CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

2014
APRIL
MAY
JUNE

The Effect of Cables and Shields on Traceability

Speed-of-Sound Measurements in Liquids Using Time-of-Flight Sensors

Uncertainty Estimation Based on Repeated Observations of a Population of Instruments

Laboratory Management: An Introduction

Electric Current Measurement

DS Series Current Transducers

±300A to ±3000A, 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

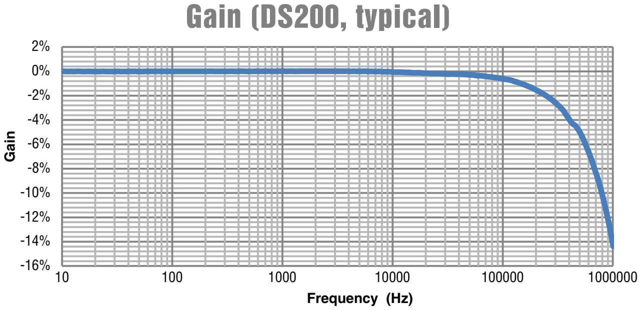
	DS200	DS600	DS2000
Primary Current, rms	200A	600A	2000A
Primary Current, Peak	±300A	±900A	±3000A
Turns Ratio	500:1	1500:1	1500:1
Output Signal (rms/Peak)	0.4A/±0.6A†	0.4A/±0.6A†	1.33A/±2A†
Overall Accuracy	0.01%	0.01%	0.01%
Offset	<20ppm	<10ppm	<10ppm
Linearity	<1ppm	<1ppm	<1ppm
Operating Temperature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

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

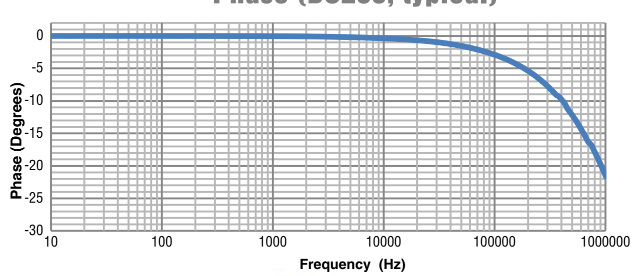
† Voltage Output options available in ±1V and ±10V

Gain / Phase

Gain (DS200, typical)



Phase (DS200, typical)



DSSIU-4 for Multi Channel Systems

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

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

DSSIU-4

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Volume 21, Number 2

FEATURES

16 **Metrology 101: The Effect of Cables and Shields on Traceability**
Jesse Morse

22 **Speed-of-Sound Measurements in Liquids Using Time-of-Flight Sensors**
Christoph von Rohden

25 **Uncertainty Estimation Based on Repeated Observations of a Population of Instruments**
Jonathan Harben

32 **Laboratory Management: An Introduction**
Kenneth Parson

DEPARTMENTS

2 Calendar
3 Editor's Desk
9 Industry and Research News
15 Cal-Toons by Ted Green
36 New Products and Services
40 Automation Corner

ON THE COVER: Sheila Casey of Los Alamos National Laboratory in New Mexico evaluates flatness of a 6-inch optical flat using a Zygo interferometer.

CONFERENCES & MEETINGS 2014

May 12-15 IEEE I&M International Instrumentation and Measurement Technology Conference (I2MTC 2014). Montevideo, Uruguay. http://imtc.ieee-ims.org/

May 13-16 ESTECH 2014. San Antonio, TX. "Launching Into the Future." http://www.iest.org.

May 20-24 METROLEXPO – 10th Anniversary. Moscow, Russia. http://www.metrol.expoprom.ru/en/.

May 29-30 IEEE Workshop on Metrology for Aerospace (MetroAeroSpace). Benevento, Italy. www.metroaerospace.org.

Jun 26-27 ASPE/ASPEN Summer Topical Meeting. Kohala Coast, HI. Manufacture and Metrology of Freeform and Off-Axis Axisymmetric Surfaces. http://aspe.net.

Jul 13-17 99th NCWM Annual Meeting. Detroit, MI. National Conference on Weights and Measures. https://www.ncwm.net/sems/event_detail/2014-annual-meeting.

Jul 15-17 North American Custody Transfer Measurement Conference. Denver, CO. http://www.ceesi.com/Training/CustodyTransferMeasurementConference.aspx.

Jul 21-24 Coordinate Metrology Systems Conference (CMSC). North Charleston, NC. www.cmsc.org.

Jul 28-31 NCSL International Workshop & Symposium. Orlando, FL. Measurement Science and the Environment. www.ncsli.org.

Aug 24-29 CPEM 2014. Rio de Janeiro, Brazil. Conference on Precision Electromagnetic Measurements. http://www2.inmetro.gov.br/cpem2014/.

Sep 3-5 11th Symposium on Laser Metrology for Precision Measurement and Inspection Industry (LMPMI). Tsukuba, Japan. http://lmpmi2014.jp/.

Sep 15-17 20th IMEKO TC-4 Symposium and Workshop. Benevento, Italy. http://www.imeko-tc4-2014.org/.

Sep 15-18 IEEE AUTOTESTCON 2014 – 50th Anniversary. St. Louis, MI. www.ieee-autotest.com

Sep 23-24 IMEKO TC-19 Symposium on Environmental Instrumentation and Measurement. Chemnitz, Germany. http://www.tu-chemnitz.de/etit/messtech/imeko/.

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EDITOR'S DESK

Legacies

"Easy come, easy go." Someone recently said this to me and it reminded me of the last time I heard it… several years ago, from a co-worker's husband who crashed a shiny, black Mercedes that his mom had just given them. When my co-worker realized her husband couldn't appreciate his own parent's hard work in order to provide well for their children, she knew it was the last straw and drove back home, far away from him. She understood what he could not—that there are those who want to build something solid for themselves, and every effort is a deliberate step in building a legacy for not only themselves, but for those around them as well, such as family or profession.

For many, we have a motivation to build a legacy where there is none before us. We do it for our children, our ego, or the greater good. Or maybe we honor the legacy by keeping it alive and relevant. Either way, the effort involved is extraordinarily admirable. The legacy ends up defining who we are, so when the owner passes on, the loss it bittersweet. Jay Bucher, who recently passed away this spring, was among those stalwart examples—builder of legacies.

In the end, there is no "easy come, easy go," because anything and everything worthwhile was hard won by someone before us.

❧

A big "Thank You" to our contributors this issue: Jesse Morse, Ken Parson, Jonathon Harben, and Christoph von Rohden!

We previously had an article on *connector* care (Oct-Dec 2012), so I was very pleased when Mr. Morse submitted his article for this issue's Metrology 101 on the use of *cables* and their impact on measurement results. Ken Parson has some great fundamentals to share for those in need of some direction in obtaining accreditation with his article "Laboratory Management: An Introduction." From his presentation from last year's Measurement Science Conference in Anaheim, Jonathon Harben provided us with his paper on "Uncertainty Estimation Based on Repeated Observations of a Population of Instruments." And finally, Christoph von Rohden contributed an interesting piece on "Speed-of-Sound Measurements in Liquids Using Time-of-Flight Sensors."

Enjoy!

Sita Schwartz

CALENDAR

SEMINARS: Dimensional

May 8, 2014 Gage Calibration Systems and Methods. Hoover AL. Mitutoyo Institute of Metrology. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

May 15-16, 2014 Hands-On Gage Calibration and Repair Workshop. Rochester, NY. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

May 19-20, 2014 Hands-On Gage Calibration and Repair Workshop. Manchester, MA. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Jun 2-3, 2014 Hands-On Gage Calibration and Repair Workshop. St. Louis MO. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Jun 5-6, 2014 Hands-On Gage Calibration and Repair Workshop. Schaumburg, IL. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Jun 9-10, 2014 Hands-On Gage Calibration and Repair Workshop. Bloomington MN. http://www.iictenterprisesllc.com/.

Jun 19-20, 2014 Hands-On Gage Calibration and Repair Workshop. Phoenix AZ. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Jun 23-24, 2014 Hands-On Gage Calibration and Repair Workshop. Oklahoma City OK. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Jul 15-17, 2014 Hands-on Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Jul 15-16, 2014 Hands-On Gage Calibration and Repair Workshop. Nashville TN. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Jul 17-18, 2014 Hands-On Gage Calibration and Repair Workshop. Colorado Spring CO. IICT Enterprises LLC. http://www.iictenterprisesllc.com/.

Aug 26-28, 2014 Hands-on Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Sep 30-Oct 2, 2014 Hands-on Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

Nov 4-6, 2014 Hands-on Gage Calibration. Aurora, IL. Mitutoyo Institute of Metrology. http://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/.

CALENDAR

SEMINARS: Electrical

May 13-15, 2014 MET-302 Introduction to Measurement Uncertainty. Everett, WA. Fluke Calibration. http://us.flukecal.com/training/courses/MET-302.

Jun 2-5, 2014 MET-101 Basic Hands-on Metrology. Everett, WA. Fluke Calibration. http://us.flukecal.com/training/courses/MET-101.

Jun 9-12, 2014 MET-301 Advanced Hands-on Metrology. Seattle, WA. Fluke Calibration. http://us.flukecal.com/training/courses/MET-301.

Sep 8-11, 2014 MET-101 Basic Hands-on Metrology. Everett, WA. Fluke Calibration. http://us.flukecal.com/training/courses/MET-101.

Oct 21-23, 2014 MET-302 Introduction to Measurement Uncertainty. Everett, WA. Fluke Calibration. http://us.flukecal.com/training/courses/MET-302.

Oct 27-30, 2014 MET-101 Basic Hands-on Metrology. Everett, WA. Fluke Calibration. http://us.flukecal.com/training/courses/MET-101.

Nov 17-20, 2014 MET-301 Advanced Hands-on Metrology. Seattle, WA. http://us.flukecal.com/training/courses/MET-301.

SEMINARS: Flow & Pressure

May 13, 2014 Principles and Practice of Flow Measurement Training Course. East Kilbride, UK. NEL, www.tuvnel.com.

Sep 9-11, 2014 Fundamentals of Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc. (CEESI) http://www.ceesi.com.

Sep 15-19, 2014 Comprehensive Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc. (CEESI) http://www.ceesi.com.

Sep 22-26, 2014 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. http://us.flukecal.com/Principles-of-Pressure.

Sep 24-26, 2014 Flow Measurement and Calibration. Munich, Germany. TrigasFI GmbH. http://www.trigasfi.de/.

Oct 6-10, 2014 Advanced Piston Gauge Metrology. Phoenix, AZ. Fluke Calibration. http://us.flukecal.com/training.

Nov 11, 2014 Principles and Practice of Flow Measurement Training Course. East Kilbride, United Kingdom. http://www.tuvnel.com/tuvnel/courses_workshops_seminars/.

Nov 17-21, 2014 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. http://us.flukecal.com/Principles-of-Pressure.

SEMINARS: General & Management

May 19-22, 2014 Effective Cal Lab Management. Everett, WA. Fluke Calibration. http://us.flukecal.com/lab_management_training.

May 21-22, 2014 Laboratory Performance Improvement Using Statistical Tools. Minneapolis, MN. WorkPlace Training. http://www.wptraining.com.

Oct 22-24, 2014 Cal Lab Management; Beyond 17025 Training. Boca Raton, FL. WorkPlace Training. http://www.wptraining.com.

Oct 27-28, 2014 **Cal Lab Benchmark Challenge: Hands on Electrical, Temperature, Pressure.** Boca Raton, FL. WorkPlace Training http://www.wptraining.com.

Nov 3-6, 2014 Effective Cal Lab Management. Everett, WA. Fluke Calibration. http://us.flukecal.com/lab_management_training.

SEMINARS: Industry Standards

Jun 16-20, 2014 Calibration Lab Operations/Understanding ISO 17025. Las Vegas, NV. Technology Training, Inc. http://www.ttiedu.com/schedule.html.

SEMINARS: Mass

Sep 8-19, 2014 Mass Metrology Seminar. Gaithersburg, MD. NIST / Office of Weights and Measures. http://www.nist.gov/pml/wmd/labmetrology/training.cfm.

SEMINARS: Measurement Uncertainty

May 27-29, 2014 Measurement Uncertainty (per ILAC P14 Guidelines). Lincoln, NE. WorkPlace Training http://www.wptraining.com.

Jun 17-18, 2014 Measurement Uncertainty (per ILAC P14 Guidelines). Boston, MA. WorkPlace Training http://www.wptraining.com.

Jun 26-27, 2014 Measurement Uncertainty (per ILAC P14 Guidelines). Anaheim, CA. WorkPlace Training http://www.wptraining.com.

Sep 9, 2014 Introduction to Measurement Uncertainty Training. Aberdeen, UK. http://www.tuvnel.com/tuvnel/courses_workshops_seminars/.

Sep 22-24, 2014 Measurement Uncertainty Training Course.

Loveland, CO. Colorado Engineering Experiment Station Inc. (CEESI) http://www.ceesi.com.

Oct 1-2, 2014 Measurement Uncertainty (per ILAC P14 Guidelines). Chicago, IL. WorkPlace Training http://www.wptraining.com.

Oct 30-31, 2014 Measurement Uncertainty (per ILAC P14 Guidelines). Boca Raton, FL. WorkPlace Training http://www.wptraining.com.

SEMINARS: Online & Independent Study

ASQ CCT (Certified Calibration Technician) Exam Preparation Program. Learning Measure. http://www.learningmeasure.com/.

AC-DC Metrology– Self-Paced Online Training. Fluke Training. http://us.flukecal.com/training/courses.

Basic Measurement Concepts Program. Learning Measure. http://www.learningmeasure.com/.

Basic Measuring Tools – Self Directed Learning. The QC Group, http://www.qcgroup.com/sdl/.

Basic RF and Microwave Program. Learning Measure. http://www.learningmeasure.com/.

Certified Calibration Technician – Self-study Course. J&G Technology. http://www.jg-technology.com/selfstudy.html.

Introduction to Measurement and Calibration – Online Training. The QC Group, http://www.qcgroup.com/online/.

Intro to Measurement and Calibration – Self-Paced Online Training. Fluke Training. http://us.flukecal.com/training/courses.

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

Measurement Uncertainty – Self-Paced Online Training. Fluke Training. http://us.flukecal.com/training/courses.

Measurement Uncertainty Analysis – Online Training. The QC Group, http://www.qcgroup.com/online/.

Metrology for Cal Lab Personnel– Self-Paced Online Training. Fluke Training. http://us.flukecal.com/training/courses.

Metrology Concepts. QUAMETEC Institute of Measurement Technology. http://www.QIMTonline.com.

Precision Dimensional Measurement – Online Training. The QC Group, http://www.qcgroup.com/online/.

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

Precision Electrical Measurement – Self-Paced Online Training. Fluke Training. http://us.flukecal.com/training/courses.

Vibration and Shock Testing. Equipment Reliability Institute, http://www.equipment-reliability.com/distance_learning.html.

The Uncertainty Analysis Program. Learning Measure. http://www.learningmeasure.com/.

SEMINARS: Temperature

May 20-22, 2014 Infrared Temperature Metrology. American Fork, UT. Fluke Calibration. http://us.flukecal.com/tempcal_training.

Jun 10-12, 2014 Principles of Temperature Metrology. American Fork, UT. Fluke Calibration. http://us.flukecal.com/training/courses/Principles-Temperature-Metrology.

Sep 9-11, 2014 Advanced Topics in Temperature Metrology. American Fork, UT. Fluke Calibration. http://us.flukecal.com/training/courses/Principles-Temperature-Metrology.

Oct 14-16, 2014 Principles of Temperature Metrology. American Fork, UT. Fluke Calibration. http://us.flukecal.com/training/courses/Principles-Temperature-Metrology.

SEMINARS: Vibration

Jun 3-5, 2014 Fundamentals of Random Vibration and Shock Testing, HALT, ESS, HASS (...). Boxborough, MA. http://www.equipment-reliability.com.

Aug 20-22, 2014 Fundamentals of Random Vibration and Shock Testing, HALT, ESS, HASS (...). Santa Barbara, CA. http://www.equipment-reliability.com.

SEMINARS: Volume

Aug 18-22, 2014 VolumeSeminar. Gaithersburg, MD. NIST / Office of Weights and Measures. http://www.nist.gov/pml/wmd/labmetrology/training.cfm.

Visit **www.callabmag.com** for upcoming and future events!

The Metrology Quality Community Lost a Voice

Jay Louis Bucher, born July 10, 1949, passed away on April 18, 2014. Jay's life was defined by a dedication to family and profession, and a passion for life.

