CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

A Tool for Validating Spreadsheets

Contemporary Evaluation of Measurement Uncertainties in Vector Network Analysis

Rules & Tools for Creating a Metrology Taxonomy

2018
OCTOBER
NOVEMBER
DECEMBER

Electric Current Measurement

DS Series Current Transducers

DANISENSE

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

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

DS200

DS2000

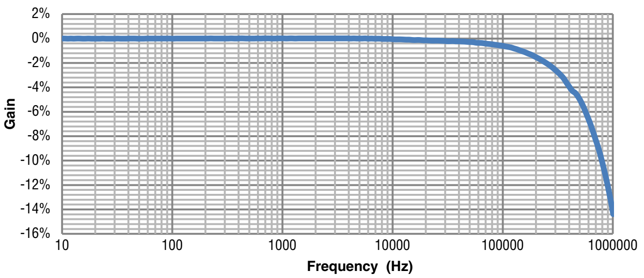
	DS200	DS600	DS2000	DS5000
Primary Current, rms	200A	600A	2000A	5000A
Primary Current, Peak	±300A	±900A	±3000A	±7000A
Turns Ratio	500:1	1500:1	1500:1	2500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†	2A/±3.2A†
Overall Accuracy	0.01%	0.01%	0.01%	
Offset	<20ppm	<10ppm	<10ppm	<5ppm
Linearity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

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

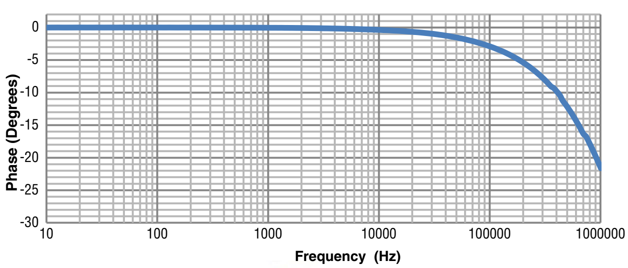
† Voltage Output options available in ±1V and ±10V

Gain / Phase

Gain (DS200, typical)



Phase (DS200, typical)



DSSIU-4 for Multi Channel Systems

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

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

DSSIU-4

Cal Lab
THE INTERNATIONAL JOURNAL OF METROLOGY

Volume 25, Number 4

www.callabmag.com

FEATURES

DEPARTMENTS

ON THE COVER: Performing precision measurements with a high resolution Supermicrometer.
Lab view: Dimensional Metrology – Tool Testing Lab, Inc.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

Mar 25-26, 2019 FORUMESURE. Nantes, France. FORUMESURE est un salon annuel, qui s'adresse aux sociétés et aussi aux institutions qui souhaitent présenter leur savoir-faire, leurs nouveaux produits et services à plusieurs centaines de visiteurs internationaux. Cet événement est organisé par le Comité Africain de Métrologie (CAFMET). http://www.forumesure.com/

Apr 8-10, 2019 CIRMS. Gaithersburg, MD. The 27th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards will focus on Strengthening the Economy and Homeland Security with Radiation Measurements and Standards. http://cirms.org/

Apr 10-12, 2019 Metromeet – 15th International Conference on Industrial Metrololgy. Bilbao, Spain. METROMEET is a unique event and the most important conference in the sector of Industrial Dimensional Metrology. http://metromeet.org/

Apr 16-19, 2019 MSC Training Symposium. Anaheim, CA. This year's theme is "Advancement in Measurement Technology." The conference is offering a series of excellent technical programs covering the various disciplines of the measurement sciences. Innovative companies will be exhibiting the latest in products and services for the measurement community. http://www.msc-conf.com/

Apr 29-May 2, 2019 ESTECH Annual Meeting and Exposition. Las Vegas, NV. The ESTECH Annual Meeting and Exposition is the leading conference for professionals in Controlled Environments/ Cleanrooms, Environmental Testing, Product Reliability, and Nanotechnology Facilities. http://www.iest.org/

May 20-23, 2019 IEEE International Instrumentation and Measurement Technology Conference. Auckland, New Zealand. The IEEE I^{2}MTC 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. It will include oral and poster presentations and business meetings of ICRM working groups. https://icrm.usal.es/

CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

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

Printed in the USA.

ISSN No. 1095-4791

EDITOR'S DESK

Call for Papers

Metrology is invisible. Try searching a major newspaper or science publication for "metrology" and see what results you get. And of those watered-down results, which ones offer any practical value to your work? For 25 years, CAL LAB has been publishing metrology related news and articles. But, just like conferences depend on papers, we depend on them too. Metrology 101 articles are not something you can just go out to a professional technical writer to generate, particularly for a niche audience such as yourselves. Even a higher level article requires an enthusiasm for the subject that a professional writer is simply not able to provide.

This is our Call for Papers! We are not owned by a media company or sizeable industry association, so our resources are pretty limited when it comes to sourcing material for each issue. How we sourced material in the past is no longer viable for the future. So I am reaching out to our readers to help us pass your knowledge onto the next generation. We need experienced techs, engineers, scientists, as well as industry-related consultants and educators to contribute their knowledge to a wider audience!

We do not have a pay-wall, rather, we freely distribute the magazine in print and digital format. Additionally, we do not hold copyrights on contributed material. We accept paid subscriptions and require them for international mailings, but we feel an obligation to the calibration community to continue providing easily accessible, relevant information. Will you help us?

Okay, moving right along to the issue at hand! Editorial Advisor Christopher Grachanen, has shared with us "A Tool for Validating Spreadsheets" as our Metrology 101 article. Throughout his career, Chris has contributed his knowledge and passion for the metrology industry. He is a wonderful example of a metrologist going above and beyond to help improve the processes in his field.

For a couple years, I've been bothering the good folks at the Federal Institute of Metrology METAS in Switzerland for a paper on their *VNA Tools* software. Our publisher attended one of their courses in Santa Rosa, California some years ago on how to evaluate uncertainty measurements for vector network analyzers using their free software. They give courses at their facility in Bern-Wabern, but sometimes in the United States too. This paper, "Contemporary Evaluation of Measurement Uncertainties in Vector Network Analysis," addresses recent updates to the EURAMET calibration guideline no. 12, *Guidelines on the Evaluation of Vector Network Analysers*, and is a must-read for anyone involved in making measurements with the VNA.

And finally, we've included a follow-up article on the progress of "Creating a Taxonomy for Metrology" from the Jan-March 2018 issue. The NCSL International MII & Automation Committee is accepting new members to help in tackling this important task. I encourage metrologists from all disciplines to consider involvement. For anyone attending the MSC Symposium in Anaheim, California or NCSLI Workshop in Cleveland, Ohio, the MII & Automation Committee will be having meetings, so feel free to attend and introduce yourself!

Happy Measuring,

Sita Schwartz

CALENDAR

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. Following the success of the previuos editions of IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace), it was decided to promote a new edition of this event, which 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. SPIE Optical Metrology returns in 2019 - 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/conferences-and-exhibitions/optical-metrology?SSO=1

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/

SEMINARS: Dimensional

Feb 5-7, 2019 Dimensional Measurement Training: Level 1. Bristol, UK. INSPHERE Ltd. A 3-day training course introducing measurement knowledge focusing upon dimensional techniques. Level 1 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training Levels - 2 & 3. http://www.npl.co.uk/training

Feb 5-7, 2019 Coordinate Measuring Machine (CMM) - Basics. Minneapolis, MN. QC Training. This course is designed for inspection personnel, engineering personnel, production personnel, entry level inspectors, and those who would like to enter into the field of dimensional measurement and CMM programming. https://qctraininginc.com/courselist/

CALENDAR

Feb 6-7, 2019 Dimensional Measurement Tools - Basics. Minneapolis, MN. QC Training Services's Basic Dimensional Measurement Tools and Methods (BDMT) class is an introduction to some of the most common gages used on the shop floor. The purpose is to provide practical instruction on the different tools available and their proper use to build workers' skill and knowledge. https://qctraininginc.com/courselist/

Feb 12-14, 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/courselist/

Feb 12-15, 2019 Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/events/seminar-gage-calibration-8/

Feb 18-19, 2019 Gage Calibration & Repair. Detroit, MI. IICT. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Feb 21-22, 2019 Gage Calibration & Repair. Chicago, IL. IICT. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Mar 5-6, 2019 Dimensional Measurement Tools - Basics. Chicago, IL. QC Training Services's Basic Dimensional Measurement Tools and Methods (BDMT) class is an introduction to some of the most common gages used on the shop floor. The purpose is to provide practical instruction on the different tools available and their proper use to build workers' skill and knowledge. https://qctraininginc.com/courselist/

Mar 7-8, 2019 Gage Calibration & Repair. Minneapolis, MN. IICT. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Mar 12-14, 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/courselist/

JOFRA® calibration

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


JOFRA
RTC Series


JOFRA
PTC Series


Crystal
nVision


Crystal
XP2i


JOFRA
ASC-400

- Remote Setpoints — Select a temperature Setpoint on your calibrator using your device.
- Stability Reporting — When the calibrator reaches the set temperature and gains stability, an emailed report is sent.
- Get an audible notification on your PC or phone when the calibrator reaches stability.
- Control and communicate with up to 5 calibrators simultaneously.
- Generate a timestamped emailed report on demand.

AMETEK®
SENSORS, TEST & CALIBRATION
ametekcalibration.com

CALENDAR

Mar 12-15, 2019 Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/events/seminar-gage-calibration-9/

Mar 20-21, 2019 Gage Calibration & Repair. Phoenix, AZ. IICT. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. Course also covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. http://www.iictenterprisesllc.com

Apr 1-3, 2019 Dimensional Measurement Training: Level 1. Telford, UK. A 3-day training course introducing measurement knowledge focusing upon dimensional techniques. This course is delivered by Hexagon Metrology, NPL Approved Training Provider. http://www.npl.co.uk/training

Apr 2-4, 2019 Dimensional Measurement Training: Level 1. Bristol, UK. INSPHERE Ltd. A 3-day training course introducing measurement knowledge focusing upon dimensional techniques. Level 1 is applicable to all industrial sectors as a stand-alone qualification or as a building block for further NPL Dimensional Measurement Training Levels - 2 & 3. http://www.npl.co.uk/training

Apr 8-9, 2019 Gage Calibration & Repair. Atlanta, GA. IICT. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. http://www.iictenterprisesllc.com

Apr 9-12, 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/courselist/

Apr 11-12, 2019 Gage Calibration & Repair. Louisville, KY. IICT. This 2-day training offers specialized training in calibration and repair for the individual who has some knowledge of basic Metrology. Approximately 75% of the workshop involves "Hands-on" calibration, repair and adjustments of micrometers, calipers, indicators height gages, etc. Course also covers NIST Traceability, Certificates of Conformance, Gage Management, Standards, etc. http://www.iictenterprisesllc.com

May 14-16, 2019 Dimensional Measurement Training: Level 1. 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. http://www.npl.co.uk/news-events/training-courses/14-16-may-2019-dimensional-measurement-training-level-1-measurement-user-insphere-ltd

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, be prepared to save the company money on calibrations and grow professionally. https://qctraininginc.com/course/gage-calibration-methods-3-day/

SEMINARS: Electrical

Feb 13-14, 2019 Electrical Measurement. Australian NMI. Lindfield, NSW. This two-day course covers essential knowledge of the theory and practice of electrical measurement using digital multimeters and calibrators; special attention is given to important practical issues such as grounding, interference and thermal effects. https://www.measurement.gov.au/

Feb 19-22, 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

Apr 22-25, 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

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. We will also teach various techniques used to make good measurements using calibration equipment. The student will be competent to make measurements after passing the final exam. https://us.flukecal.com/training/electrical-calibration-training/met-101-basic-hands-metrology

SEMINAR: Flow

Feb 5-8, 2019 Gas Flow Calibration Using molbloc/molbox. Phoenix, AZ. Fluke Calibration. A four day training course in the operation and maintenance of a Fluke Calibration molbloc/molbox system. The course's central objective is to assure optimum system use. https://us.flukecal.com/training/flow-calibration-training/gas-flow-calibration-using-molblocmolbox

CALENDAR

SEMINARS: Force

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: Industry Standards

Feb 14-15, 2019 ISO/IEC 17025:2017 – The New Standard for Laboratory Competence. Orlando, FL. QC Training. 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://qctraininginc.com/

Feb 15, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Las Vegas, NV. A2LA. This course is a one-day 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 systems, as well as the necessary steps to ensure conformity to the new Standard. https://www.a2la.org/events

Feb 19-20, 2019. ISO/IEC 17025:2017 – The New Standard for Laboratory Competence. Minneapolis, MN. QC Training. 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://qctraininginc.com/

Feb 20-21, 2019 ISO/IEC 17025:2017 for Cannabis Testing Laboratories. Sacramento, CA. A2LA. Throughout this course participants from the cannabis industry, from growers to regulators to testing laboratories, will learn how and why the new ISO/IEC 17025:2017 standard applies to them and how accreditation improves the visibility, credibility, and safety of the cannabis industry. https://www.a2la.org/events

Feb 25-26, 2019. ISO/IEC 17025:2017 – The New Standard for Laboratory Competence. Frederick, MD. QC Training. 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://qctraininginc.com/

Feb 28, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Frederick, MD. A2LA. This course is a one-day 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 systems, as well as the necessary steps to ensure conformity to the new Standard. https://www.a2la.org/events

Mar 4-8, 2019 Leading an Effective ISO/IEC 17025 Audit Team. Frederick, MD. A2LA. This course begins by introducing the participant to internal auditing philosophies and concepts of ISO 19011 and then focuses on the ISO/IEC 17025:2017 standard requirements and concepts. The course concludes by applying the auditing techniques of 19011 to the requirements of ISO/IEC 17025. https://www.a2la.org/events

Mar 11-12, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Riyadh, Saudi Arabia. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/

Mar 11-13, 2019 Internal Auditing to ISO/IEC 17025. Indianapolis, IN. ANAB. The 2.5-day training course prepares the internal auditor to clearly understand technical issues relating to an audit. Attendees of this course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://www.anab.org/training

Mar 12-13, 2019 ISO/IEC 17025:2017 - The New Standard for Laboratory Competence. Ballwin, MO. QC Training. 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://qctraininginc.com/

Mar 14-15, 2019 Auditing Your Laboratory to ISO/IEC 17025:2017. St. Louis, MO. A2LA. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2la.org/events

Mar 18-19, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Chicago, IL. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/

Mar 19-20, 2019 ISO/IEC 17025:2017 – The New Standard for Laboratory Competence. Frederick, MD. 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://qctraininginc.com/

Mar 25-26, 2019 ISO/IEC 17025:2017 – The New Standard for Laboratory Competence. Reston, VA. QC Training. 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://qctraininginc.com/

Apr 3-4, 2019 ISO/IEC 17025:2017 The New Standard for Laboratory Competence. Dallas, 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

Apr 7-8, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Bahrain. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/

Apr 9, 2019 ISO/IEC 17025:2017 Bridging the Gap from 2005. Frederick, MD. A2LA. This course is a one-day 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 systems, as well as the necessary steps to ensure conformity to the new Standard. https://www.a2la.org/events

Apr 9-10, 2019 Auditing Your Laboratory to ISO/IEC 17025:2017. El Segundo, CA. A2LA. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://www.a2la.org/events

Apr 15-16, 2019 ISO/IEC 17025:2017 for Testing and Calibration Labs. Washington, DC. IAS. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/

