CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

Progress Toward Radiation-Pressure-Based Measurement of High-Power Laser Emission

Pushing the Boundaries of Traceable Measurement

Measurement Traceability: The Unbroken Chain

2015
APRIL
MAY
JUNE

Electric Current Measurement

DS Series Current Transducers

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

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

DS200

DS2000

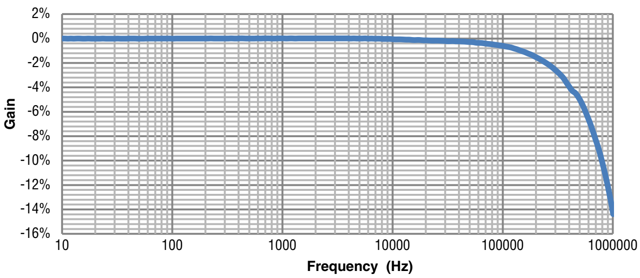
	DS200	DS600	DS2000	DS5000
Primary Current, rms	200A	600A	2000A	5000A
Primary Current, Peak	±300A	±900A	±3000A	±7000A
Turns Ratio	500:1	1500:1	1500:1	2500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†	2A/±3.2A†
Overall Accuracy	0.01%	0.01%	0.01%	
Offset	<20ppm	<10ppm	<10ppm	<5ppm
Linearity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

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

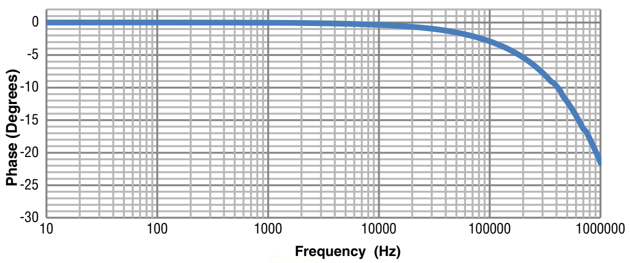
† Voltage Output options available in ±1V and ±10V

Gain / Phase

Gain (DS200, typical)



Phase (DS200, typical)



DSSIU-4 for Multi Channel Systems

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

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

DSSIU-4

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FEATURES

DEPARTMENTS

ON THE COVER: A technician tests a hydraulic torque wrench at Transcat's calibration facility in Denver, Colorado.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

May 19-21, 2015 FORUMESURE. Algiers, Algeria. Exhibition on Quality, Measurement, Accreditation and Instrumentation. FORUMESURE is an annual event, for companies and also institutions wishing to present their know-how, new products and services to hundreds of international visitors. This event is organized by The African Committee of Metrology (CAFMET) located in Angers. http://www.forumesure.com.

May 20-22, 2015 – 11th Moscow International Innovative Forum (MetrolExpo). Moscow, Russia. The symposium program is formed to promote a constructive dialogue between the producers and consumers of the instrument-making products and to successfully demonstrate the innovative engineering achievements. http://www.metrol.expoprom.ru.

May 22, 2015 – 85th ARFTG Microwave Measurement Symposium. Phoenix, AZ. The conference theme is "Measurements and Techniques for 5G Applications" with papers focusing on the measurement challenges associated with 5G as well as additional test and measurement topics. http://www.arftg.org.

Jun 4-5, 2015 IEEE International Workshop on Metrology for Aerospace. Benevento, Italy. MetroAeroSpace aims to gather people who work in developing instrumentation and measurement methods for aerospace. http://www.metroaerospace.org.

Jul 8-10, 2015 – 5th ASPE Topical Meeting on Precision Interferometric Metrology. Golden, CO. The meeting brings together specialists and practitioners from industry, government and academia in an ideal forum for the exchange of ideas. http://aspe.net/technical-meetings/aspe-summer-2015/.

Jul 19-23, 2015 NCSL International Workshop & Symposium. Grapevine, TX. This year's theme is "Measurement Science and the Quality of Life." http://www.ncsli.org/.

Jul 19-23, 2015 – 100th Annual Meeting of the National Conference on Weights and Measures (NCWM). Philadelphia, PA. The National Conference on Weights and Measures is a professional nonprofit association of state and local weights and measures officials, federal agencies, manufacturers, retailers and consumers. http://www.ncwm.net.

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EDITOR'S DESK

Education Crisis

I spent my weekend driving through Oklahoma to attend our niece's graduation. The rainbows and ominous clouds looming over scenic wheat fields were a reminder that it was tornado season… people, we need more "destination" graduations!

I'm guessing at some point, you or someone you know has complained about the disorganized and hard to navigate world of metrology education. There are a lot of resources out there for someone in want or need of continuing education. But for those actively seeking formal technical training from some kind of accredited institution, their search can be disheartening. I clicked through the links on the Education page of www.callabmag.com website recently and culled out some more listings. Schools are still dropping their metrology programs. When I get wind of a new one, I print it up in our Industry & Research News section. Sadly, it's been a year or two since I've been able to add a program to the list. Sometimes new programs only last a couple years before being discontinued.

Here in Aurora, Colorado (home of long-gone Lowry Air Force Base), our local community college, CCA, cannot remember what happened to their own metrology program. *Cal Lab Magazine* printed two articles about the CCA metrology program 13 years ago. When I came across the articles awhile back, I contacted the college several times about the program and received a mix of responses, such as "No one knows anything about that" and silence. They could have just told me the program was not sustainable due to lack of enrollment—a reasonable response. But instead, the takeaway from CCA's amnesia was that metrology programs are not relevant since nobody cares, even in the shadow of nearby biggies like Raytheon, Lockheed Martin, and National Institute of Standards and Technology (NIST). WE know metrology education is more relevant today than ever before, yet MBA and wind turbine technician programs are much easier to promote than metrology or calibration programs.

I will stop being a Grumpy Cat® and instead sing the praises of long-sustaining metrology and calibration programs at Ridgewater College in Hutchinson, MN; Piedmont Technical College in Greenwood, SC; Monroe County Community College, MI; Central Georgia Technical College in Macon, GA; California State University Dominguez Hills in Carson, CA; Butler County Community College, PA; not to mention a handful of other schools across Europe, Australia, and the Americas. All these schools are listed on our Education page at www.callabmag.com. *Cal Lab Magazine* will continue to be vigilant in keeping the online listing up-to-date.

In this issue, our good friend Kenneth Parson has contributed a piece called "Measurement Traceability: The Unbroken Chain," focusing on the practical methods of maintaining an unbroken chain of events in the lab. We also have another paper presented last year at CENAM Simposio de Metrología titled, "Progress Toward Radiation-Pressure-Based Measurement of High-Power Laser Emission," presenting efforts towards optical power measurements and improvements in the progress of a next-generation radiation-pressure optical-power meter. And finally, Mettler-Toledo contributed an article, "Pushing the Boundaries of Traceable Measurement," on calibration of microgram weights, often used for manufacture of parts at the sub-milligram range.

For those interested in posting your program information or any other metrology news, please forward to me at sita@callabmag.com!

Happy Measuring,

Sita Schwartz
Editor

CALENDAR

UPCOMING CONFERENCES & MEETINGS

Jul 20-24, 2015 – 31st Annual Coordinate Metrology Systems Conference (CMSC). Hollywood, FL. The Coordinate Metrology Society Conference (CMSC) provides a professional venue where ideas, concepts and theory flow freely among participants. The educational atmosphere encourages attendees to network and learn about the latest innovations in the field of portable 3D industrial measurement technologies. We provide technical presentations by Industry Experts, advanced Workshops and Seminars along with an Exhibition Hall filled with the world's leading providers of the metrology systems. http://www.cmsc.org.

Aug 30-Sep 4, 2015 – XXI IMEKO World Congress. Prague, Czech Republic. World Congress IMEKO represents the summit of leading researchers and practitioners who deal with measurement technology in various fields. The motto of the XXI Congress is therefore "Measurement in Research and Industry". http://www.imeko2015.org.

Sep 21-24, 2015 The International Congress of Metrology (CIM). Paris, France. The conference allows everyone to explore the developments in measurement techniques and their application for industry, and to realize the added value of measurement for improvement of industrial processes and risk management. Topics covered will be: Metrology for the future, ISO 9001:2015 requirements, Safety and metrology in food industry, Nanotechnologies, Metrology in pharmaceutical and biological environment. http://www.metrologie2015.com.

Nov 1-6, 2015 30th Annual Meeting of the American Society for Precision Engineering. Austin, TX. As the premier precision engineering conference in the U.S., each Annual Meeting offers the latest in precision engineering research through presentations from national and international speakers. Participants in the Annual Meeting have the opportunity to exchange ideas with internationally renowned experts in the field. http://aspe.net/technical-meetings/.

SEMINARS: Analytical

Jul 19, 2015 Control Charts and Stability Analysis for Calibration Laboratory Reference. Grapevine, TX (NCSLI Tutorial Session). This tutorial provides instruction on how to develop control charts for reference standards utilized in the calibration laboratory. http://www.ncsli.org/.

SEMINARS: Dimensional

Jun 8-9, 2015 Hands-On Gage Calibration and Repair Workshop. Myrtle Beach, SC. IICT Enterprises LLC. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

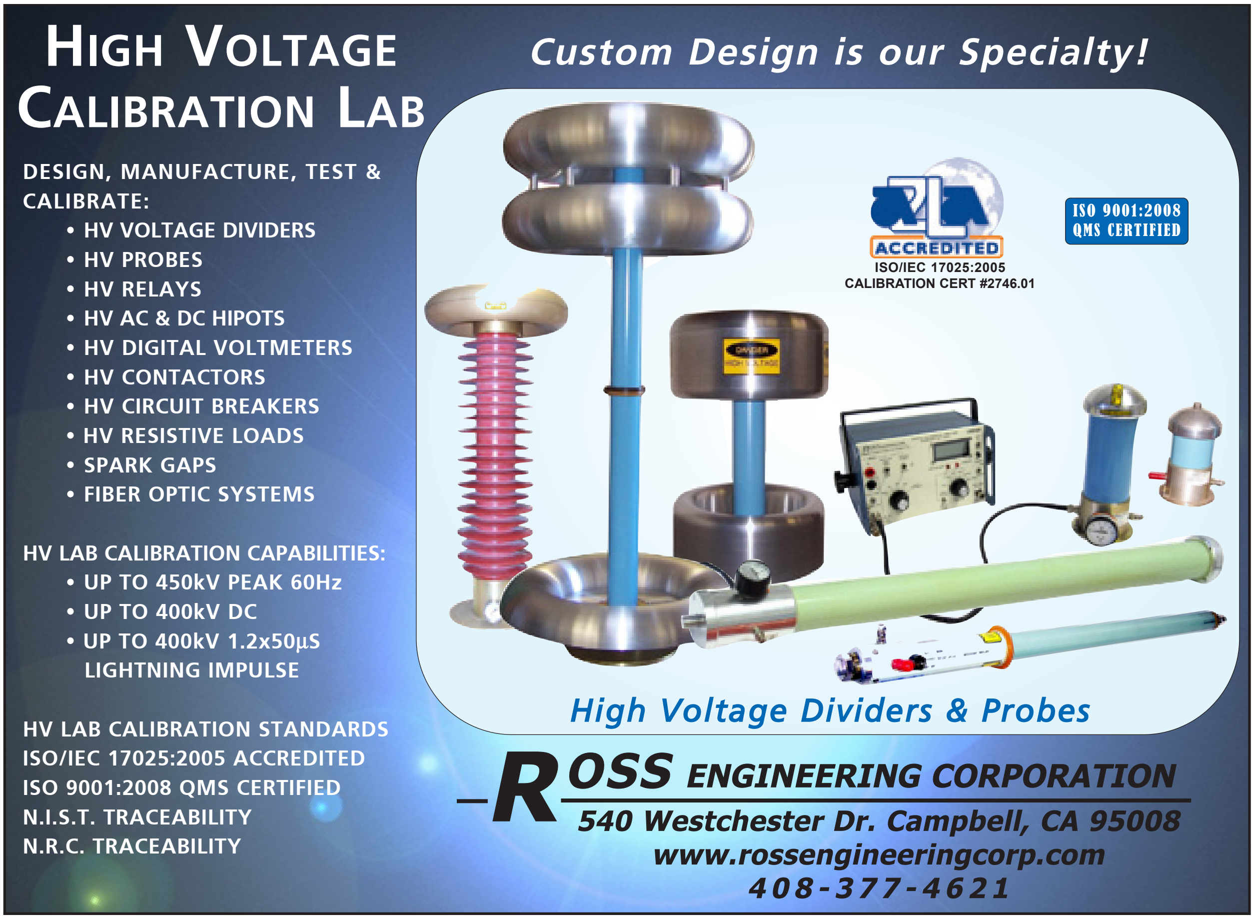
Jun 11-12, 2015 Hands-On Gage Calibration and Repair Workshop. Virginia Beach, VA. IICT Enterprises. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Jun 23-25 , 2015 Hands-On Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. This course is a unique educational opportunity designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Jun 25-26, 2015 Hands-On Gage Calibration and Repair Workshop. Bloomington, MN. IICT Enterprises. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Jul 7-8, 2015 Hands-On Gage Calibration and Repair Workshop. Schaumburg, IL. IICT Enterprises LLC. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Jul 7-9, 2015 Dimensional Metrology: Measurement, Inspection and Calibration. Plymouth, MI. Mitutoyo Institute of Metrology. This 3-day course presents



an overview of the practical science of dimensional measurement, inspection and calibration. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Jul 9-10, 2015 Hands-On Gage Calibration and Repair Workshop. Milwaukee, WI. IICT Enterprises. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Jul 19, 2015 Fundamentals of Calibration in Dimensional Metrology. Grapevine, TX (NCSLI Tutorial Session). This tutorial provides an overview of calibration techniques and key issues in dimensional metrology. http://www.ncsli.org/.

Jul 19, 2015 GD&T Workshop. Grapevine, TX (NCSLI Tutorial Session). A basic introduction to the concepts of GD&T as defined in ASME Y14.5.. http://www.ncsli.org/.

Jul 20, 2015 Intermediate Dimensional Metrology. Grapevine, TX (NCSLI Tutorial Session). This tutorial will be an overview of thermal expansion, elastic deformation, stability, refractive index of air, closure and reversal methods, and the large collection of tricks-of-the-trade that make up Dimensional Metrology. http://www.ncsli.org/.

Jul 23-24, 2015 Hands-On Gage Calibration and Repair Workshop. Arcadia, CA. IICT Enterprises. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Jul 27-28, 2015 Hands-On Gage Calibration and Repair Workshop. Las Vegas, NV. IICT Enterprises LLC. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Jul 30-31, 2015 Hands-On Gage Calibration and Repair Workshop. Denver, CO. This 2-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. http://www.iictenterprisesllc.com/.

Aug 4-6, 2015 Hands-On Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. This course is specifically designed for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Aug 18-20, 2015 Dimensional Metrology: Measurement, Inspection and Calibration. Renton, WA. Mitutoyo Institute of Metrology. This 3-day course presents an overview of the practical science of dimensional measurement, inspection and calibration. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

SEMINARS: Electrical

Jun 15-18 Applied Measurements/Instrumentation for Electrical Test & Measurement (Combined Courses 166/164). Las Vegas, NV. Technology Training, Inc. (TTi). http://www.ttiedu.com.