After graduating Pipestone High School, in Pipestone, Minnesota, Jay went on to attend Minnesota State College and later completed the auto mechanic program at the Pipestone Vocational School. He worked on the family farm and joined the National Guard, before joining the US Air Force in 1971. The next 24 years spent in service marked the beginning of an active career in the science of measurement. He held positions from bench technician on up to Senior Calibration Laboratory Manager in the US Air Force's Precision Measurement Equipment Laboratories (PMEL), with assignments at Grifiss AFB, New York; Utapao, Thailand; Offut, Nebraska; Yokota, Japan; Kusan, South Korea; and Misawa, Japan.

Jay stayed active in the measurement science industry after retiring from the Air Force and continued his education, ultimately earning a Ph.D in Traceable Calibration Technology from Almeda University in 2011. After leaving the Air Force in 1995, he held a position as Senior Metrologist with Raytheon Middle East Systems (RAYMES) in support of the Royal Saudi Air Defense Force PMEL and manager of Metrology services for Promega. During this time, he developed and managed a 'Best-in-Class' metrology and calibration program that exceeded the standards of ISO 9001 and ISO 13485, and developed a paperless records system. In 2002, Jay started Bucherview Metrology Services, through which he has consulted, trained, and conducted workshops.

Jay was a member delegate for the National Conference of Standards Laboratories International (NCSLI) from 1997 to 2012 and was the Madison Wisconsin Section Coordinator for 12 years. He was also the US North Central Region Section Coordinator and received the Section/Region Coordinator of the Year Award in August 2006 and July 2012. He has presented numerous papers and conducted tutorial workshops at both NCSLI and the Measurement Science Conference (MSC). It is at these conferences he has volunteered promoting the Measurement Quality Division (MQD) of the American Society for Quality (ASQ). Most notably, Jay led the development of *The Metrology Handbook*, sponsored by MQD. During his involvement with ASQ, he has served as Chair of the Measurement Quality Division, MQD Secretary, and CCT certification program chair. In 2004, they awarded him the Max J. Unis Award for his leadership on the Metrology Handbook project.

Jay authored seven books over the course of his career, served as managing editor/publisher of MQD's *The Standard*, column contributor of ASQ's *Quality Progress Magazine*, and has been an Editorial Advisor for *Cal Lab Magazine* for many years.

Jay is survived by his wife, Keiko, of 29 years; their daughter, Ayumi; twin sister, Rebecca Bucher Case; older sister, Megan Hess; and sister-in-law, Dalma Bucher. He was preceded in death by his parents, Lyle and Marda; older brother Donald, and nephew Carl Hess.

He will be deeply missed by the measurement science community.

The Metrology Experts of the Future Come from Braunschweig

The International Graduate School of Metrology (IGSM) will be relaunched. Also in future, the Physikalisch-Technische Bundesanstalt (PTB) and the Technical University (TU) of Braunschweig will continue to cooperate closely in the promotion and mentoring of doctoral candidates in metrology - the science of measurement. As of 1 January 2014, TU Braunschweig and PTB have founded a joint graduate school under the name of "Braunschweig International Graduate School of Metrology" (B-IGSM). Within the scope of a structured promotion, the graduate school offers doctoral candidates from the field of electrical engineering and information technology, physics, mechanical engineering and life sciences a well-founded metrological training. The offer of events comprises lectures, seminars, topic workshops and international summer schools. The B-IGSM continues the tradition of the former graduate school of the same name which had been operated by TU Braunschweig with the participation of PTB, and with financial support by the State of Niedersachsen (Lower Saxony). Since its foundation, approx. 50 doctoral candidates from 20 countries have passed through the graduate school and left it with a doctor's degree and the IGSM metrology certificate.

"For quality assurance and precision in industrial production, enterprises need competent staff members", says professor Meinhard Schilling from TU Braunschweig, chairperson of the B-IGSM. "We are training such staff members here in Braunschweig."The idea of the graduate school: during their PhD thesis, candidates for a doctor's degree who conduct research on subjects with regard to metrology and measurement accuracy will be mentored and will be given well-directed support by the B-IGSM. Scientists of PTB and TU Braunschweig jointly support the promotion and impart metrological concepts and principles in courses and lectures.

"The fact that so many subject areas cooperate in the B-IGSM shows that metrology and accuracy are real cross-sectional tasks which will, in future, become ever more important," says Dr. Corinna Kroner from PTB, course director of the B-IGSM. The graduate school has an expressly international orientation. Instruction is given in English, about half of the doctoral candidates comes from abroad. "What they get here is unique," says Schilling, "the combination of academic fundamental research at a university with the specific science of PTB with the focus on metrology is a unique feature of the B-IGSM."

The new cycle of courses starts with the summer semester 2014. For mid-October, a summer school is planned again at the International House Sonnenberg in the Harz Mountains, with lectures of renowned scientists and with student working groups.

Together with the Research Institute for Nanometrology (which is presently under construction) of TU Braunschweig and PTB, the B-IGSM is part of the Metrology Initiative Braunschweig which will strengthen and further develop Braunschweig as an international research region for metrology. For further information: http://igsm.tu-bs.de/.

Source: http://www.ptb.de/en/aktuelles/archiv/presseinfos/pi2014/pitext/pi140313_1.html

TRESCAL Pursues Its Acquisition Strategy in N.A.

Paris, April 10th 2014. Trescal (www.trescal.com), the international specialist in calibration services, announces today that it has acquired Instrument Calibration Services and Test Equipment Repair Corporation, two companies that provide calibration and repair services for a wide variety of measurement and test equipment. The two transactions consolidate Trescal's geographical footprint and enhance its calibration and repair capabilities in North America.

The deals were completed with the support of Trescal's majority shareholder, Ardian (www.ardian-investment.com), the premium independent private investment company, and underscore Trescal's position as a leading global provider of calibration services through its global network of over 67 owned calibration laboratories. This is the fourth expansion since Ardian acquired Trescal in July 2013.

Instrument Calibration Services and Test Equipment Repair Corporation — both based in Atlanta, GA, and A2LA accredited — generated roughly $4.2 million in sales last

year and have 24 employees including 18 engineers. The terms of the deals are not disclosed.

"The acquisition furthers our growth strategy in North America, and marks another significant step towards our goal of dominating the market within two years," Guillaume Caroit, General Secretary of Trescal said. "Once again, the expertise of the teams and the reputation of these companies were critical aspects of both acquisitions."

Britt Myers, President and founder of both Instrument Calibration Services and Test Equipment Repair Corporation, said joining Trescal, a market leader in test and measurement equipment services, was an extraordinary opportunity.

"I am happy to transfer my teams to Trescal, as this group is a pure player and specialist in calibration services strengthening its leadership position as a comprehensive test equipment solutions provider. I am confident that this transaction will be beneficial for both parties and their customers. Also, I would like to thank Guillaume Caroit and Lonnie Spires for their efforts and their professionalism," Myers said.

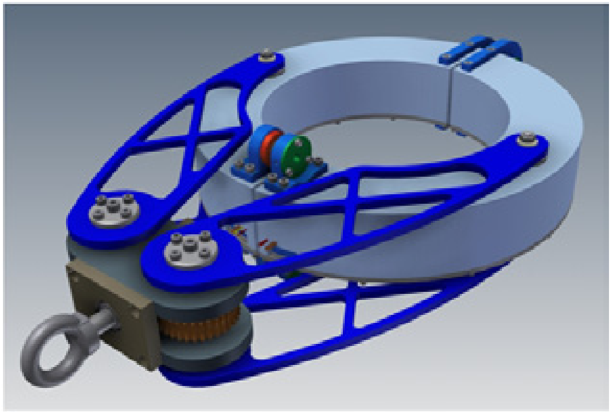
Thibault Basquin, Managing Director of Mid Cap Buyout at Ardian, also applauded the deal, noting the strong prospects for Trescal as it continues to work closely with Ardian.

"This latest acquisition fits perfectly with the strategy we laid out when we acquired Trescal," Basquin said. "Both the Ardian and Trescal teams have implemented an ambitious roadmap with a view to accelerate external growth and we are confident that new transactions will be announced in the coming months."

Non-Invasive Calibration of Current Transformers

Calibration of current transformers in the high voltage grid is usually quite cumbersome to perform because of the continuous use of the grid. For such a calibration a reference transformer needs to be placed in the same circuit as the transformer under test. This normally means that the current circuit needs to be interrupted so that the energy supply will be disrupted for a short period of time. Even when the circuit in a high voltage substation has some redundancy, utilities do not appreciate tinkering in their station because it compromises the security of supply.

In order to effectively solve this problem, VSL has developed a reference measurement instrument which allows



for accurately measuring the current in an overhead line or bus-bar without the need to break the circuit. In order to install the VSL reference system on an overhead line or bus-bar the circuit needs to be powered down only for a very short period. It would even be possible to connect the reference system "live", i.e. without powering down the grid, but at least regulations in The Netherlands do not (yet) allow for this.

The VSL "current clamp" (see figure above) can measure currents up to 2000 ampere with an accuracy of better 0.01 %. An eventual "live" installation is done using two "hot-sticks". First the "current clamp" is hung on the overhead line or bus bar after which it is closed by turning one of the hot-sticks. The system has wireless readout and provides information about the current amplitude and phase as well as on the wave shape. By comparing this with the output signals of the unknown current transformer in the grid that is in series with the VSL reference current clamp, this current transformer can be accurately calibrated.

For more information about this system contact Ernest Houtzager ehoutzager@vsl.nl

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No Compromises: JILA's Short, Flexible, Reusable AFM Probe

JILA researchers have engineered a short, flexible, reusable probe for the atomic force microscope (AFM) that enables state-of-the-art precision and stability in picoscale force measurements. Shorter, softer and more agile than standard and recently enhanced AFM probes, the JILA tips will benefit nanotechnology and studies of folding and stretching in biomolecules such as proteins and DNA.

An AFM probe is a cantilever, shaped like a tiny diving board with a small, atomic-scale point on the free end. To measure forces at the molecular scale in a liquid, the probe attaches its tip to a molecule such as a protein and pulls; the resulting deflection of the cantilever is measured. The forces are in the realm of piconewtons, or trillionths of a newton. One newton is roughly the weight of a small apple.

The new probe design, described in ACS Nano, is the JILA research group's third recent advance in AFM technology. JILA is jointly operated by the National Institute of Standards and Technology (NIST) and University of Colorado Boulder.

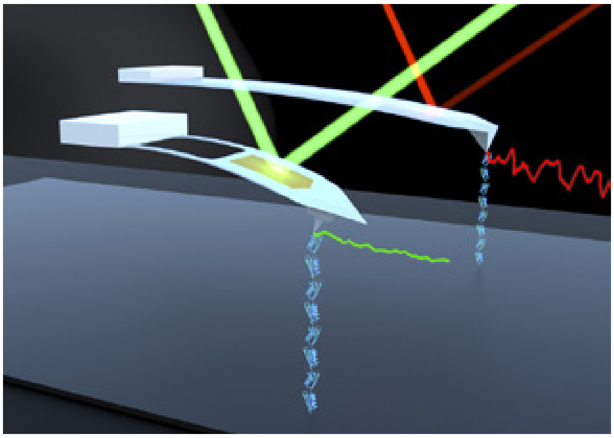
The group previously improved AFM position stability by using laser beams to sense motion and removing the gold coating from long probe tips, or cantilevers, to enhance long-term force stability. However, removing the gold reduces the strength of the signal being measured, and using long cantilevers leads to other measurement problems such as slower response to dynamic events like protein unfolding.

The latest modification overcomes these and other issues, improving precision without loss of stability, speed, or sensitivity. JILA researchers used a focused ion beam to cut a hole in the center of a short commercial cantilever and thinned the remaining support structures, thereby reducing the cantilever's stiffness and friction near surfaces. The result is excellent long-term stability and improved short-term precision, respectively, in AFM force measurements.

JILA researchers also added a protective glass cap over the gold coating at the end of the cantilever to retain beneficial reflectivity, and then removed the remaining gold to gain force stability. The modified cantilever enables rapid, precise and stable force measurements across a broad range of operating frequencies.

"Previously, we had to average the Brownian (random) motion of our favorite cantilever for about 60 milliseconds to get a measurement that had a precision of 1 piconewton," JILA/NIST biophysicist Tom Perkins says. "Now, we can get the same precision in 1 millisecond or so."

JILA researchers demonstrated significant benefits for single molecule studies. For instance, the short, soft cantilevers can quickly measure abrupt changes in force when a protein unfolds. Protein folding is required for proper



JILA's modified AFM probes measuring DNA molecules. The older mod (long cantilever, right) eliminated the usual gold coating to enhance long-term stability. The latest version (left) retains the gold coating where needed to reflect light but maintains excellent stability. Researchers also removed a large section to reduce stiffness and friction near surfaces. The new probe provides precise results much faster than before, while reducing "noise" (colored squiggles). Credit: Baxley/JILA biological function and misfolding can lead to diseases such as Alzheimer's. The new cantilevers match the response of stiffer, unmodified cantilevers but with greater stability and precision. Force stability is crucial in this application because protein folding and unfolding rates are exponentially sensitive to tiny changes (smaller than 1 piconewton) in applied load. The new device also can track fleeting nanoscale events, including protein folding, over hundreds of seconds—much longer periods than previously possible. The new design should also be applicable to rapid probing of the mechanical properties of materials at the nanoscale.

Significantly, the new cantilevers are robust enough to be reused for multiple days. Moreover, JILA researchers say the new design is simple and inexpensive to make, and thus, suitable for routine use.

"Amazingly, this project was spearheaded by a talented undergraduate. We hope other groups with similarly talented students will adopt these cantilevers. We certainly are," Perkins said.

The research was supported by the National Science Foundation and NIST.

Source: NIST Tech Beat, April 8, 2014, http://www.nist.gov/public_affairs/tech-beat/tb20140408.cfm#afm.

Take F2: NIST's Latest, Most Accurate Time Standard Debuts

BOULDER, Colo. -- The U.S. Department of Commerce's National Institute of Standards and Technology (NIST) has officially launched a new atomic clock, called NIST-F2, to serve as a new U.S. civilian time and frequency standard, along with the current NIST-F1 standard.

NIST-F2 would neither gain nor lose one second in about 300 million years, making it about three times as accurate as NIST-F1, which has served as the standard since 1999. Both clocks use a "fountain" of cesium atoms to determine the exact length of a second.

NIST scientists recently reported the first official performance data for NIST-F2,* which has been under development for a decade, to the International Bureau of Weights and Measures (BIPM), located near Paris, France. That agency collates data from atomic clocks around the world to produce Coordinated Universal Time (UTC), the international standard of time. According to BIPM data, NIST-F2 is now the world's most accurate time standard.**

NIST-F2 is the latest in a series of cesium-based atomic clocks developed by NIST since the 1950s. In its role as the U.S. measurement authority, NIST strives to advance atomic timekeeping, which is part of the basic infrastructure of modern society. Many everyday technologies, such as cellular telephones, Global Positioning System (GPS) satellite receivers, and the electric power grid, rely on the high accuracy of atomic clocks. Historically, improved timekeeping has consistently led to technology improvements and innovation.

"If we've learned anything in the last 60 years of building atomic clocks, we've learned that every time we build a better clock, somebody comes up with a use for it that you couldn't have foreseen," says NIST physicist Steven Jefferts, lead designer of NIST-F2.

For now, NIST plans to simultaneously operate both NIST-F1 and NIST-F2. Long-term comparisons of the two clocks will help NIST scientists continue to improve both clocks as they serve as U.S. standards for civilian time. The U.S. Naval Observatory maintains military time standards.

Both NIST-F1 and NIST-F2 measure the frequency of a particular transition in the cesium atom—which is 9,192,631,770 vibrations per second, and is used to define the second, the international (SI) unit of time. The key operational difference is that F1 operates near room temperature (about 27 ºC or 80 ºF) whereas the atoms in F2 are shielded within a much colder environment (at minus 193 ºC, or minus 316 ºF). This cooling dramatically lowers the background radiation and thus reduces some of the very small measurement errors that must be corrected in NIST-F1.

Primary standards such as NIST-F1 and NIST-F2 are operated for periods of a few weeks several times each year to calibrate NIST timescales, collections of stable commercial clocks such as hydrogen masers used to keep time and establish the official time of day. NIST clocks also contribute

to UTC. Technically, both F1 and F2 are frequency standards, meaning they are used to measure the size of the SI second and calibrate the "ticks" of other clocks. (Time and frequency are inversely related.)

NIST provides a broad range of timing and synchronization measurement services to meet a wide variety of customer needs. NIST official time is used to time-stamp hundreds of billions of dollars in U.S. financial transactions each working day, for example. NIST time is also disseminated to industry and the public through the Internet Time Service, which as of early 2014 received about 8 billion automated requests per day to synchronize clocks in computers and network devices; and NIST radio broadcasts, which update an estimated 50 million watches and other clocks daily.