Apr 29-May 3, 2019 Leading an Effective ISO/IEC 17025 Audit Team. Tampa, FL. A2LA. This course begins by introducing the participant to internal auditing philosophies and concepts of ISO 19011 and then focuses on the ISO/IEC 17025:2017 standard requirements and concepts. The course concludes by applying the auditing techniques of 19011 to the requirements of ISO/IEC 17025. https://www.a2la.org/events

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 8-9, 2019 ISO/IEC 17025:2017 for Cannabis Testing Laboratories. Portland, OR. A2LA. Throughout this course participants from the cannabis industry, from growers to regulators to testing laboratories, will learn how and why the new ISO/IEC 17025:2017 standard applies to them and how accreditation improves the visibility, credibility, and safety of the cannabis industry. https://www.a2la.org/events

CALENDAR

SEMINARS: Management & Quality

Feb 26-28, 2019 Calibration/Test Lab Management Beyond 17025. Orlando, FL. WorkPlace Training. Not just Management Training, this is Calibration/Test Lab Management; Beyond 17025 Training with Jesse Morse that teaches you how to get to know your lab through the application of various metrics. http://wptraining.com/

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/

SEMINARS: Mass

Mar 11-22, 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/pml/weights-and-measures/about-owm/calendar-events

Apr 29-May 9, 2019 Advanced Mass Seminar. Gaithersburg, MD. NIST. This 9 day, hands-on mass calibration seminar focuses on the comprehension and application of the advanced mass dissemination procedures, the equations, and associated calculations. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

SEMINARS: Measurement Uncertainty

Feb 28, 2019 Introduction to Estimating Measurement Uncertainty. Brisbane, QLD. Australian 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/

Mar 5-6, 2019 Understanding & Evaluating Measurement Uncertainty. Teddington, UK. National Physical Laboratory (NPL). The course includes an introduction to the philosophy behind the Guide to the expression of uncertainty in measurement (GUM) and the first Supplement to the GUM concerned with using a Monte Carlo method for uncertainty evaluation, and covers material contained within those documents. http://www.npl.co.uk/commercial-services/products-and-services/training/training-courses/

Mar 6-7, 2019 Measurement Uncertainty Budgets. Cincinnati, OH. This workshop presents a combination of lecture and classroom exercises to demonstrate the principles of measurement uncertainty analysis. https://qctraininginc.com/

Mar 13-14, 2019 Uncertainty of Measurement for Labs. Riyadh, Saudi Arabia. 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/

Mar 14-15, 2019 Fundamentals of Measurement Uncertainty. Indianapolis, IN. ANAB. Attendees of the 2-day Fundamentals Measurement Uncertainty training course will learn a practical approach to measurement uncertainty applications, based on fundamental practices. https://www.anab.org/training

Mar 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/

Mar 26-27, 2019 Applied Measurement Uncertainty for Calibration Laboratories. Reston, VA. A2LA. During this course, the participant will be introduced to several tools and techniques that can be applied in the calibration laboratory environment to efficiently and effectively create measurement uncertainty budgets which comply with ISO/IEC 17025 requirements. https://www.a2la.org/events

Mar 27, 2019 Introduction to Control Charting for Testing and Calibration Laboratories. Reston, VA. A2LA. Control charting, a graphical presentation of measurement process behavior, is an exceptionally powerful statistical tool that is easy to learn. The benefits to control charting include confidence in stability of measurement process, rapid detection of large upsets, and insight into process behavior and improved estimation of measurement uncertainty. https://www.a2la.org/events

Apr 9-10, 2019 Uncertainty of Measurement for Labs. TBA, Bahrain. 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/

Apr 17-18, 2019 Uncertainty of Measurement for Labs. Washington, DC. 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/

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 15-16, 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/


The most accurate transducer in the world
...and out of it.
mensor
CPT9000
0 ... 100
psia
0.008% IS-33
SN: 41000MEJ
RS-232 57600 N,8,1
9-18 VDC 0.40 W Max
DOM 12.18
WIKA
• 0.008% reading accuracy
• Pressure ranges up to 15,015 psi
• Temperature compensation -20 to 75°C
• RS-232 or RS-485 communication
All in a compact rugged design.
mensor
Learn more at info.mensor.com/CPT9000

SEMINARS: Pressure

Mar 4-8, 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

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/

SEMINARS: Software

Feb 11-15, 2019 MET/TEAM® Basic Web-Based Training. Fluke Calibration. This web-based course presents an overview of how to use MET/TEAM® Test Equipment and Asset Management Software in an Internet browser to develop your asset management system. You will learn a systematic approach to recording the information you need to manage your lab assets routinely, consistently and completely. https://us.flukecal.com/training

Mar 11-15, 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

Mar 18-22, 2019 Metrology.NET® Advanced User Training. Aurora, CO (Denver). 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/

Apr 8-12, 2019 MC-205 MET/TEAM® Asset Management. Everett, WA. Fluke Calibration. This five-day course presents a comprehensive overview of how to use MET/TEAM® Test Equipment and Asset Management Software in an Internet browser to develop your asset management system. http://us.flukecal.com/training

Apr 11, 2019 Software Verification and Validation, Part 1. NIST Webinar. 2 hour session on Software Verification and Validation will focus on the use of Microsoft Excel in calibration laboratories and examine the ISO/IEC 17025:2017 requirements related to software. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

Apr 25, 2019 Software Verification and Validation, Part II. NIST Webinar. 2 hour session on Software Verification and Validation will focus on the use of Microsoft Excel in calibration laboratories and examine the ISO/IEC 17025:2017 requirements related to software. https://www.nist.gov/pml/weights-and-measures/about-owm/calendar-events

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/

SEMINARS: Temperature

Mar 5-7, 2019 Practical Temperature Calibration Training. American Fork, UT. Fluke Calibration. Three day course loaded with valuable principles and hands-on training designed to help calibration technicians and engineers get a solid base of temperature calibration fundamentals. 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. https://www.nist.gov/news-events/events/2019/06/2019-nist-time-and-frequency-seminar

SEMINARS: Vibration

Feb 25-27, 2019 Fundamentals of Random Vibration and Shock Testing. Equipment Reliability Institute. After this short course, you will be able to measure vibration and shock, calibrate vibration and shock measurement systems, convert field measured data into a test program, interpret vibration and shock test requirements, supervise vibration and shock tests, specify and experimentally evaluate vibration and shock test fixtures, perform ESS, HALT and HASS. https://equipment-reliability.com/upcoming-training/

Visit **www.callabmag.com** for upcoming metrology events & webinars!

YouTube video "Scientists to Vote on Metric Makeover" and the open session of the 26th meeting of the General Conference on Weights and Measures can be viewed on BIPM's YouTube Channel: https://www.youtube.com/thebipm.

Revised International System of Units

BIPM, November 2018 - In a landmark decision, representatives from 54 of the BIPM's Member States voted on 16 November 2018 to revise the International System of Units (SI), changing the world's definition of the kilogram, the ampere, the kelvin and the mole.

The decision, made at the 26th meeting of the General Conference on Weights and Measures (CGPM) in Versailles, France, means that all SI units will now be defined in terms of constants that describe the natural world. This will assure the future stability of the SI and open the opportunity for the use of new technologies, including quantum technologies, to implement the definitions.

The changes, which will come into force on 20 May 2019, will bring an end to the use of physical artifacts to define measurement units.

The International Prototype of the Kilogram (IPK), a cylinder of platinum/iridium alloy conserved at the BIPM, which has been used as the definition of the kilogram for almost 130 years, will now be retired. It will be replaced by a definition based on the Planck constant - the fundamental constant of quantum physics. The stability of the IPK could only be confirmed by comparisons with artifact copies. The Planck constant is ready for use "For all times, for all peoples," and its invariability can be relied on.

The new definitions impact four of the seven base units of the SI: the kilogram, ampere, kelvin and mole; and all units derived from them, such as the volt, ohm and joule.

- The kilogram will be defined by the Planck constant (h)
- The ampere will be defined by the elementary electrical charge (e)
- The kelvin will be defined by the Boltzmann constant (k)
- The mole will be defined by the Avogadro constant (NA)

Although the size of these units will not change (a kilogram will still be a kilogram), the four redefined units will join the second, the meter and the candela to ensure that the set of SI base units will continue to be both stable and useful. The revised SI will maintain its relevance by facilitating technical innovations. Just as the redefinition of the second in 1967 and the meter in 1983 provided the basis for technology that has transformed how we communicate across the globe, through GPS and the internet, the new changes will have wide-reaching impact in science, technology, trade, health and the environment, among many other sectors.

Source URL: *https://www.bipm.org/en/news/full-stories/2018-11-si-overhaul.html*

The Kiwi Kibble Balance

Measurement Standards Laboratory of New Zealand News | 3 October 2018 - The Kibble balance is an apparatus that will be used to realize the kilogram after its redefinition in May 2019 based on a fundamental constant – the Planck constant. It compares the gravitational force on a kilogram mass with the electromagnetic force on a current-carrying coil moving in a strong permanent magnetic field. By accurately measuring the induced voltage, current, coil velocity (via position and time), local gravity, and force differences, a Kibble balance can relate a standard weight mass value to the Planck constant with an uncertainty of 20 parts per billion.

MSL is currently in the process of constructing a Kibble balance. There are several Kibble balances around the world, and their designs usually come in the form of beam balances or mass comparators that use pivots. MSL's Kibble balance is the only one that uses a twin pressure balance with a differential pressure sensor as the force comparator. In essence, the readings from the differential pressure sensor will give information on how well the gravitational and electromagnetic forces are balanced. The advantages of this design are that it is less complex mechanically and its size is relatively small compared to other Kibble balances.

Other key components of our MSL Kibble balance that require careful design and implementation include: the magnet system, magnetic coil, programmable Josephson voltage standard (PJVS), current source, interferometers, vacuum chamber, and air pressure and thermal monitoring systems. At present, these components are being worked on concurrently by scientists and engineers across different MSL standards teams and assembly of the Kibble balance will begin once the components are ready.

Source URL: *https://measurement.govt.nz/news-and-events/revising-the-si-msl-kibble-balance/*

NPL Speaks on Importance of International Collaboration During MoU Ceremony

NPL News | January 20, 2019 - Dr Peter Thompson, CEO at the National Physical Laboratory (NPL), delivered a speech on the importance of international collaboration in addressing global pollution during a signing ceremony of a Memorandum of Understanding (MoU) Addendum, with the National Institute of Metrology (NIM), China.

This MoU Addendum focuses on Environmental Metrology and strengthens the collaboration between NPL and NIM in this area. Simultaneously, a contract for the supply of the NPL Differential Absorption Lidar (DIAL) system to NIM was signed – the DIAL is a sophisticated remote sensing system that is able to measure and map emissions of atmospheric pollutants, in real time, and is housed in a completely self-contained mobile laboratory.

The MoU Addendum reflects the strategic plans in Environmental Metrology of both the UK and Chinese metrology institutes that, alongside the core missions of their respective governments, are working to reduce carbon emissions.

Both governments recognise the importance of clean growth, a topic which is highlighted as one of the Grand Challenges of the UK's Industrial Strategy. The UK government is committed to encouraging all nations towards this, and play a leading role in the innovations and technologies that will bring it about – as outlined in their Clean Air Strategy. China published its own plan for tackling air pollution in 2018, to continue from the significant reductions made under its previous plan.

The signing ceremony, which took place in Beijing at NIM's Changping campus, was also attended by Alasdair Hamilton, First Secretary for UK Science and Innovation in China.

Dr Peter Thompson, CEO at NPL, said:

"Today's signing is a testament to the strength of our collaborative partnership with China and the importance of international relationships in supporting and improving our environment. The signing of this extended Memorandum of Understanding and contract reflects that we have identified new ways to work together, sharing our expertise, research and strategic thinking in a project that will accelerate delivery for both NPL's and NIM's respective environmental missions.

"We look forward to working together with NIM on environmental metrology to bring about a future where people will breathe more easily and have the potential for longer and healthier lives – this is genuinely the impact of metrology."

Mr Fang Xiang, Director of NIM, said:

"Since NIM and NPL entered the first Memorandum of Understanding in 2010, the past nine years have witnessed the great collaborative results already achieved between both sides in many areas, especially in antenna metrology and environmental metrology. I strongly believe that the signing of the MoU Addendum will further strengthen the exchanges on how to be internationally leading in thinking, how to enhance the role of metrology against the context of artificial intelligence and, ultimately, bring about mutual benefits to each other in the future.

"Also, we sincerely wish that the DIAL project will embrace a smooth and successful implementation, and that its application will be widely promoted in China to greatly contribute to the settlement of air pollution."

Find out more about NPL's work around DIAL (http://www.npl.co.uk/measurement-services/environmental-monitoring/emission-monitoring-using-differential-absorption-lidar-dial) and environmental emissions monitoring (http://www.npl.co.uk/carbon-measurement/).

Source URL: *http://www.npl.co.uk/news/ceo-of-npl-speaks-on-importance-of-international-collaboration-during-mou-re-signing-in-china*

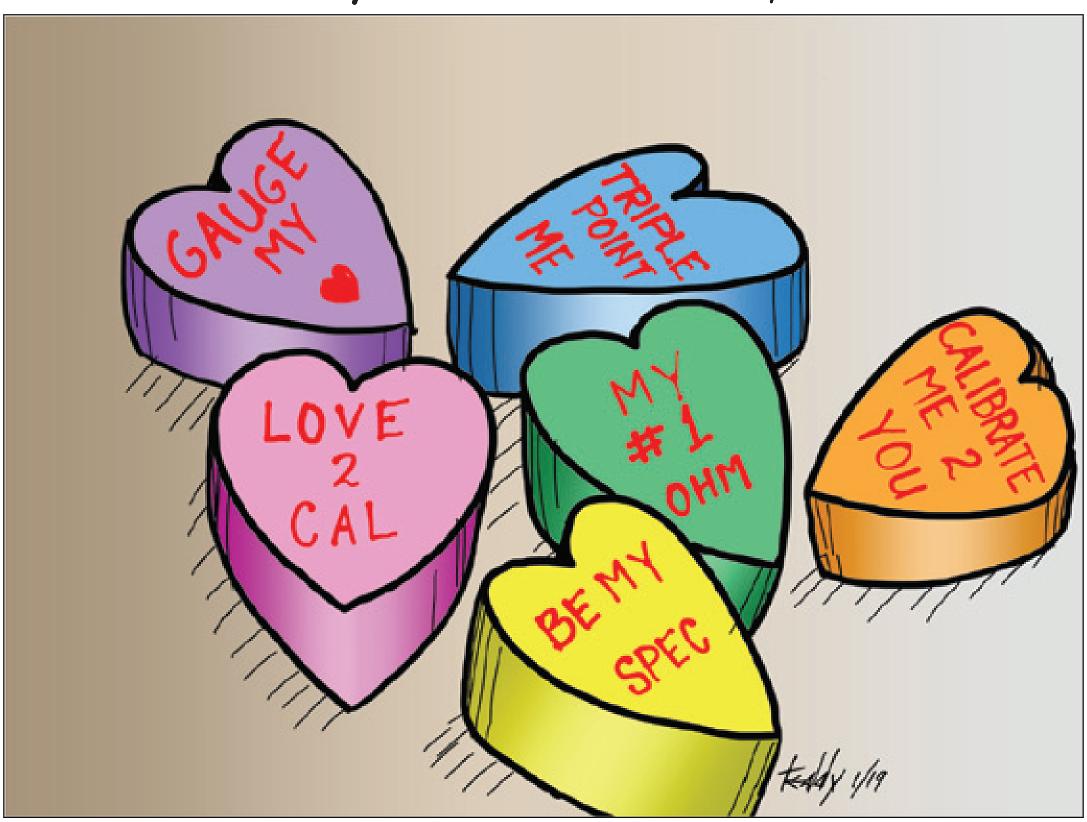
New German-Japanese Cooperation for Highest Precision

PTB News | 07.01.2019 - In the new MPG-PTB-RIKEN Centre for Time, Constants and Fundamental Symmetries, experimental physicists with a passion for precision will jointly tackle forefront topics in fundamental physics such as the question for the constancy in time of natural constants or the subtle differences between matter and antimatter. This new initiative started on January 1, 2019; the official opening ceremony will be on April 8, 2019 at RIKEN in Tokyo, Japan.

