CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

2019
JANUARY
FEBRUARY
MARCH

Development of RF and Microwave Metrology Capability

Project TracePQM - Traceable Measurements of Power and Power Quality Parameters

Periodic-ish Table of Metrology

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

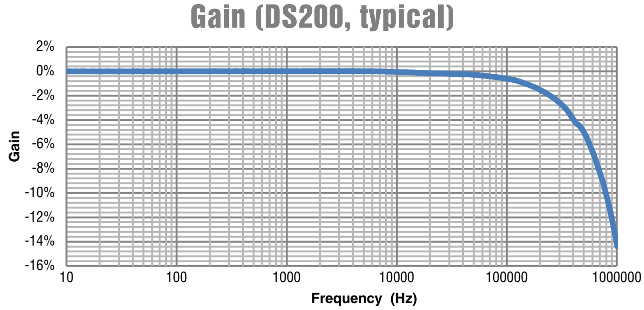
	DS200	DS600	DS2000	DS5000
Primary Current, rms	200A	600A	2000A	5000A
Primary Current, Peak	±300A	±900A	±3000A	±7000A
Turns Ratio	500:1	1500:1	1500:1	2500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†	2A/±3.2A†
Overall Accuracy	0.01%	0.01%	0.01%	
Offset	<20ppm	<10ppm	<10ppm	<5ppm
Linearity	<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˚

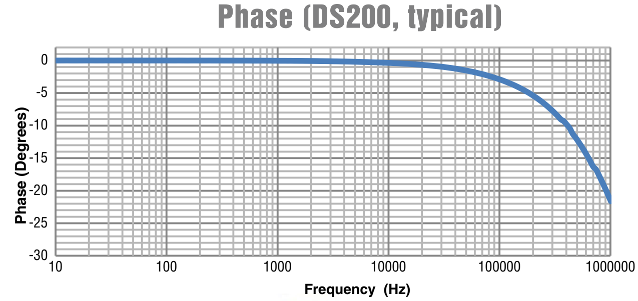
† Voltage Output options available in ±1V and ±10V

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)

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ON THE COVER: A lab technician is completing a temperature calibration at the AMETEK STC North American Calibration lab in San Luis Obispo, California.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

May 20-23, 2019 IEEE International Instrumentation and Measurement Technology Conference (I2MTC). Auckland, New Zealand. The IEEE I2MTC is the flagship conference of the IEEE Instrumentation and Measurement Society, and is dedicated to advances in measurement methodologies, measurement systems, instrumentation, and sensors in all areas of science and technology. http://imtc.ieee-ims.org/

May 27-31, 2019 The International Conference on Radionuclide Metrology. Salamanca, Spain. The ICRM explicitly aims at being an international forum for the dissemination of information on techniques, applications and data in the field of radionuclide metrology. https://icrm.usal.es/

Jun 4-6, 2019 MetroInd4.0&IoT. Naples, Italy. The 2019 IEEE International Workshop on Metrology for Industry 4.0 and IoT aims to discuss the contributions both of the metrology for the development of Industry 4.0 and IoT and new opportunities for the development of new measurement methods and apparatus. http://www.metroind40iot.org/

Jun 7, 2019 93rd ARFTG Microwave Measurement Symposium. Boston, MA. Co-located with the International Microwave Symposium. The most important part of the ARFTG experience is the opportunity to interact one-on-one with colleagues, experts and vendors of the RF and microwave test and measurement community. http://arftg.org/

Jun 18-20, 2019 North American Custody Transfer Measurement Conference. Austin, TX. CEESI. This conference brings together meter manufacturers and end users in order to share information about measurement challenges in the hydrocarbon measurement industry. http://www.ceesi.com/CustodyTransfer2019

Jun 19-21, 2019 IEEE MetroAeroSpace Workshop. Torino, Italy. The IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace) aims at reinforcing and supporting the collaborations among people working in developing instrumentation and measurement methods for aerospace. http://www.metroaerospace.org/

Jun 24-27, 2019 SPIE Optical Metrology. Munich, Germany. The International Society for Optics and Photonics. The premier European conference to meet with scientists, engineers, researchers, and product developers to discuss the latest research in measurement systems, modeling, videometrics, and inspection. https://spie.org/

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EDITOR'S DESK

Coincidence

With each issue of CAL LAB, we try to bring highly informative and interesting articles for our readers. If you didn't catch the last Editor's Desk, I encourage you to look back and refer to our Call for Papers. Senior calibration techs and metrology engineers have a lot to contribute to the calibration community. We hope you will share the knowledge by contributing an article this year.

By coincidence, we have two articles written about projects that were funded, in part, by the EMPIR program. The first, "Development of RF and Microwave Metrology Capability," came out of Turkey's NMI, TUBITAK UME, addressing characterization and modeling methods for RF and microwave equipment.

The second paper, "Project TracePQM," contributed jointly by the Czech Metrology Institute and the NMI of the National Standards Authority of Ireland, focuses on the development of a traceable measurement system for electric power and power quality parameters. The end-goal of the TracePQM project was the creation of an open-source software tool now available for download. The writers of this article hope to enlist participants in the electrical power community to use and provide the feedback needed to refine further development of the TracePQM software tool.

For those unfamiliar, the European Metrology Program for Innovation and Research (EMPIR) is a EURAMET research and development program that encourages collaboration between member NMIs, industry, and academia. More information can be found online at: https://www.euramet.org/about-euramet/.

Our last article, "Periodic-ish Table of Metrology" by Howard Zion, was originally presented at last year's NCSL International Workshop & Symposium. We cut it down to a "Reader's Digest" version in order to fit into this issue, but I assure you, it still makes for a very interesting and useful read. And isn't the topic appropriate considering 2019 is the International Year of the Periodic Table of Elements?

I hope you will check out each article and find something valuable that you can apply to what you do!

Happy Measuring,

Sita

Jun 25-27, 2019 SENSOR+TEST. Nürnberg, Germany. SENSOR+TEST is the leading forum for sensors, measuring and testing technologies worldwide. https://www.sensor-test.de/

Jul 22-26, 2019 Annual Coordinate Metrology Society Conference (CMSC). Orlando, FL. Established in 1984, the five-day conference is held each year at a different location, and attracts visitors from around the globe. CMSC is acclaimed for its comprehensive program of top-shelf white papers and applications presentations given by industry experts from science/research laboratories and manufacturing industries such as aerospace, space hardware, antenna, automotive, shipbuilding, power generation, and general engineering. https://www.cmsc.org/

Aug 24-29, 2019 NCSL International Workshop & Symposium. Cleveland, OH. Welcome everyone, to the NCSLI 2019 Annual Conference in Cleveland, Ohio. Conference theme: "Metrology in Motion." NCSLI is offering you an exceptional opportunity to attend, present, sponsor and exhibit at the Huntington Convention Center in Cleveland. This state-of-the-art conference venue is one you don't want to miss. http://www.ncsli.org/

Aug 26-29, 2019 IEEE AUTOTESTCON. National Harbor, MD. AUTOTESTCON is the world's premier conference that brings together the military/aerospace automatic test industry and government/military acquirers and users to share new technologies, discuss innovative applications, and exhibit products and services. It is sponsored annually by the Institute of Electrical and Electronic Engineers (IEEE). http://autotestcon.com/

Sep 24-26, 2019 International Metrology Congress (CIM). Paris, France. http://www.cim2019.com/home.html

SEMINARS: Dimensional

May 8, 2019 Dimensional Measurement. Melbourne, VIC, Australia. NMI. This two-day course (9 am to 5 pm) presents a comprehensive overview of the fundamental principles in dimensional metrology and geometric dimensioning and tolerancing. https://www.measurement.gov.au/Pages/Events-and-training.aspx

May 14-16, 2019 Dimensional Measurement User. Bristol, UK. NPL. A three day training course introducing measurement knowledge focusing upon dimensional techniques. This course is delivered by INSPHERE Ltd, NPL Approved Training Provider. https://www.npl.co.uk/training

May 14-16, 2019 Gage Calibration Methods. Cincinnati, OH. QC Training. This 3-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Attendees will be equipped with the knowledge to meet current and future calibration needs, be prepared to save the company money on calibrations and grow professionally. https://qctraininginc.com/course/gage-calibration-methods-3-day/

Jun 11-13, 2019 Gage Calibration Methods. Cincinnati, OH. QC Training. This 3-day hands-on workshop offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Attendees will be equipped with the knowledge to meet current and future calibration needs and grow professionally. https://qctraininginc.com/course/gage-calibration-methods-3-day/

Jun 18, 2019 Dimensional Measurement Applier. Bristol, UK. NPL. A four day training course for those who have a good basic understanding of measurement principles gained through the Dimensional Measurement User training course, delivered by INSPHERE Ltd, NPL Approved Training Provider. https://www.npl.co.uk/training

Jul 9, 2019 Dimensional Measurement User. Bristol, UK. NPL. A three day training course introducing measurement knowledge focusing upon dimensional techniques. This course is delivered by INSPHERE Ltd, NPL Approved Training Provider. https://www.npl.co.uk/training

Sep 10, 2019 Dimensional Measurement User. Bristol, UK. NPL. A three day training course introducing measurement knowledge focusing upon dimensional techniques. This course is delivered by INSPHERE Ltd, NPL Approved Training Provider. https://www.npl.co.uk/training

SEMINARS: Electrical

Jun 17-20, 2019 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. https://us.flukecal.com/training/electrical-calibration-training/met-101-basic-hands-metrology

Sep 4, 2019 Electrical Measurement. Lindfield, NSW, Australia. NMI. This two-day course (9 am to 5 pm) covers essential knowledge of the theory and practice of electrical measurement using digital multimeters and calibrators; special attention is given to important practical issues such as grounding, interference and thermal effects. https://www.measurement.gov.au/Pages/Events-and-training.aspx

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Sep 23-26, 2019 MET-301 Advanced Hands-On Metrology. Everett, WA. This course introduces the student to advanced measurement concepts and math used in standards laboratories. The student will learn how to make various types of measurements using different measurement methods. We will also teach techniques for making good high precision measurements using reference standards. https://us.flukecal.com/training

SEMINAR: Flow

May 29, 2019 Fundamentals of Flow Measurement Training Course. Aberdeen, UK. This course will cover the key aspects of flow measurement and will consider all general meter types and their application. Also included is an introduction to the UK National Standards for flow measurement, and open discussion sessions where participants can raise work-place situations for dialogue and advice. https://www.tuv-sud.co.uk/

Jun 19, 2019 Multiphase & Wet-Gas Flow Measurement Training Course. Aberdeen, UK. The demand to measure multiphase and wet-gas flows is increasing in the oil and gas industry worldwide. This interactive course will provide an understanding of the complexities of multiphase and wet-gas flows, effective metering techniques, selection and testing of meters and flow assurance strategies. https://www.tuv-sud.co.uk/

SEMINARS: Force

Apr 30-May 1, 2019 Force Calibration and Measurement Training Workshop. Phoenix, AZ. Tovey Engineering. The workshop covers relevant test standards governing calibration and use of load cells for force verification and testing. It is hands-on and held in an informal atmosphere with plenty of time for interaction with the equipment, instrumentation, and staff. https://www.toveyengineering.com/workshop

May 1-2, 2019 Force Fundamentals. York, PA. Morehouse. This two-day workshop will cover applied force calibration techniques with hands on activities and demonstrations using primary and secondary standards. Demonstrations will expose potential errors made in everyday force measurements. http://www.mhforce.com/Training/TrainingCourses

SEMINARS: General

May 29, 2019 Calibration and Measurement Fundamentals. Malaga, WA, Australia. NMI. This one-day fully interactive course (9 am to 5 pm) covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://www.measurement.gov.au/Pages/Events-and-training.aspx

Jun 20, 2019 Calibration and Measurement Fundamentals. Hobart, TAS, Australia. NMI. This one-day fully interactive course (9 am to 5 pm) covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. The course is recommended for technical officers and laboratory technicians working in all industry sectors who are involved in making measurements and calibration process. https://www.measurement.gov.au/Pages/Events-and-training.aspx

SEMINARS: Industry Standards

May 6-7, 2019 ISO/IEC 17025:2017. Doha, Qatar. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. Technical considerations include traceability of measurement and estimations of uncertainty. Quality system discussions include easy-to-understand approaches (with sample forms provided) for continual improvement (risk based thinking) and handling of customer feedback. https://www.iasonline.org/training/testing-cal-labs/

May 6-10, 2019 ISO/IEC 17025:2017 Lead Assessor Training. Pittsburgh, PA. ANAB. The 4.5-day ISO/IEC 17025:2017 Lead Assessor training course is designed to further develop your understanding of ISO/IEC 17025 and help you understand how to plan and lead an ISO/IEC 17025 assessment. Attendees will gain an understanding of uncertainty, traceability, and PT/ILC and how they are assessed. This course will prepare you to meet technical demands of being an assessor while providing practical exercises to aid comprehension. https://www.anab.org/training/17025/lead-assessor

May 6-10, 2019 ISO/IEC 17025:2017 Lead Assessor Training. Pittsburgh, PA. ANAB. The 4.5-day ISO/IEC 17025:2017 Lead Assessor training course is designed to further develop your understanding of ISO/IEC 17025 and help you understand how to plan and lead an ISO/IEC 17025 assessment. Attendees will gain an understanding of uncertainty, traceability, and PT/ILC and how they are assessed. https://www.anab.org/

May 13-14, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Delhi, India. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. Technical considerations include traceability of measurement and estimations of uncertainty. Quality system discussions include easy-to-understand approaches (with sample forms provided) for continual improvement (risk based thinking) and handling of customer feedback. https://www.iasonline.org/training/testing-cal-labs/

May 14-15, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Brea, CA. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. Technical considerations include traceability of measurement and estimations of uncertainty. Quality system discussions include easy-to-understand approaches (with sample forms provided) for continual improvement (risk based thinking) and handling of customer feedback. https://www.iasonline.org/training/testing-cal-labs/

May 15, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Frederick, MD. QC Training. ISO/IEC 17025:2017 Bridging the Gap from 2005 is a one-day course that gives an overview of the changes made to ISO/IEC 17025 in its latest revision. In this course, the participant will become aware of the significant and subtle changes to existing ISO/IEC 17025 laboratory system, as well as the necessary steps to ensure conformity to the new Standard. https://qctraininginc.com/course/iso-iec-170252017-bridging-gap-2005/

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May 20-21, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Denver, CO. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

May 30-31, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Frederick, MD. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jun 11-12, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Frederick, MD. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jun 17-18, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). San Diego, CA. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jun 18-19, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Minnetonka, MN. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jun 20, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Minneapolis, MN. QC Training. ISO/IEC 17025:2017 Bridging the Gap from 2005 is a one-day course that gives an overview of the changes made to ISO/IEC 17025 in its latest revision. In this course, the participant will become aware of the significant and subtle changes to existing ISO/IEC 17025 laboratory system, as well as the necessary steps to ensure conformity to the new Standard. https://qctraininginc.com/course/iso-iec-170252017-bridging-gap-2005/

Jun 20-21, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Lincoln (Providence), RI. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jun 24-25, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Livonia, MI. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jun 25, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Frederick, MD. QC Training. ISO/IEC 17025:2017 Bridging the Gap from 2005 is a one-day course that gives an overview of the changes made to ISO/IEC 17025 in its latest revision. In this course, the participant will become aware of the significant and subtle changes to existing ISO/IEC 17025 laboratory system, as well as the necessary steps to ensure conformity to the new Standard. https://qctraininginc.com/course/iso-iec-170252017-bridging-gap-2005/

Jul 9, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Frederick, MD. QC Training. ISO/IEC 17025:2017 Bridging the Gap from 2005 is a one-day course that gives an overview of the changes made to ISO/IEC 17025 in its latest revision. In this course, the participant will become aware of the significant and subtle changes to existing ISO/IEC 17025 laboratory system, as well as the necessary steps to ensure conformity to the new Standard. https://qctraininginc.com/course/iso-iec-170252017-bridging-gap-2005/

