CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

METROLOGY 101: HOW TO CALIBRATE A SINGLE CHANNEL ADJUSTABLE VOLUME PIPETTE

2011
APRIL
MAY
JUNE

Balance Calibration - A Method for Assigning a Direct-Reading Uncertainty to an Electronic Balance

High Attenuation Measurement of Step Attenuators

Technical Requirements for a Portable Metrology Laboratory in Hot, Arid Regions

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Volume 18, Number 2

www.callabmag.com

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ON THE COVER: Joe Keck demonstrating laser frequency calibration at Oak Ridge National Laboratory's (ORNL's) Metrology Lab in Oak Ridge, Tennessee.

CALENDAR

CONFERENCES & MEETINGS 2011

Jun 6-9 Metrology @ Hexagon 2011 International Conference. Orlando, FL. Metrology @ Hexagon 2011 will feature two sub-tracks specifically designed for Hexagon Metrology and PC-DMIS power users. Metrology @ Hexagon 2011 also offers you fantastic new opportunities for learning and networking within and across our industry. Website: http://www.hexagonconference.com/.

Jun 7-9 SENSOR + TEST 2011 Measurement Fair. Nürnberg, Germany. From Sensors to Evaluation: A Comprehensive Overview of System Expertise for Measuring, Testing, and Monitoring Tasks in all Industries. Website: http://www.sensor-test.com.

Jun 10 77th ARFTG Conference. Baltimore, MD. The 77th ARFTG Conference, Design and Measurement of Microwave Systems, is held in conjunction with the 2011 IEEE MTT-S International Microwave Symposium. Website: http://ww.arftg.org/conferences/77th_conference.html.

Jun 20-22 9th Conference on Advanced Mathematical and Computational Tools in Metrology and Testing. Göteborg, Sweden. Organized by SP Sveriges Tekniska Forskningsinstitut, Euramet, IMETKO, and Chalmer's University of Technology. Visit www.amctm.org for more information.

Jun 21-23 CEESI Ultrasonic Meter User's Workshop. Colorado Springs, CO. This annual event brings together a wealth of information as well as new ideas and new questions regarding flow measurement using ultrasonic meters. Website: www.ceesi.com.

Jul 25-29 Coordinate Metrology Systems Conference. Phoenix, AZ. The Coordinate Metrology Systems Conference (CMSC) provides a professional venue where ideas, concepts and theory flow freely among participants. Website: www.cmsc.org.

Aug 21-25 NCSL International Workshop & Symposium. National Harbor, MD. 50 Years: Reflecting on the Past – Looking to the Future. Website: www.ncsli.org.

Sep 12-14 10th IMEKO Symposium on Laser Metrology for Precision Measurement and Inspection in Industry. Braunschweig, Germany. Website: www.lasermetrology2011.com.

Sep 20-22 Quality Expo. Chicago, IL. Quality Expo is the leading quality show and conference that provides hand-on access to the newest tools and broadest array of technologies. Website: http://www.canontradeshows.com/expo/qexpo11/index.html

Sep 27-30 Metrologia2011. Natal, Brazil. A global multi-event comprising an international measuring instruments exhibition and four other associated events. Website: www.metrologia.org.br/metrologia2011/.

Oct 3-6 15th International Congress of Metrology. Paris, France. The Congress is a meeting place for specialists in metrology from industry and scientific laboratories whose aim is to contribute to the improvement of measurement in industry and research. Website: www.metrologie2011.com.

CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

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Subscription fees for 1 year (4 issues)
$50 for USA, $55 Mexico/Canada,
$65 all other countries.
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or call 303-317-6670
Printed in the USA.

EDITOR'S DESK

How Certain Are You of Your Uncertainties?

At this year's Measurement Science Conference in Pasadena, California, a group of students were wandering the floors in an attempt to find out about metrology. One young lady in particular had a hard time getting someone's attention long enough to ask questions. And so it was suggested to her that she should go right up to a booth and point blank ask them "How certain are you of your uncertainties?"

To anyone unfamiliar with metrology, this might sound a bit ludicrous, and so the young lady looked quizzical. She returned a bit later, with a big smile and exclaimed "It worked, it worked... he read me the riot act! Who should I ask next?"

If you are reading this, you know quite well how certain you are about your uncertainties and you make it your business. And uncertainties have become all the more important of late. Of course it is a perk if you can enlighten a young person as to how metrology impacts their life and make them smile at the same time. Whether it was the concept of metrology or the triumph of eliciting a productive response that made the young lady happy is subjective… either way, it was mission accomplished.

Kind Regards,

Sita

CALENDAR

Oct 24-27 3rd Metrology Forum. Accra, Ghana. Legal metrology; accreditation; temperature, volume, mass; measurement uncertainties; interlaboratory comparisons. Website: http://www.ac-metrology.com.

SEMINARS: Accreditation

Nov 7-11 ISO 17025 Compliance and Auditing Techniques Including ANSI Z540.3 Requirement. Los Angeles, CA. Workplace Training, http://wptraining.com/workshops.htm.

SEMINARS: Dimensional

Jun 9-10 Gage Calibration and Repair. Oklahoma City OK. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Jun 14-16 Hands-On Gage Calibration. Elk Grove, IL. Mitutoyo Institute of Metrology, tel 888-MITUYOYO, mim@mitutoyo.com, www.mitutoyo.com.

Jun 22-23 Gage Calibration Workshop. Houston, TX. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Jun 29-30 Gage Calibration and Repair. Denver CO. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Jul 7-8 Gage Calibration and Repair. Atlanta GA. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Jul 11-12 Gage Calibration and Repair. Myrtle Beach SC. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Jul 26-27 Gage Calibration and Repair. Omaha NE. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Aug 11-12 Gage Calibration and Repair. Portland OR. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Aug 18-19 Gage Calibration and Repair. Oakland/San Jose area CA. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Aug 15-16 Gage Calibration and Repair. Yorba Linda CA. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Aug 22-23 Gage Calibration and Repair. Las Vegas NV. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Sep 13-14 Gage Calibration and Repair. Effingham IL. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Sep 21-22 Gage Calibration Workshop. Toledo, OH. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

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CALENDAR

Sep 27-28 Gage Calibration and Repair. Minneapolis MN (North). IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Sep 29-30 Gage Calibration and Repair. Bloomington MN. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Oct 6-7 Gage Calibration and Repair. Hew Haven/Waterbury CT Area. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

Oct 10-11 Gage Calibration and Repair. Albany NY. IICT Enterprises, tel 952-881-1637, fax 952-881-4419, carlis@consultinginstitute.net, www.consultinginstitute.net.

SEMINARS: Flow

Jun 14-15 Comprehensive Hydrocarbon Measurement. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Jun 16-17 Fundamentals of Hydrocarbon Measurement. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Jun 16-17 Wet Gas Measurement. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com

Jun 20 Fundamentals of Ultrasonic Meters for Natural Gas and Liquid. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Jun 21-23 Ultrasonic Meter User's Workshop. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 13-15 Fundamental Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 19-22 Comprehensive Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 21-23, 2011 Flow Measurement and Calibration. Munich, Germany. During Octoberfest. For information in English, visit: www.trigasfi.de/html/en_seminars.htm.

SEMINARS: General Metrology and Laboratory Management

Jun 21-24 Metrology Concepts and Calibration Laboratory Operations. Las Vegas, NV. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

Jun 25-28 Met 101 Basic Hands-on Metrology. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Aug 1-4 Met 301 Advanced Hands-on Metrology. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Aug 2-3 CAPA and Root Cause Analysis Workshop. Baltimore, MD. Workplace Training, http://wptraining.com/workshops.htm.

Sep 12-15 CLM 303 Effective Cal Lab Management. Seattle. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Oct 24-27 Met 101 Basic Hands-on Metrology. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

SEMINARS: Mass & Weight

Oct 24-Nov 4 Mass Seminar. Gaitersburg, MD. NIST, http://www.nist.gov/pml/wmd/labmetrology/schedule.cfm.

SEMINARS: Measurement Uncertainty

Jun 2-3 Uncertainty in Measurement Training. La Habra, CA. International Accreditation Service (IAS), www.iasonline.org.

Jun 16-17 Uncertainty of Hydrocarbon Measurement. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Jun 27-30 Measurement Uncertainty. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

Sep 26-28 Measurement Uncertainty Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc. www.ceesi.com.

Oct 24-25 Basic Math and Statistics for Metrology Technicians. Los Angeles, CA. Workplace Training, http://wptraining.com/workshops.htm.

Oct 31-Nov 1 SPC and Excel for Metrology Applications. Orlando, FL. Workplace Training, http://wptraining.com/workshops.htm.

SEMINARS: Software

Jun 6-10 MET/CAL Database and Reports. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Jun 13-17 MET/CAL Procedure Writing. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Jun 15-16 Gage Management and MSA using GAGEpack. Dayton, OH. www.pqsystems.com/training/PublicSeminars/GageManagementGAGEpack.php

Sep 19-23 MET/CAL Database and Reports. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Sep 26-30 MET/CAL Procedure Writing. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

Oct 3-7 Advanced Programming Techniques. Seattle, WA. Fluke. Tel 888-79-FLUKE, caltraining@fluke.com, www.fluke.com.

SEMINARS: Time & Frequency

Jun 7-10 NIST Time and Frequency Metrology Seminar. Boulder, CO. http://www.tf.nist.gov/timefreq/seminars/T&Foverview.html

SEMINARS: Vibration

Jun 1-3 Fundamentals of Vibration for Test Applications. Technology Training, Inc., toll free 866-884-4338, brian@ttiedu.com, www.ttiedu.com.

Aug 23-25 Fundamentals of Random Vibration and Shock. Santa Barbara, CA. Equipment Reliability Institute, http://www.equipment-reliability.com/vibration_course1.html.

Hach Acquires Accurate Detection and Accurate Measurement in Australia and New Zealand

Hach Company (www.hach.com), Loveland, CO, announced the acquisition of Accurate Detection and Accurate Measurement (Accurate), distributors of analytical and detection instrumentation including Hach water quality analytics in Australia and New Zealand. This move gives Accurate's customers direct access to Hach's innovative water quality products and extensive service support. Hach has more than sixty years of water analysis expertise and offers personalized application support, local training, a full water analysis product portfolio, and a new loyalty program for Australian and New Zealand customers.

Hach will continue to supply Accurate's leak detection and pipe and cable location equipment to Australian and New Zealand customers, who can now easily bundle their purchases with water quality analytics. For more information on the complete offering, please visit www.hachpacific.com.

Transcat Completes Acquisition of CMC Instrument Services, Inc.

Transcat, Inc. (Nasdaq: TRNS) ("Transcat" or the "Company"), a leading distributor of professional grade handheld test and measurement instruments and accredited provider of calibration, repair and weighing system services, announced today that it has completed the acquisition of substantially all of the assets of CMC Instrument Services, Inc ("CMC"). The purchase was an all cash transaction although terms were not disclosed. The acquisition further expands Transcat's presence in the Rochester, New York calibration services market.

CMC has been servicing customers in Western New York since 1995. Their primary focus has been dimensional calibration and repair. Chris Morse, CMC's Founder and President will join Transcat working in the Company's Rochester location.

Through its distribution products segment, Transcat markets and distributes national and proprietary brand instruments to nearly 14,000 customers. The Company offers access to more than 25,000 test and measurement instruments. Transcat delivers precise, reliable, fast calibration, and repair services across the United States, Canada and Puerto Rico through its 14 strategically located Calibration Centers of Excellence. Transcat's calibration laboratories are ISO-9001 registered and the scope of accreditation to ISO/IEC 17025 is believed to be one of the broadest in the industry.

Transcat's growth strategy is to expand both its distribution products and calibration services in markets that value product breadth and availability and rely on accredited calibration services to maintain the integrity of their processes. More information about Transcat can be found on its website at: www.transcat.com.

East Hills Instruments Inc. Acquires Applied Resources Inc.