In the MPG-PTB-RIKEN Centre, worldwide leading experimental groups in atomic and nuclear physics, antimatter research, quantum optics and metrology closely collaborate in order to measure time and natural constants even more accurately using their ultra-precise equipment. The goal is to find answers to fundamental questions of physics. One of these questions is whether natural constants really are constant or eventually change in time by tiny amounts. Another question deals with the subtle differences in the properties of matter and antimatter (besides the reversed charge), which did not yet show up, although they intrinsically must exist. Otherwise, the universe would practically consist of pure radiation, since the matter and antimatter particles created in equal amounts in the big bang would have annihilated. Closely related to this test of fundamental symmetries is the search for 'new physics' beyond the Standard Model of elementary particle physics. "Here, a unique combination of outstanding scientists has joined their forces to solve these fascinating puzzles of physics," Klaus Blaum, director at the MPI for nuclear physics and one of the spokespersons of the Centre, looks forward to this research collaboration.

The broad research portfolio particularly aims for the

CAL-TOONS by Ted Green teddytoons@icloud.com



development of novel clocks based on atoms, nuclei and highly charged ions. In addition, improved measurements of fundamental constants such as the Rydberg constant, the fine-structure constant or the proton charge radius are envisaged. Further parts of the research initiative deal with stringent tests of fundamental interactions and symmetries using protons und antiprotons. To reach these goals, it is required to enhance further the presently achieved experimental precision. Therefore, the researchers intend to develop novel experimental techniques, which will outperform the state-of-the-art of contemporary methods and enable measurements at even shorter time scales and with improved sensitivity. "The combined expertise of the individual groups with their in part complementary approaches and different methods has the potential for substantial progress," hopefully emphasizes Stefan Ulmer, chief scientist at RIKEN und another spokesperson of the Centre. "It is fascinating, that nowadays manageable laboratory experiments by means of their high precision make it possible to investigate such fundamental questions in physics and cosmology," says Ekkehard Peik, leader of the department time and frequency at PTB and the third spokesperson of the Centre. An essential element of synergy arises from an intense exchange program for young scientists, who thereby will become familiar with the experiments of the partner institutes.

The new initiative started on January 1, 2019; the official opening ceremony will be on April 8, 2019 at RIKEN in Tokyo, Japan. Partners are the Max Planck Institutes for nuclear physics (MPIK, divisions Blaum and Pfeifer) and for quantum optics (MPQ, division Hänsch, Udem), the National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt, PTB) with two departments and the QUEST institute (Peik and Schmidt) as well as RIKEN with two research groups (Katori and Ulmer). The scientific activities will be coordinated at MPIK. The three partners agreed to fund the MPG-PTB-RIKEN Centre in equal amounts with overall about 7.5 million Euro for five years.

Author: Erika Show/PTB

Source: *https://www.ptb.de/cms/en/presseaktuelles/journalisten/news-press-releases.html*

A Tool for Validating Spreadsheets

Christopher L. Grachanen
Transcat, Inc.

Spreadsheets are one of the most prolific software tools used in calibration and test laboratories. From simple math computations and to sophisticated data curve fitting, spreadsheets are typically the de facto tool of choice for many data manipulations and data recording laboratory tasks. One of the challenges in using spreadsheets, aside from keeping them updated to the latest revision and preventing their unauthorized use under the umbrella of document control, is documented evidence that they are acceptable for the applications they are being used in. This typically is not a major concern when spreadsheets are used primarily for recording data and single function manipulation such as trigonometric transformation of numeric data, i.e. Cos(5) for Cosine of 5. This mindset is derived from the following guidance contained with ISO/IEC 17025:2017, General requirements for the competence of testing and calibration laboratories, Section 6.4, which states:

> Before new software (developed by the laboratory or by an external provider) is used by the laboratory, it has to be validated, except if it is standard off the shelf software. The validation activities of new software have a lot in common with method validation and acceptance test of new equipment. In short, the validation shall demonstrate that the software is fitted for its intended use. When software is included (built-in) in test equipment the validation should be included in the acceptance test and also be considered during calibration. However, in many cases built-in software could be considered as standard off the shelf software.

Regarding spreadsheets, the stated qualifier, "except if it is standard off the shelf software" is characteristically interpreted as to utilizing spreadsheets 'built in' functions either to performing single function data manipulations or multiple data manipulations via a single scripted function (combined functions). An example of a scripted spreadsheet function is 'Sum of Squares' SUMSQ(A1:A10) which performs multiple data manipulations within a single function.

The above qualifier generally does not apply to creating unique data manipulations and as such would require a spreadsheet to be validated. "Unique" is used in this context to mean data manipulations that cannot be performed independently by single or scripted spreadsheet functions but must be uniquely combined and/

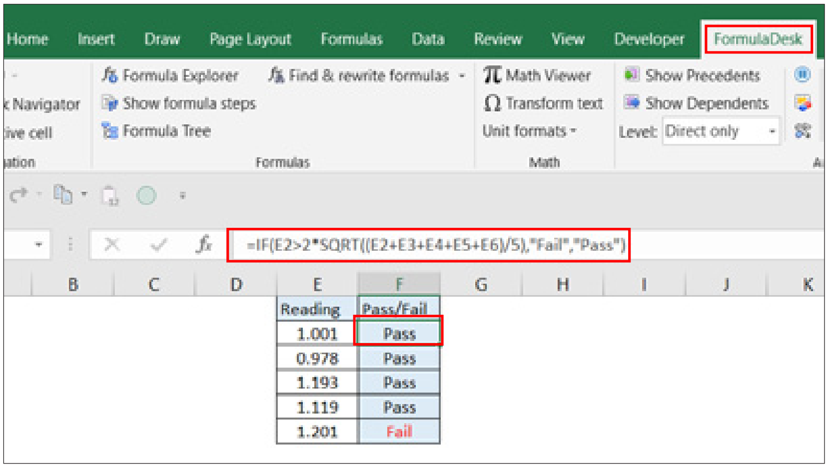


Figure 1. Spreadsheet Formula Script

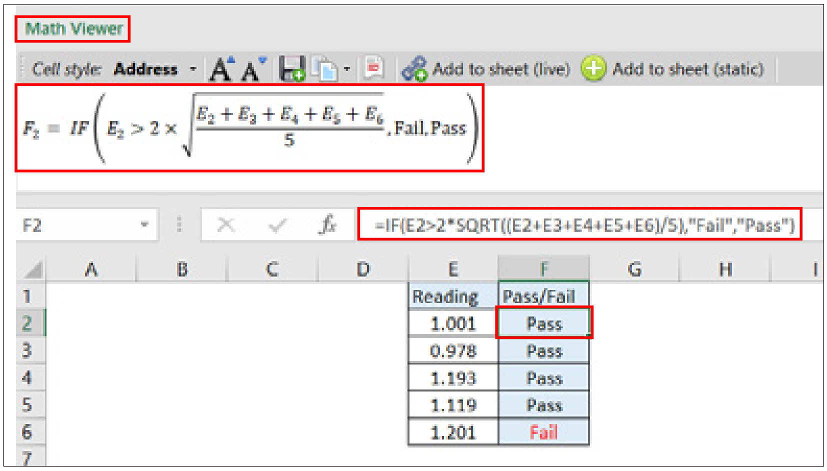


Figure 2. Math View rendering of the Spreadsheet Formula Script

or manipulated with mathematical operators, i.e. spreadsheet formula scripts. It is acknowledged that there is not industry agreement on determining what criteria should flag a spreadsheet to require validation.

Spreadsheet validation should essentially address three topics:

- Spreadsheet formula scripts (mathematical equations) are correct for their intended purpose.
- Spreadsheet formula scripts accurately reflect required mathematical equations.
- Spreadsheet formula scripts correctly manipulate data to produce accurate results.

Spreadsheet formula scripts should be documented in terms of references used to create a script to determine if they are correct for an application. An equation selected for spreadsheet formula scripting may not produce accurate results for an application based on input data, such as in the case of some measurement uncertainty equations which can be similar but unique based on measurement data.

The following two topics, spreadsheet formula scripts accurately reflecting required mathematical equations and scripts correctly manipulating data to produce accurate results, may be easily validated via a spreadsheet add-on called Formula Desk. The Formula Desk website (https://www.formuladesk.com/) has information on downloading, installing, capabilities and usage.

Formula Desk has a host of built in tools available for spreadsheet validations. I will touch on two Formula Desk tools that I frequently use to validate spreadsheets. They are Math Viewer and Formula Explorer. These tools are best explained by example (see Figures 1 through 4). The following example uses a spreadsheet with five measurements. Each of these measurements are evaluated to see if they are greater than two times the square root of mean for all measurements to determine whether it passes or fails. The Math Viewer will display the spreadsheet formula script in mathematical formula notation while the Formula Explorer will display equation steps with associated results. Thus, one can quickly determine whether the spreadsheet formula script reflects the intended mathematical equation, as well as being able to verify data sources (cell values), intermediate results and the final computed result.

Depending on the layout of the spreadsheet, one may copy and paste the Math Viewer and Formula Explorer next to the cell containing the spreadsheet formula script or create a separate 'validation' sheet.

The good folks at Formula Desk are to be applauded for providing such a useful tool to the millions of spreadsheet users worldwide who depend on spreadsheets to be correct.

Christopher L. Grachanen (chris.grachanen@transcat.com), Fellow, American Society for Quality; Technical Director of Metrology, Transcat, Inc., 1181 Brittmoore Suite 600, Houston, TX 77043.

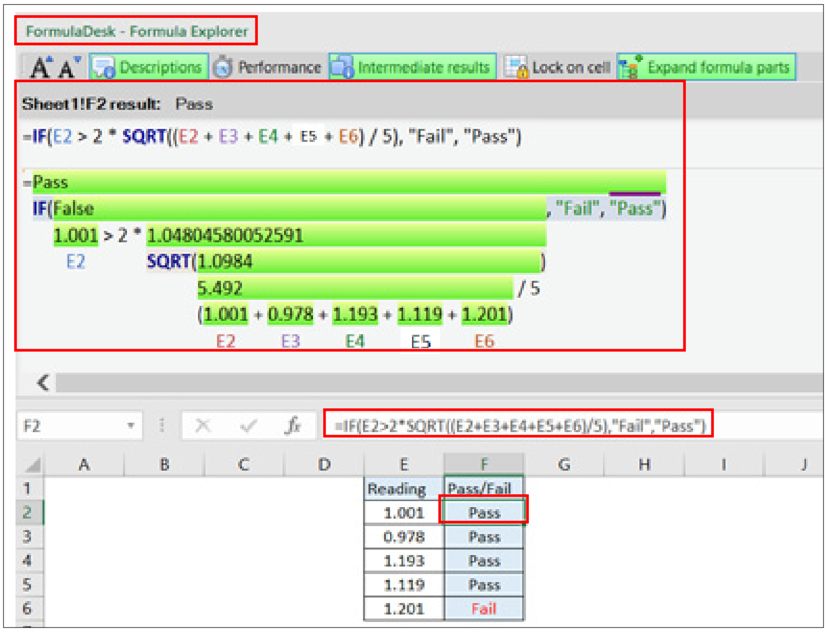


Figure 3. Formula Explorer rendering of the Spreadsheet Formula Script

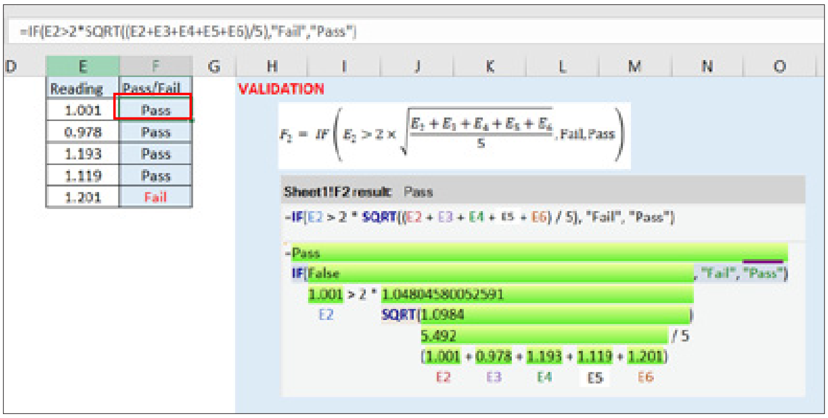


Figure 4. Validated Spreadsheet Formula Script

Contemporary Evaluation of Measurement Uncertainties in Vector Network Analysis

M. Zeier, J. Hoffmann, J. Ruefenacht, M. Wollensack
Federal Institute of Metrology METAS, Switzerland

The evaluation of measurement uncertainties in vector network analysis is a demanding task. The metrology guide EURAMET cg-12 (formerly EA 10/12) is dedicated to this topic and serves as a guideline for calibration laboratories and national metrology institutes. The guide has been revised, acknowledging the technical progress in the field. The new method promotes uncertainty evaluation based on the modeling of the entire VNA measurement process. The method is widely applicable, provides more reliable uncertainties compared to the previous method and is in agreement with relevant standard documents. Software support is needed to implement the new method and as an example the VNA metrology software *VNA Tools* is introduced.

1. Introduction

1.1 Scattering Parameters

Scattering parameters (S-parameters) are key quantities in radiofrequency and microwave metrology. They describe reflections and transmissions of a linear electrical network when exposed to electromagnetic signals. S-parameters are used in component design for systems that need to transmit electromagnetic signals reliably and fast, as e.g. communication systems. S-parameters can be cascaded easily, i.e. a system can be built from individually characterized components and the S-parameters of the whole system can be calculated mathematically. This modularity is very useful for the design of larger systems.

Figure 1 shows an example of a two-port device (e.g. an attenuation device) with input signals applied to both ports. The linear relationship between input and output signals can be written as

$$\mathbf{b}_1 = \mathbf{S}_{11}\mathbf{a}_1 + \mathbf{S}_{12}\mathbf{a}_2$$
$$\mathbf{b}_2 = \mathbf{S}_{21}\mathbf{a}_1 + \mathbf{S}_{22}\mathbf{a}_2$$

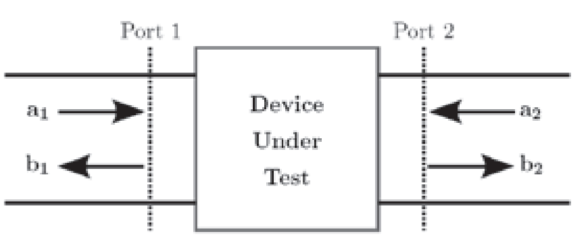


Figure 1. A two-port device with input signals, $\mathbf{a}_1$ and $\mathbf{a}_2$, and output signals, $\mathbf{b}_1$ and $\mathbf{b}_2$.

with the incoming and outgoing signal amplitudes $\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{b}_1$ and $\mathbf{b}_2$. The S-parameters $\mathbf{S}_{11}$ and $\mathbf{S}_{22}$ denote the reflection coefficients at port one and port two, respectively. The S-parameters $\mathbf{S}_{21}$ and $\mathbf{S}_{12}$ denote the transmission coefficients in both directions. This scheme can be generalized to an arbitrary number of ports and the equations can be written more economically in matrix form

$$\mathbf{b} = \mathbf{S} \cdot \mathbf{a}$$

with the S-parameters contained in the scattering matrix $\mathbf{S}$ and the column vectors $\mathbf{a}$ and $\mathbf{b}$ containing input and output signal amplitudes, respectively. S-parameters are two-dimensional quantities either described in polar coordinates with magnitude and phase or as complex numbers with real and imaginary components.

