residual Directivity will be no better than that. Reflection measurements at levels 10 dB higher than this, or -36 dB will have 3.3 dB of uncertainty and approximately 1 dB of uncertainty at -26 dB. On the other hand, a good TRL calibration can result in a Residual Directivity error as low as -60 dB! This is a huge improvement for Reflection measurement accuracy.

## Creating a TRL Calibration Kit

The frequency range of a TRL kit depends on the "line" length. The "line" can be used over a frequency range where it is 20 degrees to 160 degrees longer than the Thru or 90 degrees +/-70. For true TRL, the Thru is zero length but it can have a finite and hopefully short length. Technically, calibration with a non-zero Thru length is called LRL (Line Reflect Line). The VNA calibration software is informed of the delay length of the Thru in the definition file such that the reference plane ends up properly at the connectors and not half-way along the Thru. For a larger frequency range, multiple lines may be used with slightly overlapping frequency range.

For instance, one might have a non-zero length "Thru" of 132 pS delay and a "line" of 345 pS delay. The line is 213 pS longer than the Thru. The center frequency where the line is 90 degrees longer than the Thru is:

$$\frac{90}{360 * 213\ pS} = 1174\ MHz$$

The lowest frequency where this line could be used is where it is 20 degrees longer than the Thru or:

$$\frac{20}{360 * 213\ pS} = 261\ MHz$$

and the highest frequency of use is at 160 degrees longer than the Thru or:

$$\frac{160}{360 * 213\ pS} = 2086\ MHz$$

When the line is entered in the calibration kit definition, its actual delay and the lowest and highest frequencies of use should be entered.

"Line 2" in the above kit definition is entered in this way (Figure 2).

For a definition with multiple Lines and overlapping ranges, the range of the last measured Line is used by the VNA. As mentioned previously, the delay of each Line does not have to be known to great accuracy. It is only important that its use is limited to frequencies where it is between 20 and 160 degrees. The calibration method becomes undefined and inaccurate for Lines near 0 degrees and 180 degrees so this must be avoided. While it is possible to create "Lines" from semi-rigid or some other sort of cable, this temptation should be resisted. The characteristic impedance of such a "Line" would not be good enough and the resulting calibration would be limited to its return loss. The superior effective directivity offered by TRL and its resulting improvement in reflection uncertainty would be eliminated.

If the Thru is non-zero in length but a zero length is entered in the table then the calibration plane will be in the middle of the Thru length. This can be convenient for calibrating and de-embedding on a PCB. Two equal length transmission lines might lead from connectors to a DUT. If a separate connectorized "Thru" line is added to the PCB which is as long as the input and output lines together and another 90 degree longer "Line" and a pair of connectors which are shorted, then TRL calibration using these will result in a de-embedded calibration right to the DUT interface.

TRL clearly has some attractive properties. It isn't practical to create "Lines" for use at very low frequencies and the "Lines" themselves must have pristine characteristic impedance, but where it is possible to use this method, the results can be very impressive.

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# Redefined but Not Perfected: The On-going Saga of the Kilogram

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The International Prototype Kilogram (IPK) realized the unit of mass in the International System of Units (SI) for over 130 years. On May 20, 2019, all fundamental quantities of the SI were tied to defining constants, with mass now defined in terms of the Planck constant, the second, and the speed of light. For several years prior to the revision, the world engaged in measuring the Planck constant to very high precision, and with the Committee for Data on Science and Technology (CODATA) adjustment in 2017, the value of the Planck constant was forever fixed with no uncertainty. However, the world is still not ready for independent realizations of mass by National Metrology Institutes (NMIs), and the IPK continues to hold its position as an internationally agreed-upon realization of the kilogram. How did this happen? What does it mean for mass metrology, and how long will this situation endure? This article will answer these questions and present the ongoing international effort to finally enable the kilogram to be realizable and available "for all times and all people."[1]

## I. Background

In 2019, the International System of Units (SI) was revised in a fundamental way that makes the base quantities of mass, length, time, thermodynamic temperature, electric current, amount of substance, and luminous efficacy realizable from defining constants.[2] For this revision, the General Conference on Weights and Measures (CGPM) decided to keep the base units the same as always (kilogram, meter, second, kelvin, ampere, mole, and candela) in order to preserve continuity with previous versions of the SI. Three SI quantities already relied on a defining constant (length, time, and luminous efficacy), so the revised system brought all the quantities into a similar philosophical underpinning. Gone were the artifacts that realized the kilogram (the International Prototype Kilogram) and the kelvin (the Triple Point of Water cell), as well as the outdated and difficult-to-realize-definition of the ampere and the carbon-mass-based definition of the mole.[3] These changes, in theory, opened-up the possibility of realization of any SI unit anywhere on earth if a suitable experiment relating the unit to its defining constant(s) exists. Furthermore, the SI is now inherently scalable, as the experiment determines the magnitude of the multiplier of the base unit. For example, the unit of mass need not be realized at one kilogram; if a suitable experiment is available, it may be realized at one milligram or one thousand kilograms. The defining constants contain everything necessary to directly realize the units at any level, and with the fixing of the Planck constant $h$ and the elementary charge $e$, electrical units were brought back into the SI, ending a thirty-year absence.