Jul 11-12, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Frederick, MD. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jul 16-17, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Grayslake, IL. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jul 18-19, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Indianapolis, IN. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Jul 22-23, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Houston, TX. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Aug 5-6, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Grayslake, IL. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Aug 6-7, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Denver, CO. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Aug 13-14, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Frederick, MD. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Aug 27, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Grayslake, IL. QC Training. ISO/IEC 17025:2017 Bridging the Gap from 2005 is a one-day course that gives an overview of the changes made to ISO/IEC 17025 in its latest revision. In this course, the participant will become aware of the significant and subtle changes to existing ISO/IEC 17025 laboratory system, as well as the necessary steps to ensure conformity to the new Standard. https://qctraininginc.com/course/iso-iec-170252017-bridging-gap-2005/

Sep 11-12, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence (MS 111). Grand Rapids, MI. A2LA. This course is a comprehensive review of the philosophies and requirements of this international Standard. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2la.org/events

Sep 16-17, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Washington, DC. IAS. This 2-day Training Course examines structural components of the standard. Technical considerations include traceability of measurement and estimations of uncertainty. Quality system discussions include easy-to-understand approaches (with sample forms provided) for continual improvement (risk based thinking) and handling of customer feedback. https://www.iasonline.org/training/testing-cal-labs/

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SEMINARS: Management & Quality

Apr 30, 2019 Implementing Metrology and SPC concepts with MS Excel. York, PA. Morehouse Instrument Company. This one-day workshop prepares the metrology professional to apply the power of Microsoft Excel's mathematical and statistical tools to assist in managing the laboratory's Quality Management System including Measurement Uncertainty. http://www.mhforce.com/Training/TrainingCourses

SEMINARS: Mass

Oct 21-Nov 1, 2019 Mass Metrology Seminar. Gaithersburg, MD. NIST. The Mass Metrology Seminar is a 2 week, "hands-on" seminar. It incorporates approximately 30 percent lectures and 70 percent demonstrations and laboratory work in which the trainee performs measurements by applying procedures and equations discussed in the classroom. https://www.nist.gov/news-events/upcoming_events/

SEMINARS: Measurement Uncertainty

Apr 30, 2019 Implementing Metrology and SPC Concepts with MS Excel. York, PA. Morehouse. This one-day workshop prepares the metrology professional to apply the power of Microsoft Excel mathematical and statistical tools to assist in managing the laboratory's Quality Management System including Measurement Uncertainty. https://www.mhforce.com/

May 8-9, 2019 Uncertainty of Measurement for Labs. Doha, Qatar. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/

May 15, 2019 Introduction to Measurement Uncertainty Training Course. Aberdeen, UK. Measurement is fundamental to the control of quality, efficiency and safety. Course delegates will learn about the impact of uncertainty in industry, to identify the important sources of uncertainty in measurement systems and receive practical guidance on the design of measurement techniques to minimize uncertainty. https://www.tuv-sud.co.uk/

May 15, 2019 Introduction to Estimating Measurement Uncertainty. Lindfield, NSW, Australia. NMI. This one-day course (9 am to 5 pm) will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. https://www.measurement.gov.au/Pages/Events-and-training.aspx

May 15-16, 2019 Uncertainty of Measurement for Labs. Delhi, India. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/

May 16-17, 2019 Uncertainty of Measurement for Labs. Brea, CA. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

Jun 10, 2019 Introduction to Measurement Uncertainty. Frederick, MD. A2LA. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2la.org/events

Jun 20-21, 2019 Measurement Uncertainty Budgets. Minneapolis, MN. QC Training. This workshop presents a combination of lecture and classroom exercises to demonstrate the principles of measurement uncertainty analysis. https://qctraininginc.com/course/measurement-uncertainty-budgets/

Jun 23-24, 2019 Uncertainty of Measurement for Labs. Dammam, KSA. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

Aug 7, 2019 Introduction to Measurement Uncertainty. Denver, CO. A2LA. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2la.org/events

Aug 14, 2019 Practical Applications of Uncertainty Training Course. Aberdeen, UK. This course will enable delegates to apply the techniques - developed in NEL's Introduction to Measurement Uncertainty course - to examples tailored to the Oil and Gas sector. Case studies are used to illustrate the application of such calculations in minimising the impact of measurement uncertainty. https://www.tuv-sud.co.uk/

Aug 20-22, 2019 MET-302 Introduction to Measurement Uncertainty. Everett, WA. Fluke Calibration. This course will teach you how to develop uncertainty budgets and how to understand the necessary calibration processes and techniques to obtain repeatable results. https://us.flukecal.com/training/

Sep 10, 2019 Introduction to Measurement Uncertainty. Frederick, MD. A2LA. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2la.org/events

Sep 11-12, 2019 Uncertainty of Measurement for Labs. UAE. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/


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Learn more at info.mensor.com/CPT9000

Sep 18-19, 2019 Uncertainty of Measurement for Labs. Brea, CA. IAS. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

Sep 30, 2019 Introduction to Measurement Uncertainty. Grayslake, IL. A2LA. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2la.org/events

SEMINARS: Optical

May 13-17, 2019 Spectrophotometry Short Course. Gaithersburg, MD. The NIST Spectrophotometry Short Course is a 5-day course held at NIST Gaithersburg, Maryland. The course consists of lectures and hands-on laboratory experiments covering the fundamentals of optical properties measurements, such as transmittance, reflectance, and BRDF. Important sources of uncertainty and the relative merits of different experimental techniques, including dispersive, Fourier-transform, and laser-based schemes, are also addressed. https://www.nist.gov/news-events/upcoming_events/

SEMINARS: Pressure

Apr 29-May 3, 2019 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. A five-day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances).The class is designed to focus on the practical considerations of pressure calibrations. https://us.flukecal.com/training/

Jun 5, 2019 Pressure Measurement. Port Melbourne, VIC, Australia. NMI. This two-day course (9 am to 5 pm each day) covers essential knowledge of the calibration and use of a wide range of pressure measuring instruments, their principles of operation and potential sources of error — it incorporates extensive hands-on practical exercises. https://www.measurement.gov.au/Pages/Events-and-training.aspx

Sep 30-Oct 4, 2019 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. A five-day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances).The class is designed to focus on the practical considerations of pressure calibrations. https://us.flukecal.com/training/

SEMINARS: Software

May 13-17, 2019 MC-207 Advanced MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. A five-day procedure writing course for advanced users of MET/CAL® calibrations software. https://us.flukecal.com/training/

Jul 8-12, 2019 MC-206 Basic MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. In this five-day basic MET/CAL procedure writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. http://us.flukecal.com/training

Jul 16-18, 2019 MC-203 Crystal Report Writing. Everett, WA. Fluke Calibration. A three-day course on the basics of Crystal Reports using MET/TEAM®. https://us.flukecal.com/training/

Sep 9-13, 2019 MC-207 Advanced MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. A five-day procedure writing course for advanced users of MET/CAL® calibrations software. https://us.flukecal.com/training/

Sep 9-13, 2019 Metrology.NET® Advanced User Training. Denver, CO. Cal Lab Solutions, Inc. This 5-day training will provide an understanding of Metrology.NET and demonstrate how it can be optimized for your lab, covering: hands-on creation & configuration of a test project, development of device drivers, debugging techniques, creating and using resources in Metrology.NET, and more! http://www.metrology.net/5-day-advanced-user/

SEMINARS: Temperature

Sep 16-18, 2019 Advanced Topics in Temperature Metrology. American Fork, UT. Fluke Calibration. A three-day course for those who need to get into the details of temperature metrology. This course is for experienced calibration technicians, metrologists, engineers, and technical experts working in primary and secondary-level temperature calibration laboratories who would like to validate, refresh, or expand their understanding of advanced topics in temperature metrology. http://us.flukecal.com/training

Sep 19-20, 2019 Infrared Calibration. American Fork, UT. A two-day course with plenty of hands on experience in infrared temperature metrology. This course is for calibration technicians, engineers, metrologists, and technical experts who are beginning or sustaining an infrared temperature calibration program. http://us.flukecal.com/training

SEMINARS: Time & Frequency

Jun 11-14, 2019 NIST Time and Frequency Seminar. Boulder, CO. NIST Time and Frequency Division's annual seminar covers clocks, oscillators, atomic frequency standards, rf and optical synchronization, optical oscillators, quantum information, optical cooling and heating; making precise frequency, time, phase-noise, and jitter measurements; and establishing measurement accuracy and traceability. This 4-day course is the most comprehensive available. https://www.nist.gov/news-events/events/2019/06/2019-nist-time-and-frequency-seminar

SEMINARS: Volume

Aug 12-16, 2019 Volume Metrology Seminar. Gaithersburg, MD. NIST. This 5 day OWM volume metrology seminar is designed to enable metrologists to apply fundamental measurement concepts to volume calibrations. A large percentage of time is spent on hands-on measurements, applying procedures and equations discussed in the classroom. The seminar focuses on the comprehension and application of the procedures, the equations, calculations involved, and the operation of the laboratory equipment, review of publications, standards, specifications, and tolerances relevant to the measurements. https://www.nist.gov/news-events/upcoming_events/

SEMINARS: Weight

May 1-Jun 2, 2019 C-RMAP Tutorial 1: Balance and Scale Calibration and Uncertainties. Lake Mary, FL. This NIST Balance Calibration and Uncertainties Seminar covers the calibration and use of analytical weighing instruments (balances and laboratory/bench-top scales), including sources of weighing errors in analytical environments, methodologies for quantifying the errors, and computation of balance calibration uncertainty and global (user) uncertainty. Attention will be given to error sources, selection of reference standards, and various calibration procedures used in the weighing industry. https://www.nist.gov/news-events/upcoming_events/

Jul 25, 2019 Calibration of Weights and Balances. Lindfield, NSW, Australia. NMI. This one-day course (9 am to 5 pm) covers the theory and practice of the calibration of weights and balances. It incorporates hands-on practical exercises to demonstrate adjustment features and the effects of static, magnetism, vibration and draughts on balance performance. https://www.measurement.gov.au/Pages/Events-and-training.aspx

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FLOC Takes Flight: First Portable Prototype of Photonic Pressure Sensor

February 25, 2019 – NIST News - In collaboration with industry, researchers from the National Institute of Standards and Technology (NIST) have made the first portable prototype of the Fixed-Length Optical Cavity (FLOC), a device that uses light to measure pressure with higher accuracy and precision than most commercial pressure sensors.

This newest version is a milestone on the journey toward the creation of a device that could revolutionize the way pressure is measured with potential uses by many industries, particularly semiconductor chip and aircraft manufacturing.

In 2017, NIST and MKS Instruments, Inc. of Andover, Massachusetts, signed a Cooperative Research and Development Agreement (CRADA) to take a laboratory-scale version of the FLOC and create a smaller, more robust prototype that more closely resembles a commercial product. Thanks to the CRADA work, the joint NIST and MKS team has now successfully demonstrated a prototype version small enough to fit into two suitcases, Hendricks said.

“MKS Instruments brings over 50 years of pressure measurement, optical and laser experience to this project, and we are honored to have been selected by NIST to work with them on this important and prestigious development,” said Phil Sullivan, CTO of MKS’s Pressure and Vacuum Measurement Solutions business. “We anticipate that this work will lead to a new wide-range, compact pressure measurement standard.”

Robust, portable FLOC sensors could potentially reduce the cost of producing semiconductor chips such as those used in smartphones, as well as decreasing the cost of air travel.

The compact FLOC cavity, only about 2.5 cm long, at the heart of the new portable prototype. This image reveals the two physical channels used for the pressure measurement. When connected to the rest of the FLOC system, one channel is kept in vacuum and the other channel is filled with a gas whose pressure is being measured. Credit: MKS Instruments, Inc.

This is because both the chip manufacturing and aerospace industries rely on pressure measurements.

Semiconductor manufacturers must accurately control the pressures of gases fed into a facility’s fabrication units during the making of a chip. Conventional pressure sensors are precise, but their readings tend to drift over time, meaning they have to be taken out of service regularly to be calibrated. Since the FLOC’s pressure measurements are absolute, no calibration is required. So, FLOCs could be used to check the drift of conventional pressure sensors on the factory floor in real time, reducing the need for downtime.

Conventional pressure sensors are also used in aircraft to measure the plane’s altitude in-flight. A more precise pressure sensor could allow flight controllers to safely arrange planes more densely, saving fuel and potentially lowering the cost to air travelers.

Although it is beyond the scope of the current CRADA project, NIST scientists envision that one day the FLOC could be reduced even further in size, to a chip-scale instrument.

“The dream from the start of this project was: Could you get this whole thing shrunk down to the size where it could show up in everyday devices like your smartwatch or phone?” said NIST physicist Jay Hendricks. Better pressure sensors in cell phones could give first responders crucial information about whether a victim in a high-rise is on the tenth or eleventh floor. “That’s science fiction right now, but it’s where the technology could go,” Hendricks said.

The FLOC measures pressure by measuring subtle differences in the frequency of light passing through two physical channels called optical cavities: a reference channel in vacuum and a test channel filled with a gas whose pressure is being measured.

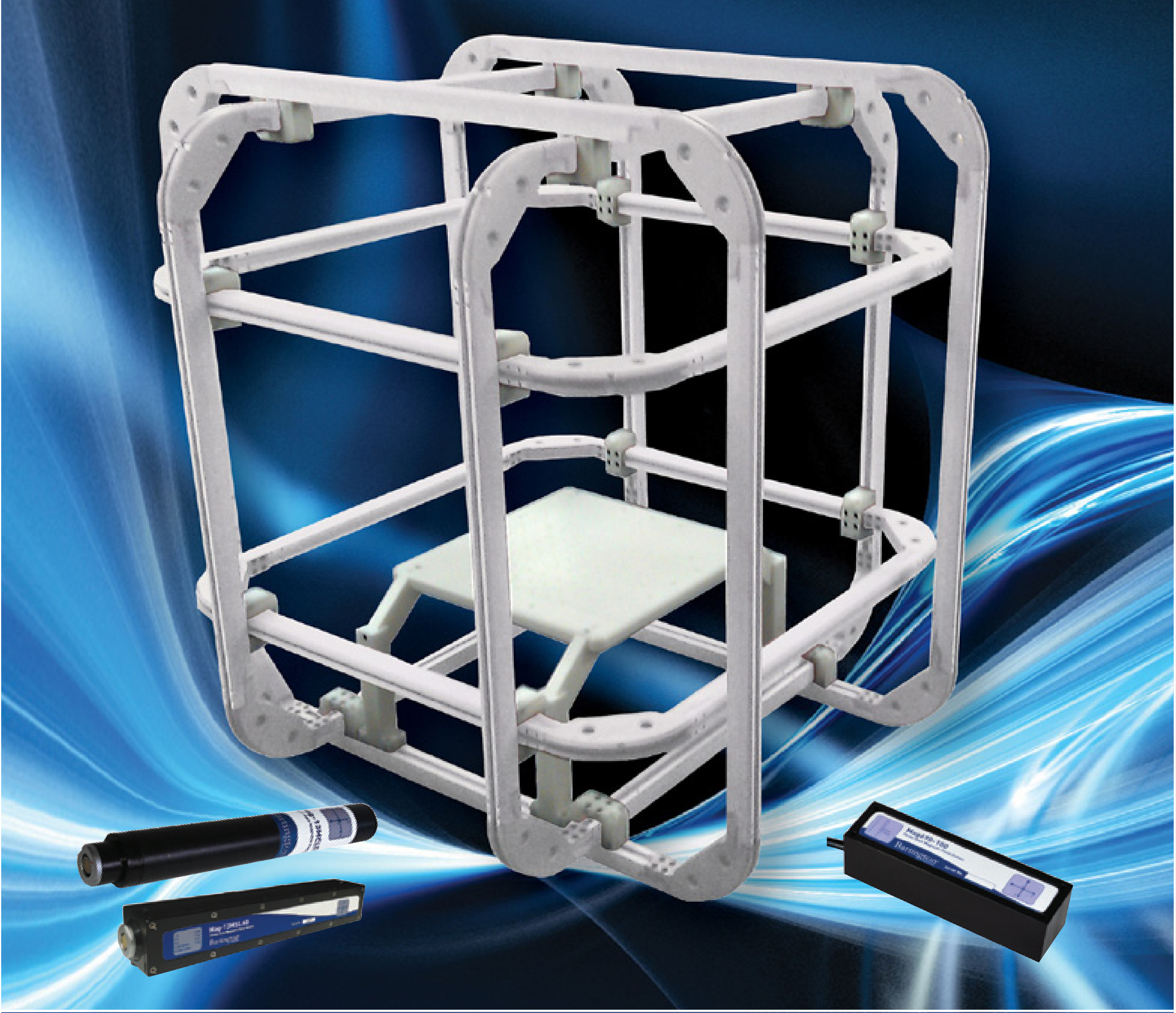
NIST first made a laboratory-grade version of the FLOC in 2014. It was designed to be sensitive and accurate enough to become a primary calibration standard, an instrument used to calibrate all other pressure measurement devices.