Jul 19, 2015 The Art of Resistance Metrology from Micro-Ohms to Tera-Ohms. Grapevine, TX (NCSLI Tutorial Session). This half-day tutorial provides an overview of calibration techniques used at NRC and NIST. The tutorial will cover calibrations from 10 micro ohms to 100 Tera Ohms and will discuss various measurement systems and techniques. http://www.ncsli.org/.

Jul 19, 2015 High Current DC measurements and Safety Considerations. Grapevine, TX (NCSLI Tutorial Session). This workshop will cover DC high current measurements using a 300A current source, several different current shunts and associated cabling. http://www.ncsli.org/.

Jul 20, 2015 Microwave Measurement Basics. Grapevine, TX (NCSLI Tutorial Session). An introduction to the measurement concepts for microwave power and scattering-parameters will be covered. http://www.ncsli.org/.

Jul 20, 2015 Microwave Power Sensor Calibration. Grapevine, TX (NCSLI Tutorial Session). Understand the types of RF power sensors, traceability of RF power, background in RF power flow, the process of calibrating a power sensor, and creating an uncertainty budget for power sensor calibration. http://www.ncsli.org/.

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Aug 17-20, 2015 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. http://us.flukecal.com/training/courses/MET-101.

SEMINARS: Flow & Pressure

Jul 19, 2015 Pressure Metrology. Grapevine, TX (NCSLI Tutorial Session). This full day tutorial covers all the fundamental challenges of calibrating pressure instruments. http://www.ncsli.org/.

Sep 23-25, 2015 TrigasFI Flow Seminar (English). Neufahrn, Germany. The material presented is based on more than 30 years experience in operation of gas and liquid flow calibration facilities and related research. http://www.trigasfi.de/.

Oct 5-9, 2015 Principles of Pressure Calibration (NEW). 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). http://us.flukecal.com/Principles-of-Pressure.

Oct 19-23, 2015. Advanced Piston Gauge Metrology. Phoenix, AZ. Fluke Calibration. Focus is on the theory, use and calibration of piston gauges and dead weight testers. http://us.flukecal.com/training.

SEMINARS: General & Management

May 14-15, 2015 Internal Auditing. Minneapolis, MN. A2LA. This 2-day training course practices the internationally-recognized approaches of ISO 19011:2011 to conducting effective internal audits. http://www.a2la.org/training/intaudit.cfm?private=no.

Jun 25-26, 2015 Internal Auditing. Frederick, MD. A2LA. This 2-day training course practices the internationally-recognized approaches of ISO 19011:2011 to conducting effective internal audits. http://www.a2la.org/training/intaudit.cfm?private=no.

Jul 19, 2015 Running the Effective Laboratory Better - Data Driven Improvements that Matter. Grapevine, TX (NCSLI Tutorial Session). This "How To" tutorial focuses on getting your calibration operation to maximum operational effectiveness, which will lead you directly to improvements in efficiencies. http://www.ncsli.org/.

Jul 19, 2015 Root Cause Analysis. Grapevine, TX (NCSLI

Tutorial Session). This one day tutorial will focus on internationally recognized approaches to conducting effective internal audits. http://www.ncsli.org/.

Jul 20, 2015 Applying LEAN in a Calibration Laboratory Environment. Grapevine, TX (NCSLI Tutorial Session). This practical and interactive one-day tutorial provides participants with a basic knowledge of the history and principles of LEAN and how those principles can apply to a calibration laboratory environment. http://www.ncsli.org/.

Jul 20, 2015 Auditing, Traceability, and Auditing Traceability. Grapevine, TX (NCSLI Tutorial Session). This tutorial will be of interest to managers and staff of laboratories with new or mature quality systems. http://www.ncsli.org/.

Aug 10-14, 2015 Fundamentals of Metrology. Gaithersburg, MD. NIST. The Fundamentals of Metrology seminar will introduce the participant to the concepts of measurement systems, units, measurement uncertainty, measurement assurance, traceability, basic statistics and how they fit into the laboratory Quality Management System. http://www.nist.gov/pml/wmd/5373.cfm.

Sep 29-30, 2015 Internal Auditing. Columbus, OH. A2LA. This 2-day training course practices the internationally-recognized approaches of ISO 19011:2011 to conducting effective internal audits. http://www.a2la.org/training/intaudit.cfm?private=no.

Oct 26-27, 2015 Internal Auditing. Frederick, MD. A2LA. This 2-day training course practices the internationally-recognized approaches of ISO 19011:2011 to conducting effective internal audits. http://www.a2la.org/training/intaudit.cfm?private=no.

SEMINARS: Industry Standards

Jun 1-5, 2015 Assessment of Laboratory Competence. Frederick, MD. A2LA. This course is a comprehensive look at the ISO/IEC 17025:2005 requirements and a detailed approach to the assessment of a laboratory's competence. http://www.a2la.org/training/aolc.cfm?private=no.

Jun 3-5, 2015 ISO/IEC Standard 17025 Training. Brea, CA. International Accreditation Service, Inc. (IAS). This course is aimed at testing and calibration laboratories. The training program is designed to provide a complete overview of the ISO/IEC Standard 17025:2005 requirements. http://www.iasonline.org.

Jun 17-19, 2015 ISO/IEC 17025:2005 and Laboratory Accreditation. Detroit/Livonia, MI. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/training/iso17025.cfm?private=no.

Jul 19, 2015 Understanding ISO/IEC 17025 Requirements. Grapevine, TX (NCSLI Tutorial Session). This full-day tutorial covers highlights of ISO/IEC 17025 requirements. http://www.ncsli.org/.

Sep 15-16, 2015 ISO/IEC 17025:2005 and Laboratory Accreditation. Frederick, MD. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/training/iso17025.cfm?private=no.

Sep 23-25, 2015 ISO/IEC 17025:2005 and Laboratory Accreditation. Dallas, TX. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/training/iso17025.cfm?private=no.

Sep 28, 2015 ISO/IEC 17025:2005 Advanced: Beyond the Basics. Columbus, OH. A2LA. The course will provide a brief overview of the requirements of this laboratory standard, as well as provide an understanding of how to apply specific sections of the Standard in your laboratory. http://www.a2la.org/training/ISO17025forAccredCABs.cfm?private=no.

Oct 5-7, 2015 ISO/IEC 17025:2005 and Laboratory Accreditation. Frederick, MD. A2LA. This course is an introductory look at ISO/IEC 17025 and its requirements for demonstrating the technical competence of testing and calibration laboratories. http://www.a2la.org/training/iso17025.cfm?private=no.

Oct 19-23, 2015 Assessment of Laboratory Competence. Albuquerque, NM. A2LA. This course is a comprehensive look at the ISO/IEC 17025:2005 requirements and a detailed approach to the assessment of a laboratory's competence. http://www.a2la.org/training/aolc.cfm?private=no.

SEMINARS: Mass

Jun 1-11, 2015 Advanced Mass Seminar. Gaithersburg, MD. NIST Office of Weights and Measures. The 9 day, hands-on seminar focuses on the comprehension and application of the advanced mass procedures, the equations, and associated calculations. >> http://www.nist.gov/pml/wmd/calendar.cfm.

Jul 19, 2015 Force Calibration. Grapevine, TX (NCSLI Tutorial Session). This course will cover applied force calibration techniques and will include live demonstrations using secondary standards to exhibit potential measurement errors made in everyday force measurement. http://www.ncsli.org/.

Jul 20, 2015 Fundamentals of Torque Calibration. Grapevine, TX (NCSLI Tutorial Session). This presentation is a review of the fundamentals of torque calibration. http://www.ncsli.org/.

Oct 26-Nov 6, 2015 Mass Metrology Seminar. Gaithersburg, MD. NIST Office of Weights and Measures. http://www.nist.gov/pml/wmd/calendar.cfm.

SEMINARS: Measurement Uncertainty

Jun 15-16, 2015 Introduction to Measurement Uncertainty. Detroit/Livonia, MI. American Association for Laboratory Accreditation, http://www.a2la.org/training/course_schedule.cfm.

Jun 18-19, 2015 Measurement Uncertainty (per ILAC P14 Guidelines). Seattle, WA. WorkPlace Training. This workshop introduces basic measurement uncertainty and traceability concepts. The concepts taught are then put in practice by developing sample measurement uncertainty budgets. http://www.wptraining.com.

Aug 3-4, 2015 Training for Measurement Uncertainty. International Accreditation Service, Inc. This IAS training program is designed to provide a complete overview of the ISO/IEC 17025 requirements concerning Measurement Uncertainty (MU) as applied to measuring equipment with calibration examples taken from mechanical engineering, physical testing, mass calibration, etc. http://iasonline.org/.

Sep 21-22, 2015 Introduction to Measurement Uncertainty. Dallas, TX. American Association for Laboratory Accreditation, http://www.a2la.org/training/course_schedule.cfm.

Oct 8-9, 2015 Measurement Uncertainty Advanced Topics. Frederick, MD. A2LA. The use of industry-proven tools covered in this workshop helps establish a laboratory's reputation in providing the correct solutions to its customers and maintaining its accreditation. http://www.a2la.org/training/muadvanced.cfm?private=no.

Oct 20-22, 2015 Introduction to Measurement Uncertainty. Everett, WA. Fluke Calibration. MET-302 Hands-On Metrology Statistics is a three-day course that will teach you how to develop uncertainty budgets and to understand the necessary calibration processes and techniques to obtain repeatable results. http://us.flukecal.com/training.

SEMINARS: Software

Jun 9-11, 2015 VNA Tools – VNA Metrology and Uncertainty Workshop. Morgan Hill, CA. VNA Tools II is free and supports most of the Vector Network Analyzers (VNAs) in today's market. This three day course provides a practical lesson with this versatile software—available at: www.metas.ch/vnatools. For registration, email: Juerg.Ruefenacht@metas.ch or Michael.Wollensack@metas.ch.

Jul 19, 2015 Calibration Management Software - How to Select and Implement for Your Environment. Grapevine, TX (NCSLI Tutorial Session). This half day tutorial will cover key factors to consider in selecting and implementing a calibration management software solution for your laboratory. http://www.ncsli.org/.

Jul 19-20, 2015 An Introduction to Instrument Control and Calibration Automation in LabVIEW. Grapevine, TX (NCSLI Tutorial Session). During this two day hands-on tutorial, session participants will explore the LabVIEW environment, learn to develop, instrument control, data-logging, and measurement analysis applications. http://www.ncsli.org/.

SEMINARS: Temperature

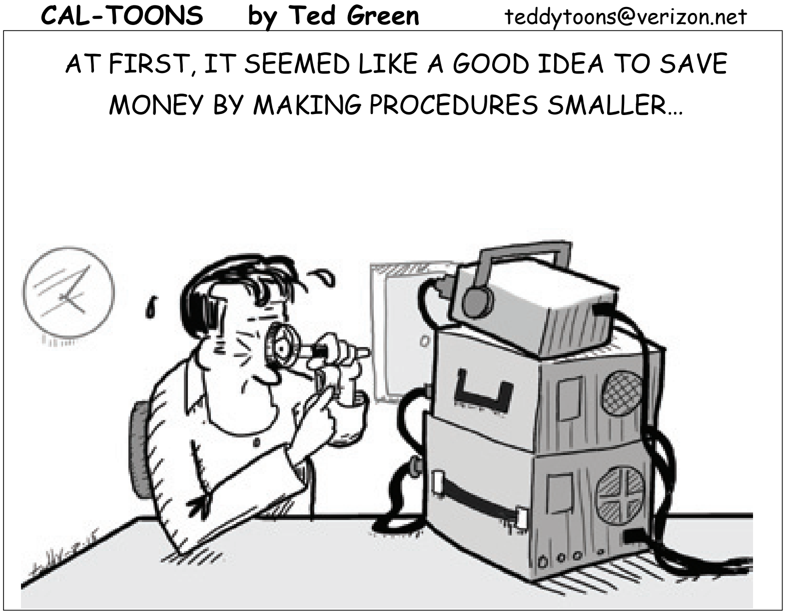
Jun 9-11, 2015 Principles of Temperature Metrology. American Fork, UT. Fluke Calibration. A three-day introduction to temperature metrology covering: ITS-90 principles, traceability, thermometry, calibration systems, measurement techniques, uncertainty budgets, quality assurance and more. http://us.flukecal.com/training/courses/Principles-Temperature-Metrology.

Jul 20, 2015 Fundamentals of Temperature Calibration. Grapevine, TX (NCSLI Tutorial Session). This presentation is a review of the fundamentals of temperature calibration. http://www.ncsli.org/.

Jul 20, 2015 Humidity Calibration Tutorial. Grapevine, TX (NCSLI Tutorial Session). This tutorial will provide an overview of basic information regarding humidity definitions, dew point, frost point, and relative humidity. http://www.ncsli.org/.

Jul 20, 2015 Advanced Topics of Temperature Calibration. Grapevine, TX (NCSLI Tutorial Session). This course continues to build on the principles established in the Fundamentals of

CAL-TOONS by Ted Green teddytoons@verizon.net



Temperature Calibration course. http://www.ncsli.org/.

Jul 20, 2015 Fundamentals of Radiation Thermometry Calibration. Grapevine, TX (NCSLI Tutorial Session). This presentation is an overview of the basic knowledge necessary to perform radiation thermometer calibrations. http://www.ncsli.org/.

Sep 15-17, 2015 Advanced Topics in Temperature Metrology. American Fork, UT. Fluke Calibration. A three-day course for those who really need to get into the details covering: ITS-90 calibration, process design, curve fitting, uncertainty analysis, and advanced procedures for reducing uncertainties. http://us.flukecal.com/training/courses/Principles-Temperature-Metrology.

Oct 13-15, 2015 Principles of Temperature Metrology. American Fork, UT. Fluke Calibration. A three-day introduction to temperature metrology covering: ITS-90 principles, traceability, thermometry, calibration systems, measurement techniques, uncertainty budgets, quality assurance and more. http://us.flukecal.com/training/courses/Principles-Temperature-Metrology.

SEMINARS: Vibration

Jul 19, 2015 Dynamic Sensors & Calibration. Grapevine, TX (NCSLI Tutorial Session). This four-hour tutorial on vibration calibration will dive into calibration theory, standards, and methodology for dynamic sensors as well as explanations of different sensor types and the operational theories behind them. http://www.ncsli.org/.

Oct 6-8, 2015 Random Vibration and Shock Testing. Santa Barbara, CA. A review of basic vibrations, sources and causes, followed by an exploration of vibration measurements, analysis and calibration. http://www.equipment-reliability.com.

SEMINARS: Volume

Aug 17-21, 2015 Volume Metrology. Gaithersburg, MD. NIST Office of Weights and Measures. This seminar incorporates statistical analysis, process measurement control methods, uncertainty analyses, traceability assessments, and builds on the concepts covered in the Fundamentals of Metrology seminar. >> http://www.nist.gov/pml/wmd/5356.cfm.

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ONLINE & INDEPENDENT STUDY

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

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

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

Basic Measuring Tools – Self Directed Learning. The QC Group. Before workers can contribute to any measurement-based improvement efforts, they must be proficient in using and reading basic measuring devices. This program is a practical, efficient way to build workers' skills and knowledge. http://www.qcgroup.com/sdl/.