The 2019 SI revision was the culmination of the ambitions of prominent scientists for at least the past 150 years. In 1870, James Clerk Maxwell, well-known for the equations that govern electromagnetics, hoped for a system of units based on the properties of atoms instead of physical artifacts. Speaking at a meeting of the British Association for the Advancement of Science in Liverpool in 1870, Maxwell told delegates that "If…we wish to obtain standards of length, time and mass which shall be absolutely permanent, we must seek them not in the dimensions, or the motion, or the mass of our planet, but in the wavelength, the period of vibration, and the absolute mass of these imperishable and unalterable and perfectly similar molecules."[4] The German physicist Max Planck, whose work on blackbody radiation led to the discovery of the Planck constant, went even further than Maxwell. Planck suggested the establishment of "units of length, mass, time, and temperature that would, independently of special bodies and substances, necessarily retain their significance for all times and all cultures, even extraterrestrial and extra-human ones, and which may therefore be designated as natural units of measure."[5]

## II. The International Prototype Kilogram

The quantity of mass is notoriously hard to define in casual conversation and is often confused with weight, yet it is the association of mass with weight that has made the practical realization of mass relatively easy. The IPK was manufactured in 1879 by the British company Johnson-Mathey to have a mass as close as possible to that of the Kilogramme des Archives that served as the mass standard at the time and dated back to 1799.[6] This previous standard was made to have a mass as close to one cubic decimeter of water as possible. The new cylindrical standard was made of 90 % platinum, 10 % iridium, with its height equal to its diameter (39 mm) in order to minimize surface area. By 1883 the mass of the new kilogram was indistinguishable from that of the Kilogramme des Archives, and in 1889 the CGPM sanctioned the IPK to serve as *the* standard of mass for the signatory countries of the Treaty of the Meter.[7] Though it is a cylinder made of platinum-iridium, the IPK was assigned to have a mass of *exactly* 1 kg after it had been washed and allowed to dry.[8] In practice, the kilogram was disseminated to the world through identical working copies that were calibrated against the IPK in order to reduce wear and tear on the defining artifact. To monitor the stability of the mass unit, over the decades of the 20th century the IPK was compared with copies that had been given to the member countries of the Treaty of the Meter as well as the copies owned by the International Bureau of Weights and Measures (BIPM). The comparisons showed that for many of the copies, the mass difference from the IPK grew as a function of time, in some cases amounting to a 50 microgram or more difference over a century.[9] Figure 1, which is Figure 2 in reference 8, shows a graph of the comparison data; note that through 1991, the copies became heavier with respect to the IPK; another way of interpreting the data is to say that the IPK was losing mass over this time with respect to the copies. As such, the world began to think about viable ways to redefine the mass unit in such a way as to recapture the metrological ideals of Maxwell and Planck and get rid of the drifting standard. Looking again at Figure 1, note that between 1991 and 2014, no change in any of the copies with respect to the IPK is discernable, as if the IPK were somehow aware of its impending replacement and decided to behave! Though an interesting phenomenon, a world-recognized standard that drifts with time for a century and suddenly stops is totally unacceptable to the international metrology community.

In 1889, the 1st CGPM sanctioned the IPK to serve as *the* standard of mass for the signatory countries of the Treaty of the Meter. Up to the time of the 2019 SI revision, the IPK was used less than a half-dozen times, meaning that for most of its 130 years of service it has resided at the BIPM safely tucked away from harm. The IPK itself is the best spokesman for its shortcomings: it is a single artifact that defined mass for the entire world. As an artifact, it is subject to damage or disappearance. The mass scale based on the IPK was relative, that is, since its mass was defined to be 1 kg (whether it really was or not), everything else in the world had a mass only in comparison with the IPK and its disseminating copies. This is a tenuous situation for an international standard, as no independent, absolute checks were possible. The revision of the mass unit based on a defining constant that could be measured and fixed enabled the possibility of an independently realizable and unchanging kilogram. However, it must be recognized that the IPK served the world well for over one hundred years; the relative system worked to within the ability of science to monitor it, meaning that the uncertainties associated with the dissemination of mass from the IPK were, until recently, much smaller than the uncertainties of the NMIs' mass measurements. Most NMIs required infrequent calibration of their national mass standards (perhaps once per decade), and though the time required for calibration as well as transit to the BIPM outside of Paris, France was inconvenient, most NMIs could rely on stable, traceable working standards while their official copies were gone.