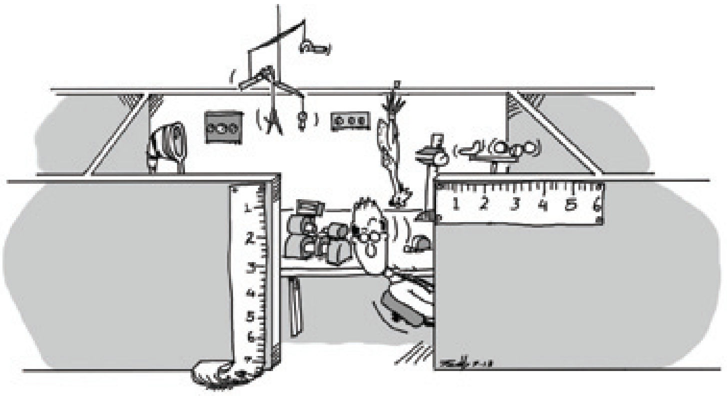
At the request of the Italian standards organization, NIST fabricated many duplicate components for a second version of NIST-F2, known as IT-CsF2 to be operated by Istituto Nazionale di Ricerca Metrologica (INRIM), NIST's counterpart in Turin, Italy. Two co-authors from Italy contributed to the new report on NIST-F2.

The cesium clock era officially dates back to 1967, when the second was defined based on vibrations of the cesium atom. Cesium clocks have improved substantially since that time and are likely to improve a bit more. But clocks that operate at microwave frequencies such as those based on cesium or other atoms are likely approaching their ultimate performance limits because of the relatively low frequencies of microwaves. In the future, better performance will likely be achieved with clocks based on atoms that switch energy levels at much higher frequencies in or near the visible part of the electromagnetic spectrum. These optical atomic clocks divide time into smaller units and could lead to time standards more than 100 times more accurate than today's cesium standards. Higher frequency is one of a variety of factors that enables improved precision and accuracy.

Source: http://www.nist.gov/pml/div688/nist-f2-atomic-clock-040314.cfm

CAL-TOONS by Ted Green teddytoons@verizon.net

NEVER, EVER ASK TOM TO MEASURE SOMETHING FOR YOU.



The Effect of Cables and Shields on Traceability

Jesse Morse
Morse Metrology

If a person making a dc or low frequency measurement fails to select the proper cables, or to properly connect the shields the traceability chain for that measurement can be violated. This can happen because the cable-to-connector circuit may introduce serious errors into the signal that arrives at a test tool, or that is supplied by the calibration standard. Under certain conditions, the magnitudes of these errors may even be larger than the desired signal.

Various hazards that cables and connections can present to the traceability chain are described and discussed. A review of a general model of a measurement setup is given along with a discussion regarding the types of cables to consider in specific dc and low frequency measurements. Also presented is suggested shielding and guarding techniques for precision measurements, which can prevent or minimize introduction of errors into a measurement due to common-mode and normal-mode signals.

Introduction

As common as they are, cables lay directly in path of traceability of all electrical measurements, and they always introduce errors that contribute to the measurement's total uncertainty. For the person doing a measurement the issue at hand is, "Is the amount of the contribution to uncertainty significant?" But, what is significant? Merriam-Webster's online dictionary defines significant as, "…having or likely to have influence or effect." So if a pair of test leads have resistance equaling 100 mΩ, it is up to the person who designs or operates the measurement system to decide the significance when they are used. For example, if the pair of test leads, in this case 100 mΩ, are used to measure a 10 kΩ two terminal resistor they will introduce a 10 ppm error. This article deals with the impact of cables and shielding on higher precision dc and low frequency ac measurements.

Traceability

A simple test lead or cable is not generally thought of as an electrical instrument when it is integrated into a calibration setup. But, in fact, they are as much a part of the setup as the other instrumentation being used. Therefore, they must be considered a possible source of measurement uncertainty, and it must be recognized that they can have a serious effect on the measurement results. It would not be unusual that this additional error goes unnoticed by the person doing the calibration. However, unless it is taken into consideration in the overall uncertainty budget the chain of traceability might well be broken. Each step in the setup configuration process requires the user to have sound metrology knowledge covering a range of issues. That knowledge is only gained through metrology training and/or hands-on experience under the guidance of an experienced mentor.

Interconnections

Aside from the uncertainty contributed by the active instrumentation in a calibration setup, how we connect them together to make our measurement is probably the largest additional contributor. Even though modern test equipment are designed to be versatile, their calibration procedures do not often provide detailed information about what kind of cabling is necessary to achieve the levels of accuracy claimed by the manufacturer. So it is often up to the knowledge and training of the person doing the calibration to select the appropriate cables for the measurement, and to make the connection in such a way as to minimize errors.

There is always some interaction when two or more instruments are connected together, plus the interconnecting cables themselves can introduce errors from various sources. Figure 1 shows a fairly common cable found in cal labs. This simple twisted pair cable can pose some rather significant obstacles to making a quality measurement.

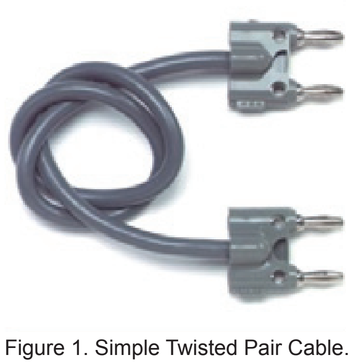


Figure 1. Simple Twisted Pair Cable.

These possible error sources affect dc, low frequency ac, and resistance measurements differently. This article examines a set of parameters that have influence on measurements. In particular, the following will be discussed:

1. Contact resistance at each point where the cable is connected.
2. Thermal voltages at each point where the cable is connected.
3. Series lead resistance of the wire in the cable.
4. External electromagnetic interference .
5. External electrical noise.
6. Leakage resistance between the twisted pair.
7. Capacitance between the twisted pair.

Depending on the precision being sought, these influences can be significant. Note that some of these possible sources of error are in series with the desired signal, and some are in parallel.

Contact Resistance

Contact resistance, which acts as a pure resistance, occurs anytime two conductors are joined together (e.g. test lead connector to instrument terminal). The magnitude of this unwanted resistance can vary from a few milliohms up to an ohm in a mechanical relay. Even a spade lug tightly connected to a terminal can have a few milliohms of contact resistance. The common banana plug cables found in all calibration labs can insert up to several tenths of an ohm in series with the desired signal. This series resistance can be a significant source of error in 2-terminal resistance measurements. One way of minimizing this error is to use a 4-terminal method of measurement. The significance of the rogue resistance is dependent on the level of precision (resolution) of the measurement. Most commonly, one will find a rule-of-thumb of using 4-terminal method below 10 kilo ohm.

Thermal Voltages

Another source of possible error in a calibration is thermal emfs at some or all connection points caused by the Seebeck Effect (thermocouple). This is particularly true when the test lead connector is a different metal than the instrument terminal. These stray voltages are even more of an issue when the connections are at different temperatures. Thermal voltages can be a major problem in low voltage high-resolution dc measurements and in low resistance measurements.

There are several techniques that might be used to minimize the impact of thermal emfs on a measurement, but the best approach is to use materials that have the smallest inherent magnitude to emf generated per degree change in temperature, and make sure that all high/low connection points are of the same bi-metal material. The terminals on most quality precision instrumentation today have terminals that are gold flashed over copper thereby minimizing the additional problem of tarnishing, which in itself is a cabling issue due to increasing contact resistance.

Having made every effort to minimize thermal emfs, one should remember that if all connections in the calibration setup are at the same temperature and all are of the same bi-metal types, they will all cancel out—being equal and opposite in emf magnitude. This is a case where one's assumption may in fact break the chain of traceability. For example, a person's fingers may heat a junction enough to cause an imbalance that would introduce an unknown error into the setup. Note that it only takes seconds to cause the temperature difference, but minutes for the junctions to return to equilibrium. A good practice is to monitor the measurement readout until it has settled. If the measurement seems to be drifting, it probably is—due to thermal re-stabilization.

And finally, one might use reversal techniques to dynamically remove offsets that change during repeated measurements. The effect of thermal emfs on a measurement can be greatly minimized by: 1) using only pure copper connectors, and 2) making sure all connections of dissimilar metals are at the same temperature.

Lead Resistance

The use of cables always inserts a resistance in series with a measurement. Inserting resistance into a setup is unavoidable, and can be quite bothersome in low resistance measurements. One major requirement for cables used in low resistance measurements is for the inserted resistance to be low and constant. A good approach to this type of measurement is the use of low thermal spade lug connectors under securely tightened binding posts, or simply a solid copper wire.

Another consideration whether the application is critical enough to require heavy gauge solid wire, rather than stranded wire. When the measurement to be made is more like a precision experiment, one might consider using 18 to 22 gauge insulated copper wire. But when the measurement must be repeated often, a better cable would be a heavy stranded cable with well-secured (gold plated) spade lug connectors.

An example of the latter is the Pomona Type 1756 cable shown in Figure 2. The spade lugs are gold plated ETP copper alloy 110 to greatly minimize the effect of thermal emf.

A caution is that cables with very heavy spade lugs may make it difficult to stack and tighten several on the same terminal. This could lead to a build-up of contact resistance. Another caution is that the strands inside the insulation may become broken over time and use. Here the problem is variability in lead resistance.

Figure 2. Example of Low Thermal Shielded Cable.

External Electrical Noise

It is not unusual that a low-level measurement must be made in an electrically noisy environment. This noise can cause a voltage-measuring instrument to display false readings. The noise may be the result of large high-frequency signal sources may be natural, such as solar radiation, or artificial, such as a generator, compressor, fluorescent light, computer monitors, or electrified cellular telephones. Unshielded twisted pair (UTP) and radio circuits are particularly susceptible to EMI. Minimizing the exposure of the system cabling to high-frequency rf sources is recommended. However, if the application is extremely sensitive to rfi, a common mode choke can be used in the system cabling. A low-pass filter may also help prevent errors due to EMI.

Any EMI error is combined with thermal offsets and resistances, which compromises the confidence in the accuracy of the measurement. Use of the proper cables can minimize these errors.

An example of a cable that exhibits excellent thermal and resistivity characteristics, which can be used in all spade lug applications for both high and low resistance, is the Pomona Electronics low thermal shielded cable Type 1756 (Figure 2). When used with line powered instruments, the shield should be connected to ground at one end only. Leave one end open-ended.

Insulation Resistance

Never take for granted that there is infinite impedance between the leads in a cable whether it is a single spade lug cable with a built-in shield, or a shielded twisted pair. Low isolation resistance can cause problems that can affect measurement results. This writer has experienced many occasions where insulation resistance between leads can be very low relative to the typical 1 x 10^{12} ohms minimum acceptable insulation resistance. This experience drives the recommendation that cal labs have a defined "Cable Maintenance Program," which includes incoming inspection of brand new cables. More often than one might think, cables right out of the package from the manufacturer have been found to be anywhere from several hundred kilohms to nearly shorted. These cables could have caused extreme errors in measurement even if properly connected.

Cables in AC Applications

In addition to mostly everything that affects various dc applications, ac measurements are subject to another condition that needs consideration: cable capacitance.

As shown in Figure 3, cable capacitance presents a parallel load to the ac source. The source must be able to supply enough current satisfy load represented by unit under test, and also to supply current to drive the load created by the cable that is connected to it.

Cabling with lowest possible capacitance should be used in ac configurations. Generally, lower capacitance (pF/ft) equates to a higher performance cable. A pair of unshielded wires separated by about 4 cm (~1.6 inches) at voltages of a half volt or higher, and frequencies up to 500 kHz can work well. This setup does not work well at lower levels, especially with high input impedance meters because of the lack of shielding. When measurements are made above 500 kHz up to about 1 MHz, the inductance of the leads also becomes a problem by attenuating the signal at the measuring device. These issues can be dealt with by using a high quality, insulated, shielded, twisted pair cable. An example is shown in Figure 4 of a Pomona Type 1167 cable.

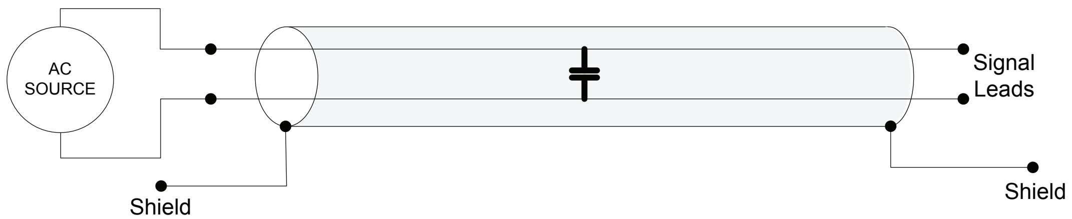


Figure 3.

Cables such this will have between 45 pF and 60 pF per meter (about 3 feet). Because of the twisting of the signal leads inside the cable, the effect of the inductance is minimized in this type cable. This cable is useful up to about 1 MHz. This cable has terminals made of Beryllium Copper and plated with gold, making them low thermal too.

A common cable used in ac measurement is the RG-58U coaxial cable. People in measurement must remember that cable impedance (capacitive reactance) decreases as frequency increases. To demonstrate the effect of this cable capacitance issue, consider an example where a Belden® RG-58U one meter long is going to be used to measure signal at a frequency of 1 MHz. This nominally 50 ohm cable has a specification of 93.5 pF/m. Calculating the capacitive reactance of the cable at this frequency shows that it represents a considerable load, ≈1703 ohms, to the source. If this is coupled with any significant internal source impedance, a reduction in signal at the measurement end of the cable will result. So, in this case a shielded twisted pair cables would be best. Coax may be used, but it should be used only in moderately accuracy situations.

Shielding and Guarding for DC Measurements

Now that we have addressed the importance choosing the most appropriate cables for a calibration setup, we now need to look at the importance of properly connecting instruments together using them. This section will discuss how errors caused by "ground loops" and "noise" in measurements caused by cabling can be minimized.

Every measurement made using instruments that are line (ac) powered is susceptible to errors due to undesirable electrical and/or magnetic signals external to the measurement setup or system. These signals are generated in numerous ways: motors, digital instruments, unshielded florescent lights, etc.

Figure 4. Pomona Type 1167 Double Banana Shielded Balanced Lead.

To shield instruments from these undesirable signals, most modern high precision instruments have incorporated into their design a Faraday shield in which all analog circuitry is enclosed. The low or common side of the output/input circuit is, or can be, connected to the shield. Incorrectly connected cabling (shields and grounds) can defeat the benefits of the instrument's Faraday shield by allowing spurious voltage to appear across the low lead. This voltage algebraically adds to the desired signal (normal mode) causing an error of some amount. Another source of error can come from incorrectly connecting to the system grounds. The difference in potential between each chassis and power line ground in a setup is called the common mode voltage. When there is a difference between two common mode voltages, a current can flow in the low connection lead. This current is usually called a 'ground loop' current. An effective way to control problems caused by normal and common mode voltages is to provide a guard circuit that will divert the error-producing currents, which create the voltages, away from the signal connecting leads between the measurement instruments.

Instrument Guard

For the purpose of measurement instruments, the internal Faraday shield is referred to as a GUARD because it "guards" the enclosed analog circuitry from unwanted effects of stray electrical current and noise. Most instruments that have a Faraday shield within their chassis will have a connection terminal called either GUARD or GRD. It must be remembered that GRD does not stand for ground (GND). Although this feature has been around for decades, it is perhaps one of least understood terminals on an instrument. The trouble is that if this terminal is not correctly used a person can unknowingly make a less than optimum measurement.

While guarding effectively eliminates problems due to ground loop signals in floating measurements and minimizes the effects of electrical noise, it only does that when all instruments in the calibration setup are connected correctly. That is, their low, guard, and ground terminals are connected correctly for the type of measurement being made and equipment being used. So, the question becomes, "How do you properly connect the shield wire of a cable to ensure against ground loops, and also greatly minimize any uncertainty caused by external electrical or magnetic noise in my measurement?" Following the guidelines presented below will help ensure all measurements are of the lowest uncertainty possible.

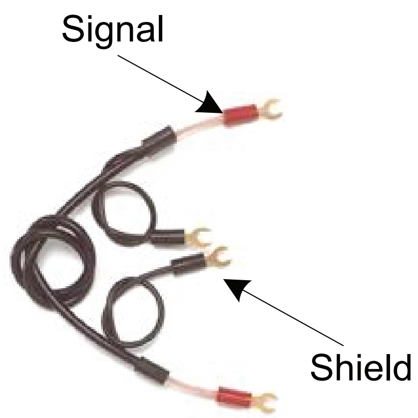


Figure 5.