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

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

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

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

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

ISO/IEC 17025 Accreditation Courses. WorkPlace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

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

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

Metrology for Cal Lab Personnel – Self-Paced Online Training. Fluke Training. A general overview of metrology principles and practices; designed to help calibration laboratory personnel prepare for the ASQ CCT examination. http://us.flukecal.com/training/courses.

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

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

Precision Measurement Series Level 1 & 2. WorkPlace Training, http://www.wptraining.com/.

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

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Professor Paul Scott has been awarded a Researcher Excellence Grant of 130,000 euros by the EU-funded European Association of National Metrology Institutes (EURAMET) for his part in a major scale project designed to demonstrate that metrology software is fit for purpose.

Online System Unveiled to Pinpoint Metrology Software Accuracy

A THREE-year research project by a University of Huddersfield professor means that advanced manufacturing companies will have on-line access to a new method of testing the accuracy of their crucial measurement software.

Professor Paul Scott was awarded a Researcher Excellence Grant of 130,000 euros by the EU-funded European Association of National Metrology Institutes (EURAMET) for his part in a major scale project designed to demonstrate that metrology software is fit for purpose.

He has now completed his component of the research by developing the mathematical fundamentals for a new system that is due to be put online by the German institute PTB (Physiklisch Technische Bundesanstalt).

Manufacturers, software developers and a wide range of researchers in fields where metrology plays an important role will have paid-for access to a webpage that can generate data, which will enable them to assess the accuracy achieved by their current software. They can then make the adjustments required to improve the performance of the software.

Professor Scott has provided a detailed account of his research in a paper delivered at the University of Huddersfield, when it hosted the 2015 Laser Metrology, Coordinate Measuring Machine and Machine Tool Performance (LAMDAMAP) conference, a major international event held under the auspices of the European Society for Precision Engineering and Nanotechnology (EUSPEN).

His presentation was entitled *Fundaments of Measurement for Testing Software in Computationally-Intensive Metrology*. Professor Scott described a new mathematical model for measurement and he explored the concept of "measurement as an inverse problem," which has particular relevance to complex modern measurement instruments such as CT scanners and white light interferometers.

Professor Scott is a mathematician who previously worked as a researcher for the firm Taylor Hobson, globally renowned for the design and development of ultra-precision metrology instruments. He applied mathematical ideas and concepts to the development and improvement of measuring instruments, and Professor Scotts's newly-completed EURAMET research is a further development of his long engagement in the field.

Source: University of Huddersfield news, March 2015, (http://www.hud.ac.uk/news/2015/march/onlinesystemunveiled topinpointmetrologysoftwareaccuracy.php).

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600 Million € Metrology Research Program Ready To Go: EMPIR Delegation Agreement Signed

April 30, 2015—EURAMET is happy to announce the signing of the Delegation Agreement for the European Metrology Program for Innovation and Research (EMPIR). The document was signed by the European Union, represented by the European Commission, and EURAMET's Chairperson Dr Kamal Hossain and Vice-Chairperson (EMPIR) Dr Jörn Stenger. This was the essential step for the realization of EMPIR.

The 43 page Delegation Agreement summarizes the successful completion of a three year process on the way to EMPIR. The fruitful cooperation between the European Commission, the 28 participating EURAMET member states, various stakeholders, organizations and EURAMET officials in numerous events and meetings was the driving force for the necessary steps. One important milestone was the successful completion of the co-decision process mid 2014: EMPIR was part of a proposal from the European Commission which was accepted by the European Parliament and the Council of the European Union.

"EURAMET appreciates the true spirit of collaboration between the European Union and the metrology community," comments Kamal Hossain. "On behalf of EURAMET I would like to express my sincerest thanks to all the people involved who gave their best to make this program come true." Now, the program will be implemented with a ten year term, including a broad range of research topics and a total budget of 600 million euros.

EMPIR and its predecessor, the European Metrology Research Program (EMRP), are co-funded by the European Union and the participating states and focus on research in metrology to address society's Grand Challenges in areas such as energy, environment and health. With EMPIR there is an increased focus on innovation activities to target the needs of industry and accelerate the uptake of research outputs. The programs enable European National Metrology Institutes, industrial organizations and academia to collaborate on joint research projects. Since 2007, 140 joint research projects have been funded under the EMRP, with a further 19 to start now, as EMPIR's Delegation Agreement was signed, and many more to come in the next EMPIR Calls.

Source: http://www.euramet.org.

INDUSTRY AND RESEARCH NEWS

Danaher Announces Intention to Separate Into Two Independent, Publicly Traded Companies

WASHINGTON, May 13, 2015 / PRNewswire/ -- Danaher Corporation (NYSE: DHR) ("Danaher") today announced its intention to separate the company into two independent, publicly traded companies. The transaction will create:

- A science and technology growth company united by common business model characteristics, including significant recurring revenue and an attractive margin profile. The company will retain the Danaher name. Collectively, its businesses generated approximately $16.5 billion in revenues (including Pall Corporation, which Danaher has signed an agreement to acquire), in their most recently completed fiscal years.
- A diversified industrial growth company ("NewCo") with market leading positions, strong brand names and tremendous free cash flow generation. NewCo's businesses generated approximately $6.0 billion in revenues in the most recently completed fiscal year.

The transaction is expected to occur through a tax-free separation.

Thomas P. Joyce, Jr. and Daniel L. Comas will continue to serve as President and Chief Executive Officer and Executive Vice President and Chief Financial Officer of Danaher, respectively, following the completion of the transaction.

James A. Lico, currently Executive Vice President with responsibility for Danaher's Test & Measurement and Gilbarco Veeder-Root businesses, will become President and Chief Executive Officer of NewCo upon separation.

Danaher will be united by common business model characteristics, including high recurring revenue and gross margins, and will be well positioned to improve profitability, grow organically and deploy capital to generate substantial earnings growth. It will enjoy leading positions in markets with favorable secular growth trends.

The science and technology growth company will include Danaher's existing Life Sciences & Diagnostics and Dental segments, Water Quality and Product Identification platforms and Pall Corporation.

NewCo, a diversified industrial growth company, will have market leading positions and outstanding brands in such areas as test and measurement, retail fueling, telematics and automation. It will comprise Danaher's Test & Measurement Instruments platform including Matco, Gilbarco Veeder-Root, Automation and Sensors, as well as its other Specialty Industrial businesses. As a smaller, standalone entity, NewCo is expected to have an outstanding margin profile and tremendous free cash flow generation allowing it to accelerate its revenue and earnings growth trajectorys while providing flexibility in capital deployment.

The Company is targeting to complete the separation around the end of calendar year 2016, subject to the satisfaction of closing conditions, including obtaining final approval from the Danaher Board of Directors, satisfactory completion of financing, receipt of tax opinions, receipt of favorable rulings from the Internal Revenue Service and receipt of other regulatory approvals.

Danaher is a global science and technology innovator committed to helping its customers solve complex challenges and improving quality of life around the world. Its family of world class brands have leadership positions in some of the most demanding and attractive industries, including health care, environmental and industrial. The Company's globally diverse team of 71,000 associates is united by a common culture and operating system, the Danaher Business System. In 2014, Danaher generated $19.9 billion in revenue and its market capitalization exceeded $60 billion. For more information please visit: www.danaher.com.

PTB Recipe for the New Kilogram

PTB – March 26, 2015 - It's a real pressure-cooker. In the international contest over the most accurate definition of the kilogram, researchers of the Physikalisch-Technische Bundesanstalt (PTB) now not only have the recipe in their pocket, they have also gathered all the components: They have set up a complex chain of many manufacturing and analytical steps in order to accurately determine two constants of nature: the Avogadro constant and Planck's constant. These are the pillars of a redefinition of the kilogram. The new skills and measurement methods which have been developed in the course of the past months and years must now prove themselves in practice: In March, PTB received a crystal made of high-purity silicon-28, from which two spheres will be manufactured and then analyzed. The values determined thereby for the Avogadro constant and Planck's constant should have an unrivaled accuracy.

"Our goal is to have PTB master the realization of the future kilogram completely autonomously,"says Horst Bettin, head of PTB's kilogram project. To this end, PTB has goal-orientatedly developed new methods and improved already known methods. Some years ago, for example, the first silicon spheres for the experiment were polished in Australia by the—at that time—only expert worldwide. Today, the complete sphere production takes place at PTB and is so exact that the deviation from the ideal sphere shape is considerably less than 100 nanometers. With the sphere interferometer it is possible to determine the average diameter of the sphere accurately down to three diameters of an atom, and a UHV reflectometer determines the thickness of oxide layers on the sphere surface down to one nanometer.

However, Bettin's confidence is based not only on technology and the skills of PTB staff members, but also on the purity of the supplied material. In the Electrochemical Plant in Zelenogorsk, Russia, thousands of centrifuges were in operation for months in order to facilitate the more than 99.998 percent isotope purity of the silicon-28. "That was a master performance at the limit of what is technically possible," praised Manfred Peters, former Vice-President of PTB, who led the complex contractual negotiations with Russia and who heads the project with Russia. Also the subsequent cleaning of the highly explosive gaseous silicon tetrafluoride ($^{28}SiF_4$) and its conversion to silane ($^{28}SiH_4$), and subsequently to polycrystalline silicon was, according to Peters, "real pioneer work which earns the highest approval." The chemically complicated process especially developed for this project took place at the Institute of Chemistry of High-Purity Substances of the Russian Academy of Sciences in Nishniy Novgorod.

In the course of the coming months, another six-kilogram crystal will be supplied. From the Russian base material, the Leibniz-Institut für Kristallzüchtung (Leibniz Institute for Crystal Growth) in Berlin will in each case grow a flawless single-crystal whose inner structure is completely regular and without fractures. Both being free of impurities and having a regular structure are preconditions for the success of the experiment. In the end, PTB will have at its disposal a nearly perfect base material for four spheres.

From the round-bodied, cylindrical single-crystals, PTB produces crystal spheres that are rounder than anything else in the world. Each sphere is then measured individually according to all the rules of the art. The aim is to connect the coarse characteristics to the fine characteristics, that is, to produce the connection between the mass of the sphere and the mass of an atom. Thus, the researchers measure the mass and the volume of the ^{28}Si sphere, as well as the arrangement of the atoms in the crystal and the abundance of the three existing silicon isotopes, which yields the molar mass of the silicon used. Thus, they know how many moles of silicon are present in their sphere and how many atoms there are in one mole. The researchers have thus determined the Avogadro constant. The goal has been reached! And since the Avogadro constant is also linked to the Planck constant via a fixed physical relation, both can be determined in one fell swoop. Already at this point, PTB scientists miscount only twice every one hundred million atoms. The goal is to miscount only by one atom for every one hundred million atoms.

And why is this all being done? Doesn't everyone already know how heavy a kilogram is? Currently, all mass measurements in the world ultimately relate to a small cylinder made of a platinum-iridium alloy, which is kept secure in a safe at the International Bureau of Weights and Measures (BIPM) in Sèvres: the international prototype of the kilogram. Numerous countries have copies of the international prototype of the kilogram. With these copies and via further transfer standards, we teach weighing instruments how heavy a kilogram is. However, physical and chemical processes change things in the course of time. There are indications that the mass of the international prototype of the kilogram has also changed slightly. At worst, the international prototype of the kilogram could be destroyed or stolen all of a sudden. Then the definition would be lost for all time.

In order to evade the transient sword of Damocles, researchers are searching worldwide for a new definition. At the international General Conference on Weights and Measures, it was agreed upon to not only define the kilogram, but also three other physical units via natural constants in 2018, if possible—thus via physical quantities whose value can be neither influenced nor changes spatially or temporally. These units are the ampere, the mole, and the kelvin. For the definition of the kilogram, the Avogadro constant would actually be sufficient, but the mass metrologists also keep their "electrical colleagues" in mind: These want to define the unit of electric current, the ampere, also via a constant, namely the charge of the electron. And if the mass colleagues were to now add Planck's constant, the units of voltage and resistance would be simply derived therefrom. Since both the Avogadro constant and Planck's constant are interlinked, internationally it has been agreed to also define the kilogram via this constant, even though this is less vivid.

This will not change the dissemination of the unit: Also in the future we will tell our weighing instruments with the aid of weights—possibly also in the form of silicon spheres—how heavy a kilogram is. But these weights can be reproduced. Because the "mother" of all kilogram weights will no longer be a physical and, thus, destroyable object, but rather a defining constant in a mathematical formula which will defy all changes.

Technically speaking, in the contest over the redefinition of the kilogram there cannot, by the way, really be a "winner," because the kilogram will not be redefined until at least two scientific approaches and the experiments of three research groups come to consistent findings: namely to determine Planck's constant with sufficient accuracy. The experiments with the silicon-28 sphere are only one possible way to determine Planck's constant—it is the way that the PTB scientists are going. Several other institutes, particularly in the USA, Canada, France and Switzerland, are focusing on the watt balance. It allows the weight force of a mass to be compensated through electromagnetic force. In view of the progress made with both approaches, nothing should stand in the way of the redefinition of the kilogram at the end of 2018.

With the new Si single crystal 28 kilogram project PTB enters its decisive stage. On March 25, 2015, it is was from the Institute for Crystal Growth, Berlin, picked up and taken to the PTB.

Source: Physikalisch-Technische Bundesanstalt (http://www.ptb.de/en/aktuelles/archiv/presseinfos/pi2015/pitext/pi150326.html).

Progress Toward Radiation-Pressure-Based Measurement of High-Power Laser Emission

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We present an overview of our efforts toward using optical radiation pressure as a means to measure optical power from high-power lasers. Early results with measurements ranging from tens of watts to 92 kW prove the concept, but validation uncertainties between 7 and 13 % must be reduced. We discuss improvements that are in progress for our next-generation radiation-pressure optical-power meter.

1. Introduction

Traditionally, high-accuracy optical-power measurements of high-power lasers involve absorbing as much of the laser power as possible in a power-sensor and measuring the resulting temperature change of that sensor. This allows high powers to be measured to ~ 1 % accuracy levels. However, since these thermal (calorimeter) power meters must absorb the incident optical power, their volume and response period must scale linearly with their optical energy capacity. For example, at a 100-kW capacity, such power meters have volumes on the order of 1 m^3. Flowing-water optical power meters measure optical power directly, allowing faster response times which are less dependent on power capacity, but their size still scales linearly with optical-power capacity. And in both cases (calorimeter or flowing-water power meter), high accuracy is dependent on the majority of the optical power being absorbed by the sensor, precluding high-accuracy absolute power monitoring during laser use.

This illustrates the potential advantages of a radiation pressure-based optical-power meter that by design minimizes optical power absorption – its size and response time do not scale with power capacity, and it allows high-accuracy laser power monitoring without interruption to the laser beam. We are investigating radiation pressure as an alternate method for laser power measurement. Here we summarize our preliminary results and discuss the next steps needed to bring this power-measurement paradigm to maturity.