1.2 Vector Network Analyzers

S-parameters can be directly measured with a vector network analyzer (VNA). VNAs are available in various configurations for different transmission line systems (coaxial, waveguide, on-wafer). They often have two test ports, but devices with four or more test ports are increasingly used as well.

VNA measurements are affected by systematic errors. Hence a system error correction needs to be performed on the VNA. Depending on VNA architecture and application, different algorithms can be applied for this.

However, the basic principle is always the same. The system error coefficients of the VNA are determined with the measurement of calibration standards with known reflection and transmission properties. The measured raw data of the device under test (DUT) is subsequently corrected with the previously determined error coefficients.

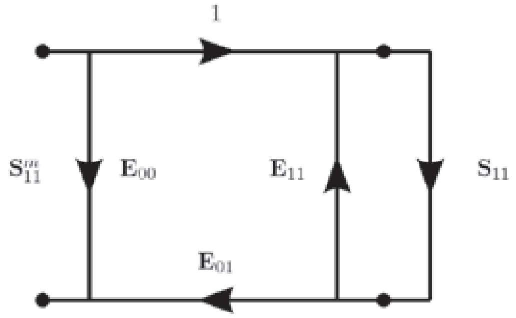


Figure 2. VNA one-port error model displayed as a signal flow graph.

Error models are applied for this procedure, approximating the VNA as a linear network. The simplest error model is the one-port model, which represents the measurement of the reflection coefficient of a DUT connected to a single test port. The signal flow diagram in Figure 2 relates the raw measured data $\mathbf{S}_{11}^m$ to the actual reflection coefficient $\mathbf{S}_{11}$ through the error coefficients directivity $\mathbf{E}_{00}$, reflection tracking $\mathbf{E}_{01}$ and source match $\mathbf{E}_{11}$. The analytical evaluation of the diagram in Figure 2, see e.g. [1], provides the relation

$$\mathbf{S}_{11}^m = \mathbf{E}_{00} + \frac{\mathbf{E}_{01}\mathbf{S}_{11}}{1 - \mathbf{E}_{11}\,\mathbf{S}_{11}} \tag{1}$$

By measuring three known standards, typically open, short and matched load, three different $\mathbf{S}_{11}^m$ are obtained. By evaluating the corresponding set of equations with algebraic methods, the three error coefficients $\mathbf{E}_{00}$, $\mathbf{E}_{01}$ and $\mathbf{E}_{11}$ can be determined. The process of measuring standards and determining error coefficients is also referred to as VNA calibration.

For the measurement of the DUT, (1) is solved for $\mathbf{S}_{11}$

$$\mathbf{S}_{11} = \frac{\mathbf{S}_{11}^m - \mathbf{E}_{00}}{\mathbf{E}_{11}(\mathbf{S}_{11}^m - \mathbf{E}_{00}) + \mathbf{E}_{01}} \tag{2}$$

and the previously determined error coefficients are used to correct the measurement of the DUT. This final step is also referred to as VNA error correction.

Two- or multi-port measurements are represented by means of error models as well. In the case of a two-port measurement, the reflections at both measuring ports as well as the transmissions in both directions are determined. More error coefficients must be determined than in the one-port case, the exact number of which depends on VNA architecture and calibration procedure. The error models and equations become more complex. Details can be found in e.g. [2, 3].

Commercially available VNAs support VNA calibration and VNA error correction via the firmware. The calculation of the measurement uncertainty however has been exclusively left to the user, at least until recently.

2. Determination of Measurement Uncertainty in VNA Measurements

The essential influencing factors and thus measurement uncertainty contributions in a VNA measurement are:

- Characterization of the calibration standards
- Noise floor and trace noise
- Non-linearity
- Drift
- Isolation
- Cable movements
- Connector repeatability

Often the characterization of calibration standards is the dominant contribution to measurement uncertainty. Depending on configuration and DUT, however, other contributions can also dominate. For transmission measurements, the unavoidable movement of the VNA test port cable might often be the predominant contribution. Depending on the ambient conditions, drift can be a factor as well.

The measurement model is a fundamental ingredient for the evaluation of any measurement uncertainty. The measurement model relates the raw VNA measurements to the S-parameters of the DUT, taking the above mentioned influences into account. This functional relationship can be used to determine the measurement uncertainty associated with the S-parameters of the DUT through uncertainty propagation. This approach complies with internationally acknowledged guidelines for measurement uncertainty calculation [4].

The error models, as the one-port model in section 1, are principally a suitable basis for creating a measurement model. The signal flow diagrams are supplemented with the above mentioned influencing factors. Mathematical expressions, which are obtained from the analytical evaluation of the diagrams, serve as the measurement model, which can be used to propagate the measurement uncertainties associated with the influence factors to the end result. However, the practical implementation is complicated by three factors:

1. The measured quantities and all error coefficients are two-dimensional variables, which are represented either in polar coordinates, with amplitude and phase, or in Cartesian coordinates, as complex-valued quantities with real and imaginary parts. Multivariate methods [5] must be applied for the correct calculation of the measurement uncertainty, taking into account unavoidable correlations.
2. The two-stage measuring process with calibration and error correction leads to long mathematical expressions for the measurement model. The

manual evaluation, e.g. the calculation of derivatives for the determination of sensitivity coefficients, is tedious and error-prone.

3. Because S-parameters and the associated uncertainties are frequency dependent it is not unusual to measure several hundred frequency points over an extended frequency range for the characterization of a DUT. This results in a relatively large amount of data, which must be evaluated.

It is therefore understandable that earlier attempts to determine the measurement uncertainty in VNA measurements looked for simplification to avoid the above mentioned difficulties.

3. The Old VNA Calibration Guide

The VNA calibration guideline was previously maintained by the European Accreditation Authority. Since 2011, the document is under the auspices of EURAMET, the European metrology organization. It is available as EURAMET calibration guide No. 12 [6] and it serves accredited calibration laboratories and national metrology institutes as a valuable guide for the calculation of measurement uncertainty in linear VNA measurements in coaxial line systems. The current version 3.0 of the guideline has recently replaced the old version 2.0. Before addressing the new updated guideline in 5, the methods of the old guide are discussed in this section to illustrate problems and need for update.

The methodology for the measurement uncertainty assessment in the old guide must be seen in relation to the available knowledge and tools at the time. Neither the correct treatment of multidimensional measurements had been well established, nor were computer-assisted evaluations of measurement uncertainty very common. To keep things simple, the modeling of the entire measurement process is avoided. Instead, it is attempted to determine uncertainties associated with VNA calibration with

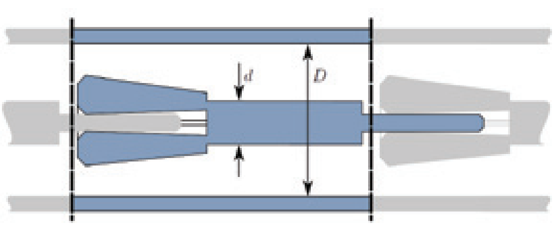


Figure 3. Cross section side view of an air-dielectric coaxial line, consisting of female connector, transmission line section and male connector from left to right. Transmission line section and connector parts are not drawn to scale for the purpose of illustration. The transmission line section has diameters D for the outer and d for the center conductor. The center conductor is not connected to the outer conductor by a support structure; instead it is kept in place when mounted. The mating counter pieces are indicated by the grayed out parts.

additional measurements using an air-dielectric coaxial line.

An air-dielectric coaxial line is a coaxial transmission line filled with air, see Figure 3. It does not have a bead structure to support the center conductor. Instead the center conductor is kept in place by the mating counter pieces when mounted. This results in a purely metallic structure. From basic theoretical considerations the characteristic impedance Z_c of the ideal (lossless and uniform) transmission line section of the air-dielectric line is given as [7]

$$Z_c = \frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}\ln\left(\frac{D}{d}\right) \simeq 59.94\ln\left(\frac{D}{d}\right) \quad (3)$$

with the diameters d and D according to Figure 3, and with the permeability μ and the dielectric constant ϵ of air. Relation (3) can be used to check how well the characteristic impedance of the air-dielectric line approximates 50 Ω by dimensional measurements of d and D. It however assumes an ideal situation by neglecting reflections at the connectors and finite conductivity. Starting point of the uncertainty evaluation is the calibrated VNA. It is correctly assumed that errors associated with the imperfect knowledge of the calibration standards and other influences are transferred to the error coefficients during VNA calibration, resulting in deviations from the true values of the error coefficients. These deviations are called residual errors.

When measuring an air-dielectric line, which is terminated first with a matched load and then with a short, the residual errors lead to a ripple being superimposed on the measurement curve. The amplitude of this ripple can be interpreted as the amplitude of the residual errors of directivity and source match, assuming that the air-dielectric line acts as an ideal 50 Ω phase shifter, i.e. reflection-free and lossless. Based on these investigations, measurement uncertainties can be assigned to the error coefficients directivity and source match. However, the residual error of the tracking coefficient cannot be determined in this way. Due to the characteristic ripple patterns in the measurements this evaluation method is referred to as Ripple Method.

In a next step, the equations representing the VNA error correction are linearized under simplifying assumptions. The simple mathematical expressions derived from there are used to propagate the measurement uncertainties from the error coefficients to the final result (S-parameter of the DUT).

This can be illustrated for the one-port case shown in section 1.2. Equation (2) is used to calculate derivatives of $\mathbf{S}_{11}$ with respect to the error coefficients. The derivatives are calculated under the assumption that the VNA is perfectly calibrated, i.e. $\mathbf{E}_{00} = \mathbf{E}_{11} = 0$ and $\mathbf{E}_{01} = 1$. The uncertainties associated with the error coefficients are then propagated to the S-parameters of the DUT $\mathbf{S}_{11}$ by means of

$$\mathbf{u}(\mathbf{S}_{11}) = \mathbf{u}(\mathbf{E}_{00}) + |\mathbf{S}_{11}^{m}|\,\mathbf{u}(\mathbf{E}_{01}) + |\mathbf{S}_{11}^{m}|^2\,\mathbf{u}(\mathbf{E}_{11}) \quad (4)$$

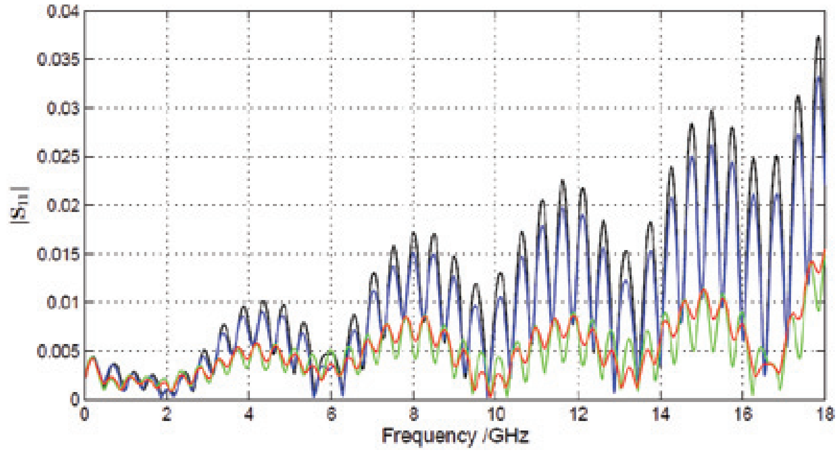


Figure 4. Four different ripple traces taken with the same air-dielectric coaxial line terminated with a matched load. The differences occur due to different longitudinal positions of the center conductor of the air-dielectric line.

The linear sum (instead of the sum of squares) is chosen in (4) because the Ripple method doesn't allow to determine the correlations between the individual terms. A worst case approach is therefore chosen. Equations for the two-port case are derived in an equivalent way.

Further contributions to the measurement uncertainty (repeatability, noise contributions, non-linearity, and cable movements) do not show up in (4). They are treated separately and relatively briefly in the old guide and typical uncertainties are assigned, assuming that these contributions are generally of subordinate importance. Uncertainty contributions based on drift are not taken into account at all.

The following are the main criticisms of the Ripple Method as it is presented in the old guide:

- Air-dielectric coaxial lines are delicate to handle because of the missing support structure of the center conductor. The handling becomes even more cumbersome with increasing frequency and correspondingly smaller line cross section. Today, however, there is a trend towards higher frequencies and methods of measurement uncertainty evaluation, which are widely applicable, are needed.
- The air-dielectric lines are assumed to be free of reflection and loss. An uncertainty contribution resulting from the deviation from the nominal 50 Ω of the line section is taken into account though. However, reflections are mainly caused by the connectors of the air-dielectric lines [8]. These reflections are unavoidable and not negligible. They lead to an additional ripple, which is superimposed on the ripple originating from the residual errors. Depending on the phase relation, this results in an over- or under-estimation of the residual errors.
- Since the air-dielectric line does not have a support bead for holding the center conductor, the longitudinal positioning of the center conductor is random. It has been shown [9] that this leads to near-field effects and poor reproducibility. Depending on the positioning of the center conductor, the reflection at the connector and thus the observed ripple can change considerably. This is illustrated in Figure 4.

  The ripple evaluation has been performed four times with the same air-dielectric airline terminated by the same matched load. By means of dielectric spacers, the center conductor of the air-dielectric line has been positioned to four different longitudinal positions, resulting in four traces with considerably different amplitudes. The variability in longitudinal positioning is given by the pin and socket recessions in the connectors of the involved components, the VNA test port, the air-dielectric line and the matched load. It should be noted that all recession values are within IEEE specifications [10] and the variability is thus quite representative for measurements performed in practice. Considering that the amplitude of this ripple pattern directly translates to an in some cases dominant uncertainty contribution, illustrates impressively how problematic the Ripple Method can be.
- The residual error of the tracking coefficient cannot be determined using the Ripple Method. This measurement uncertainty contribution cannot be reliably estimated.
- The method is limited to the treatment of the amplitude. A statement on the measurement uncertainty of the phase is not made.
- Correlations are either not taken into account or worst case assumptions are made.

4. Advances in VNA Metrology

Progress in various areas over the last years has prepared the grounds for an update of the VNA calibration guide. The major achievements are summarized in the following.

Due to memory limitations in old VNAs, characterization data of high-reflect standards (open and short) were stored in the VNA as a polynomial model and the matched load was assumed to be 50 Ω. New VNAs can store the frequency dependent characterization data of the calibration standards as a list with sufficient frequency resolution. It is therefore not important anymore that the matched load is as close as possible to 50 Ω and that the frequency response of the high-reflect standards follow polynomial functions. Instead, stability is the crucial quality criterion for calibration standards nowadays.

Comprehensive work on the characterization of VNA calibration standards has lead to the realization that the coaxial connector has a non-negligible influence and must be included in the characterization of the standards [11]. The essential assumption of the Ripple Method, that air-dielectric airlines are free from reflection can thus be refuted. Within the scope of the same work, the problem of the random positioning of the center conductor in the absence of a supporting bead and the resulting near-field effects and reproducibility problems were also identified [9]. From today's point of view, air-dielectric lines without a support bead are unstable and are only suitable as standards when additional measures [12] are taken to control the position of the center conductor.