A.R.I. operations will be relocating to E.H.I. home offices in New York. East Hills Instruments' recent acquisition is a major play in supporting its continued "best in breed" strategy on manufacturing, marketing and selling superior core instruments to the power, pharmaceutical and paper mill industries. It broadens an already strong portfolio of test equipment brands, including Magnum Pro Calibration Pumps, Winchester Engineering, Dewey Air Switch and the MASTER distribution rights for Time Electronics USA, Practical Instruments Electronics (P.I.E.) and Scandura USA.

A.R.I. has over 20 years of micro-electronic design, engineering and manufacturing experience in the process control and instrumentation industry. A.R.I. was directly involved early on with designing of number of technologically advanced instruments for such companies as; Ashcroft, Heise, Moore Industries, Beta-Hathaway, Transcat Inc. Today it continues to manufacture and sell worldwide under the A.R.I. brand name as well as private labeling its products to a number of other manufactures.

For additional information, visit: www.easthillsinstruments.com

A Measurement First: NIST 'Noise Thermometry' System Measures Boltzmann Constant

Researchers at the National Institute of Standards and Technology (NIST) have for the first time used an apparatus that relies on the "noise" of jiggling electrons to make highly accurate measurements of the Boltzmann constant, an important value for many scientific calculations. The technique is simpler and more compact than other methods for measuring the constant and could advance international efforts to revamp the world's scientific measurement system.

The Boltzmann constant relates energy to temperature for individual particles such as atoms. The accepted value of this constant is based mainly on a 1988 NIST measurement performed using acoustic gas thermometry, with a relative standard uncertainty of less than 2 parts per million (ppm). The technique is highly accurate but the experiment is complex and difficult to perform. To assure that the Boltzmann constant can be determined accurately around the world, scientists have been trying to develop different methods that can reproduce this value with comparable uncertainty.

The latest NIST experiment used an electronic technique called Johnson noise thermometry (JNT) to measure the Boltzmann constant with an uncertainty of 12 ppm. The results are consistent with the currently recommended value for this constant. NIST researchers aim to make additional JNT measurements with improved uncertainties of 5 ppm or less, a level of precision that would help update crucial underpinnings of science, including the definition of the Kelvin, the international unit of temperature.

The international metrology community is expected to soon fix the value of the Boltzmann constant, which would then redefine the Kelvin as part of a larger effort to link all units to fundamental constants. This approach would be the most stable and universal way to define measurement units, in contrast to traditional measurement unit standards based on physical objects or substances. The Kelvin is now defined in terms of the triple-point temperature of water (273.16 K, or about 0 degrees C and 32 degrees F), or the temperature and pressure at which water's solid, liquid and vapor forms coexist in balance. This value may vary slightly depending on chemical impurities.

The NIST JNT system measures very small electrical noise in resistors, a common electronic component, when they are cooled to the water triple point temperature. This "Johnson noise" is created by the random motion of electrons, and the signals they generate are directly proportional to temperature. The electronic devices measuring the noise power are calibrated with electrical signals synthesized by a superconducting voltage source based on fundamental principles of quantum mechanics. This unique feature enables the JNT system to match electrical power and thermal-noise power at the triple point of water, and assures that copies of the system will produce identical results. NIST researchers recently improved the apparatus to reduce the statistical uncertainty, systematic errors and electromagnetic interference. Additional improvements in the electronics are expected to further reduce measurement uncertainties.

The new measurements were made in collaboration with guest researchers from the Politecnico di Torino, Italy; the National Institute of Metrology, China; the University of Twente, The Netherlands; the National Metrology Institute of Japan, Tsukuba, Japan; and the Measurement Standards Laboratory, New Zealand.

Source: http://www.nist.gov/pml/quantum/constant-033011.cfm.

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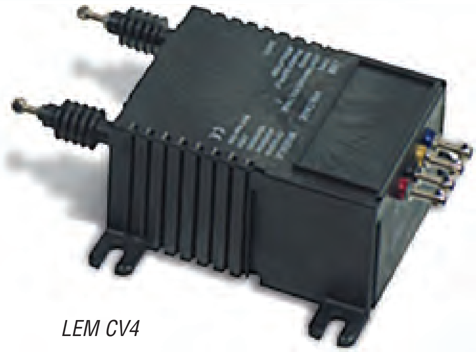

LEM CV4

Closed-Loop Hall Current Transducers

Provide an Analog Output Signal Isolated from the Primary Current Circuit

- Full-scale Primary Currents from ±100A to ±15,000A
- Amplitude Accuracy to ±0.3% at dc
- Amplitude Frequency Response dc to 300kHz (-3dB)
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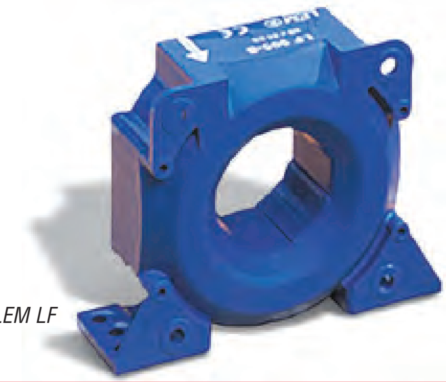
- Split Core Versions Available (±2% at dc)

Suitable for Production Line Testing where Long-term Stability and Reliability are Critical



LEM LF

Closed-Loop Fluxgate Current Transducers

Generate a Very High-Accuracy Output Signal with Electrical Isolation from the Primary Circuit

- Full-scale Primary Currents from ±60A to ±1,000A
- Amplitude Linearity to ±0.3ppm at dc
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For High-accuracy Power Measurements over an Extended Frequency Range

LEM IT Ultrastab

Closed-Loop Fluxgate Current Measurement Systems

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Lowest fs Current	40A	125A	2,500A
fs Current Range Increment	20A	125A	125A

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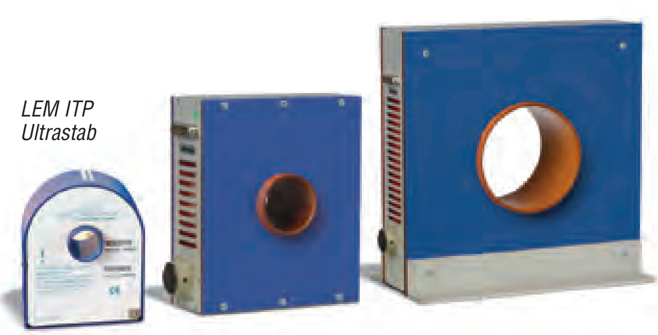
LEM ITP Ultrastab



NIST Telescope Calibration May Help Explain Mystery of Universe's Expansion

Is the expansion of the universe accelerating for some unknown reason? This is one of the mysteries plaguing astrophysics, and somewhere in distant galaxies are yet-unseen supernovae that may hold the key. Now, thanks to a telescope calibrated by scientists from the National Institute of Standards and Technology (NIST), Harvard University and the University of Hawaii, astrophysicists can be more certain of one day obtaining an accurate answer.

The NIST scientists traveled to the summit of Haleakala volcano in Hawaii to fine-tune the operation of billions of light-collecting pixels in the Pan-STARRS telescope, which scans the heavens for Type IA supernovae. These dying stars always shine with the same luminosity as other Type IA supernovae, making them useful to observers as "standard candles" for judging distance in the universe. Any apparent shift in the supernova's spectrum gives a measure of how the universe has expanded (or contracted) as the light traveled from the supernova to Earth.

Because Type IA's are valuable as signposts, astrophysicists want to be sure that when they observe one of these faraway stellar cataclysms, they are getting a clear and accurate picture—particularly important given the current mystery over why the rate of expansion of the universe appears to be increasing. For that, they need a telescope that will return consistent information about supernovae regardless of which of the roughly 1,400,000,000 pixels of its collector spots it.

Ordinary calibrations involve a telescope's performance at many light wavelengths simultaneously, but Pan-STARRS needed to be calibrated at many individual wavelengths between 400 and 1,000 nanometers. For the job, Woodward and his colleagues used a special laser whose wavelength can be tuned to any value in that range, and spent three days testing the telescope's huge 1.4 gigapixel camera–the largest in the world, Woodward says.

Woodward says that because this is one of the first-ever such calibrations of a telescope, it is unclear just how much effect the team's work will have, and part of their future work will be determining how much they have reduced the uncertainties in Pan-STARRS's performance. They will use this information to calibrate a much larger telescope–the Large Synoptic Survey Telescope, planned for construction in Chile. Source: http://www.nist.gov/pml/div685/telescope_010511.cfm.

QuadTec Guardian 500VA Plus

QuadTech, Marlborough, MA, a provider of electrical safety testers, passive component measurement solutions, ac and dc programmable power sources and dc electronic loads, released the new Guardian 500VA Plus. The Guardian 500VA Plus replaces the original Guardian 500VA in the hipot tester product family.

The Guardian 500VA Plus's R&D functions include Arc Detection Monitoring output for connection an oscilloscope and Breakdown Volt Mode. Breakdown Volt Mode is a new function that will increase the voltage in steps and dwell at each voltage step per the programmed time delay. The Guardian 500VA Plus also has the ability to measure Total and Real current.

The remote command set features SCPI commands for both control and measurement. This unit comes standard with RS232 and USB. Visit: http://www.quadtech.com

Fluke TL175 Test Leads

Fluke Corporation, Everett, WA, announced the availability of the new TL175 TwistGuard™ Test Leads, the only test leads in the world with a manually adjustable test tip guard for use in different measurement environments. By simply twisting the test lead the user can change the exposed probe tip length from 4/25 in (4 mm) to ¾ in (19 mm). When the tip guard is fully extended, the TL175 Test Leads are safety rated for CAT III 1000 V and CAT IV 600 V use. When the tip guard is retracted, the test leads are safety rated for CAT II 1000 V use.

The new TL175 Test Leads are also Fluke's first leads with WearGuard™ insulation. Each test lead is covered by two layers of silicone insulation: red or black on the outside, and white on the inside. If the TL175 Test Leads become nicked or scuffed and white insulation is visible, the user has a visual warning that the test leads should be replaced.

While the WearGuard indicator shows excessive wear, the TL175 Test Leads are designed to last longer than any other leads currently available. The dual-layer silicone insulation resists melting if it comes in contact with hot surfaces and remains flexible in cold situations. The extra-heavy duty strain relief has been tested beyond 30,000 bends without failure. The universal input plugs work with all popular brands of digital multimeters with 4 mm input jacks.

The TL175 Test Leads also offer screw threads at the base of the probe. This allows the user to add screw-on clips, probes and specialty tips. Product details can be found at www.fluke.com/TL175.

Kahn HygroPort Portable Hygrometer

Kahn Instruments' new HygroPort Portable Hygrometer can save engineers and technicians weeks of waiting time each year.

Technical improvements in the operation of Kahn Instruments' ceramic sensor technology results in faster dewpoint measurements. Dewpoints as low as -95°F can now be measured accurately in less than 10 minutes or even faster in many cases. This super-fast response does not rely on the sensor being dried by a desiccant, which means that every measurement is fast, not just the first of the day, which allows for many more measurements to be taken each day.

Efficient nickel metal hydride batteries and power management circuitry provide the user with 48 hours of use between charges, resulting much more time in the field for taking measurements.

With its Bluetooth connection, the HygroPort connects wirelessly to a PC. Set-up of the instrument and downloading of logged data is therefore quick and simple.

To maximize flexibility, measurements can be taken using the external sensor connection built into the HygroPort. Optional sensors can be used to display dew point, pressure or temperature or can be used to provide pressure and temperature compensation to the displayed moisture parameters. Visit: http://www.kahn.com.

Agilent DigV4 Test Solution

Agilent Technologies Inc. (NYSE: A) announced the industry's first digital radio frequency (DigRF) V4 test solution with dual-capture capability. This software enhancement gives engineers the ability to simultaneously apply a stimulus to devices under test and analyze the results with a single instrument, the Agilent N5343A DigRF V4 exerciser.

The new exerciser allows developers of radio-frequency integrated circuits (RF-ICs) and baseband integrated circuits (BB-ICs) as well as integrators of wireless handsets to characterize their devices using fewer probes. This capability enables faster testing and accelerated time to market.