General Guidelines for Connecting Cable Shields

1. Never use the shield as a signal carrying lead. In Figure 5 above, the SIGNAL LEAD is for the measurement signal. The other lead, SHIELD, should only be used as a shield lead. If current is allowed to flow in the shield lead a noise voltage can be induced into the center conductor via magnetic coupling.
2. In some setups only one of the two SHIELD connectors will be used. The other will be left not connected to any terminal.
3. Never connect a shield to ground at both ends; otherwise a ground loop can be created. A ground loop will cause current to flow in the shield, which will induce a noise voltage into the center conductor via magnetic coupling. The reason for having a shield connector at both ends will become clear in the discussion about making guarded measurements.
4. It is preferable that the shield connector of a shielded cable be connected to ground at the signal source whenever possible.

Making a Guarded Measurement with Shielded Cables

When an instrument is used in a setup that has a terminal marked Guard or GRD, it is important for the person setting up the procedure to know what do with it. It is imperative that the person making precision measurements with guarded instrumentation understand and follow the following guidelines:

1. Always make sure the guard terminal is connected to an instrument low terminal somewhere. This is especially important for a DMM, because failure to connect it correctly can cause damage to the instrument. Even more important is if the meter is being toggled by positive and negative dc polarity changes. The best practice in a case like this would be to return the source to zero, and then apply the other polarity.
2. Never leave the guard terminal open.
3. The guard potential should always be at, or very near, the OUTPUT LOW potential of the source, or INPUT LOW of the measurement instrument.
4. The guard should be connected to the LOW side of the circuit at the point where LOW is connected to ground.
5. The guard is connected to LOW at one point and one point only.
6. The guard is connected to ground at one point and one point only.

Here are some examples of some connection possibilities showing instruments connected according these guidelines: First, is an example configuration (Figure 6) where both the signal source (calibrator) and measurement instrument (meter) in the setup have a guard terminal, and shielded cabling is used.

Second, is an example configuration where a signal source (calibrator) with a guard is connected to a measurement instrument (meter) that does not have a guard terminal.

Summary

One of the most important instruments in a calibration is the cable that connects the other instruments together. Choosing an improper cable for a calibration can jeopardize the chain of traceability by introducing rogue quantities into the measurement. These rogues may be caused by thermal emfs, contact resistance, lead resistance, EMI, or a combination of them. It is up to the metrologist to ascertain which cables are to be used in a calibration in order to maintain the measurement's integrity and traceability.

Keeping all cables in the lab in tip top condition is paramount in always delivering calibrations with high confidence in accuracy.

Although it is important to select appropriate cabling for connecting instruments together in a calibration setup, it is equally important that the setup is properly connected so as to ensure the integrity of the measurement against external electrical and magnetic noise. A person who is not trained and/or does not follow the guidelines presented in this document stands a high probability of making measurements that contain unknown errors contributing to system total uncertainty, thereby breaking the chain of traceability.

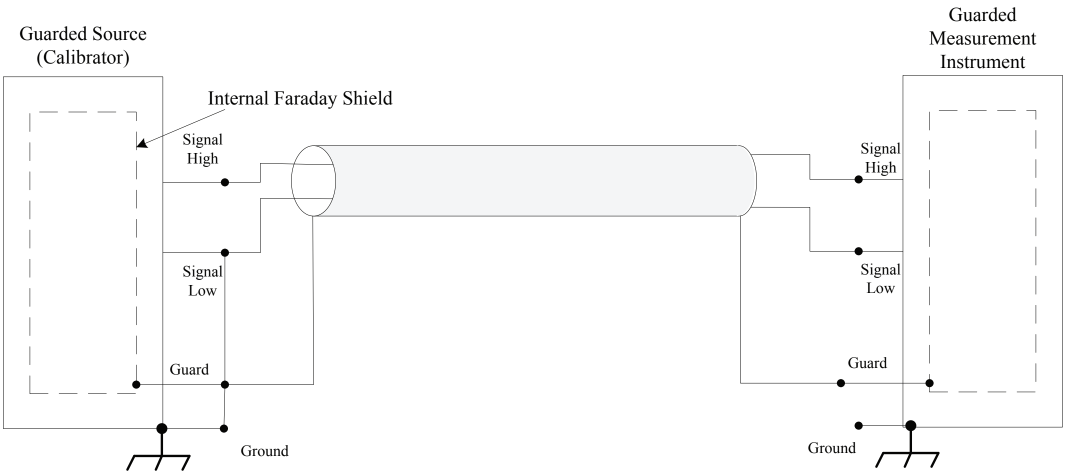


Figure 6. Guarded Voltage Source Connected to a Guarded Measurement Instrument.

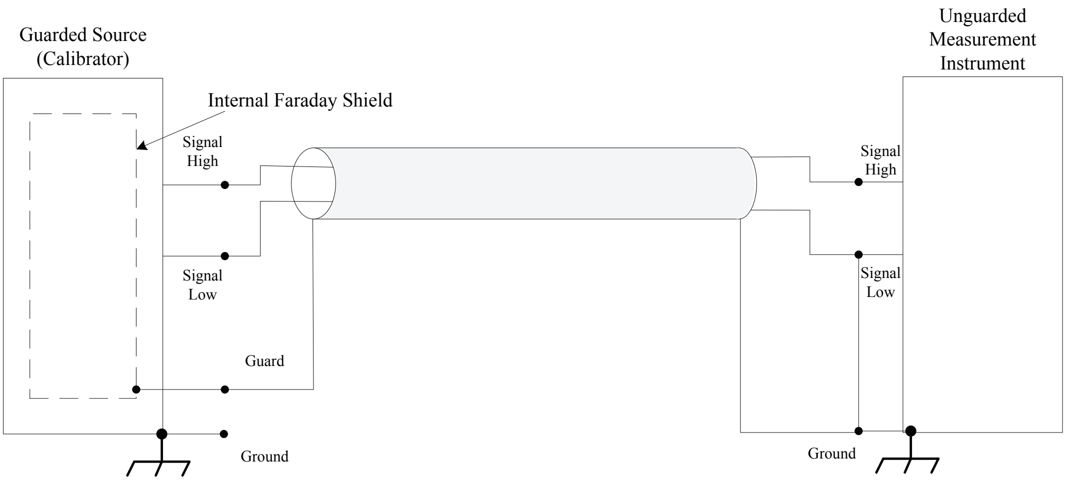


Figure 7. Guarded Voltage Source Connected to Unguarded Measurement Instrument.

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Speed-of-Sound Measurements in Liquids Using Time-of-Flight Sensors

Dr. Christoph von Rohden
Physikalisch-Technische Bundesanstalt (PTB)

Potentials and limitations of commercial sensors for in-situ speed-of-sound measurements in liquids working with the time-of-flight principle are discussed on the basis of laboratory investigations and an extended sensor calibration in pure water.

Introduction

Speed of sound as a fundamental property of all material phases is an important measurement category. It is continuously measured in industrial processes, e.g. for material and product quality control. Speed of sound is also strongly related to other physical and thermodynamic material characteristics and thus fundamental for science and engineering. As modelling is limited and cannot meet the needs in all fields of application, the demand for high accuracy measurements remains high.

Speed of sound in liquids is comparatively easy to measure with adequate precision using a variety of measurement techniques. We cater to high accuracy speed-of-sound measurements in water as a reference for similar liquids of interest. For the investigations we used commercially available sensors working with the time-of-flight technique. These sensors are originally designed for in-situ determination of sound speed in oceanic environments and are therefore constructed for robustness with respect to in-situ measurement conditions (low-corrosive materials, pressure-resistant and thermally stable composition). The instruments are calibrated and can directly output speed-of-sound in $m \cdot s^{-1}$ converted from measured flight time of sound pulses. We describe the working principle and discuss our own extended sensor calibration in pure water as the reference liquid together with the associated uncertainties. Practical aspects that rose up in our laboratory study are discussed with respect to the in-situ application in the field or laboratory.

In-Situ Speed-of-Sound Sensors

A basic and direct concept for sound velocimetry in liquids is the measurement of the time a discrete sound pulse takes to travel a known distance. High accuracy speed-of-sound measurements in liquids are carried out by a small number of specialized laboratories using pulse or pulse-echo techniques. In principle, sound pulses are emitted into the sample by a Piezo-transducer and detected by the same transducer after reflection or by a second opposite transducer. The speed of sound is then calculated from the travel time of the pulse along the known sound path.

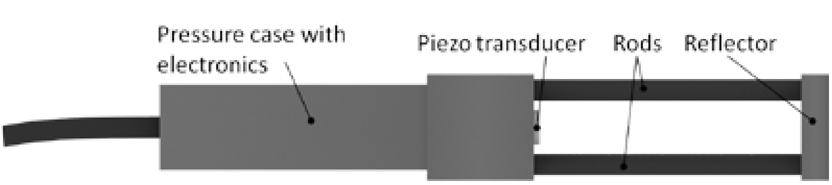

Figure 1. Layout of a modern in-situ speed-of-sound sensor designed for oceanographic field studies.

At PTB we conducted a laboratory study with commercially available time-of-flight sensors for oceanic applications. They consist of a single transducer and a reflector, which are kept at fixed distance (Figure 1). The measured variable is the time of flight of a single emitted acoustic pulse which travels along this distance and is detected after reflection by the same transducer. For high accuracy speed-of-sound, the requirements for the path length determination of ~1 µm for e.g. a typical 10 cm sound path cannot be fulfilled by ruler measurements. A ready definition of the sound path is also hampered by the thickness, construction and assembly of the acoustic transducer which is usually covered by a matching layer. Therefore such sensors require calibration in a reference liquid to account for the effective acoustic path length. The path length should be mechanically and thermally stable. For the latest time-of-flight sensor generation, the distance between the transducer and reflector planes is fixed by carbon composite rods. With this, manufacturers claim de-facto insensitivity to temperature and pressure changes within the specified range. The reflector and the sensor mount being in contact with the liquid are made of non-corrosive metal (titanium). Table 1 lists typical technical data and specifications. The sensors of different manufacturers differ slightly in dimensions, working frequency (several MHz), and presumably use specific algorithms for the time-of-flight determination.

Length of sound path / mm	(50–200)
Range speed-of-sound w / m·s^{-1}	(500–2000)
Response time / µs	~(35–140)
Time resolution / ns	~0.01
Practical resolution w / m·s^{-1}	~0.001

Table 1. Range of specifications for modern sensors for in-situ speed-of-sound *w*. The response times basically reflect the time of flight of sound pulses.

However, their functions are based on the same principle and use digital signal processing. The given overall uncertainties vary between 0.02 m·s^{-1} and 1 m·s^{-1} depending on the sensor format and the specified speed-of-sound range. The main contributions to overall uncertainty come from the availability of suited calibration liquids, the calibration procedure itself, and also from the quality of internal signal processing. Although sensor layouts for pressures covering the oceanic range up to ~1100 bar are available, our investigations are restricted to atmospheric pressure.

Experimental Issues

We carried out sensor tests in a thermostated bath filled with the pure water sample. The temperature was stabilised with PTB-calibrated standard platinum resistance thermometers (SPRT) to ~1 mK. A concise experimental issue was the deposition of microbubbles at the transducer and reflector surfaces. Starting with clean sensors, speed-of-sound output appeared to increase slowly towards a certain plateau (Figure 2) in the well circulating bath. Cleaning of the faces with a soft tissue pulled back the readings to a well reproducible value, which is therefore assumed to be the feasible. Except of peaks due to the cleaning procedure, temperature is not correlated to this. We observed this effect in water and seawater at different magnitude varying with temperature. The cleaning prior to speed-of-sound recording therefore became part of our measurement routine. The measurement cycles have been run with decreasing temperatures after a period at a temperature above the first measurement point to allow degassing. This should minimize solubility related formation of bubbles as solubility for atmospheric gases increases with decreasing temperature. Although formation or deposition of microbubbles might not be an issue at greater pressures (depths), our observation illustrates that caution is advised even when the concentration of dissolved gases in the sample liquid is close to atmospheric equilibrium.
Although we have not verified, also scaling or deposition of dissolved or suspended material at the transducer or reflector surfaces may change speed-of-sound readings in solutions or non-pure liquids. This is e.g. known for conductivity measurements in seawater where the effective cell dimensions may gradually change due to layer growth induced by biological activity. Mechanical cleaning is probably the most effective remedy.

Calibration

Speed of sound in liquids varies with temperature. The dependencies and temperature sensitivities are shown exemplary in Figure 3 for pure water and for seawater and will be used for a high accuracy sensor calibration. Pure water as the reference liquid is the medium with the lowest uncertainties available for speed-of-sound. The sensors are intended for application in typical oceanic conditions, i.e. temperatures from ~0 °C to ~35 °C and salinities up to ~40 g·kg^{-1}. Information about the original calibration procedure is limited. Typically, calibration functions with two parameters according to path length and delay time are given by the manufacturers. To assure a more extended measurement range and to include possible systematic effects other than path length and delay time, we conducted our own calibration. The reference sound speed values were calculated using IAPWS-95 equations dependent on actual temperature and assigned to the time-of-flight output of the sensors. The IAPWS-95 formulation

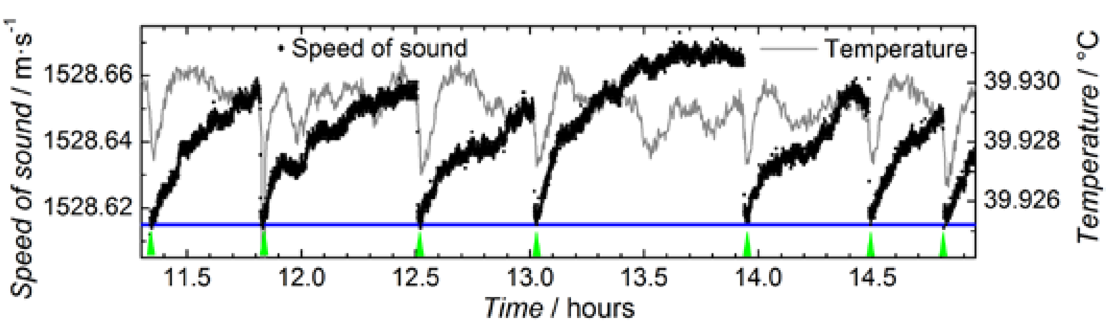

Figure 2. Example for the apparent speed-of-sound variation with time probably due to deposition of small bubbles at the transducer and reflector faces. Cleaning of the faces (green marks) resets sensor output to a well reproducible value (blue line).

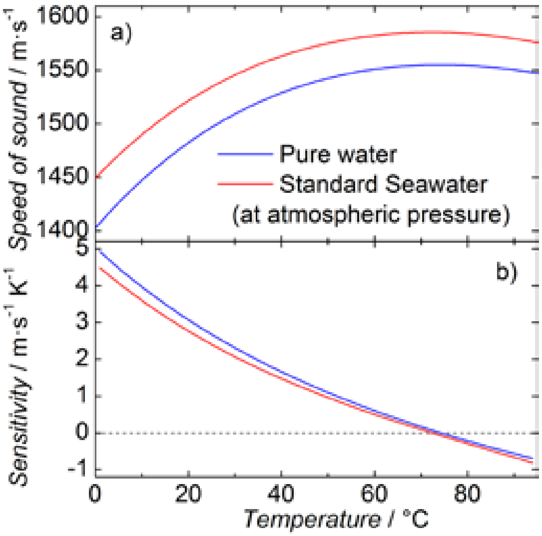

Figure 3. a) Temperature dependence of speed-of-sound in pure water and Standard Seawater (S_A=35.16504 g•kg^{-1}). b) Sensitivity of speed-of-sound to temperature changes.

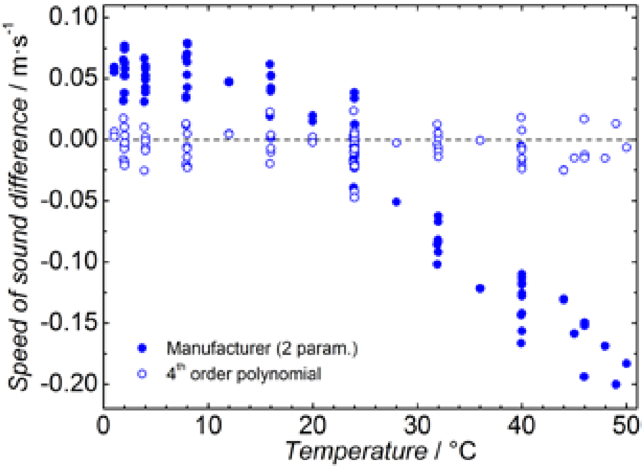

Figure 4. Speed-of-sound difference (sensor output minus expected values $w(T)$ from equation of state) using manufacturer calibration (dots) and after own calibration by polynomial fitting (= residuals) (open circles).

is recommended for the calculation of thermodynamic properties of pure water. Then 4th-order polynomials have been fitted to the data. In this way, the calibrated range for speed-of-sound is fixed to ~1400 m·s^{-1} to ~1550 m·s^{-1}. The data used for calibration cover a one year period. This approach includes general experimental variability and sensor drifts as well as possible thermal sensitivities (e.g. of electronics), time delays, phase shifts, and sound wave diffraction effects. An example is given in Figure 4. As sound speed in seawater increases with salinity (Figure 3), we extended the calibration range to ~45 °C to cover sound speed in seawater up to ~30 °C.