In 2013, a joint roadmap to the redefinition of the kilogram was issued by the Consultative Committee for Units (CCU) and the Consultative Committee for Mass and Related Quantities (CCM).[10] Surprisingly, the largest (and most unintended) motivation for redefinition of the mass unit came well after the Joint CCU-CCM Roadmap to Redefinition of the SI began. This took the form of a time-dependent discrepancy between the as-maintained mass unit of the BIPM (that is, what was disseminated from the BIPM) and the IPK during the years 1992 to 2014.[11] Figure 2 shows the estimated error in mass dissemination made by the BIPM at the one kilogram level during this time period.[12] Unfortunately,

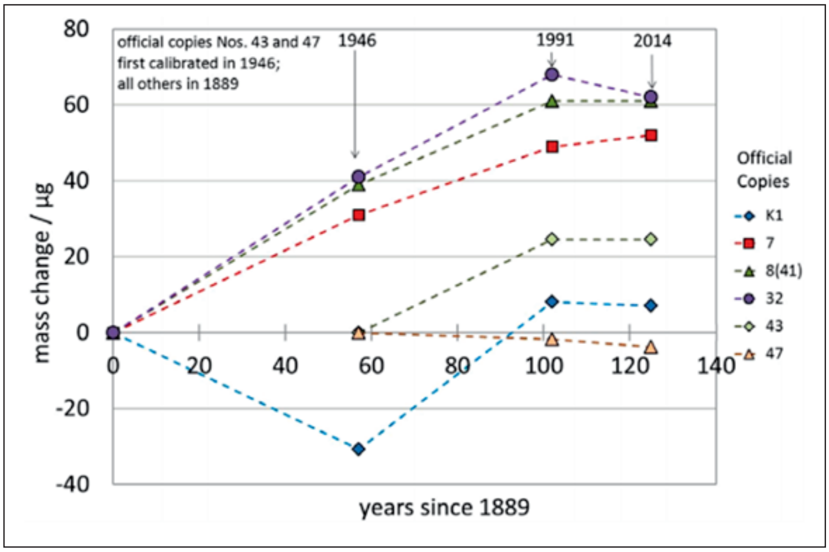


Figure 1. Evolution in mass (official copies compared to IPK) since the first calibration of the official copies. See reference 10 for further details.

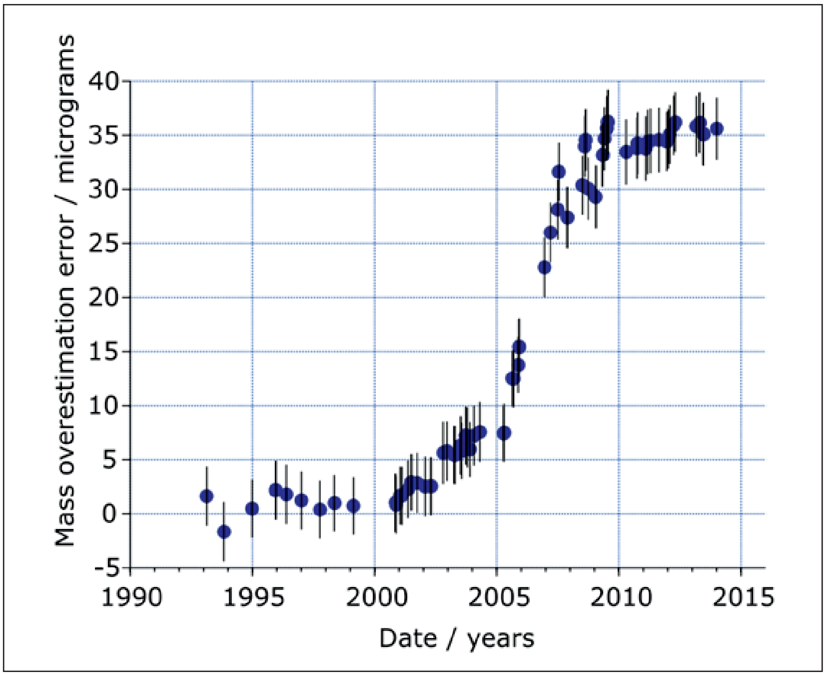


Figure 2. Estimated error in BIPM calibrations of 1kg Pt-Ir prototypes issued after the 3rd periodic verification (1988-1992). See reference 11 for further details.