The original standard FLOC fills an entire large-scale laboratory table. The optical cavity containing the gas and vacuum channels is about 15 cm (about 6 in) long, roughly the size of a travel mug. The apparatus also includes a vacuum pump, lasers to supply the light and the optics to manipulate them, in addition to a rack of electronics to process the signal.

The new portable version is more compact. Its two-channel cavity is only about 2.5 centimeters long, a little longer than a postage stamp. Both the cavity and its optics fit into a single box, and there is also a smaller electronics rack and a pump for the gas-handling system.

In their partnership, NIST and MKS staff assembled the two-channel cavity at the heart of the prototype, while MKS managed the engineering of a miniaturized version of the system.

“We built the national standard version of the FLOC, which is designed to operate in a high-precision laboratory,” Hendricks said. “But we turned to industry under a CRADA to speed up the engineering and miniaturization work



that needs to go into making something rugged, stable, transportable, low-power and able to work in a variety of different environments."

"Our focus is on the science and standards, and not typically on the engineering required for miniaturization," said NIST chemist Kevin Douglass.

Researchers also changed the wavelength of light used from visible red (633 nm) to infrared (1550 nm), used by the telecom industry and therefore a popular wavelength for commercial products.

In all, the team was able to complete the prototype in about one year, allowing demonstration of the device last fall at the AVS International Symposium and Exhibition (a conference hosted by the professional society AVS, formerly the American Vacuum Society). So far, the portable FLOC is proving to have "great signal-to-noise and resolution," Hendricks said.

Vibrations from people's steps in the showroom could have theoretically thrown off the delicate measurements, but the device was robust enough to stand up to that noise. Its range has been demonstrated from ultralow pressures used in vacuum to about 2,000 pascal (the equivalent of about 2 percent of atmospheric pressure, or 0.3 psi), and work is currently underway to test it at much higher pressures.

And there are opportunities for further miniaturization. To save time, the team used some off-the-shelf parts. Future versions can be customized to only include the functions the device needs. Meanwhile, Hendricks' team will compare the performance of the miniature version against that of the standard FLOC. The team will likely also perform shipping tests, where they test the device, pack it up, ship it somewhere, bring it back and then test it again to see if it yields the same results.

Source: *https://www.nist.gov/news-events/news/2019/02/floc-takes-flight-first-portable-prototype-photonic-pressure-sensor*

Improved Hydrophone Calibration

PTBnews 3.2018 - A novel measurement setup has been developed at PTB for the primary calibration of ultrasonic hydrophones. Hydrophones are sensors used to determine ultrasonic pressure wave in liquid media. They are mainly used in medical engineering in order to test ultrasonic equipment. The new facility covers a larger frequency range and simultaneously exhibits lower uncertainty.

Within the field of hydrophone calibration, the hydrophone's sensitivity is defined as the ratio between the electric output voltage of the hydrophone to be calibrated and the actual ultrasonic pressure; it is then transferred as a function of the frequency via the calibration certificate.

In PTB's new measurement facility, a high-frequency vibrometer uses an optical measurement procedure to determine the displacement of a thin foil placed on the water surface; this displacement is caused by the ultrasonic wave. The ultrasonic pressure is determined based on this measurement. Calibration is now performed using short excitation pulses at high amplitudes rather than longer, mono-frequency or tuned sound waves. Since the pulses generated by exploiting non-linear propagation in water exhibit a broad spectrum of frequencies, they allow hydrophones to be characterized in a frequency range from 1 MHz up to 100 MHz. The test assembly is mostly automated, allowing calibrations to be performed faster.

Moreover, pulse excitation allows the phase frequency response of the hydrophone to be determined easily. This piece of information is especially important when pulse deconvolution is used in order to reconstruct ultrasonic wave forms in a standardized way that is as objective as possible. The procedure is also suitable for sensors used in high-intensity ultrasonic fields that are often less responsive than conventional hydrophones.

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Scientific publication: M. Weber, V. Wilkens: Using a heterodyne vibrometer in combination with pulse excitation for primary calibration of ultrasonic hydrophones in amplitude and phase. *Metrologia* 54, 432–444 (2017)

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

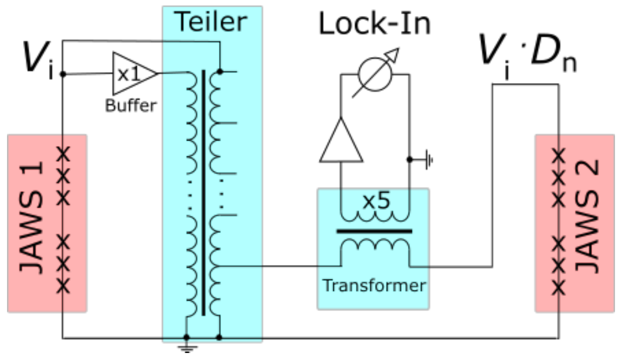
Measurement setup during a measurement with the vibrometer. The vibrometer is located in the blue housing. The foil is placed in the red lens tube and lies on the water surface. Credit: PTB

Calibrating Inductive Voltage Dividers

PTBnews 3.2018 - PTB is developing a measuring system based on pulse-driven Josephson voltage standards. This system is designed to allow alternating voltages to be measured with great accuracy at frequencies of up to 100 kHz and voltages of more than 100 V. Since the output voltages of Josephson voltage standards are limited to a few volts, it is necessary to use voltage dividers. An inductive voltage divider has now been calibrated for the first time with pulse-driven Josephson voltage standards, and the results have been compared to those obtained using a conventional calibration procedure.

Inductive voltage dividers are highprecision AC transformers used to realize voltage ratios in electric metrology as the core elements of, for example, voltage or impedance bridges. Until recently, they were calibrated using a time-consuming traditional procedure based on the socalled "bootstrapping" method in which each of the individual segments of the divider is compared with the others one by one.

The accuracy of this calibration procedure has now been checked with quantum precision by means of an inductive,



Schematics of the measurement setup for the calibration of the inductive voltage divider (in the figure: "divider") with the two JAWS voltage standard systems. The lock-in voltage amplifier together with the transformer (centre of the picture) amplifies the signal and, thus, increases the sensitivity of the measurement method.

decadic voltage divider using two independent, pulse-driven Josephson voltage standards (Josephson Arbitrary Waveform Synthesizers – JAWS). For this purpose, effective voltages of 100 mV were generated by means of one of the JAWS systems and applied to the divider as an input signal, whereas the second JAWS system was used to compensate for the output signal of the divider. The results obtained within the scope of this compensation measurement for the correction of the reactive component showed excellent agreement with the bootstrapping method: the relative difference amounted to less than 10–8.

Furthermore, it was possible to demonstrate that, when applied to the divider, additional harmonic signal components of the input signal had a negligible influence on the calibration of the divider. The conventional bootstrapping procedure has thus been verified with quantum precision and can now also be used for calibrations at higher voltages. In addition, it is planned to test the new quantumbased method for the calibration of new broadband resistive voltage dividers.

Using JAWS systems in combination with voltage dividers paves the way for novel potential applications such as the power quality analysis of sinusoidal voltage signals in power grids.

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Scientific publication: J. Herick, S. Bauer, R. Behr, M. F. Beug, O. F. O. Kieler, L. Palafox: Calibration of an inductive voltage divider using pulse-driven Josephson arrays. *Conference Digest CPEM* – "Conference on Precision Electromagnetic Measurements" (2018)

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

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Development of RF and Microwave Metrology Capability

Murat Celep and Handan Sakarya
TUBITAK UME, National Metrology Institute

The radio frequency and microwave (RF&MW) field has undergone revolutionary changes in the last 40 years and today, RF&MW technology is more pervasive than ever. This is especially true for commercial markets, where modern applications include cellular and smart phones, wireless networking, direct broadcast satellite, television, global positioning systems, wideband radio and radar systems, and microwave remote sensing systems for environment, biomedical and healthcare applications (to name but a few). The research and development in RF and microwave technology still continue with ever-increasing demands from industry. New devices and instruments which bring new challenges to the underpinning metrology play a critical role for advancing technologies. S-parameter measurements, RF power measurements and electromagnetic compatibility (EMC) tests and calibrations are important areas in microwave metrology to ensure and increase product quality and to create end user confidence.

On the behalf of the European Metrology Program for Innovation and Research program supported by the European Commission, under the coordination of TÜBİTAK - Turkey, CMI - Czech Republic, GUM -Poland, INTA - Spain, SIQ - Slovenia, RISE - Sweden, NIS - Egypt, NQIS - Greece, UPC - Spain and METAS -Switzerland, together with "15RPT01 RF Microwave" coded and "Development of RF and microwave metrology capability" project is carried out [1]. This project aimed to develop research and measurement capacities as well as expertise for EURAMET countries in RF&MW. It has done this by transferring theoretical and practical know-how between the project partners and by combining their skills to focus on microwave and EMC measurements.

Introduction

New technologies in the health, energy, security, environmental, industrial and communication sectors require novel RF&MW devices and measurement methods which currently are under research and development (R&D). However, this R&D brings new challenges to the underpinning metrology for RF&MW as it requires advanced technologies. Scattering parameter (S-parameter) measurements, RF power measurements, EMC tests and calibrations are important areas in RF&MW metrology. These are used to ensure and increase product quality and end user confidence. The reliability of S-parameter measurements depends on how well the characterization and modelling of RF&MW components is performed, therefore, the devices used for this need to be calibrated accurately and their measurement uncertainty must be calculated precisely. However, recent R&D has shown that the simplified characterization and modelling approach currently used for RF&MW components is inadequate [2].

Most of the high frequency electronic devices include short distance communication units which generate low-power ($P \leq 0.01$ mW). In order to obtain traceable and accurate measurements at low-power in RF&MW metrology, power sensors which are used for low-power measurements must be characterised accurately. Due to the difficulty of characterising harmonic effects, some national metrology institutes (NMIs) ignore the effect of higher harmonics in low-power measurements and are not able to characterise power sensors for low-power. There is also a problem with RF&MW high-power measurements ($P \geq 1$ W) used in long distance communication, broadcasting radar applications and other applications. Characterization of high-power measurement equipment such as wattmeters is generally performed using an 'attenuator and power sensor' combination in which both are calibrated at mid-power level (0.01 mW $< P < 1$ W). The characterisation parameters of the attenuator and power sensor should be at the same power levels, however, this assumption does not describe the actual situation.

EMC is the interaction of electrical and electronic equipment with the electromagnetic environment and other equipment. In order to avoid EMC related issues, electronic goods manufacturers must test their products that are electromagnetically compatible with relevant regulations. However, new verification methods are needed to increase the quality of EMC test/calibration and measurements, in particular advanced verification methods using vector network analysers (VNAs). Knowledge transfer between EMC and RF&MW laboratories is very weak, which reduces awareness in measurements/calibrations and, therefore the overall quality of both EMC and RF&MW measurements.

The gap between developed and currently developing countries is growing constantly and this situation is even more pronounced for RF&MW metrology. In order to prevent further widening of this gap in RF&MW metrology, the knowledge and expertise of the more developed NMIs needs to be transferred to those NMIs with less experience.

Development of Metrology Capability

The overall objective of the project has been to improve the European measurement and research capability for RF&MW metrology and to establish a basis for future cooperation between European NMIs. The specific objectives of the project have been summarized as given below:

a. Improvement of the S-parameter measurements with lower uncertainty and to develop/enhance impedance and S-parameters traceability across Europe by improving the measurement and research capacities of NMI partners and bringing them to a level to be able to adequately support the needs of their stakeholders.
b. Improvement of the reliability and precision of RF power measurements under low and high-power conditions, power sensor measurements for low-power, as well as to investigate the effects of higher harmonics in the response of power sensors to cover the stakeholder needs. Also, to provide the NMI partners the ability to measure and determine output reflection coefficients of signal generators via knowledge transfer.
c. Investigation of advanced calibration methods and establishment of test procedures for EMC with use of RF&MW metrology.
d. Development of an individual strategy for each partner for long-term operation of capacity development, including regulatory support, research collaborations, quality schemes and accreditation.
e. Identification of key industrial and scientific needs for stakeholders in RF&MW metrology.

This project has supported modelling of calibration standards for S-parameters and rigorous uncertainty propagation through a measurement model that represents the entire measurement process from the calibration of the VNA to the result of the device under test (DUT). Advances in modelling and new software capabilities (VNA Tools II developed by METAS) have paved the way to this more consistent approach so the project is used and in better agreement with internationally accepted guidelines. The partners were able to make comparisons on calculable primary calibration standards given in Figure 1 and S-parameter measurements for one-port, two-port and three-port devices with the help of VNA Tools II. The comparison on the S-parameter measurement has also been registered as a EURAMET EM-1426 comparison project.

This project has also addressed the traceability of power sensor calibration for low-power. The traceability approach has been based on the use of characterized adapters and attenuators. So far, TUBITAK and CMI have established their own measurement setups and performed preliminary measurements regarding characterization of diode sensors used for low power measurements. In addition, other partners (SIQ, INTA and CMI) have produced and exchanged information about their proposed measurement setups and measurement techniques for the characterization of 'attenuator and power sensor' combination under small and large-signal conditions. Moreover, SIQ, INTA, NIS, TUBITAK and CMI have produced and distributed information about harmonics effects on power measurements using low-power diode sensors and equivalent circuits. NQIS, INTA and TUBITAK have also established their own setups for the measurement of the output voltage reflection coefficient (VRC) of a microwave generator. Three comparisons on (i) the calibration of diode type power sensors, (ii) the output VRC of a microwave generator (registered as a EURAMET EM-1461 comparison project) and (iii) the characterization of a high power attenuator have been organized for the implementation and enhancement of the gained information.

The strength of RF&MW and VNA metrology is used to increase the quality of EMC test/calibration measurements; 'just-before-test' verification methods using VNAs have been already developed in the project. Such 'just-before-test' verification methods will be able to efficiently detect insidious issues just before conducting emission and immunity tests and thereby significantly increase the quality of EMC measurements. These new and effective just-before-test verification methods developed in the project have also been expanded to low frequency immunity testing by means of the fast Fourier transform (FFT)-based time domain methodology, which has been never done before. Furthermore, the extensive investigation

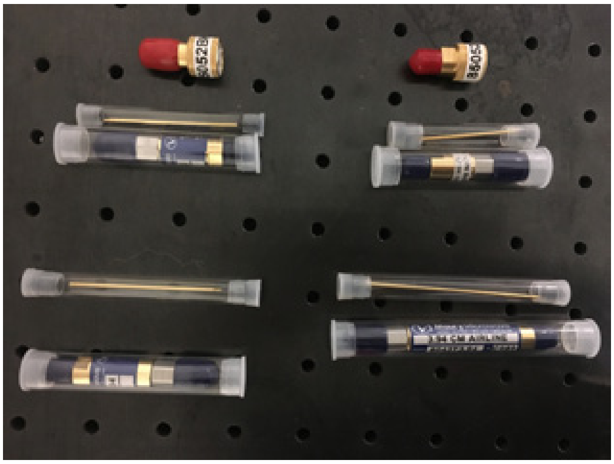


Figure 1. Calculable primary standards used for comparison.