Whereas in the range of lower temperatures (~ 0 °C – 20 °C) the original calibration seems to be consistent to ours except for a ~0.05 m·s^{-1} offset, increasing deviations exist at higher temperatures. These differences might be caused by a smaller temperature range of the manufacturer calibration and by the fact that our extended speed-of-sound range cannot reliable be covered by fitting with only two parameters.

Discussion

From our procedure we can derive a calibration uncertainty (reproducibility for speed of sound in pure water) in the order of 0.03 m·s^{-1}. A similar reproducibility can be achieved in other media of interest, e.g. seawater. However, overall uncertainties are considerably larger by at least one order of magnitude. Here, besides contributions by the pure water calibration, by salinity or impurities, temperature, sensor resolution, and statistical components, other rather dominant contributions related to the method of time-of-flight determination have to be included. The latter also might depend on the liquid properties and are more difficult to evaluate. We found this is also being reflected in systematic sound speed deviations between different sensors reaching a few decimeters per second, i.e. clearly larger than the reproducibility, although simultaneously measured in the same salt solution and seawater samples. For speed-of-sound beyond the pure water and seawater range, uncertainties further increase due to the limited availability of suitable liquids for calibration.

As a conclusion we state that with time-of-flight sensors an uncertainty of a few decimeters per second relative to pure water can be reached. Preconditions are a thorough calibration and the consideration of systematic errors due to deposition effects at the transducer and reflector surfaces. The reproducibility however is much smaller (<0.02 m·s^{-1}, Figure 4) and displays the potential of the method. An interesting application is the use of the in-situ sensors as acoustic thermometers for liquids. According to the sensitivity shown for water in Figure 3, temperature reproducibility down to a few Millikelvin can be reached by measuring speed-of sound and converting into temperature using the equation of state. This provides a contactless method to precisely track temperature changes at very low response times which is essentially given by the flight time of the sound pulses in the order of 100 µs.

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Uncertainty Estimation Based on Repeated Observations of a Population of Instruments

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This paper explores the similarities and differences between a measurement uncertainty as described in the GUM and a manufacturer's specification when the history of compliance testing results is taken into consideration. It has been suggested in certain cases where compliance to specifications is asserted, it can be sufficient to report only the historical reliability which encompasses all uncertainties as well as the intrinsic variability of the process. Consideration of metrological traceability [1] is addressed, where verification of compliance with the stated specification is asserted with only the knowledge of the historical reliability as the measurement uncertainty.

Introduction

Risk is a state of uncertainty where some possible outcomes have an undesired effect or significant loss. If the quality metric for a calibration program is to keep the probability of false accept (PFA) below 2 % [2], it has been demonstrated [3] in cases where compliance to specifications is asserted, it can be sufficient to report only the observed reliability to meet the requirement. This method has been commonly referred to as the 89 % rule, because under prescribed conditions, if the observed reliability is greater than or equal to 89 %, then the probability of false accept will never exceed 2 % and knowledge of the standard's measurement uncertainty is not required to make the claim. The 89 % rule has been applied to address unconditional risk at the program level [4] meaning no specific measurement is required to compute risk. Under specific assumptions, such as symmetric tolerance limits and normal distributions for both the standard and DUT, it is possible to comply with the 2 % rule by bounding or limiting false accept risk.

Reliability data collected from calibration history can also be used to compute a coverage factor for the specification limit being tested. This uncertainty can then be used by the customer with confidence that the in-tolerance probability will be high throughout the calibration cycle. For the first time, a method to ensure quality has been suggested that did not directly rely on the estimation of input quantities to quantify uncertainty. While this concept may appear to be a departure from accepted practice upon initial review, a careful consideration of the principle tenets reveals an underlying mathematical framework that is both intuitive and logically defendable. The inputs of measurement decision risk (MDR) are measurement uncertainty, knowledge of the historical reliability or observed uncertainty, and the specification limits being tested commonly referred to as tolerance limits. The recently released JCGM 106:2012 [5] provides a basis for the risk framework.

Types of Uncertainty

Uncertainty Terms	Symbol	Description
Process Uncertainty	u_m	"Time of test" uncertainty defined by the GUM
Bias Uncertainty	u_0	"Inherent DUT variation" between calibration events
Observed Uncertainty	u_y	Combined uncertainty containing both process uncertainty and bias uncertainty

Table 1.

The ideas presented here offer discussion on the uncertainties encountered throughout the calibration cycle (refer to Table 1[1]). The term process uncertainty is defined to mean the "time of test" uncertainty. This uncertainty as defined by The Guide to the Expression of Uncertainty in Measurement (GUM) [6] is the uncertainty at the time of test and ignores possible, but significant, external effect encountered during the period of time in between calibrations. We define a second uncertainty called bias uncertainty which is the uncertainty associated with the DUT in between calibration events. To characterize the combined effects of both uncertainty components, a third term is required called the observed uncertainty.

1 The symbols u_m and u_0 were chose to comply with [5], u_y was substituted for u_{η_m} for simplicity.

Uncertainty Definitions

Although there may be many individual uncertainty components that comprise the uncertainty of measurement, there are two fundamental types of uncertainty: the process uncertainty u_m and the bias uncertainty u_0. Typically the NIST only reports the process uncertainty. Section 7.5 and 7.6 of Tech Note 1297 [7] states that since it is not possible to know in detail all of the uses to which a particular measurement result will be used, it would be inappropriate to include "external" effects in the reporting of uncertainty. However, it is cautioned that these "external" effects such as transportation, passage of time, and differences in environmental conditions are likely to be significant compared to the reported measurement uncertainty. Implicit in this agreement, NIST is assigning the responsibility of estimating external effects on the customer.

The model set forth by Tech Note 1297 was provided by the GUM and has since been internationally accepted. This model of reporting the measurement result exclusively with the process uncertainty meets only the most fundamental requirements of competence [8]. While this model may also hold for other National metrology institutes and primary standards laboratories that have the staffing requirements and knowledge to track these so called external effects, most users of test equipment only require confidence that their instrument is working to the manufacturer's stated specifications. Therefore, it is suggested under these conditions that the observed uncertainty be reported to customers. This will provide a more meaningful number that does not require further analysis—i.e. it is not left to analyze the measurement result, the stated uncertainty, and combined external effects that might affect the accuracy[2] of the DUT between calibration events.

In the case of measurement and test equipment (M&TE), the manufacturer's published accuracy specification (or tolerance) communicates to users a range of performance that may be expected with reasonable confidence. The interval of performance specified by the manufacturer does not allow for an estimate of uncertainty to be calculated unless the coverage factor and type of distribution are provided. To estimate the uncertainty based on manufacturers specification requires that the tolerance limits be divided by a coverage factor. In this paper we will derive the coverage factor based on scientific judgment and previous collected data and not be reliant on the manufacturers claim. This methodology is compliant with Type B estimates of uncertainty contained in the GUM 4.3.4 and numerical techniques for computing this uncertainty will be demonstrated throughout the paper.

2 The term *accuracy* is used throughout this paper to facilitate the classical concept of "uncertainty" for a broad audience. It is acknowledged that the VIM [1] defines accuracy as qualitative term, not quantitative, and that numerical values should not be associated with it.

Requirements of the GUM [2]

The Guide to the Expression of Uncertainty in Measurement (known as the *GUM*) was released 20 years ago in 1994. The document was an attempt to provide international guidelines for uncertainty analysis (Strictly speaking, the GUM is not a "standard," but is only intended for guidance). It mainly speaks to estimating the process uncertainty, but since it is the de facto standard in the industry, the ideas contained in the document should be applied to estimating all types of uncertainty. Reproducibility and reliability quantify output dispersion quantities through multiple calibration cycles as estimators and can be used to calculate the observed uncertainty. Since the GUM was not written to directly address these long term effects, four relevant paragraphs are identified that show the estimation of uncertainty using observed data does not deviate from the main principles contained in the GUM.

Section 0.4 states that the ideal method for expressing uncertainty should be capable of readily providing an interval about the measurement result that may be expected to encompass a large fraction of the distribution of values. In the case where uncertainty is based on the tolerance limits and the population statistics of instruments, then mathematically it is the dispersion from the expected value. The observed uncertainty then can be used to express an uncertainty around the measured value.

Section 1.4 specifically differentiates that there is a difference in the measurement uncertainty and tolerance limits in manufacturing, as only reporting an upper and lower bound (an interval) provides incomplete knowledge of the uncertainty. Sections F.2.3.2 and E.1.2 warn against this, as such a value cannot be readily converted into a standard uncertainty without knowledge of how it was calculated and therefore cannot be used downstream for traceability without further independent assessment to determine the coverage factor.

The methods presented in this paper directly address the traceability requirement by outlining methods for computing a coverage factor for the manufacturers tolerance limits based on sampling from a population of instruments. The population is defined as units having a common manufacturer and model number (e.g., all Agilent model 3458A multimeters with Option 002). The coverage factor k is then related to the tolerance limit L though the observed uncertainty

$$k = \frac{L}{u_y}. \qquad (1)$$

While it is recognized that some of the more rigorous manufacturers provide confidence intervals with the specification, the methods of determining the uncertainty presented offer further independent assessment to determine the coverage factor required. This directly addresses the traceability requirement by providing an interval and a coverage factor based on the observed uncertainty.

Section 2.2 defines what is meant by an uncertainty. In general, the term uncertainty of measurement focuses on the measurement result and its evaluated uncertainty. Uncertainty as represented by a standard deviation attempts to quantify the possibility of errors based on available knowledge by defining the dispersion of values that could reasonably be attributed to the measurand. The uncertainty in the GUM is a "time of test" uncertainty due to the absence of long term effects such as reproducibility. As discussed, this only represents the dispersion of the measurand at the time of test. By including long term effects in the uncertainty it is believed that this will better represent the dispersion throughout the calibration cycle.

From section 3.4 of the GUM it is implicit, that the measurement can be modeled mathematically to the degree imposed by the required accuracy of the measurement and that the evaluation of uncertainty be based as much as possible on observed data. Since users of M&TE purchase the equipment based on manufacturers' claims, then it is logical to base the required accuracy and ultimately the uncertainty on these claims. Also section 3.4 states that the evaluation of uncertainty should be based as much as possible on observed data. By collecting the data of past calibration history, the observed uncertainty directly complies with this guidance.

Determining the Observed Uncertainty (u_y)

Determining the observed uncertainty can be done using both variables data [9] and attribute data [10]. The reader is likely to be most familiar with variables data. This is the numeric data that is acquired through measurements. Variables data is normally analyzed and presented in terms of location or central location (mean) and spread (standard deviation). Attribute data is purely binary in nature, good or bad, yes or no, in or out of tolerance. To calculate uncertainty using attribute data, the data must be converted to a form of variable data in order to be counted or useful. A means of determining the uncertainty is given whereby information about a DUT is collected over time. This most commonly occurs when the item is submitted for calibration. Statistics generated provide information about the stability of the process. Determining the true bias uncertainty is technically not possible since the precise value is always unknown due to the measurement process errors. The decoupling of the bias uncertainty from the observed uncertainty is discussed in this section, however this requires direct knowledge of the process uncertainty. Shown below is the relationship between the 3 types of uncertainty: process, bias and observed for both variables and attribute data.

Using Variables Data

To show the fundamental relationship between the uncertainty terms, consider a sample of n items, each having a property η where y_0 is the best estimate. For each of the n items the property of interest is measured, yielding a set of estimates $y_1, y_2, \ldots y_i \ldots y_n$ with associated observed uncertainty u_y. A measurement or observed value y_i is discussed as the sum of two components, the true or absolute value x_i of the bias and the error of measurement e_i. The variation in DUT bias values is represented by the standard deviation u_0, and the variation in errors of bias measurements is called the process uncertainty represented by the standard deviation u_m. Now suppose a reference is used to measure some property of interest from a population of n different items, representing the calibration history. The results of measurement may be represented symbolically as follows:

$$\begin{aligned} y_1 &= x_1 + e_1 \\ y_2 &= x_2 + e_2 \\ &\vdots \\ y_i &= x_i + e_i \\ &\vdots \\ y_n &= x_n + e_n. \end{aligned} \tag{2}$$

Generally speaking the x values are all different since there is variability in the item or items measured. This variability can be caused by external influences such as environmental effects or can be caused by internal effects such as drift or noise. The properties of the sample are then summarized by calculating the sample mean $\bar{y} = \frac{1}{n}\Sigma_{i=1}^{n} y_i$ and sample variance $u_y^2 = \frac{1}{n}\Sigma_{i=1}^{n}(y_i - \bar{y})^2$. Separating and estimating product variability and variability of measurement data, the variance of the observed measurements is given by

$$u_y^2 = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2 + \frac{2}{n}\sum_{i=1}^{n}(x_i - \bar{x})(e_i - \bar{e}) + \frac{1}{n}\sum_{i=1}^{n}(e_i - \bar{e})^2. \tag{3}$$

The first term in Eq. 3 gives an estimate of the inherent variaion in DUT bias, x of a larger category from which the random sample of n observations is taken. This term defines this as the bias uncertainty.

$$u_0^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2 \tag{3a}$$

The last term in Eq. 3 is a measure of the variation in the errors of measurement. This term defines the process uncertainty.

$$u_m^2 = \frac{1}{n}\sum_{i=1}^{n}(e_i - \bar{e})^2 \tag{3b}$$

The middle term in Eq. 3, known as a co-variance, gives a measure of the relation between the values of the characteristics measured and the errors of measurement.

$$u_{m0}^2 = \frac{2}{n}\sum_{i=1}^{n}(x_i - \overline{x})(e_i - \overline{e}) \qquad (3c)$$

It will be assumed, x and e are sufficiently independent to insure that limited variations in x are not reflected in the errors of measurement, that is no correlation exists between the values of the characteristic measured and the errors of measurement: $u_{m0}^2 = 0$.

Substituting these definitions back into Eq. 3 leaves the final equation, showing the relationship between the 3 types of uncertainty.

$$u_y^2 = u_0^2 + u_m^2 \qquad (4)$$

The observed variability u_y includes contributions of the inherent DUT bias variability and standard's variability, where u_m is the standard deviation of the random contributions affecting the measurement process and u_0 is the intrinsic variability of the property of interest being monitored. The efficiency with which the true values are measured depends on the relative size of the components of variability. An important point of interest here is that in the usual calibration scenario $u_m^2 \ll u_0^2 < u_y^2$ and u_m^2 and u_0^2 can never be larger than u_y^2. The quantity u_0 is of interest but is always clouded by uncertainty in the measurement process.

This analysis has deviated somewhat from the Annex B of reference [5] by expanding the sample variance in (B.3) and computing the intrinsic variance u_0^2 in place of s^2. In the case of sampling M&TE, the population is sampled from an unknown distribution assumed to be normally distributed, that represents the population variability. Making the substitution $s^2 = u_0^2$ in equation (B.9) yields a similar result as derived above, with $u_r^2 = u_y^2$. Equation B.9 counts the measurement uncertainty twice in the final outcome which does not apply to sampling a population of instrument unless a separate process was used which needs to be accounted for.