Radiation pressure has been well-understood for over a century [1-3], and the benefits of a radiation-pressure optical power meter have been recognized for many years with several prototypes considered or assembled [4-8]. However, the force measurements in these previous designs were based on torsion balances, which offer high sensitivity but have several limitations. These include a slow time response due to long oscillation periods (tens to hundreds of seconds [9]), difficulty in scaling to larger beam diameters, the requirement of operation in a vacuum environment, inability for fundamental calibration to a force standard, and limited portability. But, today, with industrial, defense, and research laser powers from kW to MW levels, and robust commercial scales with precisions at the nanoNewton level (0.1 µg) or better, a robust radiation-pressure approach to absolute power measurement in high-power lasers has become practical. Our goal in this work is not to demonstrate accurate measurement of radiation pressure, which has already been done. But rather, we seek to develop a practical radiation-pressure-based optical power meter that is capable of operating at the kW level and above, using a commercial-grade scale, to yield absolute accuracy in the range of a few percent.

We discuss the status of this work, modifications for the next-generation power meter, and collateral efforts to investigate mutual calibration between mass and optical-power measurements.

2. Demonstration of Feasibility

Figure 1 illustrates our design for a radiation-pressure-based optical power meter. It consists simply of a mirror attached to the actuator of a mechanical scale. The optical power is easily relatable to the force exerted on the mirror, and the reflected beam is available for its intended use (cutting, heating, etc.).

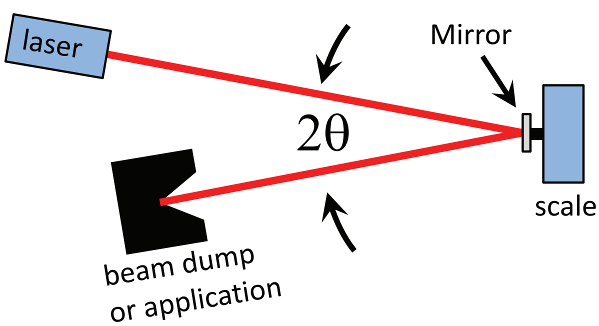

Figure 1. Prototype radiation-pressure power-meter configuration. Typically, the laser beam propagates in a horizontal plane, requiring the scale to operate in a "vertical" orientation with the mirror surface in a vertical plane.

The theory is simple. Since light carries momentum, a force is required to change a laser beam's wavevector. Specifically, light reflecting from a mirror imparts a force on that mirror. We measure that force as a means to determine a laser beam's optical power. The force $\boldsymbol{F}$ required to change an object's momentum $\boldsymbol{p}$ depends on the time rate of that change $\boldsymbol{F}=d\boldsymbol{p}/dt$. The momentum of a beam of light carrying energy E is given as $|\boldsymbol{p}|=E/c$, where c is the speed of light. So, for a beam with optical power $P=dE/dt$, a perfectly reflecting mirror will reverse the momentum of the incident light, generating a force $F=2P/c$. Accounting for an imperfect mirror and non-normally incident light,

$$F = (2P / c)\, r \cos(\theta) \tag{1}$$

where $r = R + (1 - R)\alpha / 2$ accounts for the fact that an absorbed photon imparts all its momentum, and a reflected photon imparts twice its momentum. R is the mirror reflectivity, α indicates the fraction of non-reflected light absorbed by the mirror, and θ is the angle of incidence. Equation (1) describes a maximum power-to-force conversion factor of $2/c = 6.67\times10^{-9}$ N/W for normal incidence on a perfectly reflecting mirror.

We used a commercial scale ("balance") to measure the radiation force exerted by lasers ranging in power from 10's of watts up to almost 100 kW. This work is detailed in [10] but is summarized here for convenience. Our initial goal was to demonstrate that radiation pressure could be measured for kilowatt-level laser powers with existing portable scale technology. This involved not only demonstrating the accurate measurement of the radiation force on a mirror using a commercial scale, but verifying that the force measured was indeed due to radiation pressure. The scale was an off-the-shelf direct-loading force restoration balance [11] with a 100-nN (10-µg) resolution. The direct-loading balance design is integral to the practical operation of this radiation-pressure power meter. The direct-load mechanism [11] does not require gravity for its mechanical operation, so, by removing the spring that compensates for the weight of the balance pan, we were able to operate the balance in an orientation where the force was measured horizontally. This significant feature allows the laser beams to travel and be measured in a horizontal direction (parallel to the plane of the floor) which is the usual direction of travel. This avoids the requirement to generate vertically propagating light, which is a practical laser safety issue, particularly important at the highest laser powers.

Low-power measurements were made with a 530 W Yb-doped fiber laser source, centered at 1071 nm with a 5 nm full-width-at-half-maximum bandwidth. Although the 3.5 µN of radiation force was at the low end of our scale's operation range, it provided sufficient signal-to-noise ratio to demonstrate feasibility. The mirror (dielectric coated glass substrate, 2.54-cm diameter) reflectivity was measured to be better than 0.997 over a range of incident angles between 7° and 45° for the fiber laser's operating wavelength.

At these relatively low laser powers of a few hundred watts, room air currents (and acoustic events) as well as temperature drift of the scale were sufficiently strong to obscure the identification and measurement of radiation force on the scale. To isolate the radiation force from these noise effects, the laser's output amplitude was current-modulated (100 % depth) with a 0.1 Hz square wave. This relatively slow modulation was chosen to accommodate

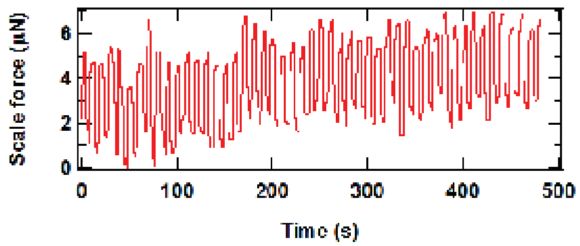

Figure 2. Scale reading (in force units) for 530 W incident power modulated at 0.1 Hz. The average y-axis value is arbitrary since it includes the initial (non-zero) mass reading of the scale.

the scale's internal digitizer circuit's effective response period of ~ 2 s. The scale reading was converted from mass to force by using the gravitational constant g = 9.80 m/s^2. Figure 2 shows typical measurement results, illustrating drift due to thermal effects and random air currents.

2.1 Effect of Air Currents

We demonstrated the significance of room air currents by taking a similar data set where the mirror was enclosed by a housing mounted against the front face of the scale with an anti-reflection-coated window in front of the mirror. This isolated the mirror from the effects of room air motion and yielded the lower-noise result seen in Figure 3. Note that a slow drift due to scale temperature remains, which we attribute to thermal heating from the incident laser power. Air currents (or acoustic noise) is even more of a concern when measuring lasers with large beam diameters since the mirror size must scale accordingly. Of course, measurement uncertainty will be affected by the uncertainty of the reflectivity of the entrance window. However, window transmission can be known to a fraction of a percent and the increased uncertainty is justified by the achievable noise reduction.

2.2 High Power Operation

To examine the upper power range, we operationally tested our meter with a 100 kW CW CO_2 laser. In order to accommodate the larger 10-cm beam diameter without drastically increasing the mirror mass, we used a 20-cm diameter silicon wafer coated with gold and a surface dielectric layer, providing R=0.998 at 10.6 µm and 45° incidence angle. With the increased mirror area the balance was particularly susceptible to slight air currents. It was partially protected by a housing with cylindrical baffles surrounding the input and output light paths (no windows were used). We measured the resultant force on the scale for a 3-s exposure of unmodulated 24 kW and 92 kW laser powers at a nominal 45° angle of incidence. The optical power measured by the scale for the 92 kW shot is shown in Figure 4. We experienced no damage during the exposure, but did see a delayed drift in the scale's background power (force) reading, which became apparent after the laser pulse ended (see Figure 4). The measured injected power level was 13 % lower than expected.

Due to limited access time with the high-powered CO_2 laser, we were unable to directly investigate the cause of the slow background increase. However, suspecting residual heating of the scale, we later tested the heat transmitted through the silicon mirror using a lower-power CO_2 laser in our laboratory (1.5 kW). We applied ~480 W/cm^2 in a 2-cm diameter spot and measured the time-dependent temperature rise at the back face of the mirror. Scaling this rise by a factor of 2.3 to account for the difference between the power density during the 92 kW shot and that achieved during our test, we found the temperature behavior shown in Figure 5. The shape of the predicted temperature rise agrees well with the background power increase that follows the 92 kW pulse. It can also be seen that at ~ 10 s an exponential decrease in this background level begins, presumably due to the onset of cooling after the laser power was removed. We currently lack accurate assessment of the temperature dependence of the scale (in horizontal orientation), so we have no correlation between

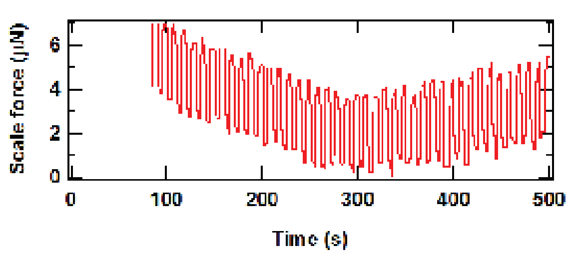

Figure 3. Scale reading (in force units) for 522 W incident power modulated at 0.1 Hz. Mirror is enclosed in a shroud with anti-reflection-coated entrance window to protect the mirror against external air currents. Compare with Figure 2. (Arbitrary y-axis offset).

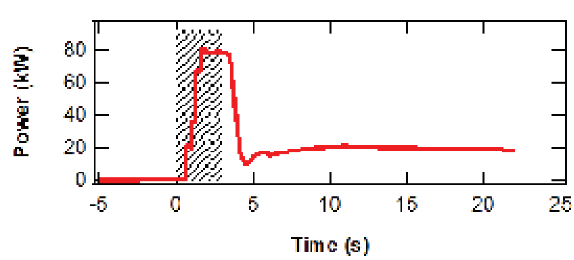

Figure 4. CO_2 laser power vs time (for ~ 92 kW injected power) measured using radiation pressure. Red curve is scale output (corrected for mirror reflectivity and angle of incidence), shaded region indicates injection duration.

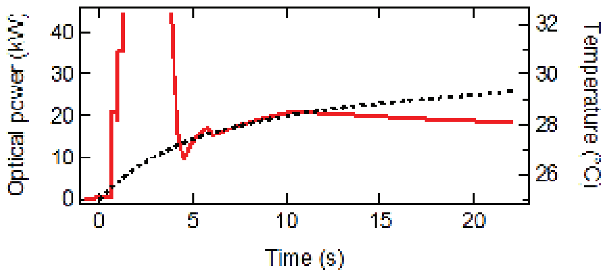

Figure 5. Qualitative comparison between radiation pressure measurement of optical power for CO_2 laser at 92 kW (solid red) and predicted temperature rise (dashed black) of the scale.

scale temperature and optical power measurement error. But qualitatively the agreement seems promising.

As the next-generation prototype is being developed, we have added insulation to the scale body and are testing an aerogel insulator between the mirror backing and the scale to drastically reduce heat transfer.

2.3 Measurement Uncertainty

In Figure 6, we plot the measurement results for both the fiber laser and the CO_2 laser measurements. The force on the scale is plotted as a function of effective optical power $PR\cos(\theta)$, which normalizes the effects of reflection and incident angle. The solid line indicates the theoretical prediction of Equation (1). As an estimate of the noise, with no laser power incident on the scale, we measure 0.1 µN of force. Within this noise, we see a linear response to laser power with a best-fit slope of 6.23×10^{-9} N/W (~7 % below the theoretical 2/c slope).

We evaluated the significance of the discrepancy in the measured force-to-power ratio by considering the measurement uncertainty. Our initial uncertainty estimates are comparable with the discrepancies seen. For the fiber laser measurements, the incident laser power was measured indirectly and is known to only ~2 % uncertainty. The scale's mass calibration was verified only down to 1 mg, so, the uncertainty over the 0.3 to 3 µN force range generated by the laser powers used could be only estimated as greater than 2 % [10]. Since that time, we have improved the mass calibration technique and are able to demonstrate scale calibration uncertainties for 1 and 2 mg to be nominally 0.5 % (measured on comparable scales as the original scale could not be retested). We expect that operating the scale in the non-standard "horizontal force" orientation should have a negligible effect on its calibration due to supporting flexures operating independent of gravity. However, due to the ~500 W maximum fiber laser power level in our laboratory, we have been unable to generate sufficient signal-to-noise ratio to verify agreement between horizontal and vertical operation to better than 1-2 %. Our future plans are to implement a multi-kilowatt fiber laser for this comparison procedure. The uncertainty on the measured mirror reflectivity is only a few tenths of a percent. From this rough preliminary work, we can only estimate the total measurement uncertainty to be on the order of "several percent", commensurate with the measured 7 % disagreement with theory. For the high-power CO_2 laser measurements, the true power was known only to a 6 % uncertainty, and the incidence angle known only to 5° (8 % amplitude uncertainty) yielding a total uncertainty (quadrature sum) of 10 %, which roughly agrees with the 13 % discrepancy measured.

3. Calibration

The ability to measure optical power in terms of force offers the intriguing possibility of using a known optical power to calibrate force-measuring instruments, and vice-versa. Figure 7 illustrates the mutual advantages of a optical-power-to-mass comparison. Plotted are the relative uncertainties of NIST's absolute optical power measurement capabilities as well as those for our absolute mass measurement facilities [12]. This illustrates

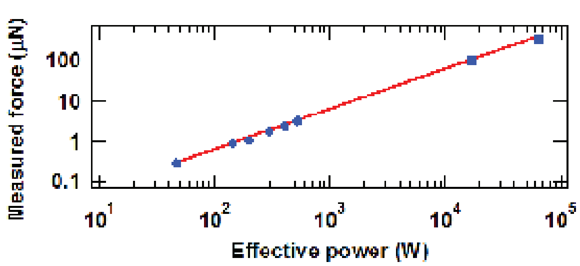

Figure 6. Measured radiation force versus effective laser power (includes mirror reflectivity and angle of incidence). Circles are from the 1071-nm fiber laser, squares are from the 10.6-µm CO_2 laser. Solid line indicates the theoretical force-to-power slope.

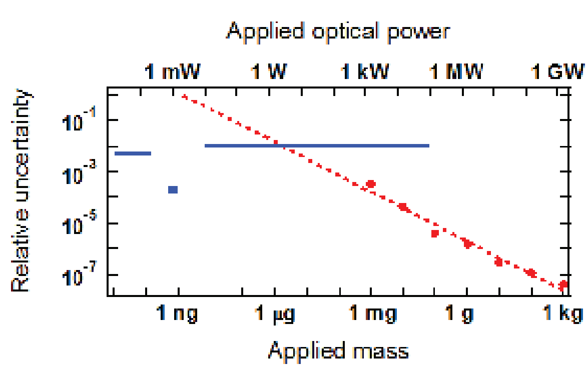

Figure 7. Measurement uncertainty for mass (red circles and predictive dashed curve, referenced to lower axis) [12] and optical power (blue square and solid lines, referenced to upper axis).

a difference in the two techniques. Fundamental mass metrology is a comparative measurement yielding relative uncertainties that depend on the mass being measured, while relative optical power measurements are for the most part independent of the power level being measured. The changes in optical power uncertainty shown in Figure 7 relate to the measurement technique used (above 10 mW are thermal calorimeter/power-meter approaches; below 200 µW are calibrated diode detection techniques; and at 1 mW is our laser-optimized cryogenic radiometer).