the IPK remained locked in its safe during this discrepancy, precluding the BIPM's discovery of the problem. In the meantime, the world noticed large changes in the calibrations of previously stable mass standards.[13] The discrepancy was meticulously investigated by the BIPM, which concluded that some BIPM working standards had lost mass due to abnormal wear caused by a malfunctioning mass comparator. The BIPM developed a model that described the data well and was able to issue corrections to all the calibrations that were affected. In turn, this enabled NMIs to correct calibrations that were done for their customers within their own national measurement systems. Corrections to erroneous BIPM calibration certificates were as large as 0.035 mg. In contrast, the combined standard uncertainty issued by the BIPM on its one-kilogram calibration certificates was about 0.007 mg. The concerning feature here is not that a problem could occur in the dissemination of the mass unit from the IPK, but that an error of many times the uncertainty could continue unnoticed for over a decade due to the unavailability of the IPK. This clearly highlighted the need for more frequent, independent realizations of mass by means other than a single artifact. In response, the BIPM restructured the calibration schedules of its working standard hierarchy so that more inter-comparisons will be made in order to prevent undetected drifting of standards.[14]

## III. The 2019 Revision of the SI

In 2019, the International System of Units (SI) underwent the most major revision since its inception in 1960. The base quantities remain the same, but all units are now derived from seven defining constants. This is recorded in the 9th edition of the SI brochure, published by the BIPM in 2019.[15] Table 1 summarizes the base quantities, units, and defining constants of the 2019 SI revision. There are no more defining artifacts like the IPK, or units based on the properties of materials, like the triple point of water. All the information needed to realize a given unit is contained within one or more of the defining constants, and realization of the system of units is available wherever an appropriate experiment exists that relates a given unit to its defining constants. The choice of an appropriate realization experiment makes the units inherently scalable, eliminating the need for separate processes to obtain the unit at the desired magnitude. This was a problem with mass under the IPK definition; the unit could only be realized at one kilogram, so laborious

| Defining Constant | Symbol | Base Quantity | Base Unit |
|---|---|---|---|
| Hyperfine transition frequency of Cs 133 | $\Delta\nu$ | Time | second |
| Speed of light in vacuum | $c$ | Length | meter |
| Planck Constant | $h$ | Mass | kilogram |
| Elementary charge | $e$ | Electrical Current | ampere |
| Boltzmann constant | $k$ | Thermodynamic Temperature | kelvin |
| Avogadro constant | $N_A$ | Amount of Substance | mole |
| Luminous efficacy | $K_{cd}$ | Luminous Intensity | candela |

Table 1. Defining constants, symbols, base quantities, and base units of the SI

multiplication and subdivision procedures employing intermediate working standards were needed to scale to milligrams or thousands of kilograms. It bears mentioning that the set of constants chosen is not unique for the realization of the SI units, only convenient. Neither are the base units themselves unique but were kept in order to maintain continuity with previous versions of the SI. Most importantly, the constant definitions equip the SI for future realizations of units using devices that either do not exist or are not yet widely available. For example, single electron current devices exist only in laboratories now, but may be used routinely to realize the ampere when they are commercialized. Similarly, technologies that can replace the International Temperature Scale of 1990 between 13.8033 K and 1234.93 K, where platinum resistance thermometers are currently used as interpolating devices would abrogate the use of a temperature scale altogether.

On November 16, 2018 the CGPM approved the proposed redefinition of the SI, and it was formally adopted on May 20, 2019—the 144th anniversary of the Treaty of the Meter, which established a permanent organizational structure (including the CGPM and BIPM) for member governments to act in common accord on all matters relating to units of measurement.[16] The SI changed forever, and much media attention resulted from the dethroning of the IPK as the world's mass standard in favor of a definition through a constant that few people without a physics background had ever heard of. During this time, the IPK became the symbol of an outdated system that was being replaced by modern scientific advances; many jokes were made about the IPK being relegated to becoming a doorstop or a paperweight now that its special status was gone. Little did the world know that there was a serious problem with the redefinition of mass that nearly held up the entire revision of the SI, a problem that would require several more years of continued cooperation by the world's premier mass laboratories before the true "democratization" of mass—independent realizations by different NMIs—would be possible. Even more unexpected was the way the world decided to solve the problem.