Using Attribute Data

Although it is becoming more common for the calibration reports to contain variables data, historically only the date of calibration along with in or out of tolerance conditions were reported when compliance decisions were made. As previously discussed, this binary data is called attribute data. The observed uncertainty u_y of the population can be inferred directly from the End of Period Reliability data (EOPR) collected during calibration events. This method is somewhat conservative and will rarely yield Measurement Capability Index $C_m = \frac{L}{2u_y} > 2$ due to the numbers of calibrations required to achieve this result. EOPR is the probability of a DUT test-point being in tolerance at the end of its normal calibration interval. It is sometimes known as *In-tolerance probability* and is derived from previous calibration events. Suppose that in a given number of calibrations, the number of as-received in tolerance events is computed. The relative frequency of conformance of that event is given by

$$p_c = \frac{\textit{Number of}\text{ as-received }\textit{IN-tolerance results}}{\textit{Total number of calibrations}}\,. \qquad (5)$$

Knowledge of the measurand is conveyed by the prior probability density function (PDF) $g(\eta)$, with some probability of being true. For test limits T_U and T_L, the probability of conformance p_c based on previously observed data is given by

$$p_c = \int_{T_L}^{T_U} g(\eta)\, d\eta = \Phi\left(\frac{T_U}{u_y}\right) + \Phi\left(\frac{T_L}{u_y}\right) - 1. \qquad (6)$$

Here, Φ is the standard normal distribution with mean of zero and standard deviation of one and T_U and T_L are the upper and lower tolerance limits. In the case $L = T_U = T_L$, the inverse normal function is used to estimate u_y from observed data. The computed coverage factor based on the tolerance limits is given by

$$k = \Phi^{-1}\left(\frac{1 + p_c}{2}\right) \qquad (7)$$

where Φ^{-1} represents the inverse normal distribution. Here, the prior distribution is assumed to be normal but in general u_y can be calculated based on any distribution. From the measurement results, the uncertainty is estimated based on the manufacturer's tolerance limits and the coverage factor using Eq. 7. Based on the attribute data, one can compute the coverage factor and obtain the standard uncertainty of the calibrated equipment which can then be used downstream for traceability.

EOPR data is valid for a given interval or period. As time passes from the calibration event, uncertainty tends to grow due to drift and external effects. The value of coverage factor computed above is based on data from a given calibration interval. Controlling uncertainty growth is covered in [11]. It should be noted that there are no finite limits that will contain 100 percent of its possible values for a normal distribution. However, ±4 standard deviations about the mean of a normal distribution corresponds to 99.994 percent limits. Thus, if the tolerance interval limits T_U and T_L of a normally distributed quantity are considered to contain "all" of the possible values of the quantity, then it is recommended to use $k = 4$.

The decoupling of the intrinsic variability from the observed variability is done via the variance addition

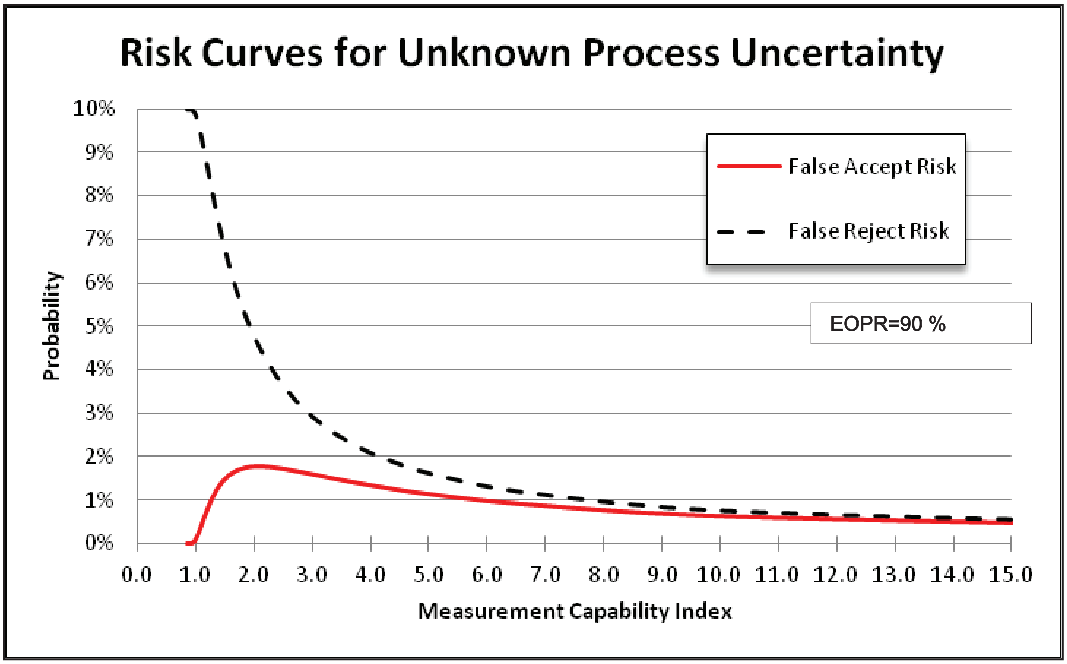

Figure 1. Probability of false accept and false reject risk with 90 % EOPR for all realistic process uncertainty values.

rule or simply $u_0^2 = u_y^2 - u_m^2$. The ability to compute an intrinsic variability implies that an immaculate value for u_0 exists, which has not been influenced by any non-ideal process factors. However, since the analysis is based on periodic calibration events, the variability does include the external components mentioned above. The process uncertainty "contaminates" the data to some degree. The observed is never a completely accurate representation of the intrinsic. The difference between the observed and intrinsic becomes more pronounced as the measurement uncertainty increases. This case can result in a significant deviation between what is observed and what is true regarding the variability data. The Eq. 4 shows that the standard deviation of the observed data is always worse (higher) than the true data. That is, the history maintained by a laboratory will always cause the DUT data to appear further dispersed than what is actually true.

Example

Example: The calibration lab where you work has an automated calibration procedure for an adjustable wire-wound precision resistor of nominal resistance $y_0 = 1500\ \Omega$ and the manufacture specification is $L = \pm 0.2\ \Omega$. A review of past calibration events reveals that customers have submitted a number of resistors with individual serial numbers a total of 40 times. 4 events were coded as being out-of tolerance and adjusted back to nominal to meet specification.

From this simple description, one can calculate the observed reliability of the calibration history by dividing the number of in-tolerance results by the total number of historical events. The observed reliability is then 90 %. By using the 89 % rule, a measurement can be made in the future with the probability of falsely accepting a resistor as being in tolerance when the true value to out of tolerance is less that 2 %.

Using the formula $u_y = \frac{L}{\Phi^{-1}\left(\frac{1+p_c}{2}\right)}$, we find that $u_y = 0.12$.

Since we know u_y contains both elements of bias uncertainty and process uncertainty, we can report this value to the customer and satisfy the accreditation requirement to report uncertainty. It is interesting to note that the observed reliability estimate does limit the process uncertainty by the fact that u_m^2 and u_0^2 can never be larger than u_y^2 where the stated quantities are related by Eq.4. If we assume $u_0^2 = 0$ then we then have a Measurement Capability Index $C_m \cong 0.83$ for the example. This is an extreme assumption but the conclusion is that the uncertainty in the process used to measure the resistors was at minimum equal to the observed uncertainty. In fact, we can plot (see Figure 1) the probability of false accept and false reject risk for all realistic process uncertainty values to gain insight into the behaviors of the curves. Notice that the false accept risk for an observed reliability of 90 % never goes above 2 % no matter what process uncertainty is used.

The next day, a customer submits another resistor for calibration. After the calibration is performed, it is determined that the resistor does not meet specification. It is realized that the observed reliability no longer meets the 89 % threshold. At this point, there is no guarantee that the PFA is less than 2% based on the 89% rule. The only way to be compliant with the 2 % rule is to calculate risk [12]. Let's assume that the process uncertainty for the measurement system was determined to be $u_m = 0.04\ \Omega$ or $C_m \cong 2.5$. At this point we can calculate the unconditional risk. For this operating point PFA ~ 2 % and PFR ~ 3.82 %; although only by a small margin, the 2 % rule is still satisfied.

Traceability

The definition of traceability requires the untangling of multiple definitions but at the root is the relationship between measurement standards and the measurement. Many organizations require a documented uncertainty statement in order to assert a claim of metrological traceability [13]. Reporting the observed uncertainty is thought to meet this requirement. It will be argued by some that using the observed uncertainty is not traceable. However, if traceable standards are used to perform the measurements and a documented uncertainty is reported, it will be hard to make this point.

The observed uncertainty is not a traditional uncertainty, however it does contain components of the process uncertainty (standards) as well as the bias uncertainty (DUT). Therefore the observed uncertainty contains a contribution of the process uncertainty dispersion, just not direct knowledge of the magnitude. Does the VIM imply that the measurement cannot be traceable without direct knowledge of the measurement standard's uncertainty? This question is best left for the reader to decide.

To be fair, until the 89 % rule and subsequently a method for computing an observed uncertainty was discovered, no one in the metrology and calibration discipline had come up with another way of insuring quality by keeping risk below a specified threshold and estimating uncertainty without direct knowledge of process uncertainty. If direct knowledge of process uncertainty is required by the VIM, then the claim of traceability cannot be made using the techniques outlined in this paper. Metrological traceability of a measurement result does not ensure that the measurement uncertainty is adequate for a given purpose or that there is an absence of mistakes, it simply ensures there is an unbroken chain of calibration leading to standards maintained by a national lab. Confidence in the measurement results is fundamentally important for laboratories and their customers. If the accuracy is not sufficient then the reliability estimate will be inefficient. While it is acknowledged that reliability can be a powerful tool in measurement decision, careful consideration must be made on how the data was collected.

Discussion of Reliablity Data

Reliability estimates the external effects that cause the uncertainty growth in between calibrations. The estimate will depend heavily on the use of the equipment and the interval at which the items are submitted for calibration. These factors cannot always be controlled especially in commercial calibration laboratories. In these cases, for the same manufacturer/model number there may be sub-populations that are highly unreliable while the rest of the population is reliable. This can be caused by extreme use of the equipment or extreme misuse. A DUT operated in a temperature controlled lab will have different external effects than a DUT operated in the desert. While keeping track of calibration data is not easy, it can provide a serious analysis tool. When basing the uncertainty on measurement data, factors other than the measurement standards affect the results. The collection of data not only relies on the technical aspects such as which standards were used but also on human factors as well. Production pressures and human bias can cause mistakes to be made.

The number of data points that is required to confidently use reliability data needs to be agreed upon. It is one of the most common questions when this topic is discussed and the decision is beyond the scope of this paper, only a brief overview will be given. While there is no definitive source of information on this subject in the metrology discipline, much information has been written about similar techniques in Statistical Process Controls (SPC). At the time of writing this paper, to the author's knowledge the best source of information on this subject can be found in RP-1, the Establishment and Adjustment of Calibration Intervals [11]. In the future, it is recommended that a document be established that provides guidance on the subject in line with best metrological practices.

Conclusion

Accreditation bodies are now requiring measurement uncertainty be reported for the calibration results, which they distinguish from the calibration and measurement capability (CMC). This paper suggests a technique that could meet these requirements and provides a wealth of information about the process itself. This method of reporting uncertainty is thought to better encompass the definition of uncertainty as it characterizes the measurand not only at the time of test, but throughout the calibration cycle. Clearly, two forms of uncertainty are now being required to perform a calibration and subsequent verification. In this scenario, the calibration lab can be accredited to the CMC by documenting the uncertainty of the standards listed in the scope of accreditation and use the techniques presented above to report the measurement (observed) uncertainty for each test point to the customer. Since the observed uncertainty is based on the manufacturer's tolerance limits, there is a baseline uncertainty to start with that everyone can agree on which also includes other relevant information about the measurand. Each lab can maintain the calibration history for a population and compute a coverage factor for the manufacturers tolerance limits. In this way, the standards uncertainty is documented and the customer is provided with an uncertainty that provides a high in tolerance probability throughout the calibration cycle.

The observed uncertainty is computed using the EOPR data derived from previous calibration events. When compliance decisions are made where the observed uncertainty is small compared to the tolerance limits, there exist a threshold that ensures the 2 % rule is met, regardless of the value of the process uncertainty. The threshold is 89 % observed reliability; this approach utilizes the behavior of the PFA model in response to input variables. If the 89 % EOPR threshold is not achieved, the bias uncertainty is still valid but other methods will need to be used to mitigate the risk of false acceptance to a level of 2 %. The analysis of reliability data provides a useful tool that the calibration lab can leverage to improve the calibration process. The 89 % rule greatly simplifies the computations required to meet the 2 % rule by harnessing the mathematics and creating a tool that can be used in an efficient manner.

The expectation to perform to the technical requirement implies some time differential between the time of calibration and use. Certainly, the DUT is expected to perform at the level specified by the process uncertainty during the calibration but what happens after the DUT is turned off and shipped back to the customer? The qualifier “time of test” immediately conveys when the uncertainty is valid. While acknowledged that the process uncertainty is important, it neglects external effects that cause the dispersion of the measurand to increase as time passes. The user of the equipment is therefore required to be aware of this and make proper adjustments to account for the increased uncertainty. While the measurement process uncertainty is used for characterizing the quality of a measurement result, it cannot be used to establish a technical requirement if prime objective is that reported uncertainty characterizes the dispersion of values associated with the measurand throughout the calibration cycle. Establishing this requirement must be done using the observed uncertainty obtained from a calibration history and other available relevant information.

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This article is a condensed version of a paper previously presented at the Measurement Science Conference (MSC), in Anaheim, California, March 18-22, 2013.

Laboratory Management: An Introduction

Kenneth Parson
Parson Consulting – International

This article covers the subject of laboratory quality/ management and addresses the issue of laboratory accreditation. I hope you will find this article interesting and informative and will help you to improve on the operation of your laboratory and help those about to embark on the difficult task of starting a laboratory that will meet requirements for Accreditation.

There is an old saying, "Say what you do"
and "Do what you say."

This saying is the essence of the whole matter of laboratory management and accreditation.

The first order of business is to (Say what you do). Developing, documenting and implementing a well designed management system is one of the most important but difficult and frustrating activities that can be undertaken by laboratory management, but it must be done.

About Laboratories

Laboratories provide a unique service. They (a) measure things, (b) quantify results, and (c) document and issue reports. They calibrate, test, and sample, and evaluate all types of measurement phenomena and materials and quantify results for the good of those being served. Written results and conclusions derived by this work by laboratories can be critical to the development and operational performance of products and services. Because of the highly technical nature and specialized work performed and the integrity and documented results, it is extremely important that laboratories be designed, developed, managed, and operated in such a way as to consistently achieve and document results that are above reproach. Results produced by laboratories must be clear, concise, and must provide error-free calculations and fully documented results. Even the smallest mistakes in a report can lead to a lack of confidence and trust in the results provided by a laboratory. This level of performance can only be achieved by personnel with the highest level of technical knowledge, skills, and verifiable competence and are able to demonstrate compliance to requirements. Laboratory operations are complex and unique to the work they perform.

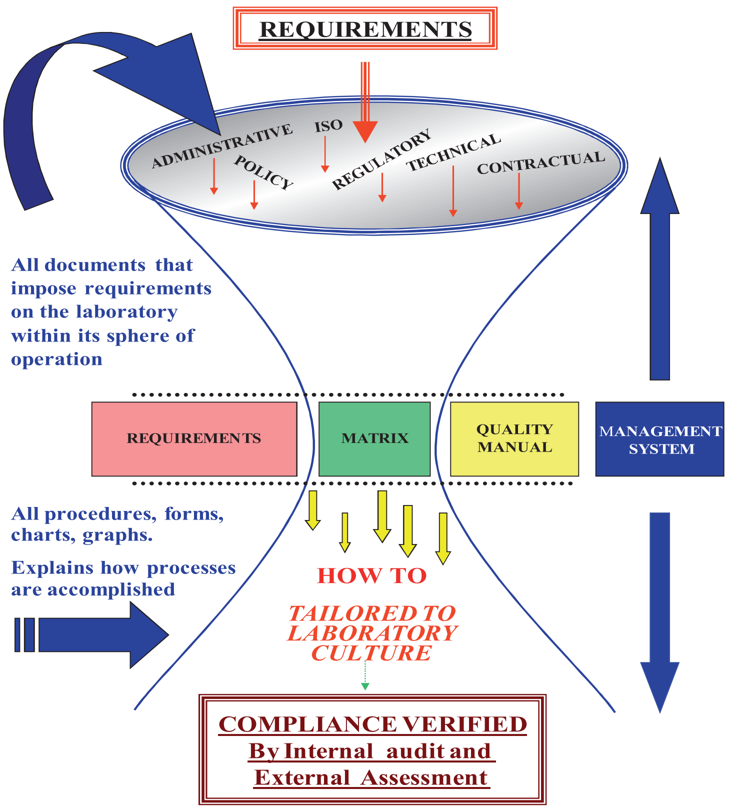
Preparing for the start-up of a laboratory or having been assigned the task of reorganizing a laboratory to make it more efficient and cost effective is a major undertaking. The following diagram depicts the functional relationship of key elements that must be considered when preparing for the development of a laboratory quality/management system. The hourglass diagram on the following page shows that a document referred to here as a Quality Manual is at the focal point of the quality system and is positioned between requirements imposed on the organization and the translation of those requirements into work procedures and instructions. This becomes a convergence zone.