At the particular optical power (mass) of 3 W (2 µg), the relative uncertainties are equal. So, above 3 W, radiation-pressure-based optical power measurement offers a theoretical improvement in measurement uncertainty. Similarly, for masses below 2 µg, using optical power to calibrate mass offers a theoretically improved uncertainty. We are currently pursuing experiments to validate this mutual calibration benefit.

4. Conclusions

We have shown that optical radiation-force measurements using a commercial scale are feasible for measurement of laser power but we are pursuing further work on the power-meter design in pursuit of a measurement accuracy on the order of 1 %.

Acknowledgements

This work is a publication of the U.S. government and is not subject to U.S. copyright. The authors thank Z. Kubarych and J. Pratt for helpful discussion, and J. Bagford and D. Siebert for use of the high-power laser facility.

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Pushing the Boundaries of Traceable Measurement in Nanotechnology Applications

Mettler-Toledo AG

In recent years, National Metrology Institutes (NMIs) around the world have fielded increasingly frequent requests for a traceable weighing standard for weights in the sub-milligram range. New weight designs springing from combined public and private research, along with groundbreaking weight manufacturing and handling methods, have successfully provided the critical stability and reproducibility required to make calibration, transfer and storage of microgram weights feasible. These advances have led to the development of accredited calibration procedures and established critical weighing traceability in the sub-milligram measurement range. Now, weighing using calibrated standards in micro-force applications is a commercial reality — helping to enhance precision and ensure uniformity for small-force measurements in nanotechnology and biotechnology applications.

Advances in nanotechnology and biotechnology are driving the need for traceable small-force measurement in the sub-milligram range. Applications where this traceable small-force measurement applies include manufacturing of objects with dimensions of less than 100 nanometers (nm) — for example, micro-electromechanical systems such as computer chips — and calibration of atomic force microscopes (AFM).

Until recently, a lack of reproducible standards to support the use of weights down to 50 microgram (µg) has been the major challenge for ensuring accuracy in these small-force measurement applications. This increasing need for traceability instigated research by NMI, Beijing, China [1]. In partnership with METTLER TOLEDO AG, Switzerland, they determined how to effectively reduce basic-unit traceability from the established 1 mg range, down to 50 µg.

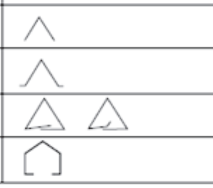
As a result of this pioneering project, traceable microgram weights in the range of 0.05 – 0.5 mg are now commercially available worldwide with a calibration certificate, and measurement authorities, such as NMIs, have changed their philosophy on microgram weight calibration. Revisions to ASTM E617 – 13, "Standard Specification for Laboratory Weights and Precision Mass Standards," have been made which now introduce weight denominations down to 0.05 mg in ASTM accuracy classes 0 – 000 [2].

The Shape of Things To Come

National Metrology Institutes (NMI's) from around the world have undertaken research in the area of mass standards and micro-mass standards, including: National Physical Laboratory (NPL), UK; Laboratoire National de Metrologié (LNE), France; Korea Research Institute of Standards and Science (KRISS), Korea and NMI, China [1, 3, 4, 5, 6].

Their work has served to demonstrate that the same challenges persist in the smaller weight classes: – challenges associated with choice of material, shape, storage, handling and production. Therefore, an evolution in weight design, storage and handling processes were necessary in order to provide the critical stability required to make calibration, transfer, handling and storage of these tiny weights feasible.

The optimum shape for microgram weights, developed to support accuracy in small-force ranges, has proven to be precisely clipped wire made from a special aluminum alloy. This alloy possesses a low enough density to enable creation of standards large enough to be seen without magnification. The material is also non-magnetic, corrosion resistant and



	Shapes of microgram weights	
0.05 mg		Inverted v-shape (chevron)
0.1 mg		Inverted v-shape (chevron)
0.2 mg		Triangle (with double horizontal bar)
0.5 mg		Lozenge (open at the bottom)

Figure 1. Shapes of microgram weights.

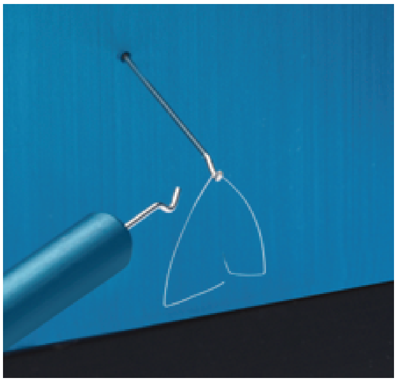


Figure 2. Aluminum handling tool with hook used for transfer of microgram weights.

sufficiently hard to be durable for long-term use. The alloy is packaged in the form of a wire coil, and the wire itself has a diameter of just 0.05 millimeters (mm), which is comparable to the width of a human hair. Wire has been shown to be significantly easier to handle than metal foil or ball shapes. The required weight is created by adjusting the length of wire. An automated process is used to cut the wire. Unique shapes are made by bending the wire to help identify each nominal weight (see Figure 1). This prevents any problems associated with mixing up the weights, as the weights are too small for nominal values to be etched onto their surface. In addition, the selected shapes allow ease of handling and are compatible with automated mass comparators due to their centric load points.

Manufacture of such small weights is not straightforward. One of the main challenges encountered in development was establishing a process robust enough to ensure precise, reproducible shapes for each nominal weight. The semi-automated process to produce the microgram weights has been perfected by a Swiss company that specializes in supplying precision components to watch manufacturers.

The microgram weights are stored in a specially designed aluminum box to prevent oxidation risk or damage which could potentially lead to an alteration in the weight of the standards. It also protects the weights from electrostatic charges. Dedicated handling tools, including an aluminum alloy rod with a hook on one end and ceramic-tipped tweezers, have also been specially designed for the purpose of picking up these delicate weights.

Accredited Calibration Assures Full Traceability

Based on the new availability and reproducibility of these weights, the National Measurement Office (NMO) in United Kingdom (UK) became the world's first mass calibration laboratory to be accredited for calibration of microgram mass standards down to 0.05 mg (50 µg) according to ISO 17025 in 2012.

An accredited calibration procedure for microgram weights allows National Metrology Institutes and clients with specialized nanotechnology applications to verify weight values below 1 milligram using a direct comparison method with the calibrated weight. This is due to the fact that a calibrated weight issued with a calibration certificate has assurance of full traceability to the International Prototype Kilogram (IPK) and thus to the International System of Units (SI).

John Pain, the UK NMO's calibration manager who provided primary support for the ground-breaking project, had the unique challenge of developing an effective method to calibrate the sub-milligram weights along with new methods of calculating uncertainty that would satisfy accreditation requirements. The calibration method developed involves comparing the weights to the department's mass standards using a combination of subdivision and substitution weighing. Standards are then confirmed traceable to the national primary standard of mass, KG18, held at the British National Physical Laboratory (NPL).

The main challenge in achieving accreditation from the UK Accreditation Service (UKAS) was passing the audit, which usually involves comparing results from the organization applying for accredited

Intercomparison micro weights

			METTLER TOLEDO				NPL				NMO						
Mass		ID No	Result	U^{95} = K2	En	Date	Result	U^{95} = K2	En	Date	Result	U^{95} = K2	En	Date	Result	U^{95} = K2	Date
0.05	mg	358931	0.05019	0.001	0.1	20.07.2012	0.05156	0.0005	2.7	04.07.2012	0.050118	0.0002	0.0				
0.1	mg	358931	0.0993	0.001	0.1	20.07.2012	0.099169	0.0005	0.0	04.07.2012	0.09915	0.0003	0.0				
0.2	mg	358931	0.20068	0.001	0.2	20.07.2012	0.200606	0.0005	0.3	04.07.2012	0.20043	0.0004	0.0				
0.2	mg'	358931	0.20183	0.001	0.0	20.07.2012	0.201943	0.0005	0.1	04.07.2012	0.20188	0.0004	0.0				
0.5	mg	358931	0.49700	0.001	0.2	20.07.2012	0.49724	0.0005	0.9	04.07.2012	0.49674	0.0003	0.0				
0.05	mg	358932	0.05132	0.001	0.4	20.07.2012					0.050926	0.0002		24.08.2012	0.050928		19.06.2012
0.1	mg	358932	0.10000	0.001	0.1	20.07.2012					0.099921	0.0003		22.08.2012	0.099915		12.06.2012
0.2	mg	358932	0.20051	0.001	0.1	20.07.2012					0.20042	0.0004		22.08.2012			
0.2	mg'	358932	0.19773	0.001	0.1	20.07.2012					0.197664	0.0004		14.01.2013			
0.5	mg	358932	0.49825	0.001	0.1	20.07.2012					0.498181	0.0003		20.08.2012	0.498055		08.06.2012
0.05	mg	358933	0.05354	0.001	0.2	13.08.2012					0.053316	0.0002		24.08.2012			
0.1	mg	358933	0.10526	0.001	0.2	13.08.2012					0.105061	0.0003		22.08.2012			
0.2	mg	358933	0.20555	0.001	0.1	13.08.2012					0.20543	0.0004		22.08.2012			
0.2	mg'	358933	0.20374	0.001	0.1	13.08.2012					0.203656	0.0004		14.01.2013			
0.5	mg	358933	0.50065	0.001	0.0	13.08.2012					0.500601	0.0003		20.08.2012			

Table 1. Intercomparison results of microgram weight set from NMO, NPL and Mettler-Toledo AG.

Nominal weight (mg)	Nominal weight (µg)	Uncertainty (µg)
0.5 mg	500 µg	0.3 µg
0.2 mg	200 µg	0.4 µg
0.2a mg	200a µg	0.4 µg
0.1 mg	100 µg	0.3 µg
0.05 mg	50 µg	0.2 µg

Table 2. Uncertainties relating to microgram weights calibrated with CMC method according to 2013 audit of National Measurement Office, UK (NMO).

status to results obtained from an already accredited laboratory. The obvious problem in this case being that there was no existing accredited calibration laboratory in the world to compare results to! Eventually, UKAS were satisfied after comparing three independent sets of data (see Table 1) generated by:

1. NMO – the applicant for accreditation;
2. NPL – the UK National Metrology Institute; and
3. Mettler-Toledo AG – the manufacturer of the microgram weights.

With three sets of results and every last detail of the process scrutinized, accreditation was awarded. The latest accreditation schedule (scope) can be viewed on the UKAS website [7].

Can Uncertainty Be Reduced Even Further?

Current levels of uncertainty for nominal values from 0.05 mg to 0.5 mg are between 0.0002 mg (0.2 micrograms) and 0.0004 mg (0.4 micrograms), as illustrated in Table 2. However, the calibration method is continually being developed. As calibration methods evolve and are further refined, uncertainties can be expected to be further minimized.

The uncertainties achieved by NMO are based on a CMC (Calibration and Measurements Capability) procedure. This could involve performing up to 28 inter-comparisons of just one weight, making automated measurement a necessity rather than an option.

Creating Greater Stability With Automated Calibration

An a5 series automated robotic mass comparator from Mettler-Toledo AG is used by the NMO for automated mass calibration. It offers NMO the capability to achieve lower uncertainties than would be possible with manual weighing. The a5 has a maximum load of 6.1 g and a readability of 0.1 µg. The automated system has greater accuracy when it comes to timing, which can prove critical in achieving the lowest possible uncertainties in the measurement.

A key benefit of the automated comparator is that it can be set up with a time delay, so that the weighing processes are performed overnight. This is an advantage because the comparator balance is more repeatable when all the external influences are stable. There is less risk of vibration or interference or other influencing factors. From a user perspective, you simply come in to the calibration laboratory the following morning and all measurements are completed for you, with all results recorded automatically.

A further advantage of an automated approach is that it avoids anyone breathing on the weights. When weighing manually, breathing on the weight is hard to avoid. This has the effect of increasing the carbon dioxide (CO_2) content around the vicinity of the balance. Carbon dioxide content affects air density, which in turn affects measurement uncertainty. Clearly, when dealing with weights that are so small, there is a benefit in eliminating any additional contributions to the uncertainty of measurement.

Development of Calibration Procedures

A calibration of a set of weights is typically carried out using one two established methods:

1. Direct comparison – which involves comparison of the weights with a reference set using a 1:1 method. This requires a full reference weight set with all required standard weights; or
2. Dissemination - also known as subdivision/multiplication. This involves calibration of the unknown masses working upwards or downwards from only one reference weight.

Figure 3. Mettler-Toledo a5 series automated mass comparator.

	1 mg	1 mg	0.5 mg	0.2 mg	0.2a mg	0.1 mg	0.05 mg	0.5 mg	0.2 mg	0.2a mg	0.1 mg	0.05 mg
1	A	B										
2	A		B					B				
3		A	B					B				
4	A		B	B	B	B						
5		A	B	B	B	B						
6	A							B	B	B	B	
7		A						B	B	B	B	
8			A					A				
9			A	B	B	B						
10								A	B	B	B	
11			A				B		B	B		B
12				B	B		B	A				B
13				A	A	A			B	B	B	
14				A	A	A	B		B	B		B
15				A	B							
16									A	B		
17				A			B				B	B
18					A	B	B					B
19				A		B					B	
20					A	B					B	
21						B			A		B	
22						B				A	B	
23						B			A		B	B
24							B			A	B	B
25						A					B	
26						A	B					B
27							B				A	B
28							A					B

Table 3. Typical design matrix used for calibration of microgram weights on the a5 comparator at NMO (UK).

Note: “A” refers to one weight (or weight set) and “B” refers to another weight (or weight set).
Note: Not every step in the dissemination scheme involves weighing a standard against an unknown weight. For example, step 1 involves weighing two known standards against each other.

The key difference of the method developed by NMO is that it is a dual system approach. This means that all calibration comparisons are done twice against two different standards. The process is initiated with two different 1 mg reference weights and disseminated from these reference weights. Therefore, two different sets are measured in parallel and the figures between each set are cross-checked, followed by substitution from one set to the other, so the weights are crossed over.

There are two main benefits of the dual approach, where two weighings are performed in parallel. The first is to maximize process efficiency. Single weighing methods may give acceptable uncertainties but can involve 2-3 times more weighings per decade, coming down from 1 kg.

The second is that the results can be cross-checked during the process. The dual method, of course, involves performing a greater number of calculations. As two weighing measurements are performed at each stage, two results that should be extremely close are obtained. This acts as a cross-check and consequently provides a higher level of confidence in the result.

Calibration is achieved by simultaneously calibrating two sets of microgram weights, using a combination of sub-division and Borda's methods, against two 1 mg stainless steel reference standards, which in turn have been calibrated by NPL mass section to their best measurement uncertainty. By using a dual system, cross-referencing the results and cross-substituting various weights in each set, a very low uncertainty is achieved. Numerous inter-comparisons are used in each calibration to achieve a good average value with a low standard deviation. An example of the typical design matrix is shown in Table 3.