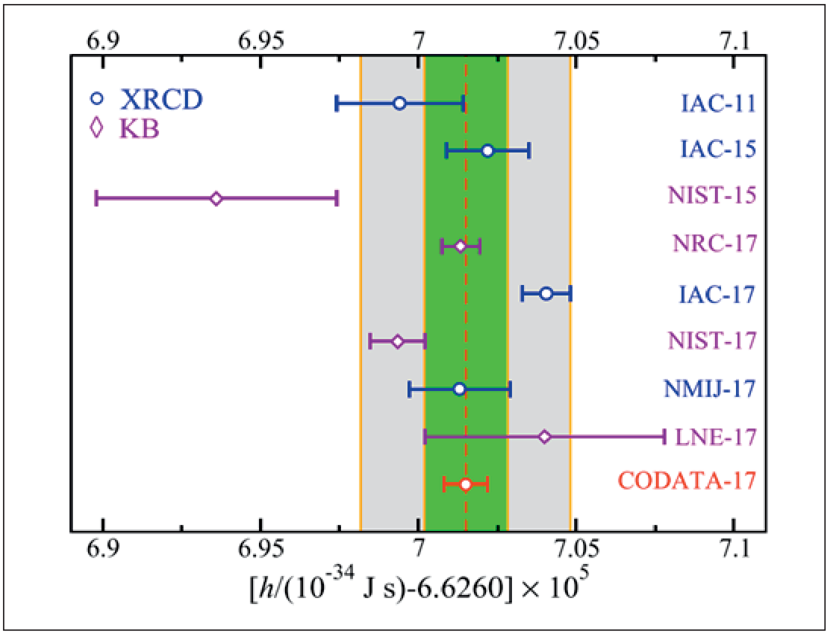


Figure 3. Data used in final CODATA adjustment of Planck constant in 2017. Values are in chronological order from top to bottom. The inner green band is ±20 parts in $10^9$ and the outer grey band is ±50 parts in $10^9$. KB: Kibble balance; XRCD: x-ray-crystal-density. Figure taken from reference 22.

## IV. The 16th Meeting of the Consultative Committee for Mass and Related Quantities

Using the Planck constant for the realization of mass required experimental confidence in the measured value of the Planck constant. The international effort required to do this began over twenty years prior to the final adoption of the revised SI in 2019. Final conditions on the world's measurements of the Planck constant that would be necessary for redefinition of the mass unit were adopted by the CCM in 2013[17] and are stated below:

1. At least three independent experiments, including work from watt balance[18,19] and x-ray crystal density (XRCD) experiments[20], yield consistent values of the Planck constant with relative standard uncertainties not larger than 5 parts in $10^8$.
2. At least one of these results should have a relative standard uncertainty not larger than 2 parts in $10^8$.
3. The BIPM prototypes, the BIPM ensemble of reference mass standards, and the mass standards used in the watt balance and XRCD experiments have been compared as directly as possible with the international prototype of the kilogram.
4. The procedures for the future realization and dissemination of the kilogram, as described in the mise en pratique, have been validated in accordance with the principles of the Mutual Recognition Arrangement adopted by the International Committee for Weights and Measures (CIPM-MRA).[21]

At the time of the 16th CCM meeting in 2017, it was decided that these conditions were sufficiently met for redefinition to occur. However, there was general concern over the agreement of some of the most recent measurements of Planck's constant and the differences that would occur if the world's NMIs realized mass autonomously. Figure 3 shows the final data that were submitted to the Committee on Data for Science and Technology (CODATA) for adjustment of the Planck constant.[22]

After lengthy discussions, the CCM drafted a resolution to the CIPM that recommended the redefinition of mass through the Planck constant, using the CODATA value of the Planck constant adjusted using the data provided.[23] The CCM acknowledged that recent measurements by some labs did not pass the chi-square test for consistency[24] of data yet believed that the effects on the final number (and its uncertainty) were not serious enough to warrant a change in timing for the redefinition. However, the CCM stopped short of recommending independent realization of mass by laboratories having Kibble balances or XRCD experiments. Instead, further technical conditions on the level of agreement between NMIs were mandated before independent realization could occur.[25] Briefly, they are the following:

- A key comparison of the world's primary kilogram realizations, piloted by the BIPM, would be carried out periodically to review the agreement among NMIs.
- From the key comparison data, a consensus value would be calculated that would allow the world's realization experiments to adjust their values; this assures that the world is disseminating the same mass scale.
- Successive rounds of the key comparison would occur every two years or so until the dispersion of the results among laboratories is comparable to the uncertainties of the individual laboratory data. After this point, independent realization would be permitted.
- Until the first results of the key comparison are available, mass will be traceable to the Planck constant through the IPK, which now carries a 0.010 mg standard uncertainty that resulted from the CODATA reduction of the Planck constant data.