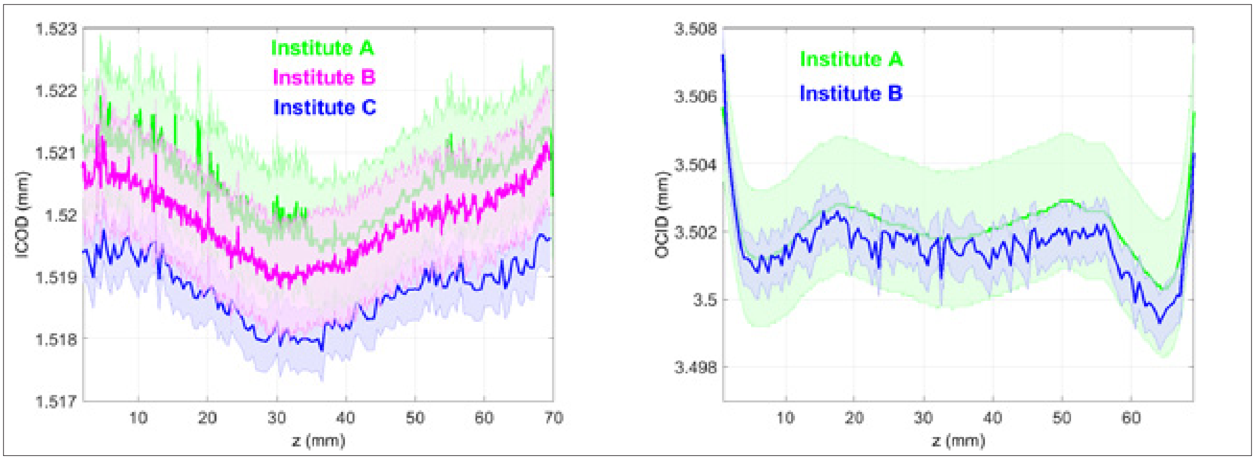


Figure 2. Measurement of the one-calculable standard.

of the three loop-antenna calibration method has been experimentally finalized by performing standard SAE-ARP950&IEEE calibration methods and comparing their results with the three antenna method. The project also transfers knowledge and awareness from the EMC field to the RF&MW field and vice-versa. Consequently, this knowledge link between the two fields will support an increase in the quality of metrology.

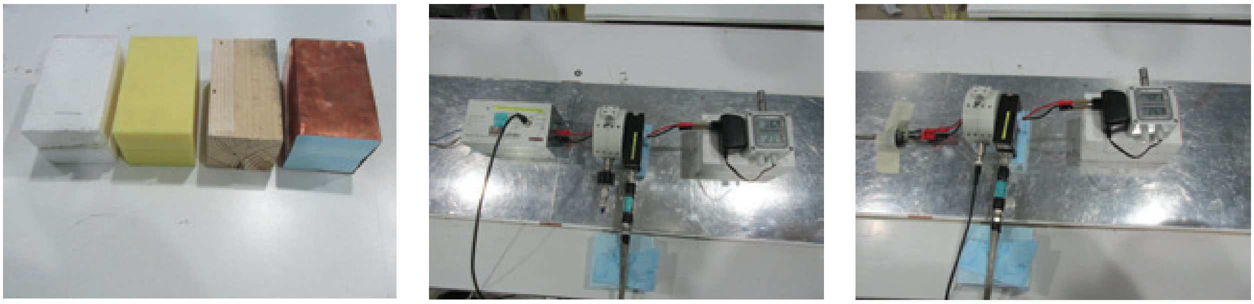
Results

In order to increase S-parameter measurement accuracy among the project partners, primary traceability and uncertainty budget for the S-parameter measurements have been established through calculable calibration standards with use of specialized software tools. Training and workshops activities have been organized to evaluate reliable VNA measurement uncertainties and applied S-parameter measurement system. Partners gained the ability for modelling of calibration standards for S-parameters and calculating rigorous uncertainty propagation through a measurement model and new software capabilities. To prove the acquired ability of the partners, two inter-laboratory comparisons on S-parameter measurements of one-port, two-port and three-port standards [3] and calculable primary calibration standards were conducted. To characterize the calculable standards, partners measured mechanical parameters of the standards. Measurement result of an 'airline' standard for outer diameter of the inner conductor and inner diameter of outer conductor are given in Figure 2 [1].

To improve project partners' power measurement accuracy and capability on the characterization of power sensors for low power measurement, a workshop on the Monte Carlo (MC) method and training on characterizing of diode-type power sensor was organized. During the training, partners gained experience in characterizing of diode-type power sensors using direct comparison technique and establishing their own measurement setup. Technical protocols for three inter-laboratory comparisons have been circulated between partners and approved; (i) power sensor measurements for low-power (diode type power sensor), (ii) measurement of output VRC of a microwave generator [3] and (iii) characterization of a high power attenuator.

This project attempted to integrate the strength of RF&MW metrology, specifically the use of VNAs, into EMC tests and calibrations. It established a link between the areas of RF&MW and EMC that did not only embrace the integration of RF&MW metrology into the EMC field but

Figure 3. Participants of the workshop held at SIQ.



(a) (b) (c)

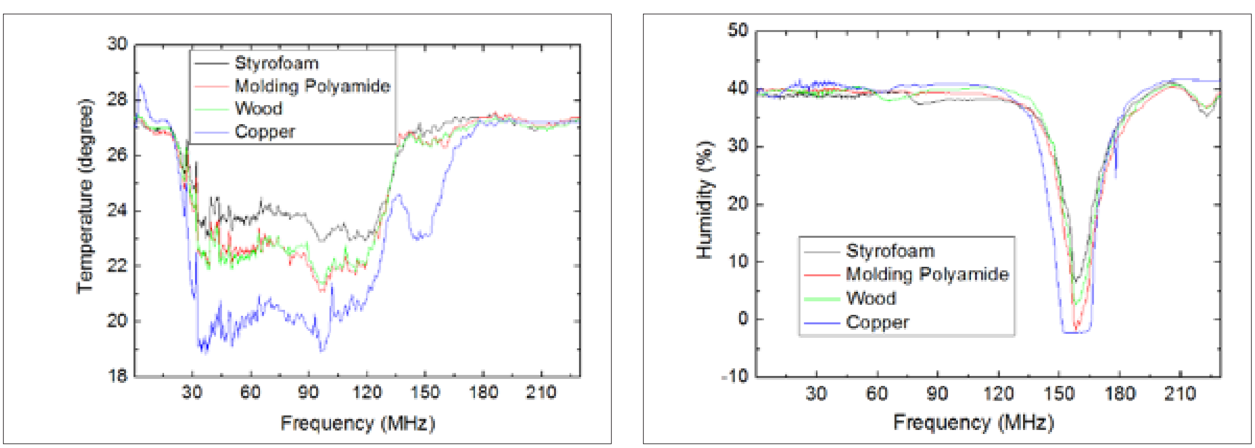
Figure 4. Conducted immunity test setups of the electronic thermometer, (a) used supports, (b) with CDN, (c) with mains without CDN [4].

also promoted an efficient knowledge transfer/exchange between the two fields. For this aim, a workshop was organized at SIQ for the project partners given in Figure 3.

Improved EMC test system verification using VNAs and just-before-tests, the effect of non-metallic objects on EMC test standards, and the traceable calibration of loop antenna using a VNA and pulse generator has also contributed in improving the EMC test and measurement capability of project partners.

The influences of a variety of support materials (styrofoam, moulding polyamide, and wood) in actual EMC tests have been investigated by means of loop impedance measurements with a VNA (Figure 4). Consequently, the effects of the support materials on the test results along with a good link to the injected current, the loop impedance and the susceptibility of the equipment under test (EUT) are shown (Figure 5). The research and results are reported in [4].

In addition to the investigation of the support material samples in actual EMC tests, S-parameters of the same samples at a high frequency, 2 GHz, have been measured by using a WR 430 waveguide. Furthermore, new and effective just-before-test verification methods that use a VNA have been developed in order to be able to detect all issues, including the most insidious ones, with conducted emission and immunity test setups just before tests. This just-before-test verification research has been also expanded to low-frequency immunity tests to verify an entire low-frequency immunity test system. In this context, the project consortium have jointly integrated a FFT-based time domain solution into just-before-test verification methods in order to easily separate low-frequency voltage ripples from the AC power frequency of the EUT by means of a simple oscilloscope and a piece of FFT-based software, which has significantly simplified low-frequency testing and just-before-test verifications and made them more accurate under the adverse AC power supply frequency in comparison with the hardware filtering solutions. Finally, the three antenna calibration method for loop antennas was successfully implemented and effectively compared with the standard methods performed as per international standards such as IEEE291, SAE-ARP958. After the comparison measurements, the advantages of the three antenna method have been clearly set out and demonstrated in terms of lower uncertainty less than 1 dB and ease of use in comparison to standard methods.



(a) (b)

Figure 5. Results of thermo-hygrometer and supports with CDN (a) temperature susceptibility level, (b) humidity susceptibility level [4].

Conclusion

At the end of this project, participating NMIs gained the necessary knowledge and skills to provide 'new' or enhanced RF&MW measurements and services for their stakeholders. To ensure this, the participation of each partner in the project was designed according to their particular needs. To achieve the desired goal, four workshops and five training sessions have been completed on Monte Carlo methods, S-parameters traceability, traceable characterization of pulse generators, characterization of calculable primary standard, advanced modelling and rigorous uncertainty calculation using specialized software, the calibration of diode type power sensors, RF&MW calibrations of EMC devices, use of EMC components in EMC testing and probability pass or fail test, respectively. The new, just-before-test low-frequency immunity verification and testing methods, which were developed in the project, have been put into service at TUBITAK and are currently being used in actual EMC tests. Also, the three loop-antenna calibration method thoroughly investigated in the project has started to be used in loop antenna calibrations at TUBITAK.

The project partners have produced a peer-reviewed paper and 11 conference papers [4-10] presented in the prestigious metrology and EMC conferences such as 6th Congreso Español de Metrología, EMC Europe 2017/2018, APEMC 2017/2018, IEEE EMC SIPI 2018 and CPEM 2018 and can be found at [11].

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Project TracePQM – Traceable Measurements of Power and Power Quality Parameters

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This paper introduces European project TracePQM focused on the development of an open, modular, metrology grade measurement system for traceable measurement of electric power and power quality parameters. The developed system uses digital sampling techniques based on commonly available digitizers and it is designed for bandwidths up to at least 1 MHz. The paper briefly describes the project itself, the motivations, its goals and achievements. An open source measurement tool, which is one of the main outcomes of the project, is introduced.

1. Introduction

With the diversification of electric power generation to include sources with fluctuating output power such as solar and wind, and with the growing number of appliances employing switched-mode power supplies, the measurement of electrical power and power quality (PQ) has increased in importance. This has led to increased customer demand for traceable, accurate measurements of power and PQ parameters as well as the calibration of power analyzers, PQ monitors and power and PQ calibrators.

Conventional power measurement techniques based on thermal converters only provide information about the root-mean-square (RMS) value which is not sufficient for PQ measurements as this must address complex waveforms. New measurement setups based on alternative measurement techniques are required. Whilst a few national metrology institutes (NMIs) have developed metrology grade power and PQ measurement systems based on sampling techniques, these systems are not generally available and they are often highly specialized. Also, there is a need for a flexible measurement system that can cater for newly developed PQ parameters and tests.

The project TracePQM [1] helps to address this issue by bringing together skilled national metrology institutes of Europe (see Figure 1) with the aim of the joint development and validation of a modular metrology grade system for the traceable measurement of power and PQ parameters using digital sampling techniques.

Figure 1. Members of the TracePQM project consortium.

2. TracePQM Project Overview

Traceable measurement of PQ parameters entails a complex range of activities. In particular, a successful implementation of a power and PQ measurement system requires knowledge and expertise in at least four fields: (i) Establishment of an appropriate measurement system including the proper, interference-free interconnection scheme of the components of the measurement setup; (ii) design and implementation of a system capable of controlling the digitizers that will, amongst other things, ensure synchronisation of particular digitizer channels; (iii) mathematical processing of the sampled voltage and current waveforms in order to obtain the required parameters such as power, power factor, and various PQ parameters including the evaluation of associated uncertainties; and (iv) validation of the performance of the measurement system to ensure traceability to the SI. Such a complex range of activities for each required PQ parameter is generally beyond the capacity of individual institutes such as smaller or emerging NMIs, universities, calibration laboratories and manufacturers of PQ instrumentation etc. Furthermore, independent development of all parts of the sampling power and PQ measurement system from scratch in every institute would result in duplication of existing designs and devices and hence a waste of resources.

The design of the modular metrology grade measurement setup must be flexible and allow new digitizers or PQ algorithms to be easily incorporated in order to cater for continuously developing customer's needs and to reflect documentary standards defining requirements for PQ meters. Ideally, any solution should focus on maximizing the use of the capabilities of existing hardware components and on simple integration of new components without the need to rebuild the entire system.

In addition, the traceability of the measuring devices and transducers over their entire operating ranges and at the required level of accuracy can be complicated, therefore harmonized and validated calibration methods are required.

2.1 Objectives

The overall aim of this project is to develop and validate a modular metrology grade system for the measurement of power and PQ parameters using digital sampling techniques. The specific scientific and technical objectives of the project are:

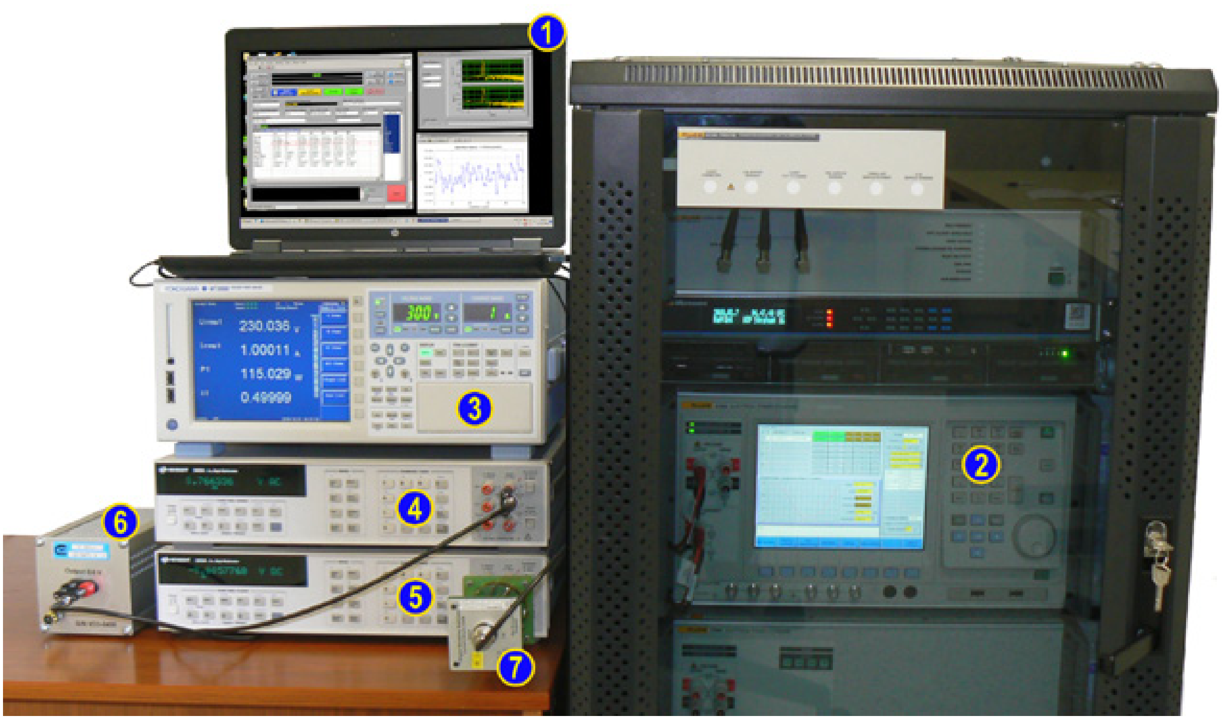

Figure 2. Example of single phase TracePQM measurement setup for calibration of power analyzer: (1) TWM measurement tool; (2) Phantom power calibrator Fluke 6105A (source); (3) Unit under calibration (Yokogawa WT3000); (4) Sampling multimeter Keysight 3458A (voltage channel); (5) Sampling multimeter Keysight 3458A (current channel); (6) External voltage divider; (7) External current shunt.