The DigRF V4 standard, driven by the Mobile Industry Processor Interface Alliance, describes a high-speed digital serial bus used between mobile baseband and RF chips. DigRF V4 is a key enabling technology for LTE and WiMAX™ devices.

Agilent's N5343A DigRF V3/V4 exerciser offers new insights that reach from individual digital bits to IQ-modulated RF signals. The N5343A allows engineers to work in the domain (digital or RF) and abstraction level (physical or protocol layer) of their choice to quickly characterize RF-ICs and rapidly solve cross-domain integration problems.

The Agilent N5345A and N5346A active probing solutions with ultralow capacitive loading (less than 0.15 pF) and high sensitivity provide system insight with minimum disturbance at the gigabit speeds used in DigRF V4 testing. Design engineers can choose between the N5345A mid-bus probe with soft touch technology for fast probing on prototype boards and N5346A flying leads probing solutions, which enable effortless monitoring of DigRF V4 links in space-constrained designs.

Additional information on the Agilent N5343A DigRF V4 exerciser is available at www.agilent.com/find/rdx.

FasCal Manifold System

FasTest, Minneapolis, MN, announces the FasCal Manifold System for pressure calibration. The manifold supports connections to up to four different devices at the same time, accommodating a wide variety of fitting configurations. The stainless steel system allows any FasCal connector—for both male and female applications—to be mounted on the manifold quickly and without the use of tape or wrenches. The company's CalMate connectors for leak-tight connections to sanitary devices can also be mounted on the manifold. The high-pressure FasCal Manifold System is rated up to 10,000 psi, with individual connectors determining the maximum overall system pressure rating.

Traditionally, the calibration engineer would be required to use a thread sealant, wrench and torque to insert a fitting in each unique test instance. In addition to causing advanced stress or wear on the threads, particles of tape sealant could break off with this method, potentially causing damage to expensive instruments. Through application of a main seal pressed against the test piece and an internal piston action, FasCal connectors automatically seal with minimum pressure, delivering fast, safe and repeatable leak-tight connections. The wrench-free connectors minimize wear from repeated threading and unthreading between devices being tested and eliminate ingress of debris from tape sealant.

With the FasCal Manifold System, up to four devices can be calibrated at the same time and swapping the port configurations can be accomplished in seconds. The system provides an ideal solution for testing and calibration labs in which the number of connections—and variety of fitting configurations—made each day require the use of productivity tools to meet demands.

Applications: The FasCal Manifold System can be used for liquid and gas calibration in a variety of industries, including:

- Aerospace
- Department of Defense
- Petrochemical
- Pharmaceutical
- Food & beverage
- Power generation
- Water & wastewater
- Industrial manufacturing

For more information, visit http://www.technical-sys.com/FasTest.htm.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NEW PRODUCTS AND SERVICES

Oak Ridge National Laboratory Accredited for Low Air Velocity Calibrations

The Oak Ridge National Laboratory's (ORNL's) Metrology Lab was recently accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) for Low Air Velocity Calibrations over the range of 0.25 to 6.4 m/s (50-1260 ft/min) using its open-channel wind tunnel with a laser-doppler anemometer (LDA) primary standard. ORNL also developed a method to provide traceability to NIST directly via length and time to provide excellent measurement uncertainties. The 30.5 X 30.5 cm (12 X 12 inch) test section is adequate to easily handle anemometers up to 4 inches in diameter.

The low velocity calibration capabilities were developed specifically to answer needs of the industrial hygiene community for fume hood face velocity measurements but is applicable to any air velocity calibration or special study.

ORNL can also provide NIST-traceable calibrations for air velocity from 6.4 to 46 m/s (1260-9000 ft/min) in a separate wind tunnel using the same LDA. ORNL plans to add this wind tunnel to its scope of accreditation sometime this year.

For more information, contact Mike Duncan 865-574-7349 or duncanml@ornl.gov or visit www.ornl.gov/sci/metrology.

Yokogawa Dura Meters for Extreme Environmental Conditions

Yokogawa Corporation of America is pleased to announce the release of the first in a series of new meters, the Dura Meter Series. The first new meter, an elapsed time meter, combines a time meter assembly with a die cast aluminum NEMA 4X housing.

The Dura Meter series is designed for severe environmental conditions across multiple industries such as oil & gas, chemical, power (electric utilities), water treatment and food processing. The Dura meter series meets ANSI Specification C39.1, is water and dust resistant, and is UL rated.

Standard options include horizontal vs. vertical mounting, hours vs. minutes, reset vs. non-reset and voltage and frequency rating. Additional options include electrical connection, customer configuration, stainless steel tag, and epoxy resin or polyurethane-epoxy combination paint.

For more information on the Dura Elapsed Time Meters and metering and instrumentation products in general, visit www.yokogawa-usa.com.

Rohde & Schwarz TS8950G / TS8980S

The R&S TS8950G and R&S TS8980S RF test systems from Rohde & Schwarz now allow conformance and precompliance testing for VAMOS. Using VAMOS, network operators can double the channel capacity of GSM base stations. To ensure that the introduction of VAMOS runs smoothly, the 3GPP standardization committee will adopt new standardized test cases in the second quarter of 2011. But manufacturers need to be able to check the VAMOS functionality of their user equipment (UE) and chipsets today. An upgrade will be available for the official test cases as soon as they are adopted.

Due to the ever increasing number of mobile device users, existing GSM networks will reach the limits of their capacity in the next few years. VAMOS, which stands for voice services over adaptive multi-user channels on one slot, is an extension of GSM that has been specified in the 3GPP standard. VAMOS doubles the voice channels of a GSM base station by using a second, software-implemented channel and the existing channel simultaneously: If the first channel is occupied, then the second channel (orthogonal subchannel) will transmit the conversation.

The R&S TS8950G and R&S TS8980S are the first test systems on the market that can be extended to cover VAMOS testing. The two systems are built around the R&S CMW500 wideband radio communication tester, which generates VAMOS signals.

This announcement was previously released at Mobile World Congress 2011.For more info, visit: http://www.rohde-schwarz.com/product/TS895xGW.

How to Calibrate a Single Channel Adjustable Volume Pipette

By Ann Lenhardt

Training Objective: Enable the pipette user to assess the performance of a single channel adjustable volume pipette. The method used for the performance analysis is the gravimetric method.

Recommended Equipment

- Analytical Balance with appropriate resolution (consult Table 1)
- Weighing Vessel with a height to diameter ratio of at least 3:1.
- Thermometer with accuracy of +/- .4 degree C.
- Barometer or local barometric pressure
- Single Channel Adjustable Volume Pipette
- A supply of tips
- DI or Double Distilled water
- Beaker for holding DI or Double Distilled water

Test Volume ν	Balance Resolution mg	Balance Repeatability mg
1 µl ≤ ν ≤ 10 µl	.001	.002
10 µl < ν ≤ 100 µl	.01	.02
100 µl < ν ≤ 1000 µl	0.1	0.2
1 ml < ν ≤ 10 ml	0.1	0.2

Table 1.

Setting the Tolerances

Pipette performance is tested against pre-determined tolerances for inaccuracy and imprecision. As a user of pipettes you have options when it comes to tolerances. You may choose to follow the tolerances that the manufacturer publishes for your particular brand, make and model of pipette. Alternatively, you may use the tolerances listed in EN/ISO 8655-2. These tolerances are the minimum performance requirements established for the manufacturers of pipettes and are contained within Table 2. When determining the tolerances for your test plan, remember that manufacturers' reported tolerances are for new instruments in excellent condition and require testing in tightly controlled environmental conditions. If your lab's temperature and humidity is not tightly controlled, you may want to follow what manufacturers refer to as either "user" or "field" tolerances and double the manufacturer's reported tolerances for the instrument under test, or use tolerances that reflect the accuracy and precision required for the work you do.

Nominal Volume µl	Inaccuracy ± %	Imprecision ± %
1	5.0	5.0
2	4.0	2.0
5	2.5	1.5
10	1.2	0.8
20	1.0	0.5
50	1.0	0.4
100	0.8	0.3
200	0.8	0.3
500	0.8	0.3
1000	0.8	0.3
2000	0.8	0.3
5000	0.8	0.3
10000	0.6	0.3

Table 2. EN/ISO 8655-2 Maximum Permissible Errors for Adjustable Volume Pipettes.

Designing the Test Plan

ISO 8655-6 requires that manufacturers test pipettes at the nominal (highest) volume, a mid point (typically 50%) and at a low point (usually 10%) of the pipette's range. 10 replicate samples are aspirated and dispensed at each of the three volume test points. The mean of the 10 samples is used to determine accuracy, and the standard deviation of the 10 samples is used to determine the precision of the pipette. Users may choose to use fewer samples; a minimum of 3 are required. The Rainin Technical Report 9804 *Comparison of Ten vs. Four Weighing Method* discusses the statistical differences between the two methods in terms of the risk of rejecting a conforming, or passing, pipette when using the four sample method. The study found that when instruments are provided preventive maintenance prior to testing, the risk of a false reject is reduced to less than 1%. Of course performing preventive maintenance prior to testing performance eliminates the possibility of obtaining As Found performance data.

For the purposes of this training, we will use what is known as a 3x5 calibration structure: 3 test volumes with 5 replicate samples at each test volume. We will use test volumes of 10%, 50% and 100% of nominal volume.

Calibrating the Pipette

First ensure that all test equipment, the pipette, the tips and the DI or Double Distilled water have been allowed to equilibrate to room temperature. Care should be taken to ensure that the analytical balance is set up on a stable laboratory bench in an area free from direct sunlight, drafts and the vibrations of neighboring equipment.

1. Place the weighing vessel in the center of the weigh pan of the analytical balance.
2. Use the thermometer to ascertain and record the temperature at the time of the test.
3. Use the Barometer to ascertain and record the barometric pressure at the time of test. While barometric pressure is required for the weight to volume conversion, its effect on volume is insignificant at 5 or 6 decimal places and therefore the barometric pressure reported for the local area at Weather.com is also sufficient.
4. Select and affix an appropriately sized tip to your pipette.
5. Dial the instrument down to the low volume (10% of nominal volume) test point.
6. Taking care to immerse the tip 2-3 mm into the DI test water, hold the pipette in a near vertical position and aspirate and dispense 3 to 5 throw away samples to introduce humidity into the tip and shaft of the pipette.
7. Aspirate the first test sample and drag the tip along the side of the vessel to remove any excess sample on the outside of the tip.
8. Dispense the sample into the weighing vessel on the weigh pan.
9. Record the balance reading.
10. Repeat steps 7 though 9 to obtain the remaining 4 samples at the low volume.
11. Discard the used tip, replace it with a fresh one, and dial up the volume to the mid point test volume (50% of nominal volume).
12. Repeat steps 6 though 9 until all 5 samples are obtained at the mid point test volume.
13. Discard the used tip, replace it with a fresh one, and dial up to the nominal volume test point.
14. Repeat steps 6 through 9 until all 5 samples are obtained at the nominal test point volume.

Calculating the Results

The values you have obtained are balance readings in mass units. A weight to volume calculation is necessary. To make the weight to volume conversion, a Z factor must be applied.

1. Convert each measurement in mass m by applying the **Z** correction factors from Table 3 at the mean temperature and barometric pressure measured and recorded at the time of the test using this equation:

$$v\,i = m * Z$$

2. Add together the 5 volumes (n = 5) at each volume test point and divide the total by 5 to determine the mean volume, $\overline{V}$. This value is expressed as either milliliters or microliters:

$$\overline{v} = \frac{1}{5} * \sum_{i=1}^{n} vi$$

3. Calculate the inaccuracy (systematic error) e_s for each test point using the following equation where v_s is the target (selected test) volume:

$$e_s = \overline{v} - v_s$$

To calculate the inaccuracy in percentage form, use this equation:

$$e_s = 100\,(\overline{v} - v_s)/v_s$$

4. Calculate the imprecision (random error) S_r for each test point using this equation:

$$S_r = \sqrt{\frac{\sum_{i=1}^{n}(V_i - \overline{V})^2}{n-1}}$$

5. The random error can be expressed as a percentage, by the coefficient of variation, by using the following equation where v_0 is the nominal volume:

$$CV = 100\,\frac{S_r}{\overline{v}} x \frac{v_s}{v_0}$$

6. Compare the results to your pre-determined tolerances to determine the performance of the pipette. Instruments that are not performing within your selected tolerances will require Preventive Maintenance and adjustment. Most manufacturers will sell adjustment tools and provide instructions for making the necessary adjustments to bring the instrument back within tolerance.