On the left of the convergent zone is a box titled "Requirements." The purpose here is to inventory all requirements imposed on the laboratory. The inventory should be organized to identify and sort all Standards, Regulations and Contract requirements imposed on the laboratory. This tool allows for the systematic inventory and assessment of all requirements. This is an important activity because it ensures management that all requirements imposed on the laboratory have been identified, recognized and accounted for.

In the middle, a tool set up in a Matrix or spread sheet format is used to correlate requirements to the need for operating procedures. This tool is used to identify and analyze requirements and to translate this information into "How To" procedures. This of course can be a major effort but must be done. It is the activity of documenting the, "say what you do" part of the effort. When this work is completed it will be used to ensure all "How To" procedure have been identified, developed and implemented. Once completed these procedures should be referred to in the Quality Manual.

The third box in the convergence zone identifies the Quality Manual. The quality manual is similar to a storybook, a road map a tour guide that conveys the culture of the organization. It is a marketing tool designed to let regulatory agencies and customers get to know you and what your organization can offer. It also provides the basic operating principles to be adhered to by the entire staff. It should document management's

Hour Glass Diagram - The Focal Point



The Quality Manual links Requirements to Compliance.

commitment, policy and operating philosophy. It should describe the location, organizational structure, document hierarchy, a list of qualified services provided and how the organization goes about its business. The quality manual should document and be responsive to all requirements as imposed by Standards, Regulatory, and Contractual requirements. The quality manual should not contain "how to" procedures but identify where they are located within the management system. This document is an essential element of any assessment process and is simply a good management practice. It should provide a commitment to customers and is a key to developing, documenting and implementing an effective management system and quality assessment process. This document should be signed, dated and promulgated by a top executive having the authority to set policy, establish goals and objectives and have the resources necessary to fund the mission.

On the right is a box titled Management System. It is the culmination of all the research, analysis, translation and documentation you have accomplished that ensures your laboratory is prepared for and can demonstrate compliance to requirements.

On the lower left below the Requirements box is the following statement -"All procedures, forms, charts and graphs. Explains how processes are to be accomplished." This includes a sample of all charts, checklists, flow diagrams, forms, and records used to document and record results of events as they are accomplished. These forms should be identified and show what they look like and explain how they are to be used, processed, filed and stored. These forms document and record information and are an important part of record keeping. Personnel should be trained to use these forms and to ensure consistency, standardization and repeatability for work being accomplished. It is these records that are used as documented evidence of results of your work.

Standard Administrative, Operating procedures and Work Instructions are the building blocks and form the foundation for the Laboratory Management System. These procedures and forms should also be identified and included in a Composite or Master list of Documentation and monitored as part of the Internal Audit process.

Getting Ready

Here are some things to consider if you want to save costs and improve on the efficiency of your laboratory's performance or if you wish to prepare for and pursue accreditation:

First - For laboratory management, there must be a reason why this new goal is worth persuing and there must be a commitment by top management to support such an effort. It will take time and patience and it will cost money. New techniques will be needed to be mastered. There will be failures in the beginning and along the way, be prepared for it. Without a goal, strong commitment, teamwork and practice it will be difficult, if not impossible to successfully compete at this international level of performance. Preparation for a project such as this is a major undertaking and should only be done with the full commitment and financial support of top management. Without top level support the effort will be stymied and fail. Although assigned to an individual for project coordination and control it should be accomplished as a collective team effort. Assign a team leader to prepare for and coordinate the effort. Develop and follow a Plan of Action & Milestones (POA&M). Management will need to monitor the effort to ensure progress as established in the POA&M. This type of project should be addressed and monitored as part of the Management review.

Second - Identify, obtain and review copies of the latest version of any Standards, Regulations and Contract requirements the laboratory must adhere to. If you wish to pursue accreditation you will need to investigate and decide on which Accrediting body you will use. You will need to select and contact the Accrediting body of your choice and obtain an application and any requirements documents that are used by the Accrediting body which, as a minimum are in compliance with the ISO/IEC 17025 Standard. Be sure the Accrediting body is recognized as part of an established Mutual Recognition Agreement.

Third - Decide what measurement parameters or test procedures and services within the laboratory are to be qualified through accreditation or accepted by a customer organization. This can be a rather complicated process. You will need to give this much thought. Here are just of few of the questions and actions you will need to consider before you embark on improvements to your system or to consider making an application for accreditation. Be prepared.

1. What is your rationale for choosing certain measurement parameters or test methods?
2. What is the pay-back and benefits to be derived?
3. Do you have a workload or prospective workload to support?
4. Do you feel confident your laboratory can perform well in the areas chosen?
5. What will it cost to prepare?
6. How long will it take to complete?

When you have completed the quality manual you will need to develop a set of Administrative, Operating procedures and Work Instructions that describe in detail how you carry out all laboratory processes. (Saying what you do).

Dress Rehearsal

A "Do what you Say" demonstration - Once you have completed this work and prepared for an assessment you will need to conduct a dress rehearsal. Once you have documented your system, do your own evaluation of your laboratory's documented quality/management system and verify your technical capabilities. Set up a test plan. Do a dress rehearsal. Find out how well your laboratory can perform. Be critical and identify those areas that need work and take appropriate corrective action and re-test to assure expected results are achieved. Do this before application to an accrediting body or prospective customer organization and before any on-site visit is scheduled. It is far better to resolve problems in-house at this stage than to allow a problem to be found and formally documented during an assessment with mandated corrective action being required and implemented within a set time frame before accreditation or acceptance by a customer is given. For those laboratories not perusing accreditation the same situation applies where you will of course need to meet customer expectations. This is the beginning of the whole effort to ensure your laboratory remains under control and can provide consistent, reliable results to customers in the most efficient manner. I hope you have found the article informative and helpful in conducting the overall management of your laboratory.

Remember, prepare to "Say what you do" and be able to demonstrate your ability to "Do what you say."

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The preceding article is a compilation of excerpts from Ken's recently published book titled *Laboratory Quality/ Management: A Workbook with an Eye on Accreditation*, available in hardback, softcover, or as an ebook at: www.xlibris.com, www.amazon.com, www.bn.com, or visit your local bookstore.

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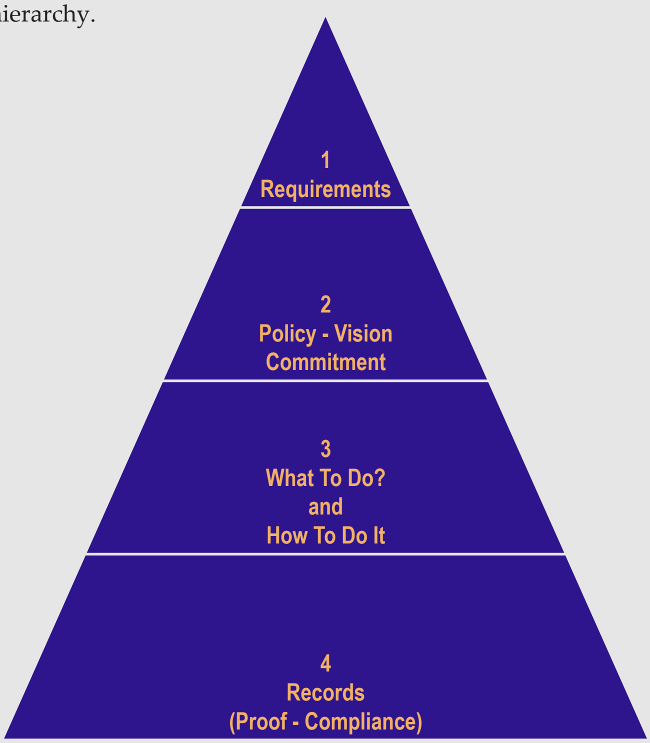
The following information is provided to further elaborate on the importance of laboratory documentation as it relates to the overall management and control of laboratory operations. A typical pyramid diagram, as shown here, identifies the structure of a documentation hierarchy. I have selected a title for each level that fits into my version of the hierarchy.



Management/Quality System Diagram
Document Hierarchy

1. Requirements - Identifies those documents that establish requirements your organization must comply with to function in your chosen field of laboratory operations and services. This should include International Standards such as, ISO/IEC 17025, ISO 9001 and any other regulatory requirements imposed on the laboratory and requirements established through contract agreements.
2. Policy – Vision – Commitment - The Quality Manual is a link pin policy document. It establishes and documents the policy and operational philosophy for the organization, "Say what you do." The quality manual will need to address all pertinent requirements as specified in requirements imposed on the laboratory organization. Note, these 'how to' procedures should not be included in the Quality Manual. Detailed information regarding how to prepare a quality manual is provided later.
3. What To Do and How To Do It - Procedures that describe in detail how the various laboratory processes and procedures are to be accomplished—"Do what you say."
4. Forms, Records, Proof and Compliance - This includes a sample of all charts, checklists, flow diagrams, forms, and records used to document and record results of events as they are accomplished. These forms should be identified and show what they look like and explain how they are to be used, processed, filed and stored. These forms document and record information and are important. Personnel should be trained to use these forms and to ensure consistency, standardization and repeatability for work being accomplished. It is these records that are used as documented evidence of results of you work. These forms should also be identified and included in a Composite or Master list of Documentation and monitored as part of the Internal Audit process.

NEW PRODUCTS AND SERVICES

ZEISS ROTOS Roughness Sensor

ZEISS (www.zeiss.com) introduces the new ZEISS ROTOS roughness sensor. This sensor enables the standard-compliant inspection of roughness and waviness on a single coordinate measuring machine (CMM) for the first time. Therefore, all features of a technical drawing can be fully captured with one CMM and displayed in one record. It is no longer necessary to transfer to a surface measuring instrument. Various measuring positions can be reached without rechucking and a fully automatic run is possible without the operator influencing the surface measurement.

ZEISS ROTOS is intended for users that inspect size, position or form on a coordinate measuring machine and also need to measure roughness and waviness on the same workpiece. Instead of clamping the workpiece on a contact stylus instrument, ZEISS ROTOS is used via the stylus changer interface on the probe of the CMM – under full CNC control.

ZEISS ROTOS can be positioned flexibly to reach all surfaces on a part without rechucking. Furthermore, the sensor features a rotating/tilting axis. The rotary axis can turn a full 360 degrees. The sensor can be tilted perpendicularly downward to provide a tilt range of 160 degrees. ZEISS ROTOS is connected to the measuring machine via the ZEISS VAST line of active probes, which dampen interferences from the machine and environment, and also determine the measuring position. Measurement data from ZEISS ROTOS is transmitted via Bluetooth to the analysis computer. The data is then imported into ZEISS CALYPSO software via a machine driver and can be exported with other measurement data in a common record.

In short, the three key benefits of a workflow with ZEISS ROTOS are: improved measuring productivity, reliable and fully automatic measuring runs, and the common record—based on the seamless interaction between the sensor, measuring machine and software.

PQ Systems GAGEpack 11 Release

A new release of GAGEpack from PQ Systems offers a "super filter" feature that enables users to see only those gages relevant to their own divisions, departments, or facilities, and for multiple departments to be managed within a single GAGEpack database.

GAGEpack is powerful gage calibration software that saves time and enhances accuracy in gage management and measurement systems analysis. It maintains complete histories of measurement devices, instruments, and gages. The latest release of GAGEpack offers additional features to render the management of gage records even more efficient and easy. These include:

- Corporate settings, creating database-wide options that correspond to previously available local settings, providing an enterprise-wide consistency of critical settings;
- Corporate reports, with settings created at the database level, allowing deployment of large-scale installations of GAGEpack;
- Enhanced language support for Italian, French, German, Spanish, and Spanish LA (for Latin America), as well as newly-available translations in Mandarin and Portuguese;
- Masters tab to store an unlimited number of master gages, along with relevant information about each gage;
- New Search and Replacement tools for calibration templates, master gages, and PM plans;
- Wider gage viewing windows to assure that all available tabs are clear, with sleeker layouts for fields on each tab;
- A default "Print after Saving" for calibration labels and certificates, replacing manual command and thus saving time and reducing steps.

PQ Systems (www.pqsystems.com) has helped those in manufacturing, healthcare, government, and service organizations demonstrate proof of their quality performance for 30 years. With headquarters in Dayton, its offices in Victoria, Australia and Merseyside, UK serve a world-wide customer base with a demand for statistical process control, gage management, measurement systems analysis, document control, quality audit tracking, and more.

Fluke 750P Series Pressure Modules

To meet the requirements of evolving pressure calibration standards and reference class accuracy pressure instrumentation, Fluke Corp. introduces the 750P Series Pressure Modules. The 48 precision modules enable gage, differential, dual range, absolute, and vacuum pressure measurement with Fluke 750 and 740 series Documenting Process Calibrators and 725, 726 Multifunction Process Calibrators.

The 750P Series is designed for the different use models specified in new calibration requirements. For applications in pharmaceuticals or custody transfers in oil and gas, there are 11 new modules with two-times more accuracy than standard modules. For industries like nuclear and pharmaceutical that now require calibration every six months, the 750P Series offer a six month specification that provides better accuracies between these shortened calibration cycles.

The new modules cover pressure calibrations from 0 to 1 in H20 to 10000 psi (2.5 mBar to 690 bar) with a 0.025 percent reference uncertainty. Digital communication to calibrators eliminates errors due to poor connections and electrical interference.

Gage pressure modules have one pressure fitting and measure the pressure with respect to atmospheric pressure. Differential pressure modules have two pressure fittings and measure the difference between the applied pressure on the high fitting versus the low fitting. Each module is clearly labeled for range, overpressure and media compatibility. All modules include NPT, metric (BSP) and M20 adapters.

For more information about the Fluke 750P Series Pressure Modules, visit: www.fluke.com/pressuremodules.

GEO2000SP-DFB-11 Humidity Generator/Calibrator

Green Energy Optimizers Corporation of New York is releasing under their own brand the GEO2000SP-DFB-11, the latest portable temperature and humidity calibrator with front panel and DFB Software control. The newly released system is the latest offering from the design and manufacturing company that has been providing instruments in the temperature and humidity sector for the last decade.

The new product line offers a portable chamber with Device Feed Back integrated into the GEO System with clean access with no external meters required for calibration. The system will accept voltage and current probe calibration with a user friendly software and printed report features and customer experimentation setup for R&D. The instrument features digital control for enhanced stability of humidity and temperature. With the included DFB (Device Feedback) Software the user experiences increased calibration productivity and universal probe calibration with printed report features. Chamber stability for temperature and humidity values within 3 to 10 minutes, with high level accuracy for temperature and relative humidity.

Lightweight, clean design and ease of portability for in-plant or laboratory calibration with front panel control and flexible device configuration with GEO's user friendly software with USB cable, Integrated Desiccant, Standard Probe Door (w/3 Sizing Options) is included with each system. Optional expansion chamber for data loggers and customized door for various probe size are available.

The GEO2000SP-DFB includes NVLAP trace documentation, lifetime software upgrades and a (1) year limited warranty for part and labor. Additionally, GEO offers unique rental and lease programs for Calibration and Laboratory Facilities. For more information visit www.geocalibration.com, or contact Bruce R. MacArthur brm@geocalibration.com 1-631-471-6157 ext. 227.

About Green Energy Optimizers, LLC.: Since the early 2000's we have produced RH Generators for laboratory and mobile calibrations. Now with our DFB product line we meet the needs for accurate calibrations at remote field sites with excellent portability and the industry's highest standards We are a best in class instrument leading the industry in the development and production of precision vapor generators for humidity-temperature calibration, moisture research systems in a space and portable format.

With over 30 years experience, GEO designs and manufactures a wide range of instruments and system solutions capable of measuring humidity and temperature in a vast range of applications and industries ranging from pharmaceutical to chemical and many more.

With a fast growing subsidiary and distribution network, GEO provides solutions in moisture and humidity to the most demanding customers globally.

GEO is headquartered in New York with additional customer support locations Hong Kong and the PRC.

Agilent Z-Series Oscilloscopes

Agilent Technologies Inc. recently introduced its Infiniium Z-Series oscilloscopes, which can be synchronized to measure up to 40 channels simultaneously with a maximum 63-GHz real-time oscilloscope bandwidth (on up to 10 oscilloscopes). With industry-leading noise and jitter measurement floors, the new oscilloscopes enable engineers to effectively test devices that incorporate the newest technologies and achieve new performance milestones.

The Z-Series includes 10 models ranging from 20 to 63 GHz, all of which are bandwidth-upgradable to 63 GHz. The Z-Series also features significantly faster processing and a next-generation user interface.

Key capabilities include:

- Sufficient bandwidth to capture the third harmonic on 28-, 32- and 40-Gbps digital signals;
- Next-generation user interface to analyze emerging technologies, including spatial modulation;
- Optional synchronization port to measure up to 40 channels simultaneously;
- Capacitive touch screen and touch-screen-friendly controls to improve the user experience; and
- USB 3.0 offload speeds, making it significantly faster to offload and analyze data.