Multivariate methods have to be applied for the correct treatment of the measurement uncertainties of complex-valued S-parameters. This has already been shown in [13]. Supplement 2 [5] of the Guide to the Expression of Uncertainty in Measurement (GUM) [4] was published in 2011. This document describes the methods of measurement uncertainty assessment of multidimensional and complex-valued measurement quantities. Thus, today an authoritative standard exists for the evaluation of the measurement uncertainty of S-parameters.

It was pointed out that measurement models for S-parameter measurements lead to long equations, which can no longer be handled by hand. In recent years, software libraries and programs have been developed, e.g. [14–16], which support multivariate treatment of measurement uncertainties of multidimensional and complex-valued measurement quantities according to [5]. These software packages are generic uncertainty calculators and are not specifically tailored to deal with S-parameters. With programming knowledge, however, the corresponding measuring models can be programmed and evaluated. In addition, there exist also software solutions specifically tailored to VNA measurements and the GUM compliant measurement uncertainty evaluation of S-parameters [17–19]. One of these tools is described further in section 7. It can be assumed that in the next few years further software solutions will be established in this area. VNA manufacturers have also started to develop firmware based solutions to display real-time uncertainties on VNA screens [20].

5. The New VNA Calibration Guide

The R&D project HF-Circuits (Metrology for new electrical measurement circuits in high frequency circuits, www.hfcircuits.org) has been a project within the framework of the European Metrology Research Program (EMRP). European Metrology Institutes, universities and industrial partners were involved in this project. In one of the work packages, EURAMET cg-12 was revised and updated [6], acknowledging progress in VNA metrology in recent years.

An important change in the new EURAMET cg-12 guide is the paradigm shift away from the Ripple Method to a contemporary GUM compliant calculation. This is further detailed in section 6. The Ripple Method is retained in modified form to ensure a certain degree of backward compatibility. Some errors in form and content [21, 22] are corrected and, in particular, the limits of applicability and accuracy are specified. Safeguards are implemented to avoid underestimation of uncertainties due to the previously mentioned problems. The missing uncertainty associated with the tracking term is dealt with. An uncertainty in phase is quoted as well and other influences, such as cable movement, are addressed more properly. Laboratories, who are equipped to use the Ripple Method, can continue for the time being without the need to buy new equipment. It is however necessary to adjust the calculation of the measurement uncertainty. Due to the safeguards, the calculated uncertainties will generally become larger.

It should be noted that it is possible to improve the Ripple Method fundamentally. This requires for the experimental part a characterized air-dielectric line with a positionally controlled center conductor, something that can e.g. be achieved with specially manufactured dielectric disks. It, however, makes the already difficult manipulation of air-dielectric lines even more tedious. For the analysis of the ripple data, advanced methods are required, which involve the transformation of the data into the time domain and subsequent filtering. Various aspects of these improvements have been discussed in literature [23–26]. Due to the high level of sophistication, these methods are not presented in the new guide.

The weaknesses mentioned in section 3 do not occur with the new GUM compliant method. In particular, this approach is based on multivariate principles, taking into account all correlations. It is less limited in terms of frequency range or the number of measurement ports and can also be applied in principle to non-coaxial measurements (waveguide, on-wafer) and even non-linear measurements. In these latter cases, however, additional sources of uncertainty might need to be considered.

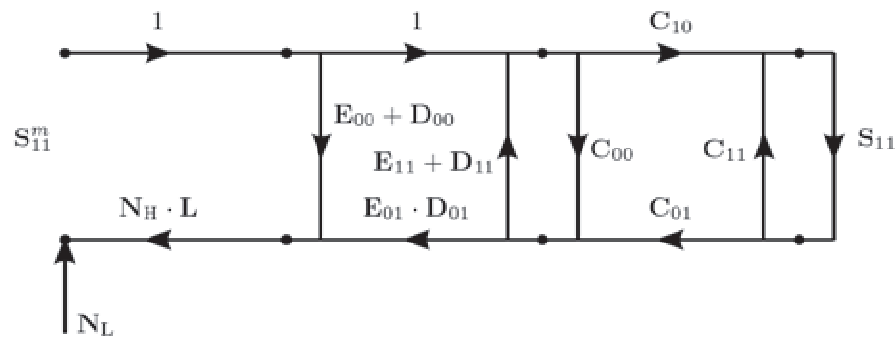


Figure 5. VNA one-port measurement model displayed as a signal flow graph.

6. Rigorous Uncertainty Evaluation

The new method is based on the evaluation of a measurement model that reflects the entire measurement process, i.e. VNA calibration and VNA error correction. Basic influences are characterized and associated measurement uncertainties are propagated through the full measurement model to the end result [27]. The procedure is therefore referred to as rigorous uncertainty evaluation.

Rigorous uncertainty evaluation is illustrated with the example of the one-port measurement already mentioned in section 1.2. Figure 5 shows a measurement model for one-port measurements as a signal flow diagram. It is based on the error model of the one-port measurement in Figure 2. The additional terms represent the influencing variables mentioned in section 2, noise floor $\mathbf{N}_L$, trace noise $\mathbf{N}_H$, linearity $\mathbf{L}$, drift $\mathbf{D}_{ij}$ and cable and connector $\mathbf{C}_{ij}$. Based on the analytical evaluation of the signal flow diagram, mathematical expressions for the VNA calibration and the VNA error correction are derived. This provides expressions in analogy to Equations (1) and (2) but now with influence quantities included. For the VNA calibration one obtains

$$\mathbf{S}^m_{11} = \mathbf{N}_L + \mathbf{N}_H\mathbf{L}\left(\mathbf{E}'_{00} + \mathbf{k}_1\mathbf{C}_{00}\mathbf{E}'_{01} + \frac{\mathbf{k}_1^2\mathbf{C}_{10}\mathbf{C}_{01}\mathbf{E}'_{01}\mathbf{S}_{11}}{1 - (\mathbf{C}_{11} + \mathbf{k}_1\mathbf{C}_{01}\mathbf{C}_{10}\mathbf{E}'_{11})\,\mathbf{S}_{11}}\right) \tag{5}$$

with

$$\mathbf{E}'_{00} = \mathbf{E}_{00} + \mathbf{D}_{00}$$
$$\mathbf{E}'_{01} = \mathbf{E}_{01} \cdot \mathbf{D}_{01}$$
$$\mathbf{E}'_{11} = \mathbf{E}_{11} + \mathbf{D}_{11}$$
$$\mathbf{k}_1 = \frac{1}{1 - \mathbf{E}'_{11}\mathbf{C}_{00}}$$

The VNA calibration remains the same as described in section 1, but Equation (5) is now used instead of (1). Three characterized standards are being measured. The measured values and the reference values of the standards correspond to $\mathbf{S}^m_{11}$ and $\mathbf{S}_{11}$, respectively. From the resulting set of equations the three error coefficients $\mathbf{E}_{00}$, $\mathbf{E}_{01}$ and $\mathbf{E}_{11}$ are determined.

For the error correction of the DUT measurement Equation (5) is solved for $\mathbf{S}_{11}$.

$$\mathbf{S}_{11} = \frac{\mathbf{k}_2}{\mathbf{k}_2(\mathbf{C}_{11}\mathbf{k}_1\mathbf{C}_{01}\mathbf{C}_{10}\mathbf{E}'_{11}) + \mathbf{k}_1^2\mathbf{C}_{10}\mathbf{C}_{01}\mathbf{E}'_{01}} \tag{6}$$

with

$$\mathbf{k}_2 = \frac{\mathbf{S}^m_{11} - \mathbf{N}_L}{\mathbf{N}_H\mathbf{L}} - \mathbf{E}'_{00} - \mathbf{k}_1\mathbf{C}_{00}\mathbf{E}'_{01}$$

Equations (5) and (6) constitute the measurement model of the VNA one-port measurement. They link measured values and influence quantities with the reflection coefficient of the DUT and thus form the basis for the measurement uncertainty propagation by means of analytical or numerical methods.

The principle remains the same for two- and multi-port measurements. But the equations become even more complicated. Software is therefore needed to support the evaluation of these equations according to [5]. The user is responsible for characterizing the individual influencing factors and making the measurements in a careful and correct way. The software takes over the complex computational part of the measurement uncertainty propagation during VNA calibration and VNA error correction. Ideally, it also provides a measurement uncertainty budget. The dominant contributions to measurement uncertainty are thus recognized. This contributes to a better understanding of the results and is a prerequisite to improve the accuracy of the measurements. By modeling the entire two-step measurement process (VNA calibration and VNA error correction), all influence quantities, which impair the measurement, are taken into account in a conceptually easily comprehensible and transparent manner. This is a clear improvement versus the Ripple Method.

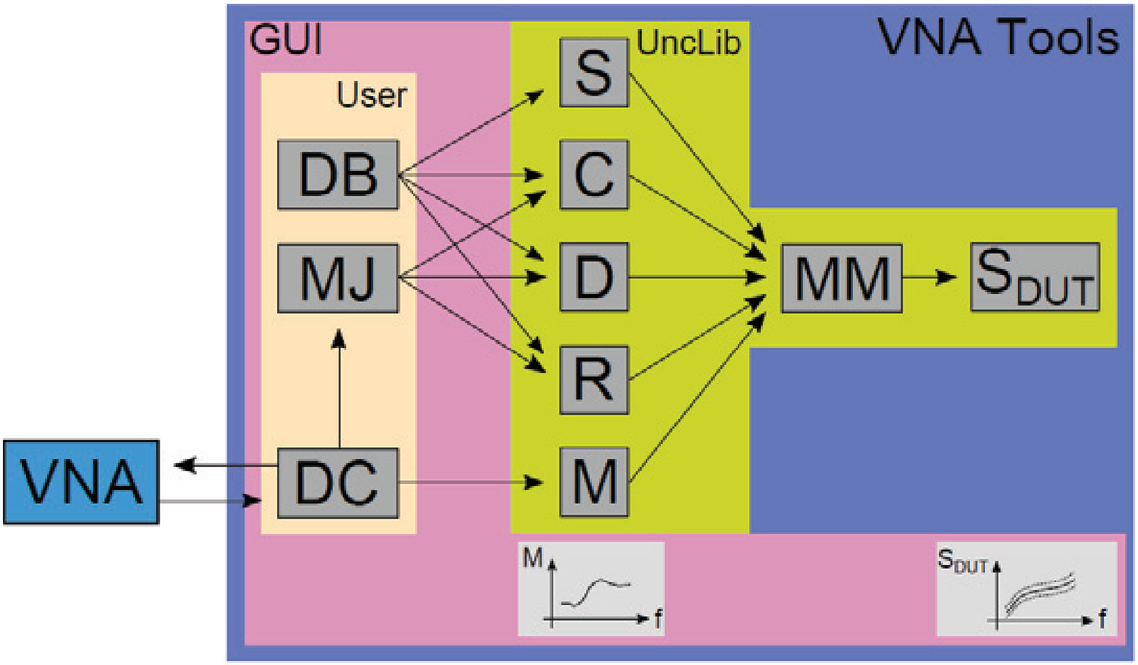


Figure 6. Schematic overview of the components in *VNA Tools* that are relevant for the evaluation of the measurement uncertainty of S-parameters. The area labeled as User contains major user actions. The user is responsible that the characterization data in the database (DB) is up to date and he interacts with the VNA through the device control (DC) to perform the raw measurements. The measurement journal (MJ) contains meta data about the measurement sequence, partly created automatically, as e.g. time stamps, partly entered by the user, as e.g. test port cable movements. Measurement journal and database add to the preparation of the basic inputs with associated uncertainties. Basic inputs are the characterization data of the calibration standards (S), cable and connector (C), drift (D), noise and linearity (R) and the raw measurements (M). The uncertainty propagation engine (labeled as UncLib) propagates the measurement uncertainties from the basic inputs through the measurement model (MM) to the S-parameters of the DUT (S_{DUT}). The graphical user interface (labeled as GUI) enables the user actions and provides means to visualize the data. More details on some of the components can be found in the text.

The influence variables $\mathbf{N}_L$, $\mathbf{N}_H$, $\mathbf{L}$, $\mathbf{D}_{ij}$ and $\mathbf{C}_{ij}$ depend on configuration and environmental conditions and must be characterized in advance. It is important that this is done correctly. The new guide provides detailed instructions for this. The characterization of these influencing variables is principally a one-off effort and must be repeated if something changes in the measurement conditions.

With rigorous uncertainty evaluation the traceability to SI units is realized by the periodic characterization of the calibration standards. The national measurement institutes offer these calibrations and ensure the traceability to SI units [28]. It is important that the calibration standards have high stability. This is not only related to long-term stability, but also connection repeatability, i.e. the stability under repeated connections with different connector orientations.

7. Software Support

This section discusses a software solution, which supports the rigorous uncertainty evaluation to the full extent. *VNA Tools* [18] is free VNA metrology software which runs on the PC and largely bypasses the VNA firmware, i.e. VNA settings and measurement sequences are steered from the software and calculations are done on the exported raw measurement values. Calculations performed by the software and data formats are documented in [29]. The software was initially developed for coaxial measurements, but supports now waveguide and on-wafer measurements too. Figure 6 provides an overview of the major components of *VNA Tools* as far as they are relevant for the uncertainty evaluation.

The software provides drivers for major VNA brands and supports the most common calibration algorithms. A custom-built optimization algorithm [17] supports over-determined VNA calibration, i.e. more standards are measured than needed for the determination of the error coefficients.

The software features a data explorer for graphical and tabular data representation and data export in various formats. Post processing of S-parameter, automation through scripting, time domain analysis, calculation of best, typical or worst measurement uncertainties with a virtual

VNA and a real time interface for high level interaction with other software programs are further capabilities. Additional features, currently under development, are mixed-mode S-parameters and the extraction of material parameters from S-parameters. Key features to support the proper evaluation of the measurement uncertainty are a measurement model containing all measurement influences, a database to quantify the sources of uncertainty, a measurement journal to record the measurement actions, and an uncertainty engine to propagate uncertainties through the measurement model. These components are shortly described in the following.

VNA Tools supports N-port measurements, where N can be an arbitrary number of ports, and the reference impedance at each port can be chosen freely. The corresponding measurement model is described in [29]. It is principally a N-port generalization of the one-port model described in section 6, taking into account the influence quantities listed in section 2. For some of these quantities, sub-models are applied, e.g. for connector and cable (the $\mathbf{C}_{ij}$ terms in Figure 5).

Special thought has been given to the correct treatment of random and systematic effects. For random influences, the associated uncertainties can be lowered with repeated measurements. For systematic influences, no dilution of uncertainty should occur with repeated measurements. The drifts of the error coefficients (the $\mathbf{D}_{ij}$ terms in Figure 5) are special in that respect. They are principally of random nature, but act as well in a systematic way due to the typically large time constant.

Measurements that are performed close in time are affected by nearly the same drift. The corresponding drift uncertainties are thus correlated and the size of the correlation needs to scale inversely with the time span between different measurements. Taking this correlation into account leads to more realistic uncertainty contributions associated with drift. Accounting for drift requires, therefore, taking the time stamp of different measurements into account in the measurement model. This is achieved with the measurement journal described further below.

VNA Tools has a database, which contains entries for the basic influences listed in section 2. The database contains characterization data related to these influences. These entries determine the size of the uncertainties associated with the basic influences. It is therefore essential to correctly determine the values in the database.