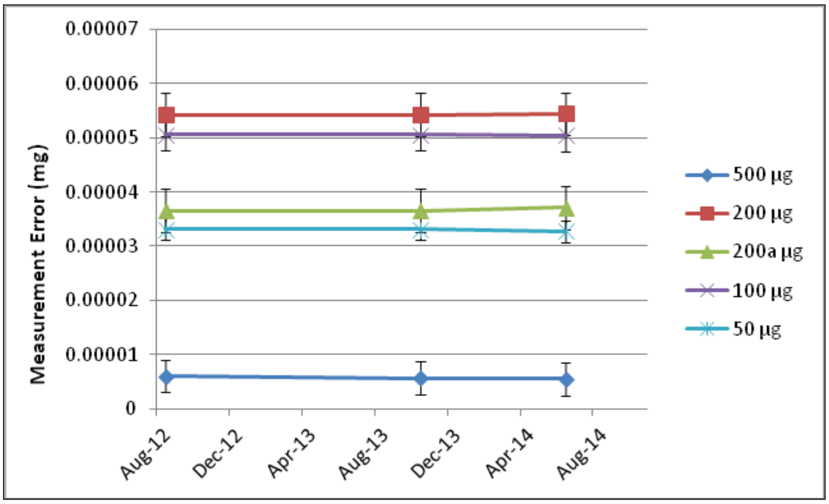


Figure 4. Stability of microgram weights over the mid-term, showing the measurement error of each of the five weights in the set. Uncertainty tolerances are displayed.

What About Stability Over Time?

Although the traceable calibration of microgram weights is a recent achievement, it is still possible to compare data from calibration results over the two year duration of the process of achieving accreditation (2012 – 2014). This data, shown in Figure 4, demonstrates that the weights are very stable, with 0.05 µg the largest recorded difference (observed for the 200 µg weight).

Worldwide Adoption of Microgram Standards

Based on this demonstrated stability and necessity of accurately weighing increasingly smaller values, the American Society for Testing and Materials – now known as ASTM International – updated their Standard Specification for Laboratory Weights and Precision Mass Standards (ASTM E617-13) in August 2013 which are now in full effect [2]. These changes introduce specifications for microgram weight denominations down to 0.05 mg in accuracy classes 0 - 000, which is valuable recognition of the progress made in the field of sub-milligram weights. The International Organization of Legal Metrology (OIML) have issued no revisions to their equivalent recommendation R111 since 2004, so at the present time the scope of nominal values does not extend below one milligram [8].

For more information about calibrated microgram weights, download the white paper "Traceability with Microgram Weights": www.mt.com/wp-microgram.

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Measurement Traceability: The Unbroken Chain

Ken Parson
Parson Consulting International

Many excellent articles have been written that cover the matter of measurement uncertainty as it applies to the Measurement Trace process. These articles usually focus on statistical or technical analysis of what must be done to achieve and document an acceptable level of measurement uncertainy while calibrating or testing an instrument or device. This article is focused more on the practical aspects on how to manage and control the use of laboratory standards and all other equipment related to measurement traceability while documenting and maintaining an unbroken chain of events. There is nothing unusual about the following discussion. It is just a reminder that if you don't have and follow steps such as these you may be operating as a weak link in your chain of traceability.

A. Introduction

Laboratory Standards that derive units of measure must be periodically calibrated and verified as traceable from the point of use to the International System of Units (SI) of measurement. This will most likely be accomplished through or by a National Measurement Institute (NMI). Normally, the readings or values presented by an instrument during calibration are recorded and passed on through a series of comparison to a higher level Standards Laboratory. This activity documents the comparison and represents each link in the chain of events that must be accomplished and documented to establish measurement traceability at the time this chain of events has occurred.

Laboratories are responsible for the physical act of calibrating or testing a device, and recording results. The chain of traceability within a laboratory must be well established and documented and accomplished in accordance with approved procedures. Doing this work in a well documented and concise manner is very important in helping to maintain a link in the traceability process. All laboratories within a chain must maintain a strong link. It takes into account the old saying that "A chain is only as strong as its weakest link." It would be a discredit to all those who rely on your laboratory to maintain anything but a strong link in the Unbroken Chain of Traceability.

At an appropriate time, standards used for this comparison are compared to a higher level laboratory. This activity documents the comparison and represents a part of the link in the chain of traceability. Depending on the nature and complexity of the unit of measure being verified, there may, and probably will be more than one laboratory involved in the transfer of a unit of measure from an NMI to a production operation which constitute the sequence of events that occurs in the measurement transfer process.

It is the unit of measure that is being examined (calibrated) and traced through a detailed series of certificates /reports as part of the measurement process. Test & measurement equipment (T&ME) are the devices used to measure things. Normally, all instruments that make quantitative measurements must be periodically calibrated and results documented and archived as part of measurement traceability and quality assurance processes. This activity must be accomplished to ensure instruments are operating within established requirements and their performance tracked. Only through proper care, handling, use and calibration can we be sure instruments are functioning properly and operating within their stated measurement capabilities.

B. Traceability

There are two significant parts to this matter of traceability: 1) Physical Trace, and 2) Paper Trace. For laboratories, measurement traceability is achieved through the physical act and the act of documenting through a paper trace. To achieve traceability, both the physical and paper trace activity must be satisfied:

1. Physical Trace:
   a. Must use well documented, technically sound, and approved procedures.
   b. The event must be accomplished by a fully qualified and authorized individual.
   c. Must be accomplished within specified laboratory environmental control limits
   d. Must use specified laboratory standards and ancillary equipment.

2. Paper Trace: Recording the event results in a Calibration Certificate, Test Report or Internal Laboratory Record.
   a. Reports must be well designed, well organized and always used to record Calibration/Test and Internal events for record purposes.
   b. These reports should document all the information needed to technically transfer the unit of measure from the higher echelon laboratory to the laboratory that submitted the Standard.
   c. All data entered must be recorded in detail in a clear, concise manner.
   d. Reports need to be archived to provide a permanent record of results.

Note: There would be little or no value in performing this physical act if the conditions and requirements specified above were not met and results not properly documented and recorded.

C. Managing Traceability

There are two principal subjects covered in this article: "Measurement Traceability" and "The Unbroken Chain." Both are addressed in International Standard ISO/IEC 17025 and stipulate requirements that must be complied with by all calibration and testing laboratories wishing to satisfy customer requirements or to achieve laboratory accreditation. Management should document, implement and maintain procedures that describe in detail how these processes are accomplished within their laboratory. For clarification, brief definitions by Webster are listed below followed by my own response regarding these definitions.

Measurement Traceability

traceability: a course or path that one follows, evidence of some past thing, to discover by going back over evidence step by step, to be traceable historically, to follow or study out in detail or step by step [1]

"Say what you do and do what you say" — Laboratory management needs to document operating procedures that explain in detail how the following actions are to be accomplished. This can be one of the most challenging jobs, but a job that must be done. However, once implemented, these "say what you do" procedures will enable your laboratory to "do what you say" in the most cost effective, efficient and consistent way that will produce high quality results.

"Keeper of the Standards" — If you manage or work in a laboratory, one of your principal responsibilities is to be sure all standards are kept secure, well protected and only handled and used by qualified personnel. Without these procedures and compliance by all laboratory personnel, there is no way to be sure standards and their units of measure have not been compromised. There is much that must be done to ensure a strong link in your traceability process.

The following is a minimum list of items that a laboratory should consider implementing to help ensure a strong link within their role in the unbroken chain of events as part of the Measurement Traceability process:

a. Identification — All laboratory standards should be clearly marked with a specially designed label that identifies the item as a laboratory standard. The label should also specify the standard's level in the chain, such as a primary standard, secondary standard, reference standard, working standard or any other type standard as used by the laboratory. Whatever standards are used should be labeled and identified. Depending on the class of standard will dictate how it should be handled, used, shipped and stored. This labeling is important because it is a visual indicator of the status of the standard and how it is to be protected. These classification of standards should be identified in a standard operating procedure along with a description that documents how each type of standard is to be identified, handled, protected and stored including environment and security.

b. Environment — Standards must be environmentally protected. All standards must be housed in an area that meets environmental requirements. The area must be equipped with all the necessary environmental monitoring equipment needed for the area. This monitoring equipment should be automated so it can continuously record conditions and set off an alarm/alert when conditions exceed established limits. There should also be a re-start procedure that describes in detail what actions must be taken and documented to ensure the standard has been returned to normal operation.

c. Security — For most laboratories, a sign needs to be located on or near the entrance where standards are located and used. It should state something like this:

This is a controlled area

Only persons qualified and identified in writing by management are authorized to enter this area and handle or operate laboratory standards.

Point of contact
Phone number

All other personnel entering this area should be accompanied by an authorized representative. Except for the personnel working in the area, all others should be required to sign a log that identifies the person's name, date and time of entry/departure and the nature of the visit. There may be locations such as production areas where standards are used as part of a final inspection and acceptance process. It can be difficult to ensure proper security under these conditions but documented procedures will still need to be developed and complied with that will ensure these standards are secure and only handled and operated by qualified personnel. There may also be cases where there is an absolute need to temporarily use a standard in a production area or out in the field. In this case, there should be a policy that the standard must be transported to the site and operated by a qualified laboratory person and must be re-verified and documented before being returned to laboratory service.

d. Handling/Shipping — Laboratory standards, and other equipment that make quantitative measurements, should be calibrated on a fixed schedule. Many of these items must be shipped to a higher echelon laboratory for re-calibration. Laboratory management needs to have documented procedures that provide detailed information about:

   1. Selecting an accredited laboratory that has been accredited to provide service as requested.
   2. Set or protect controls on the standard that must be adjusted or set.
   3. Explain how the standards are to be wrapped, packaged and prepared for shipment.
   4. Include a statement in or on the shipping container that advises shipping personnel and others that items in a package are only to be opened and handled by qualified laboratory personnel. This should also include a point of contact and a phone number.
   5. Describe in your operating procedures what steps are necessary to arrange for shipment.
   6. Procedures for return of the standards from the servicing laboratory.
   7. Arrange for full-time tracking as part of the shipping process.

e. Purchasing Services — You will need to specify exactly what services are being requested in your purchase order. The servicing laboratory will need to know what detailed calibration data is being requested. The servicing laboratory will need to know this information so they can determine costs and estimate how long the work will take along with an estimated return date. This subject was also addressed in "A Practical Guide for Selecting, Purchasing, and Receiving Calibration Service," a recent article by Pam Wright in Cal Lab Magazine [2].

f. Accreditation — It is highly recommended that you use a Laboratory that has been recognized through a Mutual Recognition Agreement (MRA) accrediting body for the measurement parameters that cover the calibration or testing services requested. Make this a documented point in the purchase order so you will be sure to get the appropriate calibration certificate or test report data needed. In today's way of doing business, if you are not using an accredited laboratory, your link will definitely be weak or broken.

The Unbroken Chain

chain : a series of things linked, connected, or associated together [3]

Laboratories make up the Chain of Traceability. Each laboratory represents a link in the Chain. Units of measure are transferred from a National Measurement Institute (NMI) – The National Institute of Standards & Technology – (NIST) is the NMI for the United States. It would be nearly impossible for an NMI to support the entire population of T&ME. So other laboratories are needed to support the overall workload.

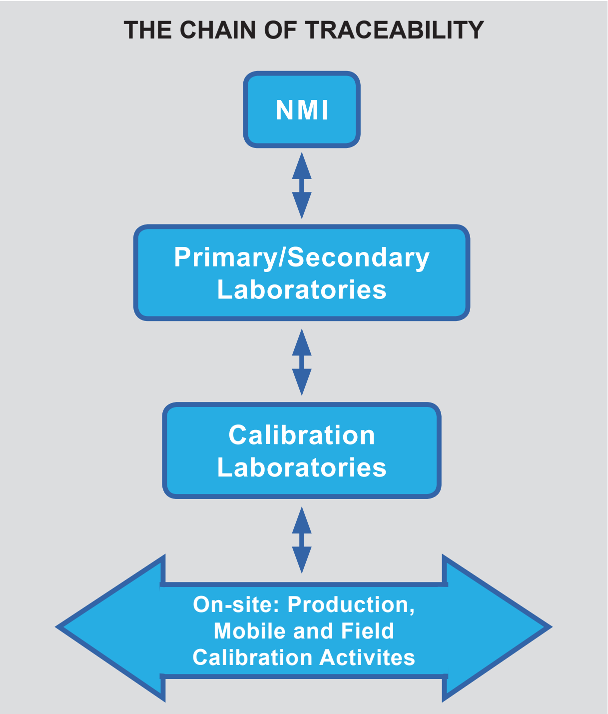
In general, there is a laboratory measurement hierarchy. The diagram to the right, on the following page, identifies laboratories as links within the chain that make the transfer of units of measure. These laboratories are functionally organized to make the most efficient transfer of units on measure from the NMI level to the end-user. Functionally, they are:

1. Primary Standards Laboratories — They interface with the NMI and support lower level laboratories. They have Primary Standards and transfer the unit of measure.
2. Secondary Standards Laboratories — These laboratories transfer units of measure from the primary laboratories to calibration laboratories.
3. Calibration laboratories established at large military and industrial facilities that provide a major amount of the calibration support for field calibration activities, on-site calibrations and for end-users.
4. On-site production, mobile and field Calibration Activities — These activities are at the end of the chain. It can be as simple as pre-calibrating a torque wrench on a torque analyzer and the analyzer then calibrated by length and mass standards and then on up the chain.

Once these certificates/reports are completed, reviewed, approved and distributed, copies are stored away and maintained for future reference and study, while in most cases, originals are provided to the end user.