## V. The Realization and Dissemination of Mass After the Redefinition

The big news is that a consensus value for the kilogram will be used to adjust the world's mass realization experiments. It is anticipated that the standard uncertainty on the consensus value will be approximately 0.020 mg[26], so a small increase in uncertainty will result as the IPK and its 0.010 mg standard uncertainty are replaced with the consensus value. Furthermore, there will be periodic updates to the consensus value (and its uncertainty) on an approximate 2-year cycle. Realization of mass in this way may continue for several years beyond this depending on the world's progress in eliminating the differences between realization experiments. Given that the first round of the key comparison is under analysis at this time (July 2020), that the first consensus value is not expected until at least August of 2020, and that another key comparison round will take place around 2022, the earliest that independent realization of mass could occur is likely 2023 or even 2025. It is important to mention that the consensus value of the kilogram will also be reflected in the pool of artifacts established by the BIPM to disseminate mass to countries that do not have primary mass realization capability.[27] This pool will continue to be updated forever based on the world's realization experiments, though any changes should be small with respect to experimental uncertainties.

Prior to the availability of the first consensus value in mid-2020, the world will continue to look to the IPK as its mass standard, albeit with a first time-ever standard uncertainty of 0.010 mg. Since the uncertainty comes from the CODATA-adjusted Planck constant data, mass will still be traceable to the Planck constant, as the IPK is just another artifact whose value comes from a measurement and currently has the value of exactly 1 kg with a standard uncertainty of 0.010 mg. It is not surprising that the IPK, although not a perfect standard, remains such an important part of the international measurement infrastructure and will see the world through this transition period as the modern realization experiments continue to improve. The mass unit has been redefined to be absolute, universal, and in harmony with quantum and Newtonian physics. Yet the realization of mass is only as good as the agreement of the experiments that science has so far developed. Without doubt, this agreement will improve to an inconsequential level in the years to come. But for now, we must live in an imperfect world of mass realization, where an historic metal cylinder continues to serve us until the coming of better days.

## Acknowledgements

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# NEW PRODUCTS AND SERVICES

## DWFritz Automation Metrology and Inspection Platform

Conventional measurement systems such as coordinate measuring machines (CMMs) are utilized for quality control in various industries. They are typically located in environmentally controlled inspection rooms, which often impact machine availability. If the parts are to be inspected in the metrology room during the production process, part “queues” are to be expected, due to limited machine availability coupled with long CMM setup times. In addition, inspection tasks requested for manufacturing often collide with other measurement requests such as those from other manufacturing lines, pre-production tests or R&D. Changeovers to measure other parts and the attendant programming also add to the delay. Further, tactile probes typically operate at slower speeds as they require physical contact with the part surface and therefore are characterized by long measurement cycle times. Moreover, contact based measurement technologies are not suitable for generating large amounts of data points required for complex surfaces. Because of these limitations, systems like CMMs are not an ideal solution for 3D inspection on the production line.

To solve these problems, DWFritz Automation has developed the ZeroTouch measuring platform. Its architecture features 5 independent axes and a rotating bridge. The system combines multiple non-contact sensor technologies such as laser and chromatic confocal sensors with multi-spectral illumination to rapidly measure in three dimensions and in real time. The sensor bridge is configurable allowing for the most optimal and appropriate sensor selections to suit part geometries and surfaces, in addition to the complex dimensions being measured. Such innovations associated with a horizontal rotary table and 3 translation axes result in higher throughput of parts and increased capacity, enabling 100% in-line inspection rather than just sampling.

The system’s proprietary software then creates a highly accurate dense 3D point cloud which can be analyzed immediately after the measurement process. Integrations to proven analysis tools enable the accurate comparison of the scan results with part CAD models or a reference part previously scanned and measured to not only check for geometric and dimensional tolerances, but for other previously undetected issues such as surface aspect defects. Using statistical process control (SPC), faults or outside-tolerance deviations can be quickly detected and appropriate reporting can be sent back to the MES. This could enable the adjustments of process parameters in upstream manufacturing processes to minimize rejects downstream. In addition, by simplifying complicated programming procedures, ZeroTouch reduces the system configuration time to just a few hours saving substantial production time and costs. Therefore, part inspection plans can be created within a few hours by using drag-and-drop functions and can be stored in the manufacturing execution system (MES) for management and retrieval.


The current system measures 240 x 150 x 190 cm (L x W x H) and weighs 3550 kg. It can measure parts measuring up to 300 x 300 x 300 mm and weighing up to 10 kg. It uses a high performance GPU PC with Intel Core i7-7700T processor, and two capacitive industrial monitors with touch screens.