As already mentioned, the new VNA calibration guide provides guidance on how to characterize the different influence quantities. For the calibration standards, it is normally just data from a calibration certificate that needs to be stored in the database. For VNA parameters such as noise, linearity and drift, the test routines described in the guide can be performed with *VNA Tools* to determine the values to be entered in the database. The entries can be made for different VNA devices and VNA settings.

For cable movements and the connector repeatability, typical values are entered for each connector family and for each individual cable, based on experience and previous characterization measurements. The database values for cable and connector can, however, be overruled by performing real-time evaluations. The connector repeatability is then evaluated for the actual combination of connectors. Several reconnections are performed with varying angular orientation and a statistical analysis provides the associated uncertainty. The test port cable is evaluated by performing the maximum movements that will occur during the entire measurement sequence.

The measurement journal completes the information that is needed to generate uncertainties associated with the influences during the measurement sequence. It contains the VNA settings and time stamp for each measurement and records each reconnection and each movement of the test port cable. Each of these actions generates an uncertainty contribution. The measurement journal allows for user entries and adds benefit to quality management by serving as a proper documentation of the entire measurement process.

VNA Tools is built on an uncertainty propagation engine [30], which performs the tedious task to propagate all generated uncertainties to the end result, usually the error corrected S-parameters of the DUT. This is done in a fully multivariate way, taking all correlations into account and following [5].

Key features and basic principles of this software are described in detail in [16]. It should be emphasized though that the uncertainty propagation mechanism is based on a concept that accounts for the dependencies on basic influences. Instead of storing uncertainties and correlations, the derivatives with respect to the basic influences are stored and updated with each computational step. Together with the uncertainties associated with the basic influences, the necessary information is available to calculate uncertainties and correlations on demand at any time by applying the basic equation of linear uncertainty propagation.

Correlations are considered in a natural way by recognizing common influences. *VNA Tools* is therefore able to recognize correlations between different DUTs (cross-component correlation) and even cross-frequency correlations. Cross-component correlation is useful to improve the reliability of measurement uncertainty in general, e.g. when using a VNA calibration kit that has been characterized with cross-component correlation. Cross-frequency correlation becomes important, if S-parameters are e.g. transformed to the time domain.

Finally, the concept of keeping track of dependencies allows specifying an uncertainty budget without much effort. As previously mentioned, this is a mandatory and useful outcome of any uncertainty analysis. An uncertainty budget also helps to understand which investments (calibration kit, test port cable, VNA hardware, etc.) are most beneficial to increase measurement accuracy.

VNA Tools supplements the new VNA guide in an ideal way. The guide provides practical instructions on how to characterize basic influence quantities of VNA measurements and how to apply best measurement practice. *VNA Tools* is taking care of the technically and scientifically demanding tasks of setting up a measurement model and propagating uncertainties.

8. Conclusion

The updated EURAMET cg-12 guide takes account of recent developments in VNA metrology and presents a forward looking and GUM-compliant approach to assess the measurement uncertainty of S-parameters. Software solutions, which are necessary to implement the improved methodology, are nowadays available.

Apart from instructions on measurement uncertainty evaluation, the new guide is supplemented by practical information. This includes the selection of appropriate VNA calibration procedures, criteria for verification measurements, advice on instrument settings, handling of cables and connectors, and aspects related to the measurement setup. These instructions are intended to ensure high quality measurement practice.

One should keep in mind that measurement models are just approximations to reality. For a reliable estimation of the measurement uncertainty, a high metrological standard in practical measurements is therefore essential.

References

[1] P. I. Somlo and J. D. Hunter. *Microwave Impedance Measurements - IEE electrical measurement series; 2*. Peter Peregrinus Ltd, London, UK, 1985.

[2] M. Hiebel. *Fundamentals of Vector Network Analysis*. Rohde & Schwarz, 2007. ISBN 978-3-939837.

[3] V. Teppati, A. Ferrero, and M. Sayed, editors. *Modern RF and Microwave Measurement Techniques*. Cambridge University Press, 2013. ISBN 978-1-107-03641-3.

[4] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML. *Evaluation of Measurement Data - Guide to the expression of uncertainty in measurement*, 2008. JCGM 100:2008; available at www.bipm.org/en/publications/guides/gum.html.

[5] BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML. *Evaluation of measurement data - Supplement 2 to the "Guide to the ex- pression of uncertainty in measurement" - Extension to any number of output quantities*, 2011. JCGM 102:2011; available at http://www.bipm.org/en/publications/guides/.

[6] *Guidelines on the Evaluation of Vector Network Analysers, EURAMET cg-12*, 3.0 edition, 2018; available at https://www.euramet.org/publications-media-centre/calibration-guidelines/.

[7] B. Weinschel. Air-Filled Coaxial Lines as Absolute Impedance Standards. *Microwave Journal*, pages 47 – 50, April 1964.

[8] J. Hoffmann, P. Leuchtmann, J. Ruefenacht, and K. Wong. S-parameters of Slotted and Slotless Coaxial Connectors. In *ARFTG Conference Digest*, number 74, pages 1 – 5, 2009.

[9] J. Hoffmann, P. Leuchtmann, and R. Vahldieck. Pin Gap Investigations for the 1.85 mm Coaxial Connector. In *Proceedings of the 37th European Microwave Conference*, number 76, pages 388 – 391, 2007.

[10] IEEE. *IEEE 287-2007 Standard for Precision Coaxial Connectors (DC to 110 GHz)*, 2007.

[11] K. Wong and J. Hoffmann. Improve VNA Measurement Accuracy by Including Connector Effects in the Models of Calibration Standards. In *ARFTG Conference Digest*, number 82, pages 1–7, 2013.

[12] J. Hoffmann, J. Ruefenacht, M. Wollensack, and M. Zeier. Comparison of 1.85mm Line Reflect Line and Offset Short Calibration. In *ARFTG Conference Digest*, number 76, pages 1 – 7, 2010.

[13] N. M. Ridler and M. J. Salter. An approach to the treatment of uncertainty in complex S-parameter measurements. *Metrologia*, 39:295 – 302, 2002.

[14] B. D. Hall. Computing uncertainty with uncertain numbers. *Metrologia*, 43:L56 – L61, 2006.

[15] B. D. Hall. Object-oriented software for evaluating measurement uncertainty. *Meas. Sci. Technol.*, 24:055004, 2013.

[16] M. Zeier, J. Hoffmann, and M. Wollensack. Metas. UncLib - a measurement uncertainty calculator for advanced problems. *Metrologia*, 49:809– 815, 2012.

[17] M. Wollensack, J. Hoffmann, J. Ruefenacht, and M. Zeier. VNA Tools II: S-parameter uncertainty calculation. In *ARFTG Conference Digest*, number 79, pages 1 – 5, 2012.

[18] METAS VNA Tools, available at www.metas.ch/vna-tools.

[19] NIST Microwave Uncertainty Framework, available at www.nist.gov/ctl/rf-technology/related-software.cfm.

[20] Dynamic uncertainty for S-parameters, Option 015, Keysight Technologies, available through www.keysight.com.

[21] B. D. Hall. VNA error models: Comments on EURAMET/cg-12/v.01, 2010. ANAMET Report 051.

[22] J. Stenarson and K. Yhland. Residual error models for the SOLT and SOLR VNA calibration algorithms. In *ARFTG Conference Digest*, number 69, pages 133 – 139, 2007.

[23] F. Mubarak and G. Rietveld. Uncertainty Evaluation of Calibrated Vector Network Analyzers. *IEEE Trans. Microwave Theory & Tech.*, PP(99):1 – 13, 2017.

[24] R. Judaschke, G. Wuebbeler, and C. Elster. Second-Order Error Cor- rection of a Calibrated Two-Port Vector Network Analyzer. In *ARFTG Conference Digest*, number 73, pages 1–3, 2009.

[25] G. Wuebbeler, C. Elester, T. Reichel, and R. Judaschke. Determination of the Complex Residual Error Parameters of a Calibrated One-Port Vector Network Analyzer. *IEEE Trans. Instr. & Meas.*, 58(9):3238 – 3244, 2009.

[26] J. Stenarson and K. Yhland. A new assessment method for the residual errors in SOLT and SOLR calibrated VNAs. In *ARFTG Conference Digest*, number 69, pages 140 – 145, 2007.

[27] M. Garelli and A. Ferrero. A Unified Theory for S-Parameter Uncertainty Evaluation. *IEEE Trans. Microwave Theory & Tech.*, 60(12):3844 – 3855, 2012.

[28] M. Zeier, J. Hoffmann, P. Hürlimann, J. Rüfenacht, D. Stalder, and M. Wollensack. Establishing traceability for the measurement of scattering parameters in coaxial line systems. *Metrologia*, 55:S23 – S36, 2018.

[29] Documentation on VNA Tools (math reference and data formats), available at www.metas.ch/vnatools.

[30] METAS UncLiB, available at www.metas.ch/unclib.

Authors

Markus Zeier (markus.zeier@metas.ch) received a Dipl. Phys. degree and PhD in experimental nuclear physics from the University of Basel, Switzerland, in 1993 and 1999. He is currently with the RF & Microwave Laboratory of the Federal Institute of Metrology METAS, Switzerland. His research interests are in RF & Microwave metrology and measurement uncertainty evaluation.

Johannes Hoffmann received a Dip. Ing. degree in electrical engineering from the University of Stuttgart, Germany, in 2005, and an Ing. degree from the Ecole Nationale Superieure des Telecommunications (ENST), Paris France, in 2005, in the course of a double diploma program. In 2009 he received a PhD from ETH Zurich, Switzerland. He is currently with the RF & Microwave Laboratory of the Federal Institute of Metrology METAS, Switzerland. His research interests are in general measurements, which involve microwaves, uncertainty calculation and numerical modeling.

Juerg Ruefenacht received a Bachelor's degree in electrical and electronic engineering from the Bern University of Applied Sciences, Bern, Switzerland, in 1986. From 1986 to 1998, he was with the Research and Development Department, Swisscon (formerly Swiss PTT). In 1998, he joined the Federal Institute of Metrology METAS, Switzerland, where he is currently with the RF & Microwave Laboratory.

Michael Wollensack received a Bachelor degree in electrical and electronic engineering from the Bern University of Applied Sciences, Bern, Switzerland, in 2003. Since then, he's been with the RF & Microwave Laboratory, METAS Bern. His research interests are metrological and scientific software, VNA calibration algorithms and VNA measurement uncertainty calculation.

A previous version of this article was first published in tm - Technisches Messen, *Volume 84, Issue 5, online: 2017-01-11, DOI: https://doi.org/10.1515/teme-2016-0061.*

Rules & Tools for Creating a Metrology Taxonomy

Hannah Eilers, Michael Schwartz
Cal Lab Solutions, Inc.

Introduction

The 141 MII (Measurement Information Infrastructure) & Automation Committee of NCSLI (National Conference of Standards Laboratories International) has been working to develop a new standard for the exchange of measurement data between systems. The overall goal is to create a set of standard, machine-readable formats for data such as calibration data found in certificates of calibration, instrument specifications, and scopes of accreditation. The concept of MII began as a paper presented at the Measurement Science Conference (MSC) in 2013 by Mark Kuster, titled "Metrology: Standardize and Automate!" [1]. Since then, Mark has expanded upon the concept through a series of articles in NCSLI's *Metrologist* [2], and members of the MII & AC have developed tools to aid in these objectives. The latest tool developed is the MII Taxonomy Builder form, an online form for MII & AC participants to go in and contribute their industry specific knowledge.

The focus of this paper is on the MII development team's progress in 2018 and is supplemental to "Creating a Taxonomy for Metrology" [3].

Calibration Lab Search

We wanted to show the potential value the MII technologies could bring to the market, so we started with a focus on the smallest data set. A calibration lab scope of accreditation proved to be a great starting point. The group proceeded to create a units of measure reference database and schema for holding data. Next, Qualer started gathering all US based scopes of accreditation, a total of 1601 with over 250 thousand CMCs (Calibration Measurement Capabilities). From that data, a search site was created in 2016; users can search all of the accredited calibration labs from around the world at http://search.qualer.com.

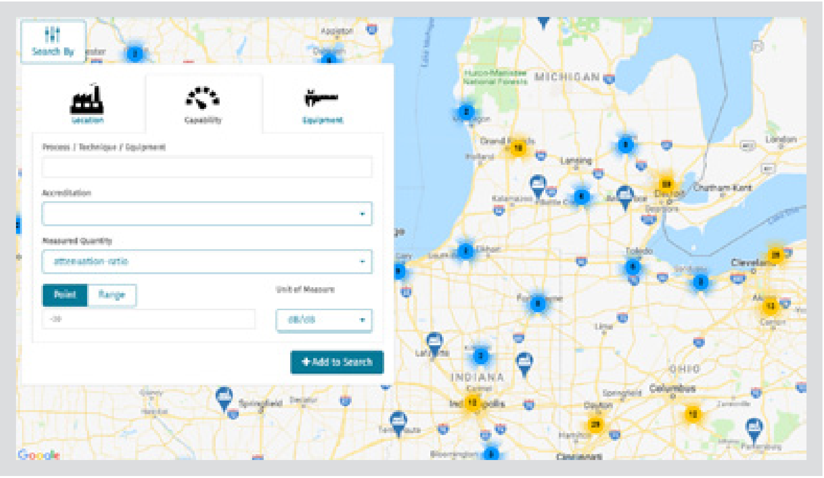


Figure 1. The robust search function of Qualer search allows the user to narrow down results and find exactly what they are looking for more quickly.

The Qualer search website allows users to search for a calibration lab based on a variety of filters such as location, capability, equipment, or specific accreditation type (Figure 1). Users can perform a search based on the unit of measure and uncertainty requirements. The examples we use in our demos of the technology was finding a lab which could calibrate 100 °C, then 1300 °C. Participants could see many labs could perform 100 °C, but not so many could do 1300 °C.

Basic Search

This search tool could quickly locate a calibration lab that works with temperature, but lacked the ability to search into finer detail. Does the lab source or measure temperature? Is it real or simulated? Is it RTD or thermocouple? What type of thermocouple? All we could discern from the search was that a lab supported temperature calibration in Celsius. Now we have to contact them or read their scope of accreditation. Not perfect, but better than a a Google search and a valuable first step.

Today, the search tool is more than a year out-of-date, but it serves as a good learning tool. Anyone can use the Qualer search tool to find a calibration lab with specific capabilities. We use the Qualer search tool during any demonstrations or paper presentations to show the potential of the MII related technologies. The Qualer search uses 1601 SoAs which means 800 of them are updated every year, 66 every month. On average 10,000 CMC lines would have to be reviewed and updated every month to keep this database current. With these weaknesses in mind, it makes more sense to have a search tool.

The biggest discovery was the need for a more specific descriptor on the CMC line. This became very apparent as we found oddities in the data set. For example, a lab had to be contacted to clarify "fpm" for them meant flashes per minute when it was wrongly assumed as a completely different measurement. It was decided the next project phase would focus on a much needed measurement "taxonomy." Creating something similar to a biological taxonomy for living organisms, this measurement taxonomy would specify key measurement information to help clarify any possible confusion with regard to test or measurement types.

The Reason for Taxonomy

The MII & AC is actively working to build this reference taxonomy database. Our initial focus will be on the measurement calibration labs from the 1601 scopes of accreditation we have already collected. This is part of the MII & AC's overall goal of creating a machine-readable format for exchanging measurement data between computer systems.