The following is a discussion about what should be included in a calibration certificate or test reports. Although I have included an example of a certificate in my book, for this article, I will simply explain here what I think should be included in such a certificate and leave design of such a report up to you. I have divided the certificate/report into 5 major parts: Organization, Accreditation, Customer, Technical Data, and Approval & Issue. These are a minimum of items a laboratory should consider to help ensure a strong link within their role in the Unbroken Chain as part of measurement traceability process:

1. Organization — Identifies information about the issuing laboratory. This primary header identifies the laboratory that has provided the service. It should include the address, phone number/email and the name of a point of contact.
2. Accreditation — It identifies the accrediting body, including its logo and accreditation number. If you are not using an accredited laboratory, then state so at this point. Your customers will want to know.
3. Customer — Identifies the customer receiving the service. This part should include name of the customer, address, point of contact and phone number/email .
4. Technical Data — This is the major part of the report. It documents the entire technical process in as much detail as necessary. It includes all data as necessary to quantify results with a statement of uncertainty. It may take more than one page. These addendum pages should be linked to the certificate number. See the discussion below in paragraph 5d on Track Numbering. The following, as a minimum, is the type of information that should be included in Part 4:



5. Approval & Issue — This is an in-process, quality assurance and final inspection of the end product, involving the following:
   a. Test/Calibrated By — Identifies the individual (by name) responsible for conducting the test or calibration.
   b. Reviewed By — Identifies individuals trained and assigned to review the report. This is a cursory quality review of the overall report to spot misspellings or any other anomalies, but does not include assessment of technical information contained in Technical Data.
   c. Approved By — Only persons approved by management who have the education, training, knowledge, and qualifications within the area of testing or calibration should be assigned to review, approve and sign these reports. The criteria here are that the individual is fully competent and technically capable of discussing results in Part 4 of the report. This is not an administrative function.
   d. Track Numbering — The following are some suggestions on how the tracking number might be organized. The tracking number should be in a register format. This number should be chronological and grouped by calendar year. At the start of this year (2015), the first report would have been 15-001-00-00 and will end with 15-365-00-00 at the end of the year with the last two groups on the right to be used to identify each calibration/test and any addendums or other pertinent activity. When automated, this type of report numbering allows you to back-track and quickly find and report on a specific calibration or test. This numbering is very important because it allows for quick tracking during a reverse traceability process. If certificate numbers are assigned and issued at the time work begins, this tracking number will link all information about the actual work accomplished and provide all the information needed, such as:
      1. Manufacturer, model, serial number and nomenclature of the unit under test.
      2. Date item was received into the laboratory.
      3. Identify the procedure by procedure number, title and date, as well as detailed information on the current calibration method used.
      4. Parameters Calibrated — Include units of measure, range, accuracy, or statement of estimated uncertainty where applicable.
      5. A record of the environmental conditions during the calibration/test process.
      6. Measurement Results — Confirms intolerance conditions and documents any out-of-tolerance conditions.

e. Out of Tolerance Notice (OOTN) Form —This is part of a quality assurance process in which a laboratory should participate. An OOTN should be designed and coordinated with all customers. It is attached to a copy of the report and used to notify the customer of any out-of-tolerance conditions so the customer is made aware and can determine if these conditions could have had an impact on any production processing. This is where reverse traceability will be needed. This is the last link in the chain of traceability.
f. Report Issue and Record Keeping — There should be a well defined and documented procedure that describes how these reports are to be provided to the customer and how copies are to be retained along with an automated log, by register number of reports organized by calendar year. The data on these forms should be entered into a computer controlled matrix format so the data can be conveniently sorted in various ways to help monitor and perform a measurement trace and to confirm that measurement traceability is being achieved and maintained through an unbroken chain of events. This register number is a key element for tracking individual events. A second benefit is that this information can be used to help organize, review and study annual workload and make workload estimates. This type of data can then be used for annual management reviews and strategic planning. This is an important tool because it helps management identify ways to improve operations.
g. Final Reports — These calibration certificates, test reports and internal records should be well designed and implemented as part of the laboratory's management system. An operating procedure needs to be developed that identifies each of these records, what they look like, a description of entries that must be recorded, how they are to be reviewed approved and processed through quality assurance. These procedures are necessary to ensure quality of content because, when implemented, they will accurately document the chain of events that have occurred over time. This activity provides a historical record of results that are now available for any study or review that demonstrates how well the laboratory chain in the traceability process is working.
h. End Product — Certificates and reports are really the end product provided to the customer. It is very important that these documents are well designed, comprehensive, complete, done well and without error. They should reflect the professionalism and technical competence of your laboratory. Spend the time here to make a good impression; it is important.

Conclusion

I hope you find some merit with the thoughts and ideas presented here. There is nothing new about these activities. If you agree with me about these activities, then you will need to document and implement detailed "Say what you do" (How To) procedures that describe in detail how you wish to have these activities accomplished in your laboratory. This will be one of the most difficult, challenging and time consuming activities you will need to take on if you wish to operate your laboratory in a more efficient, effective way. However, once done, you will find that documenting "do what you say" will help put your systems in automatic. You will have better control over laboratory operations and manage your laboratory in the best possible way. You will save money and achieve consistent, faster and high quality results. I hope you are doing your best to be a strong link within your measurement traceability process.

References

[1] "traceability." Merriam-Webster.com. 2015. http://www.merriam-webster.com (28 April 2015).
[2] P. Wright, "A Practical Guide for Selecting, Purchasing, and Receiving Calibration Services," *Cal Lab: The International Journal of Metrology,* vol. 22:1, Jan-Mar 2015.
[3] "chain." Merriam-Webster.com. 2015. http://www.merriam-webster.com (28 April 2015).

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The preceding are excerpts from the author's book titled, Laboratory Quality/Management: A Workbook with an Eye on Accreditation (ISBN13: 978-1-4797-5395-6). This book provides far more details about Records Management, Measurement Traceability and Final Reports. Copies may be obtained through xlibris.com, amazon.com, bn.com, or from your local bookstore.

NEW PRODUCTS AND SERVICES

Beamex Calibrator and Communicator – MC6 Workstation

Pietarsaari, Finland (April 1st, 2015) – In today's process industry, equipment is often calibrated out in the field. However, there are many advantages to performing maintenance and calibration tasks in the workshop, which often make this the preferred solution. For example, a workshop is a controlled environment, enabling better accuracy for calibration work. In addition, all equipment is always available and ready to use.

Beamex has been producing versatile, modular workshop calibration benches for more than 20 years. With the introduction of the new MC6 Workstation model, the calibration and communicator capabilities of the Beamex workshop offering are raised to a whole new level.

The MC6 Workstation offers calibration capabilities for pressure, temperature and various electrical signals. It also contains a full fieldbus communicator for use with HART, FOUNDATION Fieldbus and Profibus PA instruments. The ergonomic design of the panel-mounted MC6 Workstation makes it ideal for sectors such as pharmaceuticals, energy, oil and gas, food and beverage and the service industry, as well as the petrochemical and chemical industries.

The MC6 is one device with several different operational modes, which makes it fast and easy to use - and technicians have less to learn. The operational modes include Meter, Calibrator, Documenting Calibrator, Data Logger and Fieldbus Communicator.

The MC6 Workstation communicates with automatic pressure controllers and temperature blocks, enabling fully automatic calibration.

The MC6 Workstation is part of the Beamex Integrated Calibration offering, capable of communicating with Beamex CMX Calibration Management Software, enabling fully automated and paperless calibration and documentation.

Website: www.beamex.com

NREL Purchases Second AC/DC High Power Source from AMETEK

SAN DIEGO – April 21, 2015 – AMETEK Programmable Power, the global leader in programmable AC and DC power test solutions, announced that the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has placed an order for its second regenerative AC/DC High Power Source.

When installed in parallel with the previous California Instruments RS Series units purchased in 2013, the new system will have the capability to supply up to 2 MVA, making it not only the largest system built by AMETEK Programmable Power, but the largest known AC Grid Simulator in the world with the bandwidth and modularity of the RS system.

NREL's advanced energy group plans to use the high power inverter for characterization and testing of electrical grid systems. Specifically, the systems are being used at NREL's Energy Systems Integration Facility (ESIF), the nation's first facility that can conduct integrated megawatt-scale research and development of the components and strategies needed to safely move clean energy technologies onto the electrical grid.

The California Instruments RS Series of high-power AC/DC power systems provide controlled AC and DC outputs for a wide variety of Research, ATE and Test applications. The RS Series provides a powerful combination of high power density and simple installation without the need for elaborate cooling schemes.

Each of the two systems consists of four RS270 units, each capable of generating 270 kVA of power. Eight control chassis allow NREL engineers to remotely configure the system as a single 2 MVA, two 1MVA systems, four 540 kVA units, two 810 kVA unit and two 270 kVA unit, or eight, separate 270 kVA units. This capability will give NREL the flexibility it needs to simulate power grids to better understand how different renewable energy technologies interact with each other.

In addition, the systems have been customized to allow NREL engineers to control it in real time via external drive signals. These modifications bypass the system controller and allow the external signals to directly control the high-power source. This eliminates processing delays and allows the system to be used with NREL's hardware-in-the-loop (HIL) simulators.

Hardware-in-the-loop simulation is not a new concept, but adding megawatt-scale power takes research to another level. In a power hardware-in-the-loop (PHIL) experiment, portions of a power system being studied are modeled in software, while other portions exist as actual hardware.

The hardware components interact with the software model via an interface, which includes a power amplifier capable of converting digital or low-level analog representations of modeled quantities into electrical power waveforms. In this way, the power amplifier can be controlled to apply the same electrical waveform

to the hardware components that those components would have seen had they been connected to a real-world power system instead of a model. NREL will use the AMETEK grid simulator(s) as the power amplifiers for MW-scale PHIL experiments.

To learn more about AMETEK's programmable power supplies and programmable loads, contact AMETEK Programmable Power Sales toll free at 800-733-5427, or 858-458-0223, or by email at sales.ppd@ametek.com. That information also is available from an authorized AMETEK Programmable Power sales representative, who can be located by visiting http://www.programmablepower.com/contact/.

Application Note Describes Nanomechanical Measurements

April 21, 2015 (Santa Barbara, CA) Oxford Instruments Asylum Research has released a new application note, "The NanomechPro™ Toolkit: Nanomechanical AFM Techniques for Diverse Materials," written Dr. Donna Hurley, founder of Lark Scientific and former NIST project leader. The last several years have seen a surge in the development and use of techniques that enable the measurement of mechanical properties at the nanoscale. Asylum Research has been at the forefront of this activity, collaborating with outside researchers to improve existing techniques and develop new ones. The NanomechPro Toolkit is a collection of unique techniques that spans the largest modulus range, and includes techniques that measure both the elastic and viscous response, and leverages the high speed advantage of the Asylum Research Cypher AFM to make these quantitative measurements much faster than ever before possible. The application note describes the science behind each technique, advantages and disadvantages, and gives real-world examples.

As described in the application note, the NanomechPro Toolkit consists of both standard imaging modes that are included with every Asylum Research AFM as well as several optional techniques. The standard modes include force curves and force volume mapping, phase imaging, Bimodal Dual AC Imaging, and Loss Tangent Imaging. The optional modes include Fast Force Mapping Mode, instrumented vertical nanoindentation, force modulation imaging, AM-FM Viscoelastic Mapping Mode, and Contact Resonance Viscoelastic Mapping Mode.

The new application note can be found at: http://www.oxford-instruments.com/nanomechanics.

Compact Chilled Mirror Hygrometer from Michell Instruments

Rowley, MA: Since its launch in 2012, the S8000 RS from Michell Instruments has proved to be a popular reference instrument with smaller calibration laboratories enabling them to generate extra revenue by extending their service to humidity calibration. The reason? It is the smallest and lightest hygrometer in its class, which enables small calibration laboratories to extend their ranges – but without also needing to extend their premises. The easy-to-use instrument also suits in-house reference labs at larger organizations.

The S8000 RS Precision Chilled Mirror Hygrometer measures dew points down to -90°C (0.1 ppm$_V$) with an accuracy of ±0.1° C. However, unlike many other hygrometers in this class, no additional external cooling equipment is needed to accurately reach these dry dew points. Even without all the extra cooling equipment, the S8000's nearest competitor in performance weighs 28 kg more than the S8000. Designed to fit into a standard 17" rack, the S8000 is the most compact, convenient and—because it does not need extra equipment to work—the most cost effective hygrometer in its class.

This compact design was possible because of a sophisticated new optical system that detects very small changes in moisture condensed on the mirror surface. This guarantees high sensitivity and fast response when measuring low dew points.

With a high-contrast LCD touch screen, the S8000 RS is easy to operate and interrogate. USB or Ethernet connections are supplied as standard to enable remote operation and data logging via a PC or network. As with all Michell chilled mirror hygrometers, the S8000 RS is available with a 5-point calibration, traceable to national standards, with UKAS accredited calibration available. http://www.michell.com/us.

Mesa Labs Integrator Pro

Mesa Laboratories Inc. is pleased to announce the release of the new Integrator Pro MFC/MFM command, control and readout device.

The Integrator Pro powers and controls mass flow devices, allowing for in-house verifications and multipoint calibrations. Combine our new Integrator Pro with one of our DryCal primary piston provers to set up an analog MFC and MFM calibration station. It can power and control up to two voltage and two current mass flow devices at the same time. Data can be collected directly in the DryCal Pro software for instant flow comparisons and deviation percentages.

The Integrator Pro requires operation with the Mesa Labs DryCal Pro Enhanced software which is included with the purchase of a unit. Primary features of the Integrator Pro include:

- Connects to your mass flow devices via manufacturer-specific cables
- Offers manual operation mode for easy calibration set up and verifications of mass flow devices
- Simultaneously displays your Met Lab Series' flow measurements, your device's readouts and deviation percentages
- PC command interface for automated calibration with DryCal Pro or user created software
- Commands your mass flow controllers to generate specific flows, while simultaneously indicating – and verifying – their output
- Generates user-entered setpoints for most mass flow controllers
- Provides diagnostic readings of setpoint and mass flow device output, in Milliamps or Volts

For further information on the new Integrator Pro instrument, visit us online at drycal.mesalabs.com/integrator-pro/.

Mesa Laboratories develops, acquires, manufactures and markets electronic instruments and disposables for industrial, pharmaceutical and medical applications. More information is available on the company's website at www.mesalabs.com.

New Accelerometer Calibration Service to Start Soon

NIST will soon begin offering a new, state-of-the-art calibration service for accelerometers. Based on a technique called laser interferometry, the system will be sensitive enough to detect motion over distances as small as a few nanometers (the size scale of a single molecule) and frequencies up to 50,000 cycles per second (50 kHz).

Accelerometers, which detect changes in motion, are perhaps most familiar as the sensors that tell your mobile phone screen to rotate or determine whether automotive airbags should deploy based on how abruptly the car's speed changes. They are also the basis of handheld remote controllers for motion games sold by Nintendo and other companies.

But accelerometers have long been essential to the automotive and aerospace industries for identifying unwanted vibrations, to the military for inertial guidance* of submarines and weapons systems, to seismologists who study the motion of the earth, and to facilities such as nuclear power plants to provide early warning that a piece of equipment is about to fail.

"These days, they're increasingly being used everywhere, not just in smartphones but also in wearable devices such as fitness trackers and watches" says Michael Gaitan, project leader in NIST's Nanoscale Metrology Group. "They are what provide the information used by the apps that tell you how much you're moving around, so you can count your calories."

Potential uses abound. There is intense interest in combining inertial guidance with GPS for position locations in places where GPS signals cannot reach, such as inside buildings. "They have to be accurate enough that you can use them for a reasonable period of time when a GPS signal is not available," Gaitan says.

In addition, researchers studying traumatic brain injury need increasingly accurate ways to measure shock, and engineers are examining better ways to embed vibration sensors in bridges and buildings to warn of possibly unsafe conditions.

The utility of these and other applications depends critically on the accuracy of the accelerometers. Calibrating them reveals how well they can measure the distance something moves (the "throw") over a specific amount of time, how fast it can respond to that change, and whether its readings vary over time, among other considerations.

In NIST's facility, as in many others, measurements are made on a shaker table – a small platform that is vibrated at specific frequencies over specific distances. For a typical accelerometer about the size of a lipstick tube, a simple test run might take about 10 minutes to step the device from about 5 cycles per second (5 Hz) with a throw of about 8 millimeters to 25 kHz (the facility's initial upper limit for calibration measurements) at which frequency the plate moves only a few percent of the width of a human hair.

The table's motion is continuously monitored – without physical contact – by a downward-pointing laser beam from a device called a vibrometer, which is mounted on a 200-pound base plate above the shaker. The system very accurately monitors the shaker table's vibration frequency and displacement by detecting the way that laser-light waves, when reflected off the table surface, reinforce or cancel each other back at the vibrometer's sensors. The data are then compared to the output readings from the accelerometer under test over a span of approximately 1 m/s^2 to 100 m/s^2.