Preventive Maintenance

Pipettes should receive preventive maintenance on an annual basis or whenever the instrument fails to perform as expected. Preventive maintenance involves cleaning the instrument thoroughly, inside and out, inspecting each part for wear and tear,

Temperature C	Air Pressure kPa						
	80	85	90	95	100	101.3	105
15.0	1001.7	1001.8	1001.9	1001.9	1002.0	1002.0	1002.0
15.5	1001.8	1001.9	1001.9	1002.0	1002.0	1002.0	1002.1
16.0	1001.9	1002.0	1002.0	1002.1	1002.1	1002.1	1002.2
16.5	1002.0	1002.0	1002.1	1002.1	1002.2	1002.2	1002.2
17.0	1002.1	1002.1	1002.2	1002.2	1002.3	1002.3	1002.3
17.5	1002.2	1002.2	1002.3	1002.3	1002.4	1002.4	1002.4
18.0	1002.2	1002.3	1002.3	1002.4	1002.5	1002.5	1002.5
18.5	1002.3	1002.4	1002.4	1002.5	1002.5	1002.6	1002.6
19.0	1002.4	1002.5	1002.5	1002.6	1002.6	1002.7	1002.7
19.5	1002.5	1002.6	1002.6	1002.7	1002.7	1002.8	1002.8
20.0	1002.6	1002.7	1002.7	1002.8	1002.8	1002.9	1002.9
20.5	1002.7	1002.8	1002.8	1002.9	1002.9	1003.0	1003.0
21.0	1002.8	1002.9	1002.9	1003.0	1003.1	1003.1	1003.1
21.5	1003.0	1003.0	1003.1	1003.1	1003.2	1003.2	1003.2
22.0	1003.1	1003.1	1003.2	1003.2	1003.3	1003.3	1003.3
22.5	1003.2	1003.2	1003.3	1003.3	1003.4	1003.4	1003.4
23.0	1003.3	1003.3	1003.4	1003.4	1003.5	1003.5	1003.6
23.5	1003.4	1003.5	1003.5	1003.6	1003.6	1003.6	1003.7
24.0	1003.5	1003.6	1003.6	1003.8	1003.8	1003.8	1003.8
24.5	1003.7	1003.7	1003.8	1003.8	1003.9	1003.9	1003.9
25.0	1003.8	1003.8	1003.9	1003.9	1004.0	1004.0	1004.0
25.5	1003.9	1004.0	1004.0	1004.1	1004.1	1004.1	1004.2
26.0	1004.0	1004.1	1004.1	1004.2	1004.2	1004.3	1004.3
26.5	1004.2	1004.2	1004.3	1004.3	1004.4	1004.4	1004.4
27.0	1004.3	1004.4	1004.4	1004.5	1004.5	1004.5	1004.6
27.5	1004.5	1004.5	1004.6	1004.6	1004.7	1004.7	1004.7
28.0	1004.6	1004.6	1004.7	1004.7	1004.8	1004.8	1004.8
28.5	1004.7	1004.8	1004.8	1004.9	1004.9	1005.0	1005.0
29.0	1004.9	1004.9	1005.0	1005.0	1005.1	1005.1	1005.1
29.5	1005.0	1005.1	1005.1	1005.2	1005.2	1005.2	1005.3
30.0	1005.2	1005.2	1005.3	1005.3	1005.4	1005.4	1005.4

Table 3. EN/ISO 8655-6 Z correction factors for distilled water as a function of test temperature and air pressure.

replacement of worn or defective parts and annual replacement of the sealing mechanism. Some instruments use what is known as a "dry seal"; a Teflon or polyethylene seal and o-ring that slides onto the piston of the pipette and creates the vacuum necessary for the pipette to aspirate liquid into the tip. Others use what is known as a "wet seal"; a wet seal requires that grease manufactured specifically for that pipette be applied to the piston in very small amounts. The grease coupled with an o-ring, and for some instruments grease, seal and an o-ring, creates the necessary vacuum.

Preventive maintenance and calibration may also be outsourced to qualified pipette calibration service providers. Be sure to look for an ISO 17025 accredited calibration company, as these companies are routinely audited by third parties and must establish and maintain a quality system and demonstrate technical competence in order to achieve and keep accreditation. A large component of technical competence is measured by the ability of the company to determine and report the uncertainty of measurement associated with each calibration. Compliance statements reported without taking into account the uncertainty of measurement are not truly traceable measurements. The costs associated with outsourcing pipette calibration service are a small fraction of the purchase price for a new pipette.

Whether you design and implement your own in-house pipette calibration service program or outsource it to a qualified provider, ensuring that your instruments are well maintained and calibrated to deliver within specifications will guarantee two things: A long life for each pipette you've invested in and the confidence in the data produced by that pipette.

Ann Lenhardt, Director of Quality and COO at Calibrate, Inc. (919-240-4089).

Based out of Carrboro, NC, Calibrate, Inc. is North America's oldest and largest independent pipette service company. Specializing in providing on-site and mail-in pipette service solutions for all makes and models of pipettes, Calibrate is the preferred provider for customers and outsourcers alike. Contact us if you're interested in partnering with us to offer your customers an expert pipette solution. http://www.pipetpeoplestore.com/

Balance Calibration – A Method for Assigning a Direct-Reading Uncertainty to an Electronic Balance

Mike Stears
Idaho National Laboratory

Like many calibration laboratories, our laboratory provides calibrations for a wide range of instrumentation. For the most part, we calibrate the instrumentation to the manufacturer's published specifications. As one of our services, we provide calibrations of electronic balances for customers within our company; the calibrations are performed at the customer's location. In our experience, most of our customers are not using their balance as a comparator, but simply putting an unknown quantity on the balance and reading the displayed value. Manufacturer's specifications for balances typically include specifications such as readability, repeatability, linearity, and sensitivity temperature drift; but, what does this all mean when the balance user simply reads the displayed mass value and accepts the reading as the true value? What is the uncertainty in the measurement? This paper discusses a method for assigning a direct-reading uncertainty to a balance based upon the observed calibration data and the environment where the balance is being used.

1. Introduction

The method for assigning a direct-reading uncertainty to an electronic balance, discussed in this paper, requires close interaction with the customer regarding the environmental conditions where the balance is in use. The customer's uncertainty requirements for measurements performed with the balance are discussed and assessed against the operating environment. The amount of rigor the customer is able to apply to monitoring and controlling the operational environment has a significant impact on the magnitude of the uncertainty applied to the balance.

Uncertainties of the standard weights, used for field calibration of balances, are determined over the typical range of environmental conditions encountered. Environmental conditions are assessed and stabilization time for the standards is determined at the time of calibration. Measurements are then performed and the resulting data is used, along with other uncertainty contributions, to arrive at an assigned uncertainty for the balance. EA-10/18 "Guidelines on the calibration of non-automatic weighing instruments" [1] is an excellent resource for discussion of uncertainty contributions and methods to arrive at an expanded uncertainty. A spreadsheet, designed specifically for this process, is used by our laboratory to simplify the process for the calibration technician and greatly reduce the chance for an error in the calculation of the assigned uncertainty. Sections of the spreadsheet will be used throughout this paper to assist in the explanation of the process. Methods for determining the magnitude of the expanded uncertainty in this paper are somewhat conservative in order to simplify the process and minimize the cost of calibration. The methodology used is not intended for calibrations in a laboratory-type environment requiring the lowest uncertainties attainable.

2. Uncertainty of the Standards

Due to the fact that the calibration is not performed in a highly-controlled laboratory environment, an uncertainty analysis is performed for each standard weight covering the range of environmental conditions typically encountered in the field. The weight uncertainties and calibrated values are not modified, based upon observed conditions at the time of calibration, as long as the observed conditions are within the range identified in the analysis. Ranges of environmental values typical for our calibrations are (15.6 to 26.7) °C, (20 to 60) %RH, and (83.77 to 85.84) kPa. The uncertainty contributions considered are illustrated in Table 1.

The contribution for convection is based on information taken from Table F2.1 in EA-10/18. The table lists nominal values of mass and the estimated change in apparent mass as a result of temperature differences between the standard weight and the balance being calibrated. Table F1.2 in EA-10/18 lists acclimatization times necessary to reach specified levels of temperature equilibrium. The uncertainty for each weight is calculated with different contributions for convection based on temperature differences between the weight and the unit under test (UUT). Different uncertainties are calculated so that only an appropriate amount of equilibration time for the particular calibration is allowed for efficiency. Our laboratory has made the decision to calculate the standard weight uncertainties at temperature differentials of 1 °C and 5 °C. The manufacturer's repeatability and linearity specifications are used to estimate a "target" uncertainty for the specific balance. The "target" uncertainty is only used to determine the level of temperature equilibrium that will be enforced prior to performing the calibration. The "target" uncertainty is calculated as: target = [(2 * repeatability) + linearity] /

Nominal Mass (grams)	200	Nominal Density (g/cm³)	7.95	Property #:	xxxxxx
Assumed Air Density (g/cm³)	0.001200	Deviation from INL nominal (g/cm³)	0.000200	Date:	xx/xx/xxxx
Contribution	2 sigma uncertainty (micrograms)	Distribution	Divisor	Adjusted Component	Notes
Weight Calibration	57.5	Normal	2	28.75	From calibration report. If multiple weights are used, add the uncertainties together.
Drift	42.53	Rectangular	1.732	24.56	Based on calibration history. If multiple weights are used, RSS the drift values.
Convection (Δ 1 °C)	80.000	Rectangular	1.732	46.189	Taken from Table F2.1 in EA-10/18. Interpolation required for values not listed. Use 1 µg/g for weights < 10 g.
Air Buoyancy	36.7925	Rectangular	1.732	21.2428	Nominal air density at INL ≈ (1.0 ± 0.034) mg/cm³. Valid for: (83.77 to 85.84) kPa, (15.6 to 26.7) °C, (20 to 60) %RH.
Weight Density	0	Rectangular	1.732	0	Included in weight calibration uncertainty.
		Combined Uncertainty =		63.36	micrograms
		Expanded Uncertainty (k = 2)		126.7	micrograms

Table 1. Example standard weight uncertainty analysis.

range capacity. As a general rule, a temperature difference (between the standard weights and the balance) of < 5 °C will be enforced for balances where the target uncertainty is ≥ 10 µg/g. A temperature difference of < 1 °C will be enforced for balances where the target uncertainty is < 10 µg/g. These are simply guidelines used by our laboratory; they can easily be modified to meet specific needs.

The contribution for air buoyancy is based on the maximum difference between typical air densities at our location and "standard" air. Corrections are not made at the time of calibration; the full uncertainty resulting from the range of air densities is included for each standard weight.

3. Preliminary Operations

Upon arrival at the calibration location, the temperature inside of the case containing the standard weights is compared to the temperature at the location of the balance. Based upon the balance capability, a stabilization time is determined as previously discussed. The temperature at the balance is observed throughout the calibration process.

The calibration environment is discussed with the customer at this time to determine a reasonable temperature range over which a balance self-calibration is valid. This temperature range is included in the uncertainty analysis and must be monitored by the balance user when the balance is in use. The balance user must perform a daily self-calibration prior to use and any time the temperature changes beyond the limit included in the uncertainty analysis; the change is relative to the temperature at the time the last self-calibration was performed. Some balances perform a self-calibration automatically with changes in temperature. If a balance requires an external weight to perform the self-calibration, a calibrated weight is provided to the customer for this purpose if not already available. For balances that do not have a self-calibration function, a multiplier is included in the uncertainty analysis; the calibration interval may be reduced as well until the data justifies changes to the interval or uncertainty.