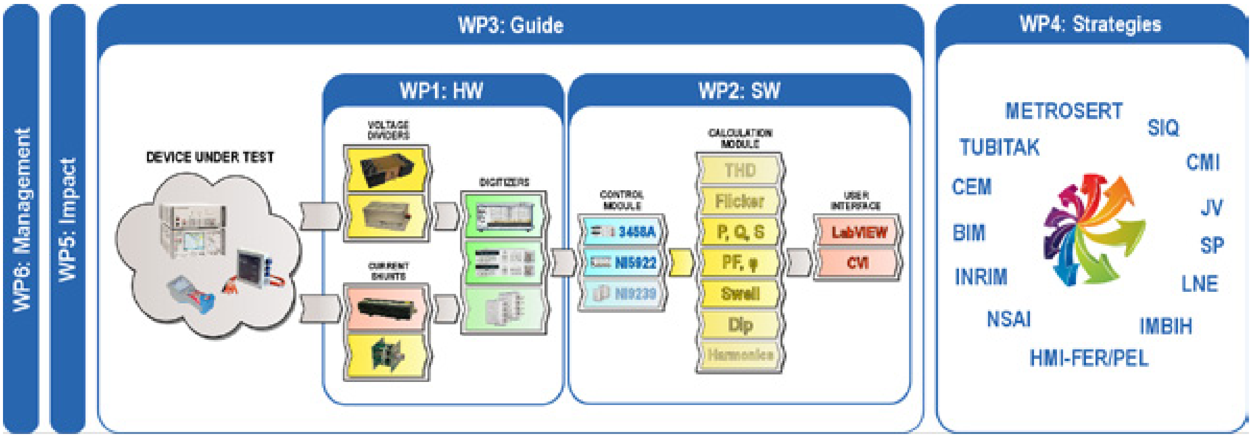

Figure 3. Structure of the project work packages. WP1: selection of HW components and development of interference-free connections, WP2; development of SW tool controlling the setup; WP3: creation of a good practice guide to assist with system establishment; WP4: development of strategies to uptake the system in partnering institutions.

(i) To review existing measurement set-ups and decide on a suitable design using, as far as possible, equipment that is already available in the laboratories.

(ii) To develop and validate a measurement set-up for sampled electrical power and PQ parameter measurements with target uncertainties more than four times smaller than the tolerances specified in documentary standards for PQ meters.

(iii) To develop an open software tool for instrumentation control, data acquisition and the calculation of electrical power and PQ parameters, including uncertainty estimation.

(iv) To develop and make available a good practice guide for the assembly and operation of the modular measurement set-up.

(v) For each partner to develop a strategy to exploit the outcomes of the project.

2.2 Progress Beyond State of Art

The project goes beyond the state of the art by making innovative and optimum use of equipment that is already available within the laboratories of NMIs and maximizing the capabilities of the chosen hardware components in order to develop the modular measurement system. The main goals and achievements are:

(i) Implementation of a reliable streaming mode for popular Keysight 3458A sampling multimeters and their synchronization allowing the acquisition of up to 16 MegaSamples per channel for any number of channels (multiphase measurements).

(ii) Improvement of National Instruments PXI 5922 digitizer stability. A method to improve the repeatability of the self-calibration function was developed.

(iii) Development of traceable calibration methods for digitizers, current shunts and resistive voltage dividers (RVD). In particular:

a. Expanded relative uncertainties for current shunt calibration of less than 100 μA/A and 800 μrad were reached at 1 MHz and validated in an international comparison.

b. Expanded relative uncertainties for RVD calibration of less than 40 μV/V at 100 kHz and below 100 μV/V and 500 μrad at 1 MHz were achieved (an international comparison to verify these uncertainties is in progress).

c. Calibration methods for the gain and phase of a digitizer were developed achieving a gain uncertainty of less than 300 μV/V at 1 MHz (to be confirmed by an international comparison).

(iv) Development of unified measurement data and correction file exchange formats allowing easy integration of new algorithms and hardware (HW) components to the system.

(v) Development of the open source measurement software (SW) capable of measuring single or multiphase signals and delivering selected power and PQ parameters.

(vi) Development of more than 10 algorithms for the most commonly required power and PQ parameters including uncertainty evaluation and validation.

(vii) Validation of the whole measurement setup by comparison to the other measurement standards available at some NMIs.

3. Traceable PQ Wattmeter

The main output of the project is the open source modular measurement tool for measurement of power and PQ parameters. Two tools were developed: (i) TWM (Traceable PQ Wattmeter) developed for the LabVIEW platform[12] and (ii) TPQA (Traceable Power & Power Quality Analyzer) for LabWindows/CVI environment, which is an alternative to TWM capable of using either the same algorithms or internal simplified processing. The following description refers to the TWM tool only.

3.1 Concept

Based on the experiences of the project partners it was decided to split the measurement tool TWM into two parts:

(i) A control module and graphical user interface (GUI) implemented in LabVIEW. The purpose of this module is to select the digitizing HW, correction files, and sampling setup and to digitize the raw waveforms.

(ii) A processing module implemented in the MATLAB/GNU Octave which can process the raw sample data in order to obtain the desired power and PQ parameters.

Both parts are capable of stand-alone operation, but they are linked together into a single interactive application.

There are several reasons for this separation of tasks:

(i) The separate implementation of the control and data processing allows easy validation of the developed algorithms and the whole processing chain using simulated waveforms, which would be problematic if the algorithms were integrated as a part of the LabVIEW or CVI applications.

(ii) New algorithms can be implemented without the need for modification of the LabVIEW or CVI module. A new algorithm can easily be implemented by simply adding m-files. The TWM will then be capable of using them with any digitizer implemented in the control module.

(iii) The control module in LabVIEW/CVI only needs to store the raw data and correction files in measurement folders and the main processing can be launched later via batch processing.

(iv) Eventually, the measurement data may be transferred to a super computer for computationally expensive algorithms or a Monte Carlo uncertainty evaluation.

(v) The same raw measurement data can be segmented and/or repeatedly processed by different algorithms to obtain more PQ parameters.

(vi) The measurement data and results are interchangeable. They can be transferred to another user for further investigation.

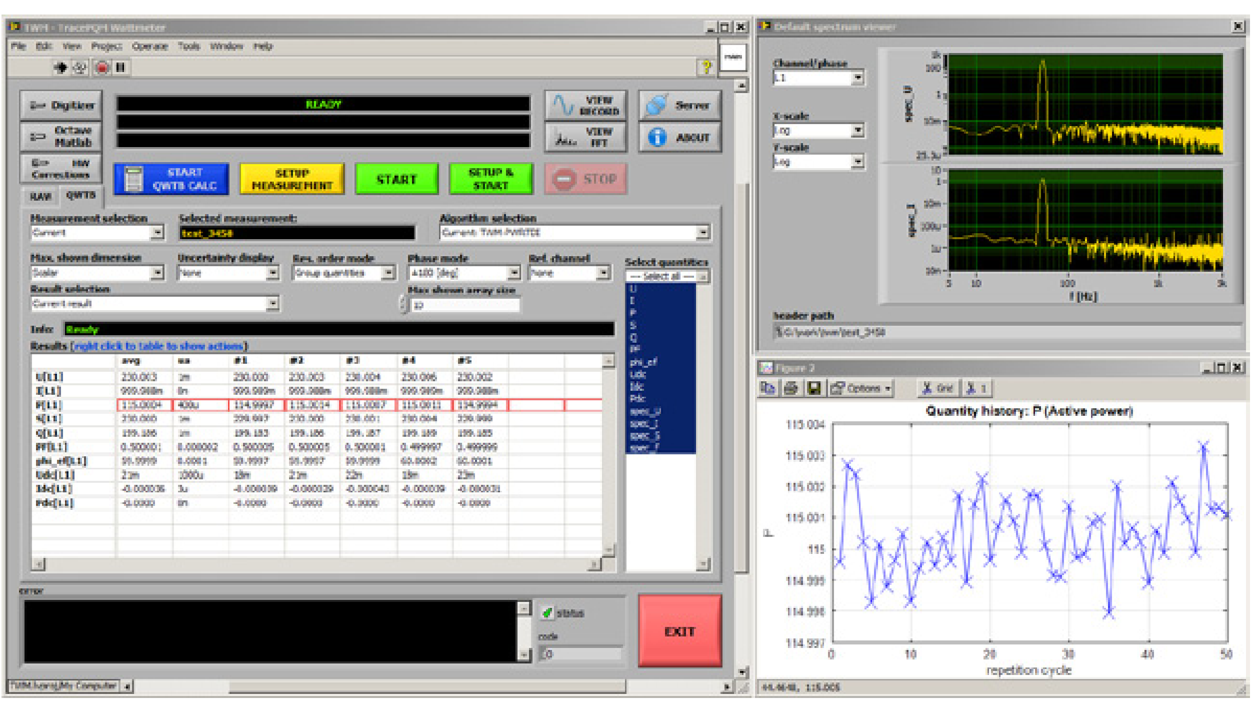

Figure 4. TWM tool front panel [12].

3.2 Functionality

The main functions of the tool are following:

(i) To digitize voltage and current waveforms from any number of channels using the selected digitizer.

(ii) To select the correction file with correction (calibration) data for each component of the measurement system (digitizers, transducers and cables).

(iii) To store the sampled waveforms in a transparent and documented format along with the correction files to form a standalone dataset that fully describes the setup configuration at the time of measurement.

(iv) To initiate calculation of the desired parameters by a selected algorithm (immediate or batch processing).

(v) To display the calculated results as a matrix or graph and to export them to an Excel file.

3.2.1 Supported Digitizers

The results of a questionnaire circulated among the project partners showed that the two most common digitizers are synchronized sampling multimeters, used for the low frequency (LF) and high accuracy measurements, and wideband digitizers for lower accuracy measurements with bandwidth up to 6 MHz (WB).

Therefore, the TWM tool was designed to operate with the following digitizers:

(i) *One or more synchronized multimeters Keysight 3458A.* The drivers allow the synchronization of an unlimited number of multimeters in various topologies (internal or external sample clock) so as to provide coherent sampling. The drivers offer a local memory mode with sample count limited to DMM on-board memory size or a streaming mode capable of capturing up to 16 MegaSamples per channel.

(ii) *One or more channels of one or more precision digitizers National Instruments PXI 5922.* Any number of cards can be synchronized using NI-TClk library. The driver supports either memory mode or streaming which extends the possible amount of sample data beyond the size of the on-board memory. The TWM uses NI-SCOPE drivers so that the tool can operate any compatible digitizer with small modifications.

(iii) *Ordinary soundcard via DirectSound driver.* This option was included to allow a user to become familiar with the operation of TWM without the need for external digitizers. Due to the AC-coupling used on most sound cards, it can only be used for phase shift measurements and simple spectral analysis.

(iv) *Simulated digitizer* used for debugging purposes only.

Note that a new digitizer can be easily included by adding the drivers and a translation layer to the tool. For example, in the near future we expect to add support for the new quantum digitizer developed in the scope of QuADC project [2].

3.2.2 Supported Connection Schemes

Practical experience of project partners has shown that the LF setup can be connected to the voltage and current transducers in a typical single-ended mode, because the sampling multimeters are isolated from ground. However, the WB setup for measurements up to 1 MHz is difficult to use with single ended connections. As shown in Figure 5, the device under test (DUT) is connected to the measurement setup such that the current shunt is floating. Therefore, the shunt must be connected differentially as shown in the topology in Figure 5. The SW tool and some of the algorithms allow for this mode of operation by compensating for the current leakage due to the common mode voltage at the shunt.

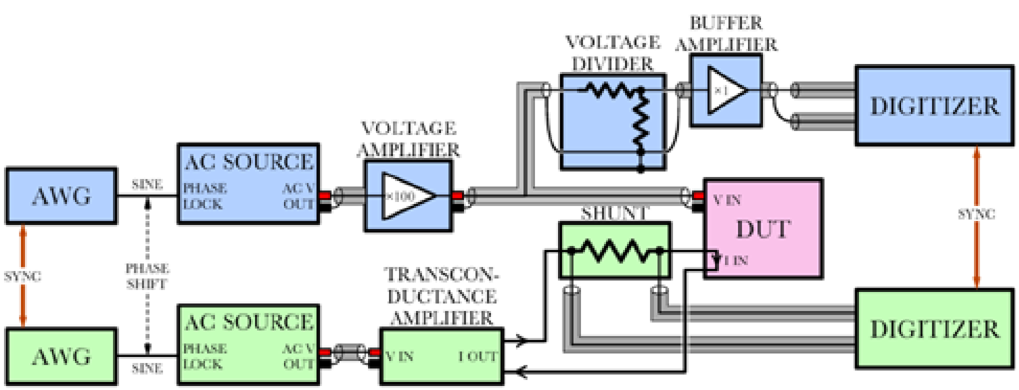

Figure 5. Wideband sampling setup for calibration of power and PQ by RISE (Sweden) [14]. Setup uses differential inputs. AWG: arbitrary function generator.

3.3 Implemented Algorithms

One goal of the project was to implement at least 10 different algorithms for the most commonly measured power and PQ parameters. A requirement of the algorithms was the ability to support non-coherent sampling which has the advantage of not requiring the digitizers to be phase locked to the measurement signal. All algorithms are designed in this way. Details on the algorithms can be found in the user guide [13] which is being composed as part of the project.

Apart from the algorithms listed below, TWM can also perform post-processing, which enables calculation of the inter-channel phase shifts or voltage ratios. This is useful to measure e.g. the unbalance of a multiphase system.

3.3.1 PSFE – Phase Sensitive Frequency Estimator

PSFE is an algorithm for estimating the frequency, amplitude, and phase of the fundamental component in harmonically distorted waveforms [4]. The algorithm minimizes the phase difference between the sine model and the sampled waveform by effectively minimizing the influence of the harmonic components. It uses a three-parameter sine-fitting algorithm for all phase calculations. The resulting estimates show up to two orders of magnitude smaller sensitivity to harmonic distortions than the results of the four-parameter sine fitting algorithm.

It is designed for single-ended transducers. It will estimate only frequency in the differential input transducer mode. The algorithm is equipped with a fast uncertainty estimator for the measured frequency.

3.3.2 FPNLSF - Four Parameter Non-Linear Sine Fit

This algorithm fits a sine wave to the recorded data by means of non-linear least squares fitting method using a 4 parameter (frequency, amplitude, phase and offset) model. An estimate of signal frequency is required with accuracy of at least 500 ppm. Due to non-linear characteristic, convergence is not always achieved.

This algorithm, in general, is not suitable for distorted signals. It offers good results for signals with low harmonic content if at least 10 periods of signal are recorded with preferably at least 50 samples per period.

3.3.3 MFSF - Multi-Frequency Sine Fit

MFSF is an algorithm for estimating the frequency, amplitude, and phase of the fundamental and harmonic components in a waveform. It also returns a harmonic distortion estimate. When all sampled signal harmonics are included in the model, the algorithm is efficient and produces no bias. It can handle aliased harmonics and even non-harmonic components, provided their frequency ratio to the fundamental frequency is exactly known a-priori. It is based on the methods given in [5] and [6].