The Z-Series leverages key technologies used in the 90000 Q-Series oscilloscopes. They include RealEdge technology, which comprises a combination of Agilent-proprietary architectures, next-generation microcircuits/thin-film components, and advanced application of Agilent's indium phosphide semiconductor process. RealEdge enables high-frequency capability while maintaining the industry's lowest noise and jitter measurement floors (75 fs).

These new oscilloscopes allow engineers to take advantage of Agilent Infiniium oscilloscopes' industry-leading hardware and software advancements that have been years in the making. These improvements include seamless integration of elements such as:

- The ability to join multiple Z-Series oscilloscopes together using Agilent's exclusive software to form a system of 40 channels or more (N8822A);
- Compatibility with more than 40 measurement-specific applications, including jitter, triggering and measurement software, analysis tools and full-compliance certification test suites;
- Breakthrough Infiniium offline analysis software, which lets engineers analyze data using oscilloscope software on a PC or laptop instead of tying up the instrument for analysis;
- N2807A PrecisionProbe Advanced software that helps engineers characterize and correct for cables to the full 63 GHz; and
- Agilent's flexible and innovative InfiniiMax III probing technology for bandwidths up to 30 GHz.

Customers who have previously purchased the 90000 Q-Series can upgrade their units to Z-Series performance by ordering the N2105A and N2109A upgrade kits. Additional information about Agilent's new Infiniium Z-Series is available at www.agilent.com/find/ZSeries.

NEW PRODUCTS AND SERVICES

Rohde & Schwarz ZNBT - 24 Test Port VNA

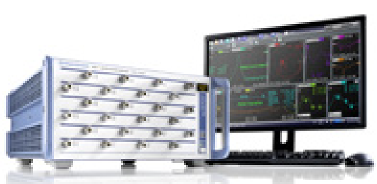
Rohde & Schwarz has added the R&S ZNBT to its portfolio of multiport network analysis solutions. The instrument covers the frequency range from 9 kHz to 8.5 GHz, and the base model is equipped with four test ports. Depending on application requirements, the analyzer can be enhanced to include 24 ports. The R&S ZNBT is primarily used in the development and production of active and passive multiport components such as frontend modules for multiband mobile phones.

When fitted with its maximum number of test ports, the R&S ZNBT is capable of determining all 576 S-parameters of a 24-port DUT. It requires no switching, and therefore carries out multiport measurements faster than switch matrix-based multiport systems. Alternatively, the R&S ZNBT can also measure multiple DUTs in parallel. Previously, users had to operate several network analyzers in parallel to achieve such high throughput.

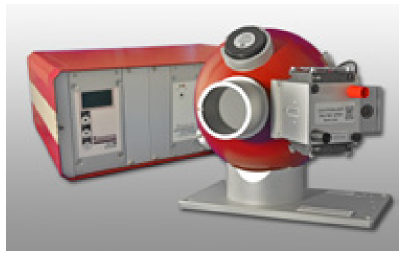
The R&S ZNBT also does away with the loss introduced by matrix switches, making it possible to deliver measurements with the instrument's full dynamic range of 130 dB, a high output power level of 13 dBm and low trace noise. This makes multiport measurements with the R&S ZNBT highly stable, reproducible and precise.

The network analyzer can be controlled via an external monitor, mouse and keyboard or via an external touchscreen. It features the same intuitive operation as the R&S ZNB, and all of its functions can be accessed in no more than three operating steps. As a result, defining even complex multiport measurements is just as fast and easy as configuring conventional two-port measurements. Automatic multiport calibration units from Rohde & Schwarz save users time when calibrating multiport test setups.

The R&S ZNBT multiport vector network analyzer is now available from Rohde & Schwarz. For more information, visit www.rohde-schwarz.com/product/znbt.



Gigahertz-Optik Integrating Sphere Source Calibration Standard



Gigahertz-Optik introduces the ISS-17-VA Integrating Sphere Source calibration standard for spectral radiance and luminance. A unique and key feature of Gigahertz-Optik ISS series is a variable light intensity output while maintaining a constant color temperature.

The term "Uniform Light Source" best describes the distinguishing property of an "integrating sphere light source" as it produces an illuminance field with excellent luminance homogeneity. Through spectral radiance calibration of the illumination field the integrating sphere light source can be used as a calibration standard for comparison of imaging spectrometers as well as for spectral radiance calibration of spectral meters. In these applications halogen lamps at 3100K color temperature are used to ensure optimum intensity in the blue spectral range. Another desirable feature of halogen lamps as spectral radiance and luminance calibration standards is a continuous and stable luminous spectrum. According to many published standards this type of lamp (CIE Standard Illuminant A) is specified for luminance responsivity calibrations at 2856K color temperature.

The ISS-17-VA Integrating Sphere Light source is 170 mm in diameter with a 50 mm diameter illumination field. The sphere is coated with Gigahertz-Optik GmbH's own highly diffuse and reflective Barium Sulfate. The coating provides a hemispherical scattered reflection over its entire usable spectral range. The light source is designed in the form of a simplified satellite sphere thereby guaranteeing homogenous light distribution within the sphere. Thanks to an adjustable aperture between the light source and the integrating sphere the intensity of the spectral radiance and luminance can be varied while maintaining a constant color temperature. A reference detector on the integrating sphere monitors the luminance level and color temperature. This enables the ISS to be operated at 2856K and 3100K color temperatures.

Internationally traceable luminance, spectral radiance and color temperature calibration is performed and certified by Gigahertz-Optik's optical radiation calibration laboratory following ISO 17025 guidelines.

For more information please visit: http://www.gigahertz-optik.de/147-1-ISS-17.html

Fairview Microwave Low Loss LL335i and LL142 Cable Assemblies

Fairview Microwave, Inc. a preeminent supplier of on-demand microwave and RF products, introduces a new line of low loss test cables using LL335i and LL142 coax. Rated to 18 GHz, these new low loss cable assemblies are ideal for test environments where a rugged, phase stable cable assembly is required.

Fairview Microwave's new LL335i and LL142 cables allow for higher power transmission because the resulting higher temperatures do not have a negative effect on the cable due to the thermal stability of the PTFE tape dielectric. Where phase stability requirements are critical, Fairview's new low loss cables allow for a 75% lower phase shift due to the precise construction of these cables. This cable configuration offers attenuation levels 20 to 35% lower than comparable mil-spec cables.

Fairview's new RF cable assemblies come equipped with a choice of stainless steel TNC, SMA and N-Type connectors and a heavy duty booting to improve strain relief. These low loss test cables from Fairview are made with LL335i or LL142 coax, which operate at higher power with better phase stability from traditional cables with solid dielectrics. A double shielded flexible coax provides shielding greater than 95 dB and VSWR of less than 1.35:1.

You can view the complete offering of these coaxial cables from Fairview Microwave by visiting http://www.fairviewmicrowave.com/rf-products/low-loss-ll335i-and-ll142-cable-assemblies-to-18-ghz.html. For additional information, Fairview can be contacted at +1-972-649-6678.

New Yokogawa Arbitrary/Function Generators

Yokogawa Corporation announces the introduction of two new Arbitrary/Function Generators, the FG400 Series. The product line consists of the Model FG410 single channel unit and the FG420 two channel version.

The FG400 easily generates basic, application specific and arbitrary waveforms. The sine wave frequency range is 0.01 μHz to 30 MHz. Output waveforms consist of Sine, Square, Pulse, Ramp, Parameter-variable, Noise (Gaussian distribution), DC and Arbitrary. The output voltage is 20Vpp open circuit or 10Vpp 50Ω. A unique benefit to the user is the isolated outputs. This allows the unit to be used in the development of floating circuits, like motor drives, inverters, power supplies and other power electronic devices.

The FG400 function generators have the arbitrary waveform function as standard. They can generate waveforms that are acquired by Yokogawa's DL850E ScopeCorder or DLM4000 Digital Oscilloscope and the XviewerLITE software (freeware).

When more than two channels are needed, multiple FG410 and FG420 generators can be synchronized together to generate up to 12 phases by using six FG420 generators. The phase of each channel is synchronized to the master unit and can be individually adjusted.

Applications for the FG400 Series Arbitrary/Function Generators include generating application-specific waveforms like those needed to evaluate the response characteristics of mechanical/electrical circuits and to emulate power supply circuits.

With the addition of the FG400 Series Arbitrary/Function Generators, Yokogawa can now provide instruments for waveform generation that can be used with their highly recognized power measuring instruments and waveform measuring instruments. A total solution can be provided with precision instruments for both source and measurement.

For further information about the FG400 series of Arbitrary/Function Generators, visit our website tmi.yokogawa.com.

Pasternack Adds Line of L and S Band High Gain Amplifiers

Pasternack Enterprises, Inc., an industry leading manufacturer and supplier of RF, microwave and millimeter wave products, releases a new portfolio of L and S band high gain amplifiers covering 1.2 - 1.4 GHz and 3.1 – 3.5 GHz specifically used for commercial and military radar applications as well as observation satellites and communications systems.

Pasternack's new high gain amplifier modules are optimized for 1.2 – 1.4 GHz and 3.1 – 3.5 GHz radar applications, packaged in hermetically-sealed metal enclosures and exhibit outstanding performance in high gain, gain flatness, high output power and low noise. These RF amplifiers utilize a hybrid microwave integrated circuit design and advanced GaAs pHEMT technology to produce an unconditionally stable module. They are also designed with built-in voltage regulation, bias sequencing, and reverse bias protection for added reliability and over-voltage protection is installed externally for easy repair.

A total of six new L and S band high gain amplifiers are offered in this latest release from Pasternack. Two of those products are low noise amplifiers (LNA) which demonstrate noise figure performance of 1.1 dB to 1.5 dB at high gain levels of 40 dB typical gain while also exhibiting excellent gain flatness. Also offered are 10 Watt and 20 Watt high power amplifiers that have exceptional gain performance of 40 – 47 dB with 1.0 dB to 1.5 dB gain flatness. Pasternack is also releasing an L-band driver amplifier that displays solid gain performance of 47 dB while delivering competitive gain flatness of 1.5 dB.

The new 1.2 – 1.4 GHz and 3.1 -3.5 GHz high gain amplifiers from Pasternack are in stock and available to ship the same-day. For additional details, visit http://www.pasternack.com/pages/Featured_Products/l-and-s-band-high-gain-amplifiers.htm. Pasternack can be contacted at +1-949-261-1920.

Built-in Data Logging Capability Now Added to the Additel 681 Series Digital Pressure Gauges

Additel has added a data logging option to all of the gauges in the 681 Digital Pressure Gauge Series. This optional feature allows for up to 21,843 records to be stored internally in the 681. Each record includes date, time, pressure, and temperature. Data logging can easily be set up through the front panel of the 681 and allows for user-selectable record rates from 1 to 99,999 seconds.

The Additel 681 Series Digital Pressure Gauges cover from ±1 inH2O (±2.5 mbar) to 36,000 psi (2,500 bar). The 681 Series can be offered in gauge, absolute, compound and differential pressure types. Panel mount and intrinsically safe configurations are also available.

The Additel 681 Digital Pressure Gauge with data logging option is available now. For more information visit: http://www.additel.com/products/Digital-Pressure-Test-Gauges/3.html. For information on Additel products and application, or to find the location of your nearest distributor, contact Additel corporation, 22865 Savi Ranch Parkway, Suite F, Yorba Linda, CA 92887, call 1-714-998-6899, Fax 714-998-6999, email sales@additel.com or visit the Additel website at **www.additel.com**

Additel Corporation is one of the leading worldwide providers of process calibration tools. Additel 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 14 years in the industry, Additel has successfully developed Portable Automated Pressure Calibrators, handheld Digital Pressure Calibrators, Documenting Process Calibrators, Multifunction Process Calibrators, Digital Pressure Gauges, and various Calibration and Test Pumps.

AUTOMATION CORNER

Structure is EVERYTHING!

Michael L. Schwartz
Cal Lab Solutions, Inc.

So what is good structure in software? What makes one language, design or architecture better than another? These are all very difficult questions to answer. So far, I have not found a litmus test; but I have noticed some features in what I call good code that ultimately lead to good structure.

Having spent most of my life as a software developer, always striving to write better code, I have discovered there are thousands of ways to solve a problem; some better than others each with their own set of advantages and disadvantages. Every developer is constrained by his knowledge, experience and time limitations to prototype new ideas. There is always a region of unknown improvements and great ideas that never get implemented.

Is it easy to spot well-structured code? To this question I have to say yes, good structure in code just stands out. I was teaching a class of electrical engineering students last year when a student turned in some code that read like poetry. It was clear, concise and well organized. The logical thought process of what he was trying to accomplish in code jumped off the screen as if were yelling "YES, it is that simple!"

As I reviewed my student's code, I realized some people are just gifted, having natural knack for things. For most of us mortals though, it's a process of continual improvement. We build up a library of knowledge, what works very well and what does not no matter how hard we try. Over time, our value as a programmer is not in what we know works, but in what we know doesn't! And from our library of knowledge, we formulate patterns that lead to structure and eventually complete architectures.

This brings me back to when I first started writing automation software to control test equipment. I was at White Sands Missile Range all caught up in a debate over what was the best software to use for a specific project. At that time it was a tossup between LabView, Visual Basic and C++. Each of the engineers on the team were giving reasons and examples why the team should choose one language over the other. As I was stating my case, one of the senior developers, who had remained quiet until he chimed in with **"Syntax is Symantec, Structure is Everything!"** Then he continued with "You can do anything in any language, they key is in how you organize the software."

> *Syntax is Symantec,*
> *Structure is Everything.*

Over the years I've learned good structure comes from knowing more than one language. Because the syntax and structure of each language is different, sometimes forcing the developer to think about how to accomplish a task outside his box of knowledge.

So what defines good structure? Software shouldn't be complicated; it should be **simple and intuitive**. We as software engineers should always think in terms of simplification and understandability. Too many developers have a complicated mind set when the approach a problem. Yes the algorithm may be very complicated, but it should be coded so both the compiler and a person can understand it.

This brings us to the second most important feature of well structured code. It should be **readable**! Compressing code into fewer and fewer lines of code is only good as long as the code remains readable. Napoleon believed that a good battle plan should be understood by all his commanders down to every corporal. Applying it to software, quality code should be readable by all members of your team.

Another peeve of mine is Spaghetti Code! Code that jumps all over the place is hard to follow; if it's hard to follow, then I categorize it as unreadable. Jumping around in code and interdependencies between separate modules are the biggest indicators of poorly structured code.

A good structure should incorporate **modularity**. Breaking the overall project up into manageable pieces that are then assembled into the complete software solution will allow each piece to be updated independently. But the level of modularity has to be contained into logical groups of related objects. Defining the dividing lines in a large software project is a very complex operation and may take several iterations to get it right.

The hardest concept I have to teach my new programmers when they are learning structured programming is **delegation**. In software I define delegation as the process of pushing responsibility to the lowest level of code. The best example of poor delegation and poor structure is when I see a LabView application that has set the GPIB address on the first page. The problem is the GPIB address now needs to be wired from the top of the application all the way down to the VI's that communicate with the instruments. It's not spaghetti code, but on a complicated calibration procedure it can look like a wiring nightmare.

I have started using Legos® as a metaphor for describing software design. There are tens of thousands specialized little Lego® pieces, as well as those core building blocks—just like there are different languages and tools to support each language. So like Legos®, software can also be assembled in an infinite number of ways. ❧

SIMPOSIO DE METROLOGÍA 2014

20 ANIVERSARIO CENAM

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Santiago de Queretaro, Qro. Mexico

TOPICS:

- Metrology in Mexico, challenges and prospects.
- Metrology in the Industry.
- Development of measurement standards and measuring systems.
- Chemical metrology and its applications.
- Metrology on bioanalysis.
- Metrology on nanotechnology.
- Traceability on measurements.
- Uncertainty of measurement.
- Proficiency tests
- Legal Metrology and Standardization
- Metrology in Scientific research
- Metrology in Education

ACTIVITIES:

- Courses (October 6th and 7th).
- Plenary sessions.
- Oral sessions.
- Poster sessions.
- Industrial expo of specialized providers on measuring services and equipment.
- National Meeting on Electrical Metrology (ENME), October 6th and 7th.

On the occasion of the 20th anniversary of CENAM, this edition of the *Simposio de Metrologia* will have the presence of national and international experts on metrology, people of industry, researchers, teaching staff, manufacturers and suppliers of instruments and measurement equipment sharing their experiences and highlighting the meaning of metrology on society and its impact and evolution over the years.

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