This measurement taxonomy database is meant to be a working reference database of measurement categories or type-definitions. It will define the broad parameters of each measurement without specific information related to the measurement technique or specific equipment being used. Taxonomy is needed because a unit of measure can be extremely vague. For example, without knowing the type of measurement, an angle measurement of "120°" could be easily misinterpreted. Is it a physical angle? Maybe an electrical phase? Or even a torque angle measurement? Unless you know exactly what the nature of the measurement is, mistakes interpreting a measurement can be easily made. These miscommunications cost time and money to support customers and rework solutions. In this is the value of a taxonomy database; to provide specific information about the data beyond the simple unit of measure.

Metrology Experts Needed

We see this taxonomy reference database as part of the core foundation to exchange metrology data between systems. That is why it's imperative to create a solid foundation to further build on. This is not an easy task. Across the industry, engineers have created multiple names for the same measurement, same specification, and same CMC definition. A bandwidth test on an oscilloscope, a frequency response test on a spectrum analyzer, or a flatness test, are all fundamentally the same test. The user creates a reference power level at a specified frequency and changes the frequency while keeping the power level consistent.

We need involvement from the metrology community and we need experts to help define these generic taxonomy measurement definitions. Measurements we have defined here have taken several discussions in the MII group in order to agree on each definition. We need as many experts as possible to talk through each measurement from a variety of perspectives, from the NMI (National Metrology Lab) to the production lab.

Consider the taxonomy key "Source.Volts.AC.Sinusoidal." This example demonstrates the need for industry expertise. If we agree "Source.Volts.DC" is a good definition for DC voltage, we cannot use "Source.Volts.AC" for AC voltage, because we don't know the waveform shape (sinewave, squarewave, triangle wave, arbitrary waveform, pulse). If the voltage measurement of an AC signal is in RMS voltage, we don't need specific knowledge of the signal type, unless we need to convert from (or to) volts peak to peak.

Also, as part of the taxonomy definitions, we must include any specific properties. In the "Source.Volts.AC.Sinusoidal" example, we need two properties: volts RMS and frequency. We can optionally define impedance in the property definition. Again, this is where industry experts are needed to contribute their opinions on what influence quantities are required in taxonomy definitions.

Taxonomy Builder

The MII committee created a web-based user-friendly tool to help define this new taxonomy. Users can create complete definitions ready for community input and can use MII help documents for aiding in proper form completion. Additionally, there is a wikidot page (http://miiknowledge.wikidot.com/) guiding quantities and UoMs.

This online form, named the "MII Taxonomy Builder," requires 10 or more input fields, depending on the measurement being described. The form is divided into four sections: general information, input influence quantities, cross-reference sources, and deprecation information.

An important note: Currently only those on the MII & AC have access to the taxonomy builder form. The committee encourages newcomers from all measurement disciplines! We have virtual meetings, as well as in-person meetings during the annual NCSLI Symposium (https://www.ncsli.org). Again, more information and references can be found on the wikidot page.

The first section of the MII Taxonomy Builder form prompts the user for details regarding the type of entry and whether it is of a source or measure type (see Figure 2). Quantity is the next required field, with a brief field definition below it to guide the user through the form. Process and description come last. The field of "taxonomy key" is built automatically by the form as the user gives more specific information.

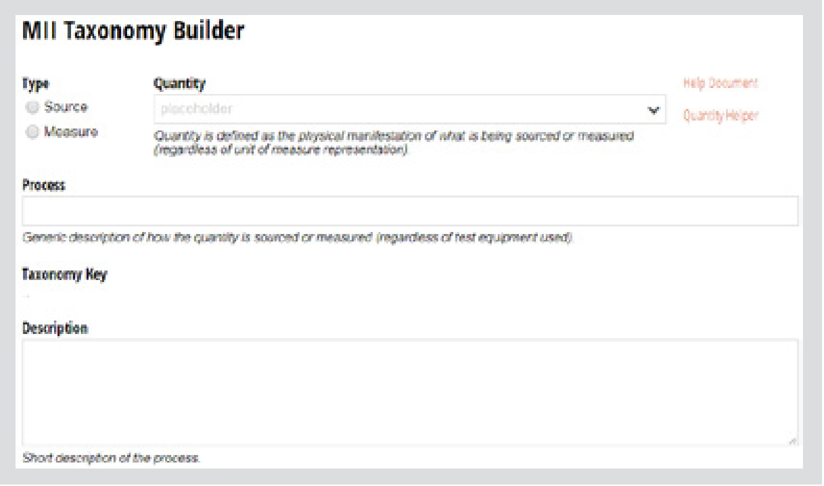


Figure 2. Screenshot from MII Taxonomy Builder form, section 1, covering general information and links to external documents.

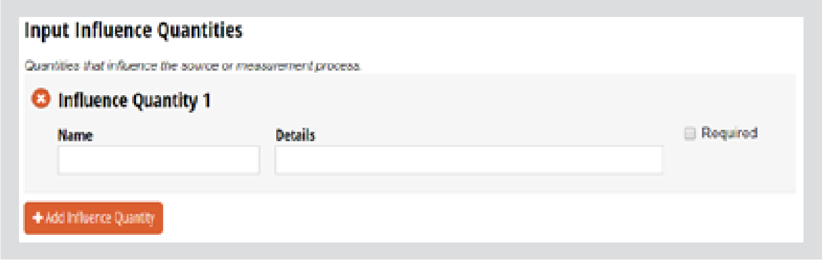


Figure 3. Screenshot from MII Taxonomy Builder form, section 2, covering input influence quantities.

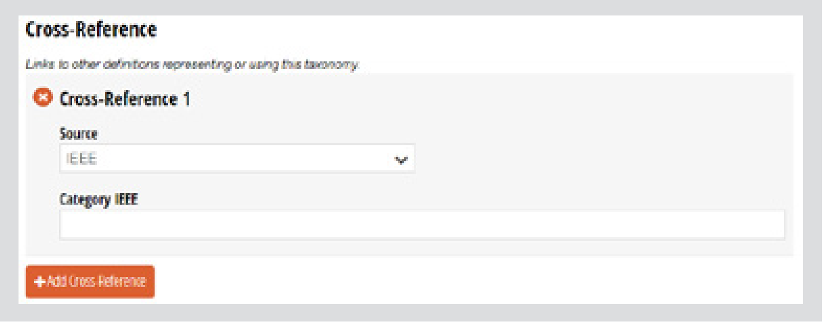


Figure 4. Screenshot from MII Taxonomy Builder form, section 3, covering cross-reference sources and categories (example source of IEEE used).

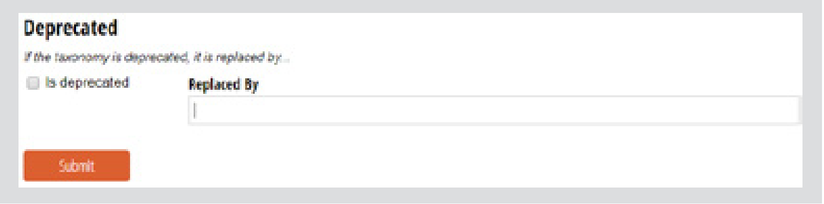


Figure 5. Screenshot from MII Taxonomy Builder form, section 4, covering deprecated taxonomy and replacement information.

Using "Source.Volts.AC.Sinusoidal" as an example: the user would select source, then volts from the quantity drop down, and type "AC.Sinusoidal" in the process text box. The form would then create the "Source.Volts.AC.Sinusoidal" as the taxonomy key. Finally, for the description, the user would need to type "Generate an AC voltage sinusoidal signal from a given voltage in RMS and frequency setting. Optionally, the input impedance may be specified."

In the second section of the form (Figure 3), the user will be asked for input influence quantities (they can add more if there are more than one). The checkbox indicates whether or not this input is required or optional. Influence quantities contain the properties of what is being generated or measured. Required quantities are the minimum inputs needed.

Using the "Source.Volts.AC.Sinusoidal" example, input influence quantity names would be "Voltage" and "Frequency" required and "Impedance" being optional.

The cross-reference section of the form allows for links to other organizations' categories for the taxonomy definition. The form will prompt the user for more information depending on the cross-reference source they select. Figure 4 shows an example of IEEE being selected as the cross-reference source. The form automatically expands to include an IEEE category field asking for more information. Additional sources can be selected, including BIPM (KCDB), ANAB, ISO 80000, NVLAP, NCSLI RP-9, NIST SP-811, SI, and others.

The deprecated section (Figure 5) is here because we know we will not get every taxonomy definition 100% correct with the first release of the standard. When a definition for "Source.Volts.AC" is deprecated, it can be replaced by "Source.Volts.AC.Sinusoidal" which is a better taxonomy definition. A user can mark a taxonomy as deprecated in section four by checking the box and including information in the "Replaced By" field.

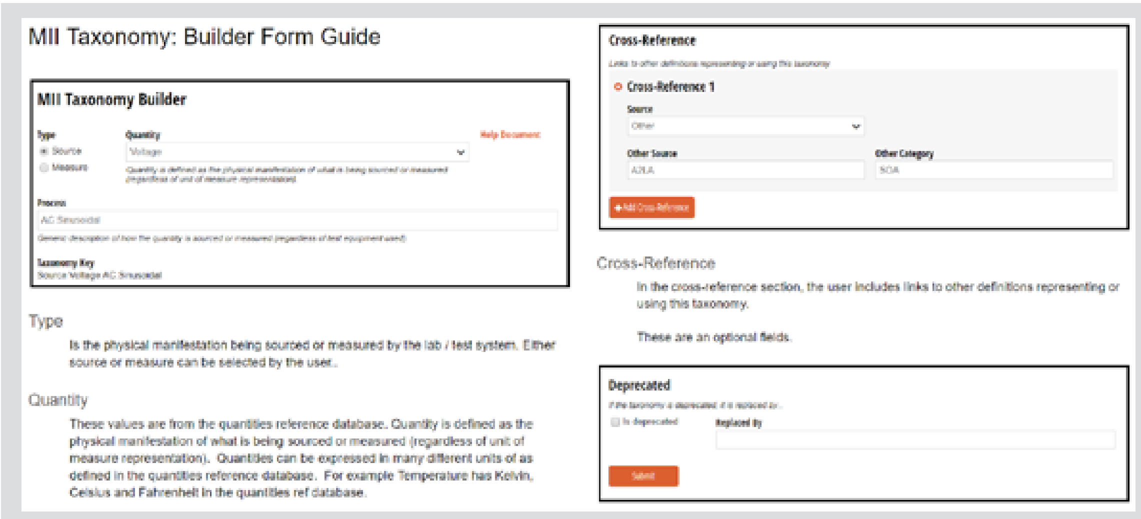


Figure 6. Screenshots from the online help document for the MII Taxonomy Builder form.

In Figure 6, we see the online help document for the taxonomy builder form. The full help document can be accessed here: https://docs.google.com/document/d/1F75c9C4oAw5o-y2u7nlyeqh4C4E1K7qVG7xGzcn_Y0Y/edit?usp=sharing. This form includes in-depth descriptions of exactly what information should be included in the form. The help document goes over every field of the taxonomy builder form and includes a series of useful references, an example SOA document, as well as a UoM database XML link. For first-time users, this help document is an absolute must read, as some of the field names can be misinterpreted and the wrong information passed into the taxonomy builder form.

The wikidot page is a working units of measure table with an ontology mapping of alternate representations (Figure 7). This table covers 110 different quantities in the units of measure columns (UoM1-UoM5). This level of specification is paramount in the concise building of the measurement taxonomy.

Community Involvement

Measurement community members are encouraged to participate in the transfer of instrument specifications, scopes of accreditation, and testing/calibration certificates. Since the internet became commonplace in daily business, scientists and engineers in the measurement community have envisioned a way for machines to remotely communicate with each other in order to increase efficiency. Unfortunately, concise communication has been thwarted by a lack of standardization. A common taxonomy between systems is a first big step in the overall goal of machine communication. When machines are given common definitions specific to each category of measurement, we can use machines to communicate across industries and disciplines worldwide.

Interested in sharing your knowledge or learning more? For more information, be sure to visit the wikidot page (http://miiknowledge.wikidot.com/).

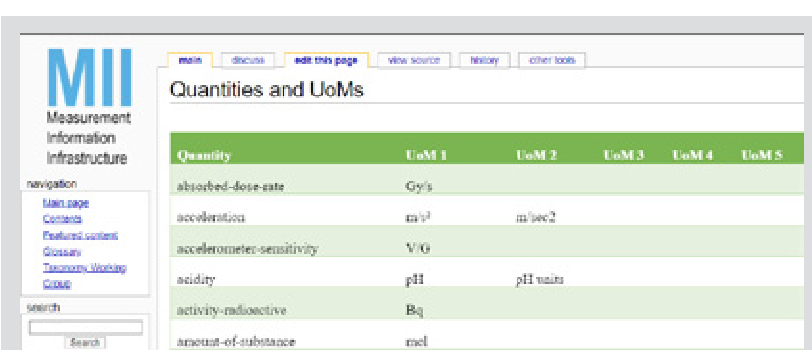


Figure 7. The wikidot page helps the technician user with aspects of quantity and UoMs for the MII Taxonomy Builder form.

References

[1] Available online: https://www.callabmag.com/metrology-standardize-and-automate/.

[2] NCSLI *Metrologist* online: http://www.ncsli.org/mo

[3] Schwartz, Michael, "Creating a Taxonomy for Metrology," *CAL LAB: The International Journal of Metrology*, Vol. 25, No. 1, p31-37. Available online: https://www.callabmag.com/creating-a-taxonomy-for-metrology/.

Starrett High Performance Automatic Vision System

ATHOL, MA U.S.A. (December 12, 2018) - The L.S. Starrett Company (http://www.starrett.com), a leading global manufacturer of precision measuring tools and gages, metrology systems and more, has introduced its AV450 Automatic Vision System. Versatile, accurate, fast, and American made, the new 3-axis vision system allows users to cost-effectively achieve high throughput in their inspection process, and is ideal for both repetitive, larger part-run applications and routine quality assurance.

Featuring a larger X,Y,Z measuring envelope of 18" x 14" x 8" (457 mm x 356 mm x 203 mm), the Starrett AV450 has high-resolution video zoom optics and it can be pre-programmed (CNC) for repetitive part inspection, or driven manually via a trackball for individual measurements. With its highly stable mechanical design and precision linear bearings, smooth stage motion, maximum performance and throughput is easily attainable.

Throughput is further enhanced by either QC5000 or MetLogix™ M3 software that controls video edge detection and multiple-channel fiber optic or LED illumination. Computer-controlled Quadrant (LED) ring lighting, sub-stage lighting, and optional through-the-lens lighting meets the most challenging illumination requirements.

Accuracy of the Starrett AV450 Automatic Vision System is 2.5 + 5L/1000 and reading resolution is 4 µin (0.1µm).

Magnification on a 24" monitor, 1:1 pixel setting is 37x to 240x 6.5:1 zoom and 25x to 300x with a 12:1 zoom. The system has a 1.3 mega-pixel color digital video camera and a precision granite base.

The AV450 has an external motion control unit and includes a Windows®-based operating system with an operator interface via a desktop PC with a 24" touchscreen monitor, as well as Wi-Fi network connectivity.

CAD files can be imported/ exported and reports can be generated and archived. M3 metrology software supports 3-axis measurements and 2D geometric constructs (such as points, lines, angles, rectangles and slots) and corrections for level, skew and datum origin. Touch-screen functionality with a pinch, swipe and touch provides intuitive operation for all users.