The MFSF is equipped with a Monte Carlo uncertainty calculator and also a fast uncertainty estimator limited to certain types of signal and algorithm setup.

3.3.4 MODTDPS – Amplitude Modulation Analyzer in Time Domain Using Analytical Signal

MODTDPS is an algorithm for calculation of the amplitude modulation parameters of non-coherently sampled signals in the time domain. It was designed for basic estimation of the amplitude modulation parameters of a sinusoidal carrier modulated by sine wave or rectangular wave with a duty cycle of 50 %.

The algorithm is equipped with an uncertainty estimator, which covers most of the operating range.

3.3.5 THDWFFT – Total Harmonic Distortion from Windowed FFT

This algorithm is designed for the calculation of the harmonics and Total Harmonic Distortion (THD) of a non-coherently sampled signal. The uncertainties of the measured harmonics are relatively high, but as the method was designed to compensate for spectral leakage, it offers good accuracy for signals with very low distortions.

The algorithm supports direct processing of multiple records which are used to produce an averaged spectrum before the main calculation. This approach is superior to repeated calls of the algorithm for each record as it reduces the noise. The algorithm supports only single-ended transducer connection.

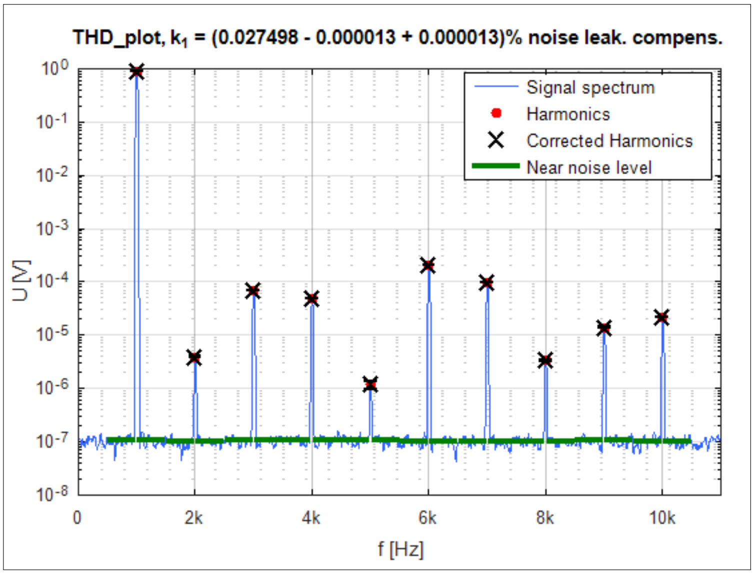

Figure 6. Example of harmonic distortion measurement by THDWFFT algorithm.

The algorithm returns: (i) Full spectrum; (ii) Identified harmonics; (iii) THD coefficients according various definitions; (iv) RMS noise estimate; and (v) THD+Noise estimate. An example of the algorithm output is shown in Figure 6.

3.3.6 WRMS - RMS Value by Windowed Time Domain Integration

WRMS is an algorithm for calculating the RMS value and DC component of a signal based on a time domain integration of the windowed signal $y(t)$. The windowing function eliminates the effects of non-coherent sampling as was demonstrated in [7] and [8]. Therefore, it is effective even for non-coherently sampled waveforms. The algorithm itself, excluding the uncertainty contributions from the calibration of the transducers and digitizers, can achieve errors of less than 1 ppm with proper selection of a sampling rate and windows size.

The WRMS algorithm is able to accommodate single-ended or differential input sensors. The algorithm is also equipped with a fast uncertainty estimator, as well as a Monte Carlo uncertainty calculation function for more reliable but slower uncertainty evaluation.

3.3.7 PWRTDI - Power by Time Domain Integration

PWRTDI is an algorithm for the calculation of power parameters using a time domain integration of $u(t)\cdot i(t)$ product. It is based on the use of a window function to eliminate the effects of non-coherent sampling as was demonstrated in [7] and [8]. The algorithm itself, excluding the uncertainty contributions from the calibration of the transducers and digitizers can achieve errors of less than 1 μW/VA with proper selection of a sampling rate and windows size.

The algorithm can calculate all basic parameters: active power, reactive power, apparent power, RMS voltage, RMS current and power factor. It also returns the DC components of voltage, current and power. The user may choose optional AC coupling mode to emulate AC coupling input. The other capabilities of the PWRTDI are the same as for WRMS algorithm.

3.3. 8 Flicker - Flicker Algorithm

Flicker is an algorithm for evaluation of the short term flicker parameters. It calculates instantaneous flicker sensation *Pinst* and short-term flicker severity *Pst*.

The sampling rate has to be higher than 7 kHz. If the sampling rate is higher than 23 kHz, the signal will be down sampled by the algorithm. A long sampling time of more than 600 s is required to allow for filter settling.

The algorithm requires either the Signal Processing Toolbox when run in MATLAB or a signal package when run in GNU Octave. It is limited to a carrier frequency of 50 or 60 Hz.

The algorithm was implemented according IEC 61000-4-15, [9], [10] and [11]. It is equipped with a simple uncertainty estimator based on the worst observed error of the algorithm from the *Pst* values tabulated in IEC 61000-4-15 for various sampling rates.

3.3.9 HCRMS - Half Cycle RMS Algorithm

HCRMS is an algorithm for the calculation of the so called half cycle RMS values or sliding window RMS values of a single phase waveform. It calculates RMS value of the signal according to the IEC 61000-3-40: (i) Class A - half-cycle step; and (ii) Class S – "sliding window" step (20 windows per period for this implementation). Examples of the calculated values for the modes A and S are shown in Figure 7.

The algorithm is designed so it can handle non-coherent sampling and compensate for slow frequency drifts.

In general, the algorithm works better with higher sampling rates. At least 100 samples should be recorded per period of the fundamental component (= sampling rate 5 kSa/s for 50 Hz networks). The higher the sampling rate the better, because the RMS algorithm will better suppress the harmonic and interharmonic content.

The algorithm is for single-ended input only and is equipped with a fast uncertainty estimator.

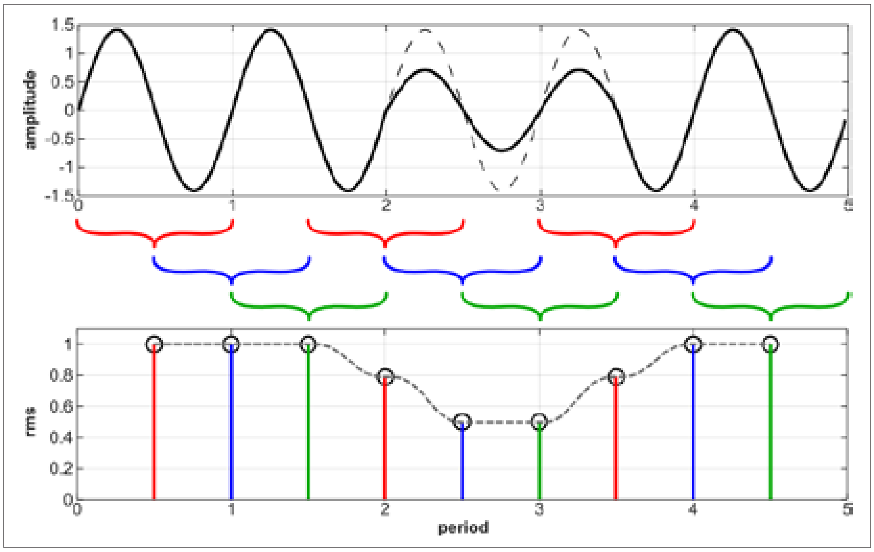

Figure 7. Half-cycle RMS values from HCRMS algorithm. The circles are RMS detected according A-class, the dashed line is measured according S-class.

3.3.10 InDiSwell - Interruption, Dip, Swell Detector

This algorithm detects the power quality events "dip,""swell," and "interruption" for single phase systems according to the IEC 61000-3-40, "class A" (half-cycle step) or "class S" (sliding window). It returns relative event time, duration and its residual RMS value in percent relative to the entered nominal level. Note that the result provided for the classes A and S should be identical as long as the event is synchronized with the nominal frequency. However, that is rarely the case of real life situations, so the selection must be made depending on the prescription for the given PQ meter test or PQ event calibrator.

The algorithm internally uses RMS envelope detector HCRMS, so the accuracy of the detection depends on its properties. Similar to the HCRMS algorithm, this algorithm will, in general, work better with higher sampling rates. The algorithm is for single-ended input only and it is equipped with a fast uncertainty estimator.

An example of the detected event as plotted by the algorithm is shown in the Figure 8.

4. Conclusion

The EMPIR project TracePQM and its achievements were presented. The most important outcomes of the project will be the good practice guide and an open SW tool for power and PQ measurements, which will be freely available to download from the project website and will assist end-users to establish new or enhanced measurement facilities for power and PQ.

A development version of the TWM tool was already released and the consortium of the project would like to encourage readers interested in digital sampling techniques to download and try the tool and provide the consortium with feedback so it can better steer the future development to ease the uptake.

5. Resources

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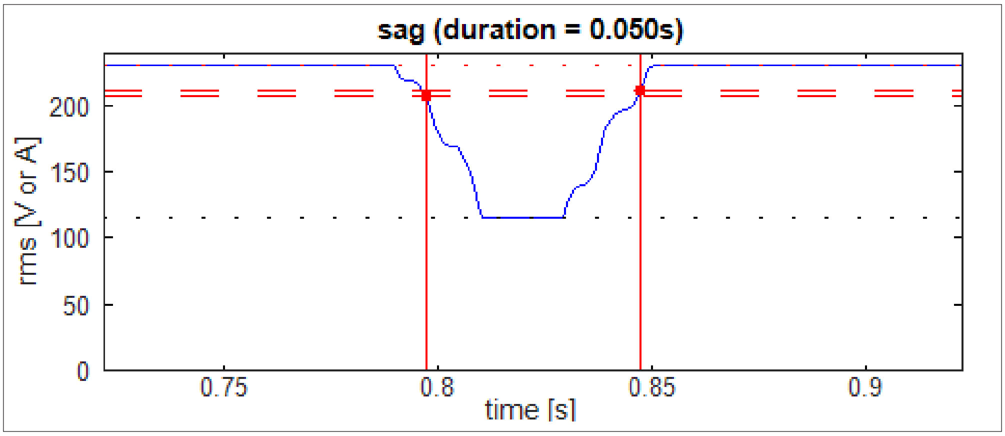

Figure 8. Example of sag measurement by InDiSwell algorithm.

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Periodic-ish Table of Metrology

Howard Zion
Transcat, Inc.

Introduction

The universe of Inspection, Measurement, and Test Equipment (IMTE) encompasses so many independent manufacturer/model numbers that it can become extremely difficult to manage, whether for the company that owns the equipment or the suppliers from whom the equipment owners purchase the equipment and/or suppliers that are used to service the equipment for calibration, adjustment, preventive maintenance, and repair. Over the past 15 years, Transcat has developed a hierarchy that is extremely effective for organizing the universe of IMTE into Categories, Disciplines, Groups, and Sub-Groups. This hierarchy has been loosely referred to as the Periodic Table of Metrology (hence the "-ish" in the title). While it is not necessarily periodic in nature, as is the Periodic Table of the Elements, there are some patterns associated with this hierarchy that bear some similarity to it. This system has been used for tracking equipment types (subgroups) in databases and spreadsheets, for assigning qualification of technicians by subgroups, for determining list pricing of services, discounting schemes, training of personnel, routing of equipment to service centers and to individual workstations, determination of lab standards required for calibration, development of standard service times and standard cost models, identification of 'new capability' development, reporting and management of client inventories, et.al. It has become the skeletal structure of our business and has many other applications that may be useful.

Early Development

In early 2002, I was working on a new way of breaking down equipment types into useful clusters, mainly focusing on a means of making Transcat's pricing more consistent for similar types of inspection, measurement, and test equipment (IMTE). Prior to this time, Transcat had developed a 'pricing matrix' which was a database of make/models, each having an independent price. This matrix also indicated each of Transcat's calibration laboratories with their respective capability for each make/model. The first problem with this matrix was pricing inconsistencies for similar types of instruments. The second problem was the inconsistency in manufacturer name spellings, model number variations, and item descriptions, which is a common problem with many databases. These inconsistencies resulted in multiple entries of the same make/model; if the make/model couldn't be found, a new one was entered with a dash instead of a space or a slash instead of a dash. Whenever we ran management reports, we had to first 'scrub' the data in order to determine how many of each type of IMTE existed in the database (or a subset of the database if filtered). Depending on the amount of data, that scrubbing process could take from minutes to hours just to clean up the data sufficiently to run a Pareto list. A third problem with the 'matrix' was that, with multiple service centers across North America, there were some lab capability inconsistencies. This created mis-shipments, causing delays for our clients and increasing our freight cost.

With these problems in mind, my goal was to find a solution that would tie a price to a 'type' of instrument and then allow each service center to show capability (or no capability) by 'type' of IMTE rather than having to determine that for every model in the database, but still allow changes at the make/model level. And rather than continue to data-scrub reports every time we needed them, another goal was set to scrub the 'matrix' once and then lock it down from having too many hands in the pot, so to speak, in order to prevent that problem from recurring.

My first pass at developing IMTE types was to create classes of similar instruments. In doing, I quickly realized that I needed to group related classes together, which I did under a number of Metrology disciplines. Then it became apparent that related disciplines needed to be grouped under Metrology Categories. The categories were influenced by my Air Force PMEL background, using Electrical, Dimensional, and Physical as the headings for the Metrology Categories. I also separated Reference-level Standards into a category distinguishing it from the three industrial-level categories.

The index codes that I first created (Figure 1) contained a letter representing the Metrology Category, followed by a letter representing the Metrology Discipline, followed by a two-digit number representing the class of IMTE. For example, PC01 was the initial code that was created to represent Conductivity Meters, using "P" to indicate the Physical category, "C" for the Chemical discipline, and "01" for Conductivity Meter.

Shortly thereafter, our marketing department noted that our enterprise software system (IBM AS400) used the term

Code	PA	PB	PC
Description	Physical: Anemometers (Air Velocity), Flowmeters	Physical: BioMedical	Physical: Chemical, Biological
Class 1	Air Sampler	Arrhythmia Analyzers	Conductivity Meter
Class 2	Air Velocity Meter	Autoclave / Sterilizer	pH Meter
Class 3	Anemometer	Defibrillator Analyzers	Salinity Meter
Class 4	Balometer	Digital Infusion Analyzers	Turbidimeter
Class 5	Bubble Flow Generator	ECG Simulators	Viscometer
Class 6	Bubble Flow Meter	Electrosurgical Analyzers	Oxidation Reduction Potential Meter (ORP or Redox Meter)
Class 7	Flow Calibrator	Infusion Pump Analyzers	Dissolved Oxygen Meter (DO Meter)
Class 8	Flowmeter	Non-Invasive Blood Pressure Analyzers	Hydrometer
Class 9	Mass Flow Controller	Pacemaker Analyzers	Colorimeter
Class 10	Mass Flowmeter	Patient Simulators	Buret and Pipette (Volume)
Class 11	Rotameter		MicroPipette (Volume)
Class 12	Sampling Pump	Pulse Oximetry Analyzers	Syringe (Volume)
Class 13	Variable Area Flowmeter	Simulator	Moisture Meter

Figure 1. Early version of Transcat's IMTE Classification Index (partial; circa 2003)

'class' and 'subclass' as its nomenclature for structuring product part numbers assigned to different warehouses. To avoid confusion when talking about classes in the enterprise system vs. these index codes, we changed the nomenclature for these new Metrology index codes from 'class' to 'group.'