If the balance has more than one range, it should be verified with the customer which ranges are to be calibrated. It should also be discussed with the customer whether the full range of the balance is used or whether calibration of a limited range is desired; this could improve the uncertainty assigned to the balance for the limited range. The normal usage of the balance, regarding weighing schemes, should be discussed to determine whether the standard weights should be measured as increasing or decreasing loads. Prior to taking data, the balance should be checked to ensure it is level. The balance should be exercised by placing a weight approximately equal to the capacity of the balance on the weighing pan at least once. If available, perform a self-calibration function for the balance.

Temperature Range (user specified): ±	1	°C
Balance Range:	500	grams
Resolution (Decimal Points):	4	digits

Balance Temperature Sensitivity Coefficient ±	1	µg/g
Assigned weight for performance of self-cal:	internal	

Repeatability Test		
Reading Number	Value (grams)	
1	300.0003	
2	300.0002	
3	300.0001	
4	300.0001	
5	300.0001	
6	300.0002	
7	300.0001	
8	300.0001	
9	3000.0003	
10	300.0002	
Standard Deviation =	0.0000823	grams
Mfg Repeatability spec:	0.00012	grams

Linearity Test		
Calibrated conventional mass of weight (grams)	As-found (g)	As-left (g)
0.0099985	0.0099	0.0099
0.0999996	0.0999	0.0999
1.0000066	1.0000	1.0000
9.9999734	10.0000	10.0000
100.0000926	99.9999	99.9999
300.0001938	300.0003	300.0003
500.0004327	500.0005	500.0005

Corner Loading	
Quadrant	Reading
CNTR	300.0001
BL	300.0001
BR	300.0001
FL	300.0002
FR	3000.0001

Linearity Result		
Maximum deviation from calibrated weight:	0.000192638	grams
Mfg linearity spec (k=2):	0.0002	grams
Weight Uncertainty		
Largest uncertainty of all weights used (k=2):	0.0002568	grams
RSS Weight Uncertainty & Max Deviation:	0.000321023	grams

Greater of standard deviation or mfg repeatability spec:	0.0001200	grams
Greater of (RSS Weight Uncertainty & Max Deviation) or mfg linearity spec:	0.000321023	grams
Enter balance readability(d):	0.0001	grams
Temperature drift of sensitivity:	0.0005000	grams

Expanded uncertainty calculated as [2 * SQRT ((Repeatability)^2 + (Linearity/1.732)^2 + (Readability/3.46)^2 + (TemperatureDrift/1.732)^2)]

Expanded uncertainty =	0.000729	grams (k=2)
If no self-cal being performed prior to use, multiply uncertainty by a minimum of 5.		
Multiplier (enter 1 if self-cal performed):	1	
S&CL Assigned Uncertainty = ±	0.00073	grams (k=2)

Temperature:	23.6	°C
Humidity:	42	%
Property Number:		
Date:		
Customer:		
Location:		
Comments:		

Manufacturer:	
Model:	
Serial No.:	

Table 2. Example calibration spreadsheet.

Temperature Range (user specified): ±	1	°C	Balance Temperature Sensitivity Coefficient: ±	1	µg/g
Balance Range: 500	grams		Assigned weight for performance of self-cal:	internal	

Table 3. General information.

4. Calibration

Once the details of the calibration have been determined, the measurements are taken. Table 2 illustrates the spreadsheet used for the calibration process.

The yellow shaded areas of the spreadsheet are the fields required to be filled in by the calibration technician. The remaining fields are automatically filled in by functions built into the spreadsheet.

4.1 General Information

There are seven buttons along the bottom of the spreadsheet (not shown), the appropriate button is selected to set the resolution of the spreadsheet to match that of the balance being calibrated prior to taking data. The temperature range, over which a self-calibration is valid, is entered as discussed with the customer. The manufacturer's specification for the temperature sensitivity coefficient is then entered. The combination of these two entries is used in the calculation of the assigned uncertainty. Next, the assigned weight for the performance of self-calibration is entered. If internal weights are not used, the asset number of the assigned external weight is entered. The balance range, or sub-range, being calibrated is also entered. See Table 3.

4.2 Repeatability

Once the required stabilization time has been allowed, the balance has been exercised, and the self-calibration has been performed; the repeatability test is started. Repeatability tests are performed with a test load ≥ 50 % of the range being calibrated [1]. Ten measurements are taken of the test load with a zero-check performed prior to each measurement of the test load. The weight is placed in the center of the weighing pan. The standard deviation of the measurements is calculated by the spreadsheet and the manufacturer's specification is entered by the calibration technician as shown in Table 4.

Repeatability Test		
Reading Number	Value (grams)	
1	300.0003	
2	300.0002	
3	300.0001	
4	300.0001	
5	300.0001	
6	300.0002	
7	300.0001	
8	300.0001	
9	300.0003	
10	300.0002	
Standard Deviation =	0.0000823	grams
Mfg Repeatability spec =	0.00012	grams

Table 4. Repeatability test.

4.3 Eccentricity Test (Corner Loading)

Eccentricity tests are performed to provide the information to the customer; however, the results are not normally included in the assigned uncertainty of the balance. The same test load that was used for the repeatability test may be used. The load is measured in the center of the pan and then in each of the four quadrants successively as shown in Figure 1. The balance is "zeroed" between readings as necessary. If the manufacturer provides a specification for eccentricity, the readings are analyzed for conformance to the specification; corrective action can be taken as necessary after all as-found data for the entire calibration is recorded.

Corner Loading (Eccentricity)	
Quadrant	Reading
CNTR	300.0001
BL	300.0001
BR	300.0001
FL	300.0002
FR	300.0001

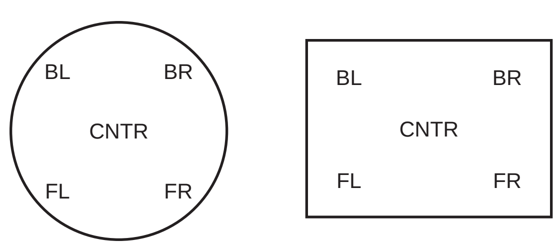

Figure 1. Datasheet entry and load positions.

4.4 Linearity Test

The linearity test section of the spreadsheet does not actually verify the manufacturer's linearity specification for the balance; it is simply used to determine the errors of indication for the balance over the range being calibrated. The measurement data could be used to verify the linearity specification, but this is not included in the methodology our laboratory typically uses to assign a direct-reading uncertainty. The test weights are selected to provide nominal indications of "1" on each consecutive digit of the balance readout starting with the second least significant digit; the minimum nominal value test weight used is 1 mg. Multiple test points are normally selected over the most significant decade of the balance range. The test weights are selected through a pick list for each entry as shown in Table 5.

The calibrated values of the test weights and their associated uncertainties are in a second worksheet behind the calibration worksheet; the pick lists are populated from the test-weight worksheet. Having the test weights selected through a pick list greatly reduces the risk of having an error in the calibrated value of any weight listed as a standard. The uncertainty for each test weight used in the calibration is automatically pulled into the calibration worksheet for inclusion in the uncertainty analysis and determination of the assigned direct-read uncertainty. Calibrated values and uncertainties of the test weights are updated when the weights are calibrated; this is the only time the values of the test weights are manually entered into the worksheet. The values and uncertainties entered for the test weights are double checked by a second person at the time of entry.

Once the test weights have been selected, the weights are measured on the balance and the as-found data is recorded. When all of the data is recorded, it is reviewed to determine whether adjustment of the balance is necessary. The manufacturer's linearity specification is used as a basis for determination of adjustment; the uncertainty of the test weights should be considered when making this decision. If the balance is not adjusted, the as-found data is duplicated in the as-left column of the worksheet. If it is determined that the balance is to be adjusted, the manufacturer's adjustment procedure is followed. After adjustment, the test weights are measured again and the data recorded in the as-left column of the spreadsheet. If the adjustment achieved the desired results, all of the data for the calibration is complete.

Linearity Test		
Calibrated conventional mass of weight (grams)	As-found (g)	As-left (g)
0.0099985	0.0099	0.0099
0.0999996	0.0999	0.0999
1.0000066	1.0000	1.0000
9.9999734	10.0000	10.0000
100.0000926	99.9999	99.9999
300.0001938	300.0003	300.0003
500.0004327	500.0005	500.0005

100.00009264
120.00007016
150.00001671
179.99998143
200.00018777
300.00019384
400.00028648
500.00043267

Table 5. Pick-list selection of test weights.

5. Uncertainty Calculation

The determination of the assigned uncertainty can be handled in different ways. The uncertainty calculation in the calibration spreadsheet produces a single uncertainty for the entire range calibrated. The uncertainty determination is based on a combination of the measurement data and the manufacturer's specifications.

The worst-case deviation from the calibrated weight values in the as-left data is root-sum-squared (RSS) with the largest individual uncertainty of the test weights used; the result is compared to the manufacturer's linearity specification and the larger of the two is included as the linearity contribution in the combined uncertainty. The standard deviation of the repeatability data is compared to the manufacturer's repeatability specification and the larger of the two is included as the repeatability contribution in the combined uncertainty. These comparisons and calculations are performed automatically by the spreadsheet.

The balance readability (scale interval or *d*) is entered by the technician for inclusion in the combined uncertainty. The spreadsheet multiplies the temperature sensitivity coefficient by the user-specified temperature range to arrive at the temperature drift of sensitivity contribution to the combined uncertainty.

Individual uncertainty contributions are converted to a one-sigma level through division based on the distribution. The repeatability contribution is considered using a normal distribution; the linearity, readability (*d*/2), and temperature drift of sensitivity are considered using a rectangular distribution. The one-sigma uncertainty contributions are combined using the RSS method to arrive at a combined uncertainty. The combined uncertainty is multiplied by a k-factor of two to produce the expanded uncertainty. Calculation of the expanded uncertainty is handled automatically by the spreadsheet. The spreadsheet illustration of the uncertainty contributions is shown in Table 6.

Linearity Result		
Maximum deviation from calibrated weight:	0.000192638	grams
Mfg linearity spec (k=2):	0.0002	grams
Weight Uncertainty		
Largest uncertainty of all weights used (k=2):	0.0002568	grams
RSS Weight Uncertainty & Max Deviation:	0.000321023	grams
Greater of standard deviation or mfg repeatability spec:	0.0001200	grams
Greater of (RSS Weight Uncertainty & Max Deviation) or mfg linearity spec:	0.000321023	grams
Enter balance readability(d):	0.0001	grams
Temperature drift of sensitivity:	0.0005000	grams
Expanded uncertainty calculated as [2 * SQRT((Repeatability)² + (Linearity/1.732)² + (Readability/3.46)² + (Temperature Drift/1.732)²)]		
Expanded uncertainty (k=2):	0.000729	grams
If no self-cal being performed prior to use, multiply uncertainty by a minimum of 5.		
Multiplier (enter 1 if self-cal performed):	1	
S&CL Assigned Uncertainty (k = 2): ±	0.00073	grams

Table 6. Combining uncertainty contributions.

The expanded uncertainty is modified by a multiplier if the balance does not have a self-calibration function. If this is the initial calibration of the balance, in the current environment, the multiplier is normally set at five. The multiplier can be modified by the calibration technician based on calibration history of the balance and acceptable risk to the customer. The multiplier could be significantly reduced if the customer is willing to incorporate a check standard into the measurement process to monitor performance of the balance. All customers are encouraged to use check standards to provide measurement assurance regardless of the capabilities of the balance. If the balance has a self-calibration function, the multiplier is set at one. The product of the expanded uncertainty and the multiplier is the direct-read uncertainty assigned to the balance.

If the balance being calibrated has more than one range, the calibration process described is repeated for each of the ranges. A separate spreadsheet is generated for each range to arrive at an individual uncertainty assigned to a specific range.

The assigned uncertainty does not include any contribution for samples weighed by the customer. Any additional uncertainty specific to a sample such as density of the sample, static electricity, magnetism, moisture, temperature, etc. must be analyzed by the customer for impact on the measurement results. Calibration personnel should be available to assist with questions regarding uncertainty contributions.