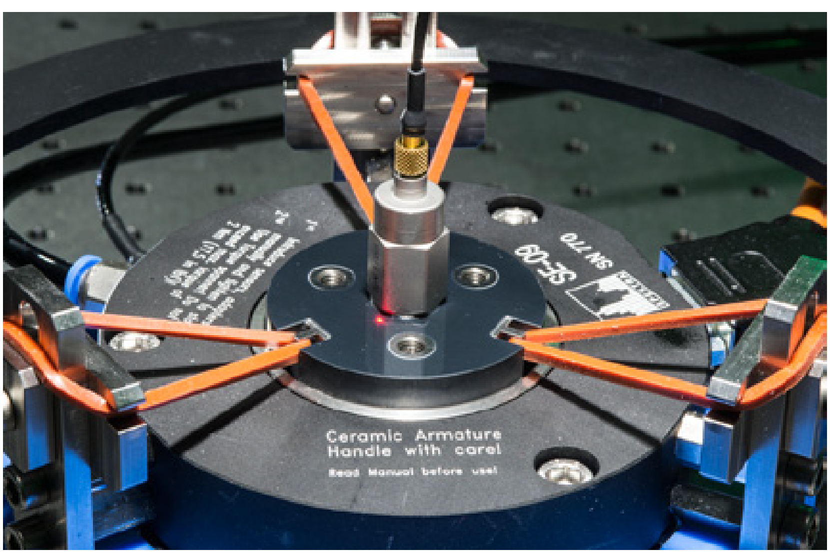
To measure the performance of accelerometers over much lower frequencies, which require longer throw distances, the NIST facility also contains two other instruments—mounted on a cubic meter of granite – that allow for motion over as much as 50 mm.

Although project researchers sometimes work collaboratively with manufacturers, the principal customers for the service will be calibration laboratories, many of which have contracts that call for NIST-traceable measurements, as well as large facilities such as nuclear plants that require periodic verification of sensors in safety systems.

When planning how to upgrade their calibration capabilities to meet the latest demands, the project scientists decided against building a full custom apparatus. Instead, they chose to obtain the kind of commercially available, high-tech system used at the world's top metrology institutes.

NIST's new primary calibration system is custom made to stringent NIST-required specifications. At present, the researchers are finishing a complete suite of tests on the system, and will soon publish the uncertainty budget – an analysis listing all possible sources of uncertainty in different aspects of the measurements, and the relative magnitudes of each. So far, they have determined that the system performance exceeds the manufacturer's claimed specifications. This finding, subject to further testing, may enable NIST's calibration service to lower its uncertainties even further as in the future.

"Although acceleration calibrations have been conducted at NIST and the world's other national measurement institutes since the 1960s, a new wave of microsensor technologies is driving new consumer portable technologies and are poised to



The accelerometer under test (hexagonal object) is attached to the 'shaker table' disk at the center of the apparatus. The red dot on the table surface is produced by the laser beam from the vibrometer above (not shown). Credit: NIST.

be a prime application of the internet of things,"** Gaitan says.

"These applications are driving high-volume sensor manufacturing, resulting in a $15 billion world market with a 13% compound annual growth rate. It is projected to grow to $22 billion by 2018. The testing and calibration requirements of these sensors are becoming more complex and demanding as more functions, such as gyroscope and compasses, are integrated together with the accelerometers. NIST is working together with the sensor manufacturing industry to advance measurement technologies and standards to meet these needs."

For more information about this service, contact: vibration@nist.gov.

* Inertial guidance uses motion sensors to determine the location of an object by tracking its path from a well-defined starting point.

** The "internet of things" refers to the rapidly expanding number of applications in which embedded computing devices communicate with one another over the Internet.

Source: "New Accelerometer Calibration Service to Start Soon," February 19, 2015, NIST Physical Measurement Laboratory News (http://www.nist.gov/pml/div683/grp03/accelerometer-calibration-service.cfm).

R&S Microwave Vector Signal Generator

Rohde & Schwarz has released a 40 GHz version of the R&S SGU100A RF upconverter. This version expands the frequency range of the R&S SGS100A vector signal generator from 12.75 GHz to 40 GHz, making it the smallest microwave device of its kind on the market for continuous signals between 80 MHz and 40 GHz. Though compact (two height units and ½ 19" rack width or one height unit and full 19" rack width), the combination of the R&S SGS100A and the R&S SGU100A offers outstanding performance. The setup is perfectly suited for ultrawideband aerospace and defense applications, as starting from 12 GHz the R&S SGU100A can be used with a 2 GHz I/Q modulation bandwidth. Together with the R&S SMW200A high end vector signal generator with a frequency range up to 40 GHz, a compact system with a maximum of three phase coherent outputs up to 40 GHz can be set up, making it ideal for testing phased array antenna systems.

The R&S SGU100A is now available from Rohde & Schwarz as a pure CW upconverter and as a version for I/Q-modulated signals. For more information, visit www.rohde-schwarz.com/ad/press/sgu100a.

Transmitter for Very Low Air Velocity

(Engerwitzdorf, April 2, 2015) The new EE660 air velocity transmitter from E+E Elektronik measures air velocity down to 0.15 m/s and is particularly suitable for laminar flow control and other clean room applications. The E+E thin film sensor used in EE660 operates on the hot film anemometer principle which is characterized by high accuracy, excellent long-term stability and lowest sensitivity to dirt. The low angular dependence additionally simplifies installation of the transmitter.

The air velocity transmitter is available for wall or duct mounting as well as with remote probe. The large, flush-mounted LCD display with backlight is 180° rotatable and ensures optimal readability of the measured data.

The EE660 has a current and voltage output, whereby both signals are available on the terminal. The measurement range and the response time can be selected via jumpers. An optional kit facilitates easy adjustment of the transmitter and configuration of the display.

External mounting holes allow quick and easy installation of the transmitter with closed cover. This keeps the electronics protected from construction site pollution. In addition, the electronic components are located on the underside of the PCB and are thus safe from mechanical damage during installation. http://www.epluse.com/en/.

Mitutoyo America Corporation New East Coast M³ Solution Center

AURORA, IL – May 6, 2015 – Mitutoyo America Corporation announces the opening of a new M³ Solution Center in New England. Located in Marlborough, MA, this new 7,600-sqaure foot facility is conveniently located for customers to schedule appointments for product demonstrations, assistance with application challenges and metrology solutions, as well as product and educational training seminars. The newest M³ Solution Center is located at 753 Forest Street, Suite 110, Marlborough, MA 01752.

"Our goal is to provide timely metrology solutions to our customers, in a region that is home to the aerospace, defense, medical, energy, automotive and plastics industries. The benefit of opening this new M³ Solution Center is the accessibility in offering experienced metrology specialists to our customers in order to provide up-to-date and knowledgeable metrology information for any situation they may encounter," says Steve O'Loughlin, Northeast regional sales manager.

To commemorate the grand opening, an open house will be held from 8 a.m. – 4 p.m. on Thursday, June 4, 2015. The festivities will include presentations on metrology, live demonstrations, facility tours, refreshments and raffles. If interested in attending the event, RSVP to gus.gustafson@mitutoyo.com or call (978) 852-8326.

Mitutoyo's nationwide network of Metrology Centers and support operations provides application, calibration, service, repair and educational programs to ensure that our 6,500+ metrology products will deliver measurement solutions for our customers throughout their lifetime. Website: http://www.mitutoyo.com/support/m3-solution-centers-and-showrooms/.

RESTful Communications for Metrology

Michael Schwartz
Cal Lab Solutions, Inc.

I have spent the better part of the last two years researching the ins and outs of enterprise solutions. I wanted to truly understand what makes these systems function, from both an implementation and user experience point of view. Then, I wanted to apply the principal of system-of-systems design to the World of Metrology Software.

What I discovered, at the heart of all of this, is a thing called Representational State Transfer, "RESTful," software architecture style for creating truly scalable applications. It allows you to transfer the representation state of a software object from one system to another. In layman's terms, you can think of it as building a plan; on the transmission end, everything known about an object is documented, packaged up and then sent to the receiver, where the documents are read and used to build a copy of the original object.

This allows software systems to work with each other in new and exciting ways. Take for example scalability; a software system that is designed to be scalable will allow you to offload tasks to other applications or other computer systems in the work cluster. This offloading further allows you to build a system of systems where applications and servers can specialize in specific tasks—even perform those tasks in other applications.

The uncertainty calculation can pose a specific problem in metrology software. We have several applications all calculating our uncertainties and each doing it just a little bit different. And, somehow the auditor always finds that one calculation less than our scope of accreditation.

So here is where RESTful communications and system of systems design can address that specific problem. We know there are three parts to an uncertainty calculation: the formula or uncertainty model; the data and values for the measurement; and finally, the uncertainty calculation or result. Once we have broken these items up, we need to define their responsibilities. The data and values from the measurement is our starting point. Data is represented by all the items about the measurement required to make an uncertainty calculation based on the model. The software making the measurement or the technician performing the calibration will collect all the required data and pass this data onto the uncertainty calculator.

The uncertainty calculator is really just a mathematical formula that can be stored in a format which tracks all the changes to it over time. When the data is passed to the calculator, it should be able to generate the uncertainty results. It's the calculator's responsibility to perform the same calculation every time.

The result from the calculation should be in a format that works across all metrology disciplines and should document the exact calculator used for future audits.

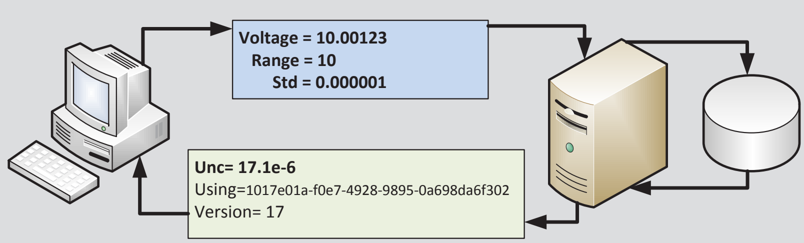
The goal is to make the uncertainty calculation resemble a function call by passing measurement data into the function and getting the result back. Only in this example, the calculation can be done locally or on a completely different computer.

In this example, I would like to use a 3458A Measure DC Voltage. In our uncertainty model, the calibration interval of the 3458A is fixed and the environment is closely monitored. So for each measurement, we need to know the average voltage measured, the range setting of the 3458A, and the standard deviation of the 25 measurements made. We pass them up to the service in name value pairs, where the service makes the calculations and returns the uncertainty calculation along with the ID and revision of the specific calculator used to make the calculation.

Offloading uncertainty calculations like this allows automated calibration procedures to be decoupled from the uncertainty calculation. Now, uncertainty calculations can be updated and maintained independently. Additionally, it allows the same uncertainty calculation to be called from multiple systems—all saving your lab precious time and money as you prepare for the next audit. ❧

Example of an Uncertainty Calculation in VB.NET

```
' Create Parameters List
Dim Params As New List(Of Parameter)
Params.Add(Parameter.NewParameter("Voltage", "10.00123"))
Params.Add(Parameter.NewParameter("Range", "10"))
Params.Add(Parameter.NewParameter("Std", "0.000001"))
' Create Link to Specific Calculator
Dim UncCal As New Uncertainty("1017e01a-f0e7-4928-9895-0a698da6f302", "", Params)
UncCal.Calculate()
```



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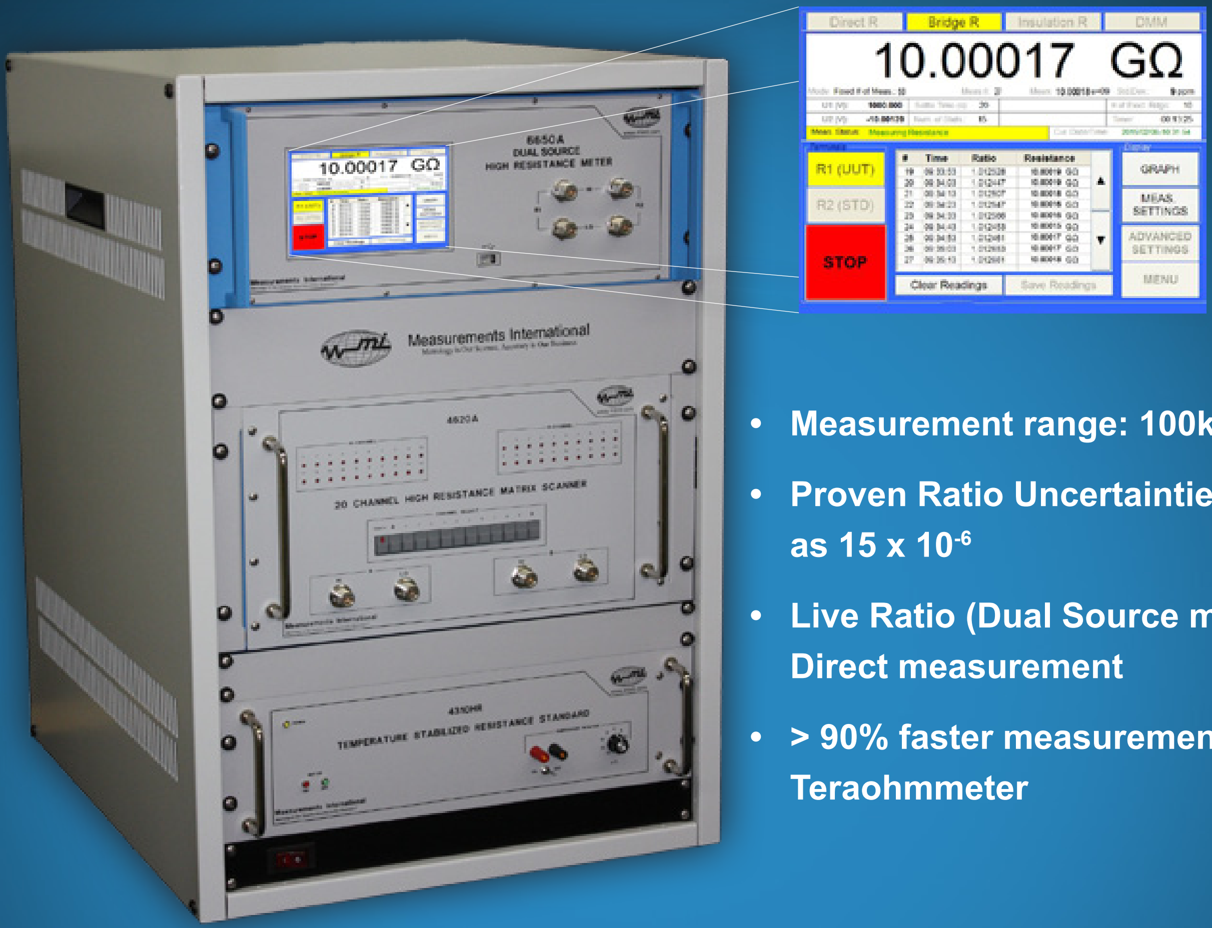

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