From 2002 to 2006, as I gathered data from our (then) 15 commercial service centers and 3 private, client-based labs, I saw a need for separating the 'groups' (previously classes) into two different clusters of instrument types: those that generated, or sourced, a value and those that measured a value. In order to fit this into the hierarchy, the two-digit 'group' codes that represented instrument types were moved down one level to become 'subgroups' and the distinction of 'source' vs. 'measure' was inserted as a new two-digit code that is used to indicate a 'group' of similar 'sourcing' instruments or a 'group' of similar 'measuring' instruments. The subgroups were then sorted and placed appropriately into these new groups. The subsequent revision of the classification index included this refined adjustment: Category-Discipline-Group-Subgroup.

At a later date (circa 2007), I saw a need for an additional category. This was for equipment mainly used by the Pharmaceutical, Biotechnology, Medical Device, Nutraceutical, and Food Industries. I created a separate 'Life Sciences' category for these. Once the Life Sciences category was added, the Chemical discipline was moved out of the Physical category and into the Life Sciences category. The Chemical discipline was appended to include Biological IMTE. The Biomedical discipline was also moved to the Life Sciences category.

Structure

In late 2008/early 2009 I started formulating a Periodic Table of Metrology using this hierarchy. While there is not truly a periodical trend within the table, the familiar format of the Periodic Table of the Elements easily adapts to the Periodic Table of Metrology (PToM), shown on the following page as Figure 4. The Metrology Categories are color coded: Orange for Dimensional, Blue for Electrical (electromagnetic spectrum of frequencies), Green for Physical, Violet for Life Sciences, and Gold for Reference-level. Each Metrology Discipline within a Metrology Category is portrayed as an 'elemental symbol' with its two-letter index code for Category and Discipline (Figure 2). The description of the discipline is displayed below the discipline code. Beneath that is the number of groups within the discipline, to the left, and number of subgroups in the discipline, to the right. This is followed by the sourcing/measuring range and also the range of accuracy for IMTE that are found within the discipline. Just below that is the Engineering Unit associated with the UUT Range, and the base SI unit is found at the bottom of the elemental block. In the top, left corner is the Metrology Element number and in the top, right corner are the Traceability Echelons (Figure 3).

For the most part, the hierarchy/structure of this indexing system is based on the perspective of the instrument's intended design and usage (where possible) rather than solely on the type of Metrology measurement required for calibration of the instrument. In this way, the training of

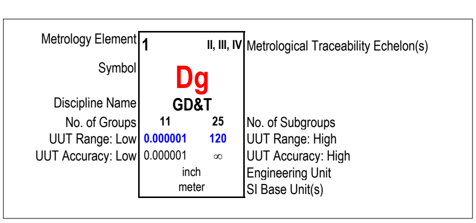

Figure 2. Elemental Symbol in the PToM

Notes:
- Metrological Traceability Echelons:
  - I (NMI's)
  - II (National or Standards Labs)
  - III (Working Cal Labs)
  - IV (Process Calibrations)
  - V (Product)

Figure 3. Metrological Traceability Echelons

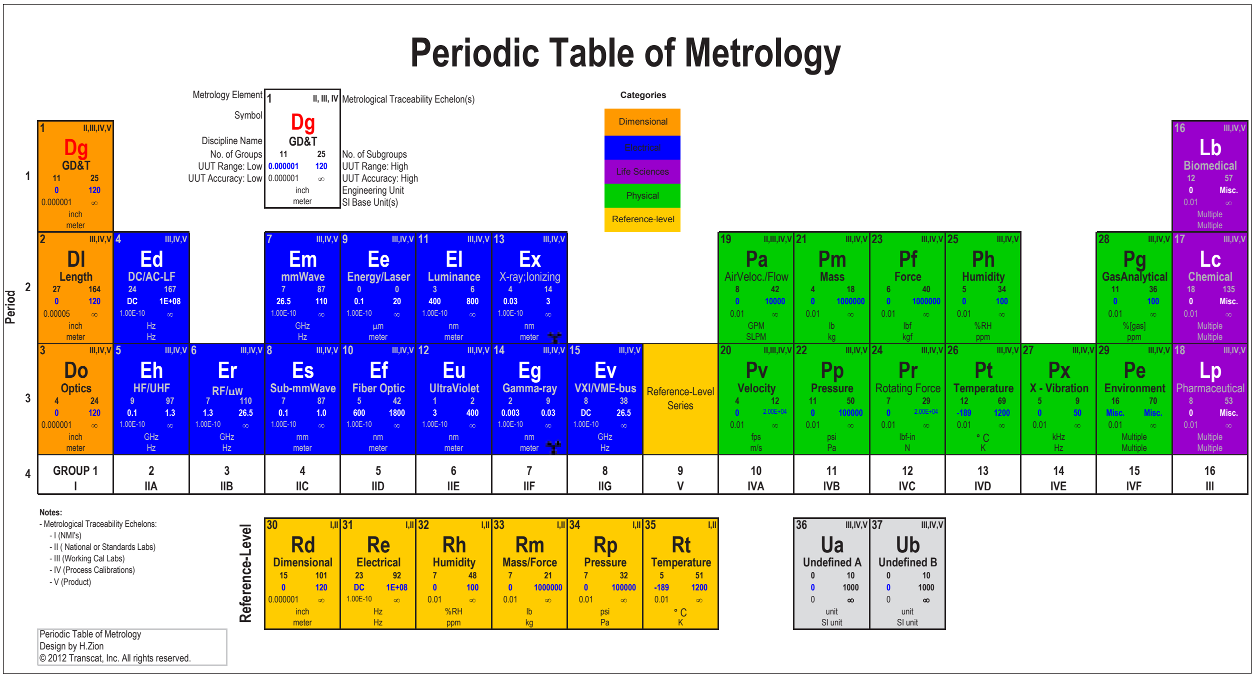

Figure 4. Periodic Table of Metrology (PToM)

the technician begins with the requisite understanding of how the instrument is used rather than taking a narrower view of the specific calibration measurement. This broader approach will often help the technician to relate to the instrument user in explaining the metrology process (e.g., OOT condition) and will increase the likelihood that all uncertainties associated with the measurement will be considered.

Dimensional Disciplines

The Dimensional category covers all types of IMTE that are used to measure length, width, depth or combinations of these. Although the Dimensional Metrology disciplines have similarities in that they all contain instruments that measure the parameter of Length (or length in up to three dimensions: X, Y, and/or Z), there are distinct differences between traditional length instruments (which are contained in the DL discipline), non-contact instruments (the DO discipline), and instruments & tooling that require ANSI/ASME Y14.5-2009 specifications for Geometric Dimensioning and Tolerancing (GD&T).

Metrology Disciplines currently included under the Dimensional Category:

1. Dg (Dimensional-GD&T)
2. Dl (Dimensional-Length)
3. Do (Dimensional-Optics)

Electrical Disciplines

The Electrical category is subdivided according to different ranges of frequency across the Electromagnetic Spectrum. The decision for subdividing the disciplines was based largely upon two factors: differences in types of cables, connectors, and adapters designed for transmission of specific frequencies, and therefore technician expertise, and also an averaging of the IMTE with regard to their designed specification for frequency range. There are 12 Metrology Disciplines within the Electrical Category of the PToM:

1. Ed (Electrical-DC/AC-LF)
2. Eh (Electrical-HF/UHF)
3. Er (Electrical-RF/Microwave)
4. Em (Electrical-Millimeter-wave)
5. Es (Electrical-Submillimeter-wave)
6. Ee (Electrical-Energy, Power, Beam Profile, and Spectrum Photonics: Laser Instruments)
7. Ef (Electrical-Fiber Optic)
8. El (Electrical-Luminance/Illuminance)
9. Eu (Electrical-Ultraviolet Radiation)
10. Ex (Electrical-X-Ray; Ionizing Radiation)
11. Eg (Electrical-Gamma Radiation; Ionizing Radiation)
12. Ev (Electrical-VXI/VMEbus and PXI/PCIbus Architecture Instruments)

Physical Disciplines

The Physical disciplines of Metrology have been traditionally defined as the Mechanic (including Fluid Mechanics) and Thermodynamic parameters of Physics, separating the Electrical parameters as a distinct subset, or category. Although Length is part of Mechanical Physics, it has also been separated as a distinct category of Metrology due to the sheer volume of items related to Dimensional measurement.

This leaves the Mechanical disciplines (Velocity, Flow, Force, Gas, Mass, Pressure, and Vibration) and Thermodynamics (Temperature, Dewpoint, and Humidity). Derivatives of these disciplines are also included in the Physical Disciplines (e.g., Linear Velocity vs. Rotational Velocity, or Revolutions per Minute - RPM; Linear Force vs. Rotational Force, or Torque; Mass vs. the vector force due to the effect of gravity on mass, or Weight). There are 11 Metrology Disciplines within the Physical Category of the PToM:

1. Pa (Physical-Air Velocity, Flow, and Leak Rate)
2. Pv (Physical-Velocity/Linear Speed and RPM/Rotational Speed)
3. Pm (Physical-Mass/Weight)
4. Pp (Physical-Pressure/Vacuum)
5. Pf (Physical-Force and Hardness)
6. Pr (Physical-Rotating Force/Torque)
7. Ph (Physical-Humidity/Relative Humidity)
8. Pt (Physical-Temperature)
9. Px (Physical-X; Vibration)
10. Pg (Physical-Gas Analysis)
11. Pe (Physical-Environmental)

Life Science Disciplines

The Life Sciences cover a broad spectrum of specialized instrumentation used in industries such as: pharmaceutical, biopharmaceutical, biotechnology, biomedical, chemical manufacturing and analysis, animal care, food, nutraceutical, et.al. Many of these instruments are unfamiliar to calibration technicians working in the traditional Metrology disciplines. However, the fundamental measurements are similar to, or the same as, many of the measurements made in the Physical, Dimensional, and/or Electrical disciplines. With that in mind, these Life Science disciplines are under development and will continue to expand as necessary.

There are currently three Metrology Disciplines within the Life Science Category of the PToM:

1. Lb (Life Science-Biomedical)
2. Lc (Life Science-Chemical/Biological)
3. Lp (Life Science-Pharmaceutical)

Additional disciplines may arise if sufficient evidence shows the need for specialized IMTE utilized for a specific Life Science industry. As an example, animal care/veterinary medical devices and testing products is regulated by the USDA (not the FDA). Many of the IMTE used in this industry are sufficiently represented by subgroups in the LC, ED, PP, and PT disciplines. However, if another Life Science industry was to be added which had associated with it a specialized IMTE that does not fit any other disciplines/subgroups, a separate Life Science discipline would need to be created.

Reference-Level Disciplines

The Reference Level Metrology disciplines cover instruments in the next higher level of the SI traceability chain with regard to instruments set forth in the other Metrology categories (those that are used in industrial manufacturing processes). These Reference level instruments are also known as Primary Standards and are typically more accurate instruments which are used to calibrate the lesser accurate secondary instruments.

There are currently six Metrology Disciplines within the Reference Level Category of the PToM:

1. Rd (Reference level-Dimensional)
2. Re (Reference level-Electrical)
3. Rh (Reference level-Humidity/Dew/Frost Point)
4. Rm (Reference level-Mass/Weight/Force/Torque)
5. Rp (Reference level-Pressure/Vacuum)
6. Rt (Reference level-Temperature)

Positive Outcome

This classification index not only resolved the pricing inconsistency issues, but it gave rise to other applications for these subgroups. Working with our Financial Planning & Accounting (FP&A) department, we developed a Standard Cost Model for each subgroup. This gave us important information regarding our cost to perform calibrations by instrument type, as well as incremental margin estimates on 'producing one more piece.'

Since a subgroup was tied to each make/model in our database, the service centers could now identify calibration capability on a more efficient scale, selecting entire subgroups, groups, or even disciplines and making a global change with one click of the mouse.

We then created a 'technician qualification matrix' in our software that allowed managers to identify different levels of expertise for each technician according to groups or subgroups of IMTE.

With that in place, the make/model could be correctly quoted by Sales, shipped to the correct lab the first time, assigned to a workstation and, upon login at a workstation, technicians could work down the list of IMTE on a First-

In-First-Out (FIFO) basis, only being allowed to work on IMTE in the subgroups for which they are qualified. We know the standard cost for each calibration, the incremental cost to 'add one more' of the same subgroup and, therefore, know the profit per piece.

Having scrubbed a large portion of the 150,000+ models in our database, we can now run reports and obtain meaningful information for business decisions. One area where we use this subgroup information is to identify IMTE for which Transcat has no capability but for which Transcat manages the calibration on behalf of our clients using approved vendors. We regularly evaluate the volume and cost of these outsourced items to determine the Return-On-Investment (ROI) and decide whether or not to make the investment in Standards and personnel training (and automation, if applicable) when considering adding a new capability to our portfolio of calibration services. This also supports our acquisition strategy when performing due diligence on the purchase of a competing company.

Newfound Applications

We have extended the PToM to identify technical training requirements. These requirements by Metrology Discipline, Group, or Subgroup identify expertise as well as gaps for new hires and for succession planning of our technical staff. Today we are developing a more formal Build-a-Tech program to invest further in the development of our technical personnel.

We recently used the PToM as a table to indicate a client's inventory of IMTE (Figure 5). The client hired Transcat to perform a campus walk-down to identify and document IMTE in 5 out of 37 buildings on their campus. The remaining buildings were exempt because they did not house any IMTE.

We displayed the volume of IMTE superimposed on the PToM to indicate the number of instruments per discipline. We included a pie chart as a Pareto tool to quickly identify the disciplines containing the largest volume of IMTE. Once familiarized with the PToM, it is easy to see that the majority of the IMTE owned by this client are the types found in the Physical and Life Science categories. Within these, the majority lies within the Pressure (Pp), Temperature (Pt), Chemical (Lc), and Pharmaceutical (Lp) disciplines. The largest volume disciplines are outlined with a yellow box. To handle 'other' equipment, we used the Unassigned (Ua) discipline for IMTE not easily assigned to a subgroup. We also use another elemental block (Xx) to identify equipment that does not have quantified source or measure capabilities (i.e., no traceable values), but which require preventive maintenance (PM) actions.

We also broke out the number of instruments per building on their campus map (Figure 6). The numbers on this map in parentheses indicate total volume including labware/glassware (and they had a LOT of it!). We showed the figures with and without the glassware to get a better idea of the general IMTE they owned. While it was no surprise that the majority of their IMTE inventory resided in two buildings, they had originally thought their total volume of IMTE was about 2,000 instruments. This was very useful information for them and for us since we

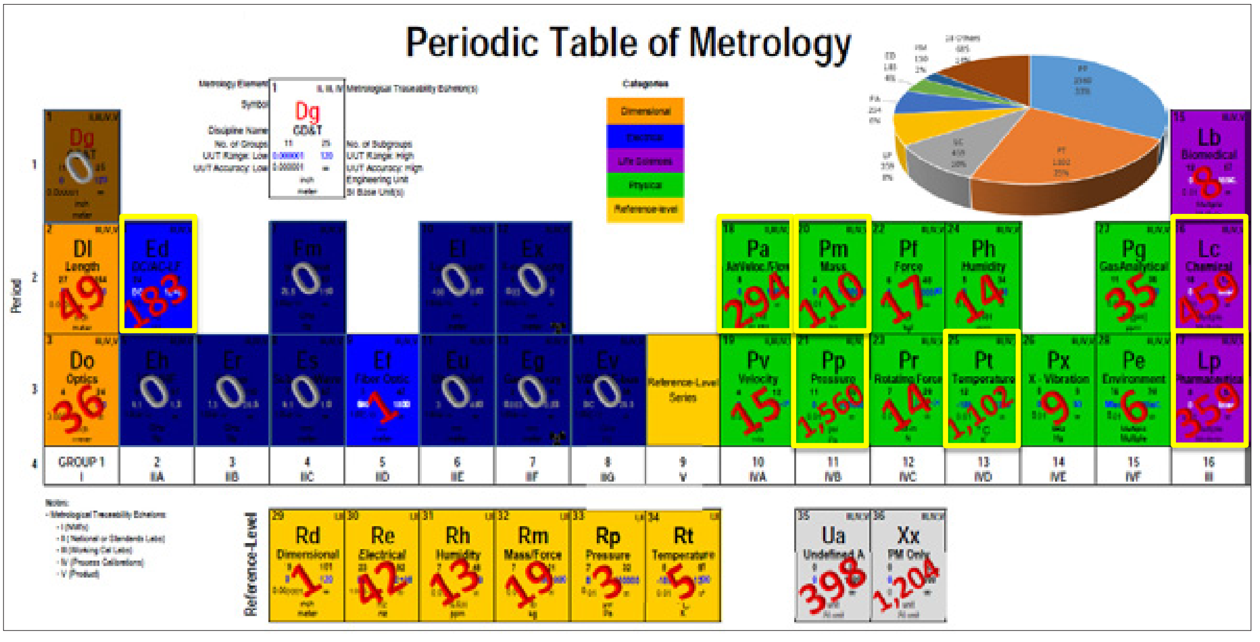

Figure 5. Use of the PToM for Inventory Management

subsequently placed a permanent technician at their campus to perform calibration work. This, along with the spreadsheet containing the IMTE details, makes it easier for our technician to find the equipment and manage the workload.