6. Conclusions

In our experience dealing with customers regarding balance use and calibration, most did not fully understand all of the uncertainty considerations or how to make a meaningful estimate of their measurement uncertainty. This process was implemented to engage the customer in the calibration process and provide a meaningful estimate of the balance uncertainty in the environment where it is being used. This process has become an educational experience for the customer as well as our calibration personnel. The process outlined is one method to assign a direct-reading uncertainty to an electronic balance; additional tests may need to be added to meet all of the requirements for specific applications. This process is meant to provide an efficient and consistent method for calibration personnel to perform the calibration and assign the uncertainty in the field. The uncertainty calculations are meant to cover a wide range of environmental conditions and are not meant for balance use in a tightly controlled environment where the lowest uncertainties attainable are desired.

References

[1] European co-operation for Accreditation, *Guidelines on the calibration of nonautomatic weighing instruments*, EA-10/18, 2005.

Mike Stears, Idaho National Laboratory, 208-526-2343.

High Attenuation Measurement of Step Attenuators

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This paper introduces a solution for high attenuation measurement of step attenuators. Fundamentally, this high attenuation measurement method is based on the cascaded 2-port network and S-parameter theory. This method is to compute the S-parameters of high attenuation (> 80 dB) using the measured S-parameters of lower attenuation (< = 80 dB) settings, the calculations of which depend on attenuator card sequence and physical structure of the step attenuator. Such a method can measure attenuation as low as 120 dB. This is *not* a straight dB addition; rather, this solution can offer considerable accuracy only using a VNA (Vector Network Analyzer) and T-matrix (as known as transmission parameter or cascade parameter) method which can make the calculations easier. Measurement uncertainties are derived from uncertainties of cascaded S-parameters, for example, measurement uncertainty for 80 dB @ 18 GHz is less than 0.8 dB and 110 dB @ 18 GHz is less than 1.0 dB.

1. Introduction

There was a need to verify the accuracy of an attenuator in a new synthesizer product. This method provides a simpler procedure for the calibration lab using an automatic measurement system to perform high attenuation measurement of step attenuators. This T-matrix method was originally suggested by the project manager, and finally implemented by software engineer. The author of this report, as metrologist of the project, provided principle verification, experimentation results review and measurement uncertainty analysis. This method was also approved by an expert from Agilent Component Test Division.

This measurement system has been used to calibrate a large number of step attenuators for many years. This paper describes the T-matrix measurement method for achieving high accuracy, and will introduce details using cascade parameters to represent each through and attenuator section based on the attenuator's physical structure.

2. T-Matrix Description

The following discussion applies to a cascade of N-port networks. For the sake of simplicity, however, we will limit our analysis to two-port networks only. When cascading a number of two-port network in series, a more useful network representation is needed to facilitate the calculation of the overall network parameters.

This representation should relate the output quantities in terms of input quantities. Using such a representation will enable us to obtain a description of the completed cascade by simply multiplying together the matrix describing each network.

A 2-port network (Figure 1) can be used to model many components; the attenuator is a typical example [2]. The 2-port network can be characterized by a S-parameter matrix (Figure 2). For 2-port networks, the S-parameters are defined as:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

The inputs and outputs of the 2-port network can be denoted as:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

where S11 is the input reflection coefficient with the output port terminated by a matched load (a_2=0).

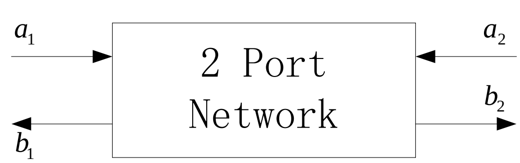


Figure 1. 2-port network.

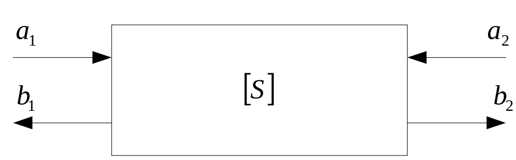


Figure 2. S-parameters for 2-port network.

Therefore:

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0}$$

Similarly, S_{21} is the forward transmission coefficient indicating with the output port terminated by a matched load (a_2=0):

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0}$$

S22 is the output reflection coefficient with the input terminated by a matched load (a_1=0):

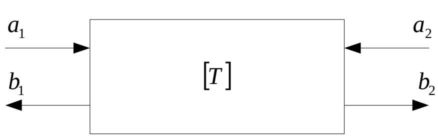
$$S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$$

S12 is the reverse transmission coefficient with the input terminated by a matched load (a_1=0):

$$S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$$

Transmission matrix [T] is expressed in terms of the waves at the input port and the waves at the output port. Using this definition, the transmission matrix formulation becomes very useful when dealing with multistage circuits or infinitely long periodic structures such as those used in circuits for traveling wave tubes, etc.

The transmission matrix for a two-port network, as shown in Figure 3, is defined as:



$$\begin{bmatrix} b_1 \\ a_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_2 \\ b_2 \end{bmatrix}$$

Figure 3. T-parameters for 2-port network.

The relationship between S- and T- parameters can be derived using the above basic definition as follows: [1]

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} -\dfrac{S_{11}\cdot S_{22} - S_{12}\cdot S_{21}}{S_{21}} & \dfrac{S_{11}}{S_{21}} \\ -\dfrac{S_{22}}{S_{21}} & \dfrac{1}{S_{21}} \end{bmatrix}$$

The reverse relationship expressing [S] in terms of [T] matrix can also be derived with the following result: [2]

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} \dfrac{T_{12}}{T_{22}} & \dfrac{T_{11}\cdot T_{22} - T_{12}\cdot T_{21}}{T_{22}} \\ \dfrac{1}{T_{22}} & -\dfrac{T_{21}}{T_{22}} \end{bmatrix}$$

For a cascade connection of two-port networks, as shown in Figure 4, the overall T-matrix can be obtained as follows:

$$T = T_1 * T_2$$

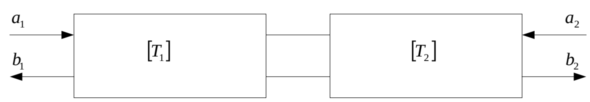


Figure 4. T-parameters for 2 cascaded networks.

Thus, the total T-matrix is the multiplication of the two T-matrices. This is the theoretical basis for step attenuator measurement.

3. T-Matrix Method for Step Attenuator Calibration

The description of calibration method with T-matrix method will use an Agilent 8496B step attenuator as an example. Step attenuator sections are connected in a cascade. Each section consists of a precision, thin-film attenuator card, a lossless thru-line and a ganged pair of edge line transmission lines. The edge lines are flexed to

8496A/B Attenuator Sections				
Atten (dB)	**1 10 dB**	**2 20 dB**	**3 40 dB**	**4 40 dB**
0				
10	X			
20		X		
30	X	X		
40				X
50	X		X	
60		X	X	
70	X	X	X	
80			X	X
90	X		X	X
100		X	X	X
110	X	X	X	X

Table 1. Attenuator Switching Order.

make contact with either the attenuator card or the thru-line. The edge line contacts are gold-plated leaf springs which ensure long life and high repeatability.

Table 1 shows the attenuator switching order. Figure 5 shows the attenuator card sequence and physical structure of step attenuator 8496B.

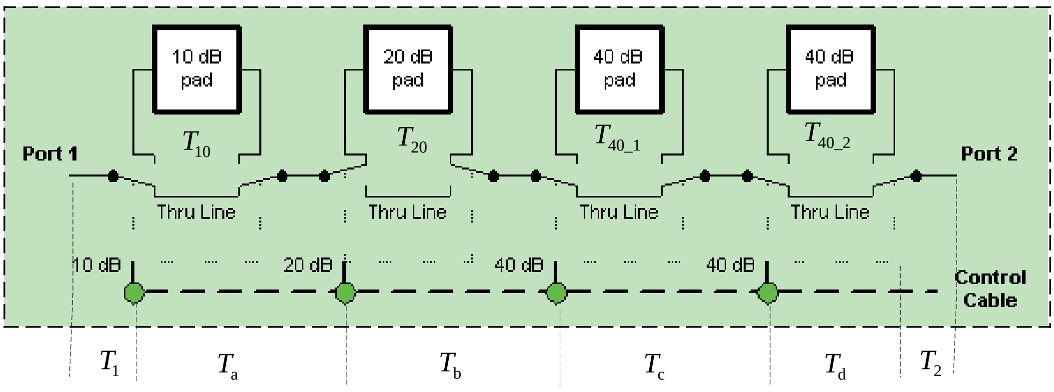


Figure 5. 8496B individual pads connection.

Below are 110 dB attenuation calculations, using this Agilent 8496B step attenuator as an example.

$$T_{0\_m} = T_1 * T_a * T_b * T_c * T_d * T_2 \Longrightarrow T_{0\_m}^{-1} = T_2^{-1} * T_d^{-1} * T_c^{-1} * T_b^{-1} * T_a^{-1} * T_1^{-1}$$

$$T_{0\_m} = T_1 * T_{10} * T_b * T_c * T_d * T_2 \Longrightarrow T_{10} = T_1^{-1} * T_{10\_m} * T_2^{-1} * T_d^{-1} * T_c^{-1} * T_b^{-1}$$

$$T_{20\_m} = T_1 * T_a * T_{20} * T_c * T_d * T_2 \Longrightarrow T_{20} = T_a^{-1} * T_1^{-1} * T_{20\_m} * T_2^{-1} * \mathrm{T}_c^{-1}$$

$$T_{40\_1\_m} = T_1 * T_a * T_b * T_{40\_1} * T_d * T_2 \Longrightarrow T_{40\_1} = T_b^{-1} * T_a^{-1} * T_1^{-1} * T_{40\_1\_m} * T_2^{-1} * T_d^{-1}$$

$$T_{40\_2\_m} = T_1 * T_a * T_b * T_c * T_{40\_2} * T_2 \Longrightarrow T_{40\_2} = T_c^{-1} * T_b^{-1} * T_a^{-1} * T_1^{-1} * T_{40\_2\_m} * T_2^{-1}$$

Combine above parameters to get attenuation 110 dB:

$$T_{110\_m} = T_1 * T_{10} * T_{20} * T_{40\_1} * T_{40\_2} * T_2$$

$$= T_1 * (T_1^{-1} * T_{10\_m} * T_2^{-1} * T_d^{-1} * T_c^{-1} * T_b^{-1}) * (T_a^{-1} * T_1^{-1} * T_{20\_m} * T_2^{-1} * T_d^{-1} * T_c^{-1}) * (T_b^{-1} * T_a^{-1} *$$

$$T_1^{-1} * T_{40\_1\_m} * T_2^{-1} * T_d^{-1}) * (T_c^{-1} * T_b^{-1} * T_a^{-1} * T_1^{-1} * T_{40\_2\_m} * T_2^{-1}) * T_2$$

$$= T_{10\_m} * (T_2^{-1} * T_d^{-1} * T_c^{-1} * T_b^{-1} * T_a^{-1} * T_1^{-1}) * T_{20\_m} * (T_2^{-1} * T_d^{-1} * T_c^{-1} * T_b^{-1} * T_a^{-1} * T_1^{-1}) * T_{40\_1\_m} *$$

$$(T_2^{-1} * T_d^{-1} * T_c^{-1} * T_b^{-1} * T_a^{-1} * T_1^{-1} *) * T_{40\_2\_m}$$

$$= T_{10\_m} * T_{0\_m}^{-1} * T_{20\_m} * T_{0\_m}^{-1} * T_{40\_1\_m} * T_{0\_m}^{-1} * T_{40\_2\_m}$$

Note: T_{0_m}, T_{10_m}, T_{20_m}, $T_{40\_1\_m}$, $T_{40\_2\_m}$ and T_{110_m} can be measured directly.

Comparing the results of direct measurement and T-matrix measurement will provide data as shown in Table 2. Measurement conditions are shown using an Agilent 8496B as the DUT, with an Agilent PNA and 8902A/PSA, testing at 1 GHz and 18 GHz.