For more information on the ZeroTouch high-speed measurement platform and other solutions such as automation and metrology systems for many industries, visit www.dwfritz.com.

DWFritz Automation was founded in 1973 by Dennis Fritz and is headquartered in Oregon, USA. The company started out by offering engineering services, and by the 1980s counted global brands like HP, Intel, and Boeing among its clients. In the 1990s, DWFritz Automation focused increasingly on the development and manufacture of high-precision automation and metrology systems for many industries, including aerospace, medical technology, mechanical engineering, automotive, and consumer electronics. Today, the company employs over 500 people at locations in the US, France and China.

## Rohde & Schwarz New 1.35 mm E-band Coaxial Connector

By adding the R&S NRP90T und R&S NRP90TN models to its portfolio of thermal power sensors, Rohde & Schwarz releases the very first test and measurement instruments in the market to support the novel, robust 1.35 mm precision coaxial connector. The connector covers frequencies up to 90 GHz and shall be included in the next releases of both IEEE and IEC relevant standards. Rohde & Schwarz has been a partner in the 1.35 mm E connector development project since its beginning in 2017.

Munich, May 18, 2020 — An expert group with collective knowledge of microwave signal transmission initiated the joint project to develop and implement a new coaxial connector optimized for E-band frequencies. Emerging applications in particular for automotive radar from 76 to 81 GHz, plus the WiGig extension IEEE 802.11ay operating up to 71 GHz, highlighted the need for a novel, robust coaxial cable connector suitable for industrial applications at frequencies up to 90 GHz. The group consists of Germany’s national metrology institute, the Physikalisch-Technische-Bundesanstalt (PTB), Rohde & Schwarz GmbH & Co. KG, Rosenberger Hochfrequenztechnik GmbH & Co. KG and SPINNER GmbH.

The result is the 1.35 mm E connector, with a precise metric fine thread, a reliable pin-gap, and an integrated groove for optional push-pull locking. The design was accepted in 2019 for the next edition of the IEEE 287-2007 for precision coaxial connectors, and also by the IEC, which will publish it as the IEC 61169-65.

Now, Rohde & Schwarz has implemented the E connector for the first time in a test and measurement instrument. The R&S NRP90T and R&S NRP90TN for frequencies up to 90 GHz are the latest additions to the thermal power sensor family. Like all other members of the family, the new models feature both the highest accuracy and fastest speed of measurement available for thermal power measurements. The R&S NRPxxT power sensors operate locally, connected to a PC, selected Rohde & Schwarz instruments, or an R&S NRX base unit. The R&S NRPxxTN sensors can also be operated remotely via a LAN.

The E connector closes the gap between the well-established 1.85 mm connector (the V-band connector) and the 1.00 mm connector (the W-band connector). The V-band connector, introduced more than 30 years ago, is suitably robust for industrial applications, but is restricted to a maximum frequency of 70 GHz. The W-band connector, on the other hand, supports a maximum frequency of 110 GHz, but requires a fine-mechanical accuracy during assembly, and frequently loosens in use.

All four partners in the 1.35 mm E connector working group are delighted with the progress of their cooperation: Daniel Blaschke, head of development for RF & Microwave Power Meters at Rohde & Schwarz, says: "Power sensors are often the first T&M instruments for which customers request native support of a new connector type. We are happy to be the first to introduce a model equipped with the novel E connector, thanks to this fruitful partnership." Dr. Hans-Ulrich Nickel, head of RF Research & Development at the SPINNER Group, comments: "We initiated the 1.35 mm project to obtain a robust and future-oriented interface solution up to 90 GHz. It fills me with great joy to see the rapid adoption of our 1.35 mm portfolio." Hauke Schütt, Executive Vice President Test & Measurement from Rosenberger, adds: "The new 1.35 mm connectors draw a lot of interest in the 70 to 90 GHz range. We are excited that we are already able to offer a wide range of solutions." Dr. Karsten Kuhlmann, head of the working group High-Frequency Basic Quantities at PTB, says: "International standardization and traceability to national standards are key ingredients for the successful introduction of a new RF connector system."

For further information on the R&S NRP90T and R&S NRP90TN thermal power sensors, go to www.rohde-schwarz.com/_63493-197529.

### Additel 875-1210 and 878-1210 Thermocouple Calibration Furnaces

Brea, Calif., May 19, 2020–Additel Corporation introduces their new ADT875-1210 and ADT878-1210 Thermocouple Calibration Furnaces which cover a temperature range of 100°C to 1210°C. Each unit comes standard with Additel's patented tri-zone "Adaptive Control" to provide the best performance specifications possible relating to stability, radial and axial uniformity and loading.