Options for the AV450 include a Renishaw touch probe kit, Optimet laser probe, 0.5x, 1.5x and 2.0x auxiliary lenses, an LED dark-field quadrant illuminator and a DXF/ field-of-view option for automatic comparison to CAD files. Other options include a CNC rotary axis fixture, touch probe change rack, calibration standards, part fixtures and workholding devices.

For more information on the AV450 Automatic Vision System visit (http://www.starrett.com/metrology/product-detail/AV450) or contact Mark Arenal at 949-348-1213, marenal@starrett.com or contact The L.S. Starrett Company, 121 Crescent Street, Athol, MA 01331 U.S.A. Telephone: (978) 249-3551, Fax: (978) 249-8495, email: general@starrett.com, internet: (http://www.starrett.com).

About The L.S. Starrett Company

Founded in 1880 and headquartered in Athol, MA U.S.A., The L.S. Starrett Company (http://www.starrett.com) is a leading global manufacturer of precision measuring tools and gages, optical comparators and vision systems and force and hardness testing solutions. Starrett also manufactures laser measurement systems, custom engineered granite solutions, custom gaging, band saw blades, power tool accessory saw blades, workshop tools and jobsite tools. The Starrett brand is recognized throughout the world for exceptional quality and precision. Skilled personnel, superior products, manufacturing expertise, innovation and excellent service and support have earned Starrett its reputation as the "World's Greatest Toolmakers". Starrett has over 1,600 employees worldwide and annual sales exceeding $200 million. The company has six manufacturing locations in the U.S.A., including facilities in Massachusetts, North Carolina, Georgia, Ohio, Minnesota and California. Starrett also has three international manufacturing facilities. Plants are located in Brazil, Scotland and China, in addition to distribution centers and offices located worldwide. The L.S. Starrett Company is publicly traded on the NYSE, symbol SCX.

NEW PRODUCTS AND SERVICES

New Humidity Generator by Thunder Scientific

The Model 2900 Automated Humidity Generation System is a self-contained system and provides an extremely accurate means of producing atmospheres of known humidity using the fundamental "two-pressure" principle. This system is capable of continuously supplying relative humidity, dew point, frost point, parts per million, or other calculated values for instrument calibration and evaluation as well as for precision environmental testing. This system will automatically generate manually entered humidity and temperature set points in addition to user created multipoint profiles. All desired humidity's, temperatures, flow rates, and time intervals may be programmed.

Features

- Traceable to SI
- 0.5% of Reading RH Uncertainty
- High Flow Capability of 50 L/min
- Based on NIST Proven "Two-Pressure" Principle
- HumiCalc® with Uncertainty Mathematical Engine
- Embedded ControLog® Automation Software
- Generate: RH, DP, FP, PPM, Multipoint Profiles
- Externally Driven Chamber Fan
- Multi-point Touch LCD
- Fluid Jacketed Chamber Door

For more information, visit: https://www.thunderscientific.com/humidity_equipment/model_2900.html.

New Thermo-Anemometer from AEMC®

The new model 1227 Thermo-Anemometer from AEMC® is designed to record temperature, air velocity and airflow. It is battery powered, compact, lightweight, and simple-to-use with direct access to all functions. All measurement results are easily accessible on the instrument's front panel simply by pressing 1 button.

Measurements can be displayed and recorded in user selectable English and metric units. Using the MAP mode function it can be manually triggered to record spot readings to create point by point maps of air speeds within an area or it can be set for automatically timed recording sessions. User selectable configuration, data analysis, and report generation can be accomplished with the free DataView® software included with the logger.

Key Features of the AEMC® 1227 Include:

- Compact, lightweight, and simple-to-use
- Data logging function stores 1 million measurements per channel
- Single button function access
- Min, Max, and Average measurements available
- USB and Bluetooth communication
- Blue electroluminescent backlit display
- Battery or USB powered
- Includes FREE DataView® software for data storage, real-time display, analysis, and report generation

Applications:

- Greenhouses and environmental studies
- HVAC installation and maintenance
- Office environments, labs, factories, schools
- Weather monitoring

For more information on the 1227 Thermo-Anemometer from AEMC® or to find the ideal solution for your application-specific needs, contact a CAS Data Logger Applications Specialist at (800) 956-4437 or visit our website at www.DataLoggerInc.com.

NEW PRODUCTS AND SERVICES

Additel Precision Controller and Pressure Module

We are pleased to introduce our new precision accuracy ADT160A pressure modules and ADT780 series controllers with an improved accuracy to 0.01% of reading from 30% to 100% of span. These new precision sensors have been specially selected and treated to give you the best performance in your pressure module or controller. These new absolute sensors are available from vacuum ranges to 1,000 psia (70 bar.a). The 0.01% of reading specification is a 1-year specification including long-term stability, calibration uncertainty and hysteresis.

- ADT160A and Controller models ranging from vacuum to 1,000 psia (70 bar.a)
- Precision accuracy to 0.01% of reading (1-year specification including long-term stability, calibration uncertainty, and hysteresis)
- Specification for most models is 0.01% of reading from 30% to 100%FS
- New precision sensors are available in all controller configurations or can be used externally as an ADT160A pressure module.

Product Availability

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

About Additel

Additel Corporation is one of the leading worldwide providers of process calibration tools. Additel Corporation is dedicated to the design and manufacture of high-quality handheld test tools and portable calibrators for process industries in precision pressure calibration and test instrumentation. With more than 18 years in the industry, Additel has successfully developed Dry Well Calibrators, Pressure Controllers, Portable Automated Pressure Calibrators, handheld Digital Pressure Calibrators, Documenting Process Calibrators, Multifunction Process Calibrators, Digital Pressure Gauges, and various Calibration and Test Pumps.

AW-Lake FAC-S™ Analog Output Sensor

Oak Creek, Wisconsin-November 13, 2018- AW-LAKE COMPANY introduces the FAC-S™ Analog Output Sensor that hardwires with any flow meter to provide voltage, current or Bluetooth connectivity of readings. Ideal for use on any AW-Lake Gear or Turbine Flow Meter, the FAC-S produces a scalable voltage or current output for download to a PLC or other control system. The sensor also supports a Bluetooth interface for remote programming and flow monitoring from a smart phone. The microprocessor-based FAC-S Sensor supports process monitoring, data acquisition and signal conditioning in various industries.

A Bluetooth-enabled mobile app connects to the FAC-S, enabling wireless setup and troubleshooting from a mobile device. Workers no longer need to walk to/from the device to monitor or adjust equipment. Instead, initial setup and programming tasks is performed from the convenience of a smart phone or tablet. The mobile application also supports basic scaling and advanced functions, allowing for remote correction of non-linear flow meters to keep a linear analog output. Using the Bluetooth mobile application, users have a wireless flow monitor in their hands!

The FAC-S Analog Output Sensor features a large input range from 0.25Hz to 5,000 Hz with five user-selectable outputs including 4-20mA, 0-5V, 1-5V, 0-10V, and 2-10V. It joins the FAC-R, a remote version that interfaces with flow meters, tachometers, pumps, motors and linear/rotational encoders.

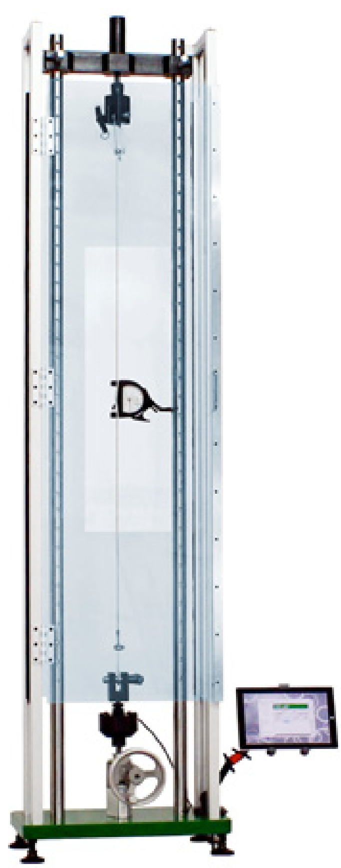
For more information on the FAC-S Analog Output Sensor, refer to the website at https://aw-lake.com/product/fac-s-analog-output-sensor-with-bluetooth/ or contact Marcia Reiff, Marketing Manager, at 800-850-6110, e-mail mreiff@aw-lake.com.

NEW PRODUCTS AND SERVICES

Morehouse Instrument Company Offers New Mechanical Tensiometer Calibrator

York, PA, January 3, 2019 – Morehouse Instrument Company has introduced new mechanical force calibrating machine. Mechanical Tensiometer Calibrator (model PCM-2MD-T1) is an easy-to-use solution for problems associated with calibrating force instruments and cable tension meters (tensiometers) up to 2000 lbf capacity. This machine provides the user with fine and stable control on the applied force and offers a large working area which long enough to test tensiometers on standard cables lengths of up to 5 ft. The system has several time-saving features that eliminate the need for stacking weights and enable a quality force calibration on a wide range of force sensors such as shear web load cells, S-type load cells, force gauges, button load cells, beam load cells, etc.

Morehouse Mechanical Tensiometer Calibrator provides safety, convenience, and fast turnaround for your force calibration laboratory by its all-around safety shield, fine calibration force control, and versatility in calibrating a large variety of instruments. For more information, visit: https://www.mhforce.com/ or call +1 (717) 843-0081.



Trade-In Program for New Digital Deadweight Tester

San Marcos, Texas, January 2019 – CPD8000 and DPG10 users may now trade their devices in and upgrade to the CPD8500 Digital Deadweight Tester. This program allows users to have the absolute CPD8500 chassis, new interface, removable environmental module, precision vacuum and barometric transducer, and an internal automatic lubrication box while retaining the internal load cell of their original instrument. Trade-in customers receive credit on the new CPD8500 in lieu of the usable parts from their existing instrument.

With the CPD8500, users maintain the original instrument's functionality and can also linearize the load cell and calibrate the various internal sensors with an in-instrument 11-point calibration and adjustment menu. The instrument's software is now equipped with a warning system which improves troubleshooting and helps prevent piston damage.

The design of the new CPD8500 houses all its sensors in one sturdy, low vibration case. Sensors are completely removable and interchangeable. The environmental module features ambient temperature, pressure and humidity sensors to detect changing ambient conditions and their impact on measurements. Accessory hardware is reduced as the CPD8500 includes its own internal lubrication box. The motor life has been extended to two years.

Mensor can upgrade existing CPD8000s with functional absolute bases manufactured after January 2012. All trade-ins would be inspected to ensure functionality of the load cell and to determine if an upgrade is possible. The CPD8500 upgrade has a limited warranty.

For upgrade configuration requirements and full warranty details, visit www.mensor.com, or contact us to request a quote.

AUTOMATION CORNER

Software is Cheaper Labor

Michael Schwartz
Cal Lab Solutions, Inc.

Over the years I have watched several labs go through the decision process to purchase new hardware. Most labs have the same process: look at the work load requiring the new hardware, and calculate the payback of new equipment. Upper management usually wants to know what the Return on Investment (ROI) looks like. And the numbers usually speak for themselves. The only variable is usually the time frame—how soon does spending this money save the company money?

If getting a new calibrator for the lab would end up making the lab more money, it would be a good investment. So if a new calibrator costs $60,000, with an annual calibration of $4,000, it costs a total of $64,000. If the company wants to see a ROI within one year, the manager would have to show the $64,000 will make the company at least $64,000 within one year.

As a programmer, what has always annoyed me is how software has such little value compared to hardware! Management gets sticker shock for software but not for hardware.

So let's continue with the above example. Buying a new calibrator can at best double the workload. Whereas software can double, triple even quadruple the workload. In fact, 4x the throughput with automation is not uncommon—it's the average. So why is software so undervalued?

I recently quoted a customer $4,000 for a Yokagawa WT3000 calibration procedure. This was the first time I quoted this customer and I know it was sticker shock. But a manual calibration of this hardware is six hours, while automation can run in just one (6x the time savings). A customer supporting 10 of these units could save $6,250 per year as $125/hour loaded shop rate. The math is simple: 10 * 5 * $125 (#Units * SavedHours * ShopRate). The software would pay for itself after just seven calibrations.

I understand if a lab only supports one or two of these units; the justification is not there, but the argument for spending money on automation should be easier than purchasing new hardware. In the above example, you still have five hours you can use that hardware for other work. Whereas if you would have spent money on new hardware before software you would have the additional cost of man hours to operate the hardware.

Two remote calibrations running on a $100 compute stick, using Metrology.NET.

I had this conversation with a lab manager I have known for years, and not surprisingly, he was in 100% agreement with me. He explained it from a lab management perspective: the real value is not only in the time savings but also in the cost of labor. Automation allows him to hire less skilled labor and that saves money in the long run—he is looking at the long-term problem the industry is facing.

His focus is on finding and training the next generation of calibration technicians, as he loses his more experienced technical staff. How will his lab operate 10 years from now? He envisions automation at the center. Because of the military draw down 20 years ago, there are less highly qualified calibration technicians. But with software, he can hire less skilled technicians, put them in front of a computer, then use his higher skilled technicians to problem solve and train the newer people—a logical division of labor, like the doctor and the nurse.

This lab manager doesn't see the purchase of software as a capital expense, but rather as a labor expense. So, the $4,000 for the software gets wrapped into the $125/hour loaded shop rate. If he can pay a technician $17 per hour vs. $35 per hour, that gives him a budget of $37,500 per year to spend on software. I thought this was genius, I've always said "Your best employee was a $1,500 computer with a GPIB card," but never took the time to do the math per technician costs as opposed to per procedure cost justifications.

Software is not only cheap labor, but will save you calibration time in the long run, reduce hardware costs, and lower labor costs of a high quality calibration lab. ❧

49th Annual

MSC Training Symposium

Disneyland Resort and Hotel
Anaheim, California | April 16-19, 2019

2019

ADVANCEMENTS IN **MEASUREMENT** TECHNOLOGIES

- NIST Seminars
- Tutorial Workshops
- ASQ - CCT Training
- Symposium Sessions
- Exhibit Hall

Register Online

annualconf.msc-conf.com/registration

Since 1979, the **MSC Training Symposium** has been a leader of education in the measurement community. This year's 2019 Symposium's theme is: *Advancements in Measurement Technologies*. As we approach the next decade, understanding the technological advancements in all areas of our industry are more important than in prior years. With new innovations comes the need to comprehend and educate. This year's symposium will offer numerous exceptional measurement related courses and technical sessions presented by industry professionals and innovative manufacturers.

INNOVATION SPOTLIGHT SPONSORS

Morehouse — THE FORCE IN CALIBRATION SINCE 1925

CalLab Solutions — Fusing Software With Metrology

Pond Engineering

Additel

Automatic Handheld Pressure Calibrator Introduction

Taking portable pressure calibration to a whole new level!

World's First Handheld Automatic Pressure Calibrator

- ***Fully automatic calibrator with built-in pump and controller***
- ***Switchable internal pressure modules for expandable ranges***
- ***Accuracy (1 year) of 0.02%FS***
- ***External pressure modules available (measure only)***
- ***Less than 4 lbs (1.8 kg) for handheld operation***
- ***Source pressure, measure pressure and electrical***
- ***Optional HART communications***
- ***Optional data logging and task documenting***
- ***USB, Wi-Fi, and Bluetooth communications***
- ***4 Channels***

Phone: 714-998-6899
Fax: 714-998-6999
E-mail: sales@additel.com

Corporate Headquarters
2900 Saturn Street #B
Brea, CA 92821, USA

Salt Lake City Office
1364 West State Rd. Suite 101
Pleasant Grove, UT 84062, USA

www.additel.com