Note: The results of "T-matrix Measurement" are measured with a network analyzer PNA and calculated to get the results when attenuation is larger than 40 dB. The results of "Direct Measurement" are measured with 8902A measuring receiver and spectrum analyzer manually, and all results are measured directly.

This method has been used for Signal Integrity Analysis; see references 3 and 4 for technique details .

Freq. = 1 GHz	Attenuation Measurement results (dB)			
Attenuation	T-matrix Measurement	Direct Measurement	Difference	Measurement Uncertainty
0	0.17	0.16	0.01	0.05
10	10.04	10.05	-0.01	0.06
20	19.93	19.92	0.01	0.07
30	30.01	29.98	0.03	0.08
40	40.06	40.03	0.03	0.09
50	50.1	50.09	0.01	0.12
60	59.99	59.98	0.01	0.19
70	70.03	70.03	0.00	0.16
80	80.12	80.07	0.05	0.11
90	90.16	90.12	0.04	0.11
100	100.05	100.01	0.04	0.12
110	110.09	110.06	0.03	0.14

Freq. = 18 GHz	Attenuation Measurement results (dB)			
Attenuation	T-matrix Measurement	Direct Measurement	Difference	Measurement Uncertainty
0	1.11	1.24	-0.13	0.12
10	10.03	9.99	0.04	0.15
20	20.09	20.09	0	0.15
30	30.22	30.22	0	0.16
40	40.32	40.27	0.05	0.19
50	50.37	50.34	0.03	0.25
60	60.52	60.47	0.05	0.3
70	70.54	70.48	0.06	0.37
80	80.64	80.57	0.07	0.38
90	90.68	90.96	-0.28	0.38

Table 2. Validation results.

4. Uncertainty Analysis

This measurement uncertainty analysis is for all step attenuators (DUT) Transmission (S21, S12) calibration by using a network analyzer. The information is based on the network analyzer specified frequency range (options are considered due to DUT frequency range requirement). The raw measurement uncertainty analysis data was derived from the Agilent VNA Uncertainty Calculator (Uncertainty Test revision spread sheet) A.2.6.1, DLL Revision 4.7.0.8 for the attenuation below or equal to 65 dB attenuations [5]. For high attenuation measurement uncertainty analysis, refer to the arithmetic below to drive its uncertainty using the uncertainties of 10 dB, 20 dB, 30 dB and 40 dB, based on the measurement methodology (T-Matrix). Table 3 shows the calculated measurement uncertainties based on the attenuation settings being measured.

Frequency (GHz)	Measurement Uncertainty (dB)				
	10 dB	20 dB	30 dB	40 dB	50 dB
1	0.055	0.065	0.076	0.089	0.122
2	0.055	0.065	0.077	0.090	0.128
2	0.090	0.099	0.109	0.123	0.148
3	0.094	0.103	0.113	0.129	0.160
4	0.099	0.107	0.116	0.135	0.171
5	0.103	0.111	0.120	0.140	0.181
6	0.107	0.115	0.124	0.145	0.190
7	0.111	0.118	0.127	0.150	0.198
8	0.114	0.122	0.130	0.154	0.206
9	0.118	0.125	0.134	0.158	0.213
10	0.122	0.128	0.137	0.162	0.220
11	0.125	0.131	0.140	0.166	0.226
12	0.128	0.135	0.143	0.170	0.231
13	0.131	0.138	0.146	0.173	0.236
14	0.135	0.141	0.149	0.177	0.240
15	0.138	0.144	0.152	0.180	0.244
16	0.141	0.147	0.155	0.183	0.248
17	0.144	0.150	0.158	0.186	0.251
18	0.147	0.153	0.161	0.189	0.255
19	0.150	0.156	0.164	0.192	0.257
20	0.153	0.159	0.168	0.195	0.260
21	0.156	0.163	0.171	0.198	0.263
22	0.159	0.166	0.174	0.202	0.265
23	0.163	0.170	0.178	0.205	0.268
24	0.166	0.173	0.181	0.208	0.270
25	0.169	0.177	0.185	0.211	0.272
26	0.173	0.181	0.189	0.215	0.275
26.5	0.175	0.183	0.191	0.216	0.276

Table 3. Measurement Uncertainty.

As an example, Figure 6 indicates a connection of two attenuation sections; the measurement uncertainty of attenuation (A+B) dB can be derived with the formula below:

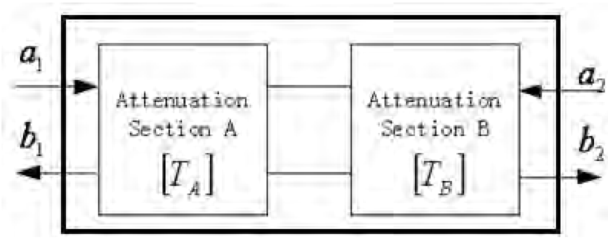


Figure 6. Two individual pads connection.

This analysis is also used to get measurement uncertainty for high attenuation with pads connection.

References

[1] Matthew M. Radmanesh, Radio Frequency and Microwave Electronics Illustrated.
[2] Hewlett-Packard Co., Application Note 95-1, S-Parameter Techniques.
[3] Agilent Technologies Co., Application Note 5989-5765EN, Part 3: the ABCs of De-Embedding.
[4] Agilent Technologies Co., Application Note 1364-1, DeEmbedding and Embedding S-Parameter Networks Using a Vector Network Analyzer.
[5] Agilent Technologies Co., VNA Uncertainty Calculator, http://www.home.agilent.com/agilent/editorial.jspx?cc=US&lc=eng&ckey=1000000418:epsg:sud&nid=-11143.0.00&id=1000000418:epsg:sud&pselect=SR.General

$$S_{11} = f_{11}\,(S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru})$$
$$S_{12} = f_{12}\,(S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru})$$
$$S_{21} = f_{21}\,(S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru})$$
$$S_{22} = (f_{22}\,(S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru})$$

$$\Delta S_{11\_1} = (f_{11}\,(S_{11}^{A}+\Delta S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru})$$
$$- f_{11}\,(S_{11}^{A}-\Delta S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru}))/2$$

$$\vdots$$

$$\Delta S_{11\_12} = (f_{11}\,(S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru}+\Delta S_{22}^{thru})$$
$$- f_{11}\,(S_{11}^{A}, S_{12}^{A}, S_{21}^{A}, S_{22}^{A}, S_{11}^{B}, S_{12}^{B}, S_{21}^{B}, S_{22}^{B}, S_{11}^{thru}, S_{12}^{thru}, S_{21}^{thru}, S_{22}^{thru}-\Delta S_{22}^{thru})))/2$$

$$S_{11\_type\_B} = SQRT(\,(\Delta S_{11\_1})^2+(\Delta S_{11\_2})^2+....+\,(\Delta S_{11\_12})^2\,)$$

$$S_{11\_MU} = K\_factor*SQRT(\,(S_{11\_type\_B})2+(S_{11\_type\_A})2\,)$$

5. Conclusion

This method considers mismatch impact between each pad and thru lines inside the step attenuator using cascaded T-parameter; this system has been used to calibrate a large number of step attenuators with impressive results, the actual measurement results and measurement uncertainties show this method can acheive adequate measurement accuracy as the direct measurement, but can reduce calibration time for cal labs. This method has also been a valuable tool for characterization of other fixed attenuators with high attenuation.

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Acknowledgement: The author wishes to express her gratitude to the people from Agilent Technologies Co. Ken Wong (Expert from Component Test Division) and Dahai Sun (Manager from WCSS) for investigation support and Yu Gu (Senior software engineer from WCSS) for operation and software implementation.

Technical Requirements for a Portable Metrology Laboratory in Hot, Arid Regions

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This paper presents a proposal for establishing a portable laboratory in hot, arid regions to provide the necessary maintenance services for equipment used in remote sites as on-site services. A portable, on-site metrology laboratory eliminates the need to ship instruments and reduces the calibration turnaround time, thus reducing downtime for the production equipment and lowering the cost of calibration. The proposal stresses the importance of the portable laboratory approach in hot, arid regions with typical applications such as electrical measurements and fluids flow metering. Technical requirements needed for the portable laboratory as well as the expected challenges and difficulties are also discussed.

1. Introduction

Hot, arid regions cover about 19% of the entire land surface of the world [1]. This ratio is increased in the Arabian world, where this type of environment occupies vast areas. Although contributions of the arid regions to the world economy are still negligible, the effect on the environment of the world, e.g., desertification, pollution, water use and global warming is very well recognized. Therefore, it is a smart investment when establishing industrial projects in these areas to consider specialized requirements of the climate and environment.

Recently, due to the increase of government interest to invest in these zones, many companies and projects have been established to cover a wide range of society's requirements. For instance, projects related to electrical power production and the petroleum industry have grown exponentially. These industries and others, such as water desalination, reclamation of the desert and specialized research, need high level, reliable equipment. Instrumentation and highly trained human resources represent the essential requirements of investment success in these areas. As a result, advanced technical training for operations such as maintenance, inspection and calibration are strongly recommended to validate the confidence in the equipment used.

It is essential that devices used in production are checked and tested or calibrated using suitable and accurate equipment with traceability to a recognized standard [2]. The importance of the traceability of calibration or measurement is to ensure that the measurements are accurate and credible by referencing them to a recognized national or international physical standard. In addition, the instrumentation system and its associated tools require metrological services on a defined, regular basis using the necessary equipment and standards.

Many pieces of modern test equipment have automatic or self-calibration features designed within the instrument itself. This type of equipment generally has a reference standard built into the instrument and, at regular or predefined times, performs a calibration of the instrument. This is normally only a one-point check and is not considered to be a verification of the item's overall performance. Traceability of this automatic check may be questionable. The specialized team may specify further calibration requirements. Other instruments, such as electronic scales, have an auto-zero feature. Auto-zeroing instruments only removes the drift inherent in the design of an instrument to reset the zero point each time the instrument is used. This type of instrument generally requires a regular calibration check and more care when used to perform measurements at industrial sites [3].

2. The Portable Laboratory Approach

Why are portable labs strongly recommended? Simply because it is possible to perform rapid, high-quality services (calibration, maintenance, repairing, inspection, etc.) on-site beside the production lines. In fact, this approach is becoming more accepted and even required by some companies. People who use field-portable equipment quickly realize that it is more efficient to perform maintenance and calibration in the field.

It is important to note that when a portable laboratory conducts on-site services, the instruments must be capable of generating and documenting effective data. Many advances have been made in the development of field-portable calibration instrumentation. Some of the categories of instruments that fall within this definition of field-portable now include gas chromatographs and mass spectrometers, to name just two in the field of the petrochemicals industry. Many of these instruments are small or hand-held, robust, offer very rapid results in the field, and are useful for a wide range of investigations.

3. Typical Applications

Portable laboratory capabilities can be useful at any time when immediate data is required in order to facilitate critical decisions in the field. Typical examples of areas where portable laboratories have a great opportunity to provide field analyses include health and safety, environmental monitoring, industrial hygiene, plant security and integrity, process monitoring, site characterization and remediation and emergency response situations [3].

In addition to urgent situations, the major application of the portable test facility will be periodic measurement equipment calibration. The most sophisticated industrial equipment will not be very useful from an industrial and economical point of view unless it is calibrated. Through calibration, adjustments made to measurement equipment ensure that it performs as expected and that it can be relied on to deliver predictable, accurate results that meet quality standards and lead to customer satisfaction.

4. Technical Requirements

The portable laboratory should be equipped with all necessary instrumentation for sampling, measurement and test equipment required for the correct performance of tests or calibrations, as well as instrumentation for data analysis processing and storage. It should also include instrumentation for monitoring and recording environmental conditions in the service laboratory.

Practical steps should be taken to ensure good housekeeping inside the laboratory. The laboratory should have procedures for safe handling, transport, storage, use and planned maintenance of measuring equipment to ensure proper functioning and in order to prevent contamination or deterioration. In the following sections we briefly describe the major elements of the proposed portable laboratory.

4.1 Land-Carrier Truck

Figure 1 depicts a typical carrier truck with the service laboratory room attached. The horsepower of these types of trucks is recommended to be around 200 horsepower due to the difficult driving conditions in hot, arid regions.