The ADT875-1210 and ADT878-1210 can be purchased with a process calibrator option to combine the many features found in a multicomponent temperature calibration system with the calibration furnace. This option includes the ability to measure and control the furnace with a reference grade thermocouple and (4) device under test channels which can measure, mA, voltage or thermocouple. In addition to these measurement functions this calibrator has full documenting capability of creating tasks, saving "as found" and "as left" results, providing pass/fail criteria and HART communication capability for simplified transmitter calibrations/verifications.

The Additel 875-1210 and ADT878-1210 Furnaces 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

Additel Corporation is one of the leading worldwide providers of process calibration tools. Additel is dedicated to designing, manufacturing, and delivering the highest quality handheld test tools and portable calibrators for process and calibration industries. For many years Additel has successfully developed automated pressure calibrators, digital pressure test gauges, digital pressure calibrators, pressure test and calibration pumps, and multifunction process calibrators. In recent years, Additel has expanded its product offing to include temperature calibration tools that are helping to make metrology simple. Coupled with our accredited calibration laboratory in Brea, CA, Additel products, calibration services and customer support are second to none.

# Is Basic Dead?

Michael Schwartz
Cal Lab Solutions, Inc.

Microsoft recently announced they will be dropping future support for Visual Basic .NET (VB.NET) and focusing more on C# and other language support. I find this to be a great loss, especially for metrology. For more than 50 years, Basic has been a staple in calibration and automation. It has proven to be a suitable solution for many problems.

Introduced in 1964 at Dartmouth College, Basic was designed to be an easy to use, high-level programming language. Designed as a language for people in other fields than computer science, Basic could be used to solve many automatable tasks. Then in 1972, Hewlett-Packard introduced Rocky Mountain BASIC (RMB) with the 9830A Controllers. RMB quickly became a powerful tool in the automation of calibration procedures. It is still used today by both Keysight in their STE-9000 programs and Northrup Grumman in their Sure-Cal software.

For me, I started programming in Basic back in middle school on the TI-99, then moved up to an Apple IIe as a freshman in high school where I was the teacher's assistant in the computer lab. It wasn't until I was stationed at White Sands Missile Range when I got my first taste of instrument control. Back then it was Visual Basic or LabView, and because Visual Basic was installed on my computer, the choice was a simple one.


Visual Basic was introduced in 1991 by Microsoft and it made writing application for Windows very easy. At the time, most applications were built using VB as the front end and C++ on the back end. In my case, VB was used for the User Interface and National Instruments drivers and a GPIB Controller on the back end allowed me to control signal generators and spectrum analyzers with ease.

Then in 2002, Microsoft launched Visual Basic .NET as part of the .NET Framework. This was a huge improvement from the older VB 6 applications because it compiled in a true executable with all the compiler optimizers C++ and C# had. I could now write an application in VB.NET that would run just as fast as a C# or C++ application.

And the best feature of the .NET framework was you could program in almost any language you wanted—Visual Basic, C#, Pascal, and Fortran were several flavors of .NET. Similar to Java, they all compiled to a Common Language Runtime (CLR) called managed code. And there were tons of advantages, but for me is was that .NET was a 100% Object Oriented Programming language. Everything was an object all the way down to an integer.

This was about the time I started the company, and marked a turning point for me and Cal Lab Solutions. We decided to standardize on VB.NET and C# as the main programming languages for the company. As we built more and more tools in .NET we always looked at VB.NET first. After all, it was the programming language initially designed for people who were not programmers.

Any programmer can write code; good or bad doesn't matter as much as "Can the next guy understand the code?" This was the biggest reason we chose VB.NET. I can put out a job posting for a programmer and get 100 applicants within an hour. But finding a good metrologist is another story. VB.NET makes it easy for a calibration tech to pick up programming, because Basic was designed for novice-programmers.

The problem with C++, C#, Java and many other languages is that they are hard for a non-programmer to comprehend. I jokingly call it cryptography, but little things make a difference; for example, "y = x++." This code will store current value of x in y, then x will be incremented by 1. This is because part of the original design of C was to do as much as possible using only the fewest of characters, when programming punch cards was time consuming.

For metrology and automation, VB.NET is a way better choice than C#. Take for example C# code "if(x==y) {DoSomething();}." The same code in Basic "If x=y Then DoSomething()" needs very little explanation. Imagine having to explain to an auditor reviewing your code the difference between "x++" and "++x" or "=" vs "==."

I hope VB.NET never goes away! Microsoft's announcement only said they will not be expanding the features in the language. And that is okay, because VB.NET does everything it needs to do. It is a great tool for Metrology! ❧

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