Summary

The hierarchy in the Periodic Table of Metrology provides a skeletal structure to managing inventories of IMTE for multiple clients, standardizing pricing and cost, routing equipment to the correct service center, workstation, and technician, identify training requirements and training gaps as well as capability gaps and ROI, and perhaps many other uses yet to be discovered. It would bode well for a standardized equipment hierarchy classification system such as the PToM to become industry accepted protocol that would be useful for commercial calibration companies, internal calibration programs, accreditation services, proficiency testing organizations, et.al. Obviously, there are some traits that Transcat has made to tailor the PToM to our business needs. But a standardized PToM with categories, disciplines, groups, and subgroups could be developed which would standardize how the universe of Inspection, Measurement, and Test Equipment is managed at all levels in the Metrology traceability chain, from the BIPM and NMIs to IMTE used for product testing or services. More importantly, standardizing this type of instrument reference will simplify information trade between databases, improve efficiencies to quickly understand capabilities of each organization, and provide a powerful tool for managing business. Imagine what it can do for your organization, especially if your suppliers and/or clients use the same format!

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This article is a condensed revision of a paper presented at the NCSL International Workshop & Symposium *(https://www.ncsli.org/), August 27-30, 2018, in Portland, Oregon.*

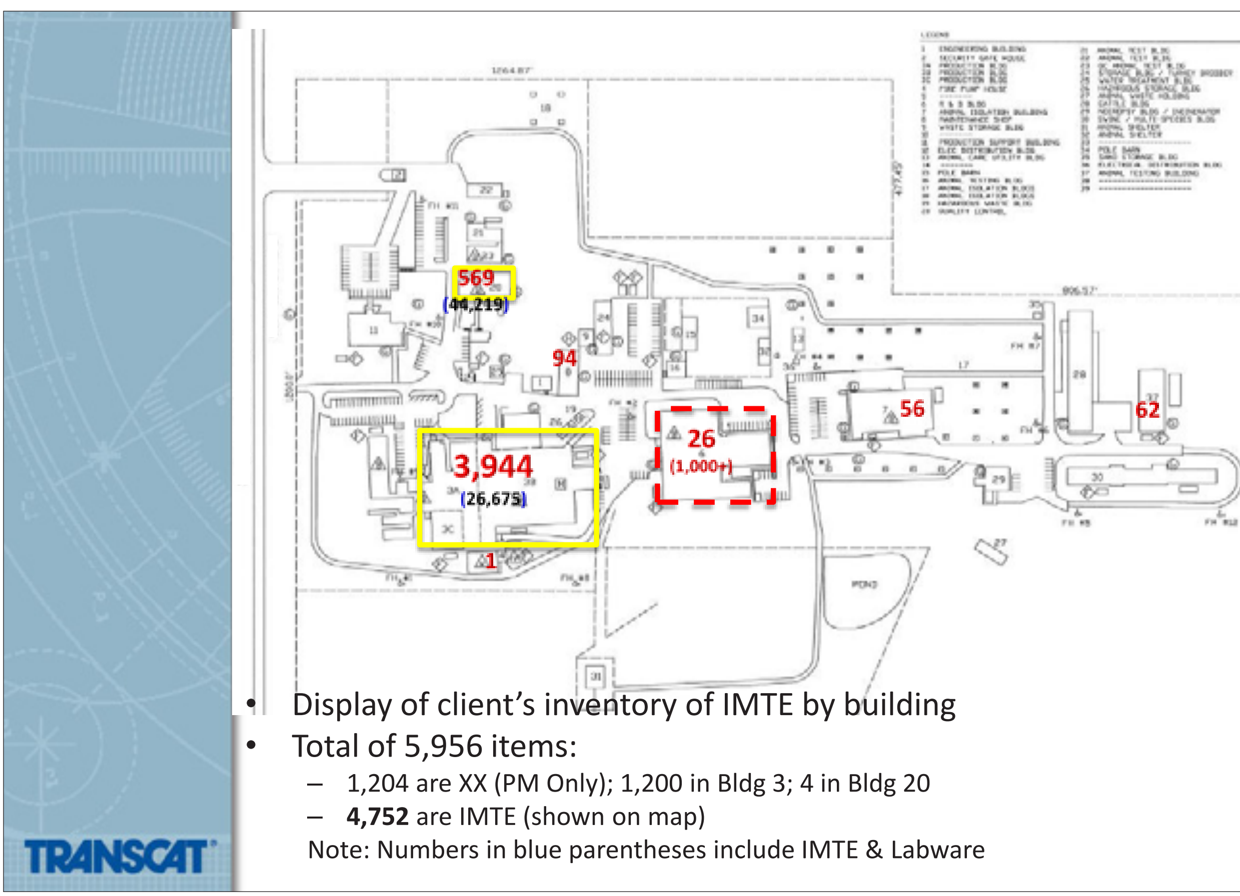

Figure 6. Inventory Management (campus map)

New R&S NRX RF Power Meter

Rohde & Schwarz has equipped the new RF power meter with a touchscreen based operating concept that guides the user through configuration. The R&S NRX has up to four measurement channels, for which Rohde & Schwarz offers a wide range of power sensors. For the first time, both terminating and directional power sensors are supported in a single instrument.

Munich, March 18, 2019 — High-precision RF power measurement for modern applications is a challenge. Rohde & Schwarz is launching the R&S NRX on the market so that users can transparently configure their measurements and perform them conveniently. The R&S NRX even makes it possible to perform triggered and synchronized multichannel measurements with different power sensors.

The user operates the instrument via the integrated high-resolution 5″ touchscreen. Measurements are configured using large buttons. The system supports the user with a logical calibration and draws attention to conflicts in case of doubt. If required, the instrument can also be operated using the buttons on its front panel.

The R&S NRX comes as standard with two robust sensor ports, which can be optionally upgraded to four. In addition, sensors can also be connected via USB or Ethernet.

The user can connect all terminating power sensors from the Rohde & Schwarz portfolio to the sensor connectors. The R&S NRX-B9 sensor interface module integrates the directional power sensors of the R&S NRT-Z family into the measurement to determine power in both transmission directions.

With the optional R&S NRX-B1 sensor check source module, users can test sensors for a pending measurement. The high-precision 50 MHz/1 GHz reference generator module generates continuous-wave signals as well as pulsed steep-slope signals. The R&S NRX is superseding the proven R&S NRP2 power meter. For more information, visit www.rohde-schwarz.com/ad/press/nrx.

Fluke Calibration Launches Digitizing Multimeter

Everett, Wash., March 26, 2019 – Fluke Calibration introduced today two best-in-class digital multimeters, the 8588A and the 8558A 8.5-Digit Multimeters. These long-scale precision digital multimeters offer superior accuracy and long-term stability over a wide measurement range.

The 8588A Reference Multimeter is the world's most stable digitizing multimeter. Designed for calibration standards laboratories, this reliable digital multimeter holds the industry's best one-year dc voltage accuracy and pushes the speed envelope by producing a stable 8.5 digits reading in a mere one second, enabling it to outperform any other long-scale reference multimeter on the market. With more than 12 functions, the 8588A helps consolidate your lab's cost of test into a single measurement instrument.

The 8558A 8.5-Digit Multimeter digitizes 5 million readings per second, the industry's fastest, for high-resolution system automation in calibration labs and manufacturing test environments. It further supports a minimum of 100,000 readings per second at 4.5 digits across GPIB, USBTMC or Ethernet, and a 15 million reading data storage in the instrument memory, allowing full flexibility to make timely and correction decisions for system throughput and efficiency.

These instruments offer a straightforward, intuitive user interface and color display with an easy-to-access configuration menu that makes it easy to train new users. A graphical display lets you easily visualize trends, histograms, complex waveforms, and statistics. Repeatable system-specific tasks can be automated quickly and easily. Fast, high resolution data capture gives you the quantity and quality of information you need for increased productivity and faster access to results and answers.

The 8588A and 8558A work with Fluke Calibration MET/CAL™ Calibration Software, in 8508A emulation mode, allowing you to increase throughput while ensuring calibrations are performed consistently every time. This powerful software documents calibration procedures, processes and results for ease in complying with ISO 17025 and similar quality standards.

To learn more about the 8588A Reference Multimeter visit: http://www.flukecal.com/8588A

To learn more about the 8558A 8.5-Digit Multimeter visit: http://www.flukecal.com/8558A

New North American Calibration Lab

SAN LUIS OBISPO, USA – AMETEK STC has announced that they have expanded their A2LA accredited calibration lab and repair department in San Luis Obispo, CA, to now include temperature calibrators. This means that all JOFRA temperature calibrators can now be serviced in California, rather than Denmark, saving North American customers valuable time.

The North American calibration lab has been the main service center for the company's Crystal pressure products for over 20 years, combining high quality service and repair with quick turnaround times. Now, with the expansion to temperature calibrators, AMETEK STC can bring this same quality service to JOFRA products.

AMETEK STC has updated their easy-to-use online RMA system, so it will now automatically direct North American customers to the new calibration lab. This efficient process saves even more time, as customers don't have to wait for returned call or email. Instead, they can get an RMA number and shipping instructions within seconds.

AMETEK STC (Sensors, Test, & Calibration) is among the world's leading manufacturers of calibration instruments for temperature, pressure, and process signals. For more information on the full line of JOFRA and Crystal Engineering calibration products visit www.ametekcalibration.com.

Ralston Instruments New Field Gauge LC10

Newbury, OH, March 21, 2019 - Ralston Instruments (www.ralstoninst.com), a leader in the advancement of pressure calibration equipment, is pleased to introduce its new Field Gauge LC10 line of pressure and temperature gauges. Responding to a need for an affordable gauge with high-end features, the Field Gauge LC10 is compact, tough, and reliable and offers numerous customization options.

"Our main engineering focus has always been to create products that make the user's job easier, and the Field Gauge LC10 is a perfect example," stated Doug Ralston, Senior VP of Engineering. "It features a large LCD display that shows numbers and bar graphs clearly with a bright backlight. And with just the tap of a button, a tech can easily switch from among 15 standard engineering units. Similar products allow for only two. But one of the biggest advantages of the Field Gauge LC10 line is that our FieldLab desktop software is included, which allows you to create custom engineering units, remove unneeded units, and configure other settings quicker and easier than ever." Ralston noted that the FieldLab Desktop software also supports direct logging of readings from a gauge over USB. "Our software extends the gauge with high end data logging for pressure monitoring or calibration testing on process gauges as an affordable alternative to a data logging gauge."

The Field Gauge LC10 is available in 11 pressure ranges from 5 psi / 35 kPa to 10,000 psi / 70 Mpa, a compound gauge from negative to positive 15 psi, and a vacuum gauge up to 30 inHg / 760 mbar. Its measurement precision is ASME grade 3A and ISO Class 0.25 (+/-0.25% of full scale).

For nearly 50 years, Ralston pressure calibration products have been trusted by calibration labs and field technicians in energy production, health care, petrochemical production, storage and distribution, and many other industries around the globe. From hand pumps and compressed gas control devices to hoses, adapters, and complete calibration kits, all Ralston products are made in the USA using innovative design and precise manufacturing techniques.

Moving Metrology Forward

Michael Schwartz
Cal Lab Solutions, Inc.

I just got back from the 2019 A2LA Technical Forum in Reston, Virginia and I was uber impressed with the size of the show. If you saw me there, I am sure we talked about software. Since this is an Automation Corner, I am going to continue. I wanted to write about the conversations and how software has changed over the last 20-ish years.

I remember when I went to my first NCSLI show in San Diego, California. I was amazed at the number of people and technologies at the show. I remember asking the staff "Why was there nothing about software?" I was expecting to see a track or at least a session on software in metrology. After all, I was a metrologist who wrote code and there was software everywhere. I was quickly told this isn't a software show, it's a metrology show kid. I was surprised people didn't see the connection.

Now roll the clock ahead to today and NCSLI has the 141 Measurement Information Infrastructure & Automation Committee. Software is viewed as having a more significant overlap with metrology, but most important, metrologists are actively learning about software and database technologies.

This was my personal highlight from the A2LA Tech Forum. Yes, I talked with several people about metrology and measurement uncertainties, even earned an Artel "Pipetting Gold Metal" with a 0.07% repeatability. But the best part of the show was the technical level of software knowledge held by many of the people at the Forum. We talked about everything from MET/CAL® 9.0 to R:Base—yes, people are still using R: Base!

People who know me know not to give me a beer and mention software. But this time it was me listening more than talking. I was impressed by the level of knowledge as we talked about loosely and tightly coupled software—how software that is tightly coupled has little to no flexibility. A Fluke MET/CAL® script is a good example of this, you have to have pretty much the exact standard called for in the procedure or the software doesn't work, whereas loosely coupled software lets you make changes. Loosely coupled software means modules to the software can be changed or added without the need to recompile the software.

Many people confuse flexible standards as loosely coupled software, but it is really not. Having the ability to use standard A or standard B is not loosely coupled, because that feature "Was a Known" when the software was developed. Loosely coupled software will support drastic changes over greater amounts of time.

A good example of loose coupling is dynamic link libraries (DLLs). Many modern applications allow for DLLs to be created and added or updated to the application, without modifications to the main application. Over time, the operating systems have changed from Windows XP to today's Windows 10. Yet, many applications still work because of the loose coupling between the application and the OS.

The hard part of creating loosely coupled software is creating a well-defined and flexible interface, while at the same time, keeping it generic will help it stand the test of time. This is the hardest part of my job as a metrology software architect. Often I have to rethink my design over and over again until I get it right. Then comes several hours of trial and error followed by pondering "why didn't that work?"

But over the years, I have found small, simple blocks of code that come together like Legos work best. And it doesn't matter what language they are written in. For example, back in 2011 we wrote a paper on "Using Fluke MET/CAL® to Implement a Flexible Measurement Driver Model with Expanded Measurement Uncertainties and Error Checking"; we still use that model today in several languages from C# to Java.

This is where I apply "Syntax is Semantics, Structure is Everything!" Meaning, it doesn't matter what language (the syntax) is used, it is all about the structure of the software. Good software architecture, "The Structure," can be written in any language.

This has been the mantra for our company. We have learned good design structure from LabView®, C#, Java, and implemented it into our MET/CAL procedures, where we perfected and tweaked it in a limited scripting language, only to bring it back into more powerful tools by creating things like Specialized Applications for Metrology (SAM) and Metrology.NET®.

Having great conversations with metrology engineers about advanced software concepts is what I enjoyed most about this year's A2LA Tech Forum and the industry as a whole. We were talking about structure of code and the pros and cons of how the software is structured until wee hours of the morning. ❧

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