Figure 1. Carrier truck with a service laboratory.

4.2 Pertinent Environmental Conditions

It is well known that one of the most expensive components in the service room construction is the air conditioning system. Labs need more controlled air than almost any other type of facility and supplying that air can be expensive. Particularly, for any type of calibration or for accurate measurement, certain environmental conditions must be monitored and documented; otherwise the final results will be affected by environmental sources of error. The requirement is stated in ISO Standard 17025 *Requirements for the Competence of Calibration and Testing Laboratories* (Section 5-3-2), "the laboratory shall monitor, control and record environmental conditions as required by the relevant specifications, methods and procedures or where they influence the quality of the results." This is a vital requirement that must be provided in the portable laboratory. There should also be effective separation between neighboring areas in which there are incompatible activities. ISO Standard 17025 *General Requirements for the Competence of Calibration and Testing Laboratories* is the international standard that provides metrologists with all managerial and technical requirements for accredited calibration and testing. Instrument calibration is normally performed at a nominal temperature of 20°C (68°F) and should not be calibrated outside a controlled environment. On-site calibration should be performed at environmental conditions of [5]:

$$T = (23 \pm 3)\ ^\circ C$$
$$RH \leq 70\%$$

The storage and usage of a calibrated item of equipment has a direct relationship to the calibration assessment program. If the location or usage of the equipment changes, this needs to be taken into consideration. For example, a torque wrench used daily that has a transit container and is stored on a tool board may have a six-month calibration interval. If it is transferred for use in a different working environment such as the tarmac, then consideration should be given to reducing its calibration interval. This is, of course, a main advantage of the portable lab where the possibility for recalibration on-site is always available.

4.3 High Quality Workshop System

Industrial enterprises in the hot, arid regions have a large number of equipment, engines, instruments, appliances, measuring devices and auxiliary tools. As with all equipment, maintenance is important to proper operation. Maintenance should be performed periodically on an established frequency and directed toward ensuring that the instruments continue to meet the required accuracy for field measurements. All preventive and corrective maintenance should be performed using components and procedural recommendations at least as stringent as those specified by the instrument manufacturer. If the manufacturer does not provide routine maintenance procedures, a procedure should be written and approved by staff and management in the organization performing the maintenance.

4.4 Qualified Personnel

In accordance with ISO/IEC 17025, all equipment of the technical services inside the portable lab should be operated by authorized and highly qualified personnel. The portable laboratory management should ensure the competence of all who operate specific equipment, perform tests and/or calibrations, evaluate results, and sign test reports and calibration certificates. Staff that is still undergoing training, should have appropriate supervision. Personnel performing specific tasks shall be qualified on the basis of appropriate education, training, experience and/or demonstrated skills, hence the importance.

A qualified team consisting of industrial engineering (field of metrology) and industrial technicians (field of instrumentation) is sufficient for performing all technical and metrological services on-site. They need up-to-date training in appropriate applications such as: uncertainty analysis, methods of measurement, error analysis using statistical methods, maintenance skills, repair and instrument calibration in general. Therefore, the management of the portable laboratory should formulate the goals with respect to the education, training and skills of the laboratory personnel regularly. In addition, the laboratory should have a policy and procedures for identifying training needs and providing training of the new personnel. Training programs should be relevant to the present and anticipated tasks of the laboratory for all metrological features on-site. Up-to-date instructions on the use and maintenance of equipment (including any relevant manuals provided by the manufacturer of the equipment) shall be readily available for use by laboratory personnel as well.

Above all, the laboratory manager should understand the laboratory protocol, ensure it is followed, and should at least annually evaluate the staff competence and the training needs. In smaller operations, the manager may also be in charge of day-to-day operations.

5. Examples of Typical Portable Laboratories

Unlike primary standards, whose most important characteristics are their traceability to physical primary standards resulting in the minimization of absolute uncertainties (with less concern for usability or cost issues) the key criteria for secondary transfer standards are portability, low cost and the ability to calibrate measurement equipment and instruments in the industrial environment. In the specialized published literature many integrated portable measurement facilities have been reported. Most of the relevant facilities needed for the hot, arid regions, such as the Arabian Gulf, are briefly described in the following sections.

5.1 Electrical Measurements Facility

One of the important divisions of the industrial and research sectors is the electrical metrology services (calibration and measurements). This activity usually covers the majority of electrical measurements such as AC & DC voltage, current intensity, electrical resistance, inductance, capacitance, electrical power and energy consumptions. Therefore, it is strongly recommended to support the proposed portable lab with the pertinent instruments to perform these specific measurements.

The goal of the electrical metrology division in this proposal is to provide the world's most technically advanced and fundamentally sound basis for all electrical measurements in the industrial sectors of the hot, arid zones. In addition, it is essential to use the advanced technical preparations and the proper environmental conditions inside the portable lab to enhance the metrological services in these regions.

In addition, the calibration laboratory should maintain documentation, such as: [3]

(1) Laboratory protocol;

(2) Laboratory records (personnel and facilities);

(3) Calibration / testing records and procedures.

Historical records should be maintained to detail any changes or revisions in procedures or protocols. The laboratory protocol describes the laboratory operations, i.e., what the laboratory is expected to do and how it is expected to do it. This documentation should also include the detailed calibration procedures for each instrument routinely calibrated. The laboratory records, on the other hand, are those records that document the activities of the laboratory. In other words, the calibration records are those records that document the maintenance, calibration, and testing of each instrument and source used.

There are many "smart" instruments now available in the field of electrical calibration, and measurements can cover a wide spectrum of the common functions and ranges usually with greater accuracy and efficiency than manual calibrations.

Multi-function calibrators have been designed to source direct and alternating voltage and current and resistance. The new generations of digital calibrators are now used in advanced laboratories to meet the high level of accuracy and precision required. Highly accurate digital multimeters are both high performance and feature rich, yet also remarkably easy to use. These digital multimeters perform the expected functions, including measuring volts, ohms and amps. Basic DC voltage accuracy of up to 0.0024%, 10 A current ranges, and a wide ohms range give an unbeatable combination of measurement capabilities. Hence, these meters are durable and dependable enough to deal with all types of electrical and electronic services in the industrial sectors of these regions.

5.2 Portable Flow Transfer Standards for Flow Metering of Fluids

Flow metrology and flow metering is one of the most important metrology activities in arid countries where the economy is mainly based on the production and exportation of oil and gas. Flow metering devices are used in industrial applications such as natural gas processing, pipeline transport of hydrocarbons mixtures, oils, water and gas produced from wells. The accuracy of flow measurements are of capital importance from a technological and economical standpoint. There is a growing industry trend toward improved flow measurement accuracy and more timely measurements information concerning petrol and gas produced, bought and sold through international transactions. Calibration of flow meters used for custody transfer is crucial.

Instead of removing the flowmeter from service for calibration, flow transfer standards allow users to "bring the calibrator to the flowmeter." A typical portable flow metering facility is shown in Figure 3 . They are intended for inline calibration and validation of meters using the actual process gas or liquid conditions. These portable facilities are extremely useful to calibrate custody transfer meters in far fields metering and piping stations. Information and Communication Technologies ICT can be successfully embedded into these systems to transfer and deliver in-field calibration results online to clients and generate calibration reports for decision makers.

Good flow transfer standards have the capability of measuring and correcting the influences of line pressure and temperature effects on flow especially in hot, arid zones where dramatic temperature gradients can be experienced daily. Automated flow transfer standards utilize advanced calibration software to compile flow data and save information of interest. Users can download reports showing data points for the meter under test and compare that information with output from a master meter. They can also generate calibration data sheets in volumetric or mass units, which can be stored for future reference. This capability enhances calibration management programs by providing a record of traceability to recognized calibration standards.

6. Challenges and Difficulties Facing Portable Laboratories

Many challenges and difficulties may face the portable laboratory approach. One of the big challenges in developing a field-portable laboratory can be the lack of field analysts and specialists. Training or retraining highly qualified people to go out in the field, with the accompanying travel schedule and logistical obstacles, is not easy. Life on the road in arid regions is difficult, especially if that person is used to sitting in a laboratory during working office hours. The choices are either to take a metrologist and teach him to be a field analyst or take a field person and teach him to be a metrologist.

The field analyst must be creative, not in the analytical routine but in the logistics. This person must play the role of a field analyst and the role of Quality Assurance / Quality Control, providing reporting, maintenance, client services and marketing department representative all in one. This person is not only expected to be the entire staff, but is expected to be an integral part of the customer's team. Clients and customers want more than just discrete data points, they want results and more importantly, information that the field analyst is expected to provide them in order to take decisions about a process or an industrial situation; the field analyst should also have the ability to deal with unexpected weather conditions and perform his duties with efficiency.

Another obstacle to the portable approach is the status quo mindset that many companies have that "things have to be the same as they always have been and the only way you can deliver high quality measurement results is if you are bounded between the four walls of a laboratory." The status quo mentality affects regulators, end-users and laboratories.

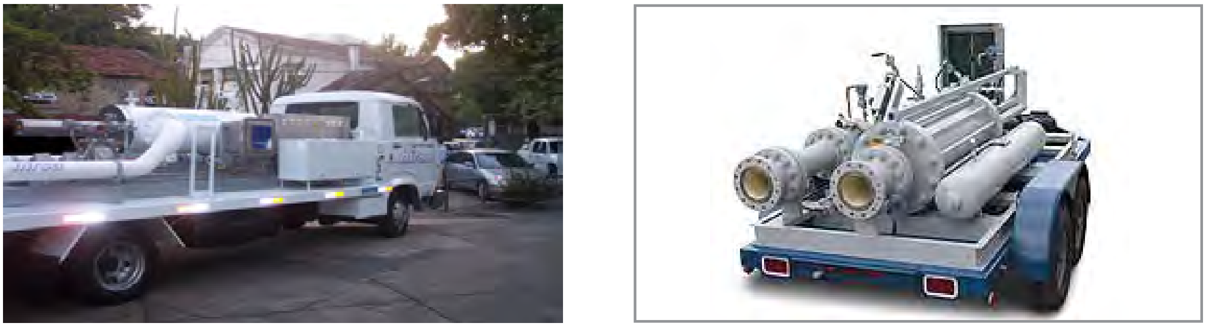

Figure 3. Typical portable flow master meters.

7. Conclusions

The present paper discussed the advantages and challenges of using portable laboratory facilities in hot, arid zones such as the Arabian Gulf region. It has been shown that portable laboratory capabilities are very useful in remote industrial situations where immediate data is required for decision making and on-site calibration reduces turnaround time and expense. Operations in which portable laboratories have a great opportunity to provide field analyses include health and safety, environmental monitoring, industrial hygiene, plants security and integrity, process monitoring, odor investigations, site characterization and remediation, and emergency response situations.

This paper also described typical requirements to establish a portable laboratory, including suggested equipment, technical procedures and training. Two models of the equipment needed for the measurements of electrical quantities and flow metering of fluids were also briefly described.

Acknowledgement: The authors acknowledge the funding of the Saudi Binladen Group for the present research under " Teacher Mohamed BinLaden Research Chair on Quality and Productivity Improvement in he Construction Industry" Initiative (www.uoh.edu.sa/dept/qicrc/).

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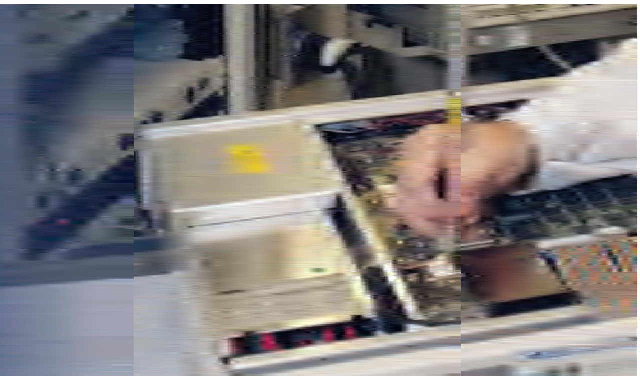

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