# CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

Practical Aspects of High Resistance Measurements

Factors That Affect the Calibration Accuracy of Universal Testing Machines

Pressure-Indicating Film Characterization of Wafer-to-Wafer Bonding

Test Sieve Weaving Uncertainty

2010
JANUARY
FEBRUARY
MARCH

CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

VOLUME 17, NUMBER 1

www.callabmag.com

# FEATURES



# DEPARTMENTS



**ON THE COVER:** Accurate Instrument Repair (AIR), Inc. in Orange County, California: Cylindrical ring gauge calibration using a laser measuring machine in a primary dimensional lab, kept at 68 ±1 °F. As experts in dimensional metrology, AIR uses the latest in precision measurement equipment with primary artifact measurement capabilities in the millionths of an inch. AIR now also offers a wide range of capabilities including force, torque, pressure, temperature, humidity, electonic, on-site and accredited calibration services. Photo courtesy of AIR, Inc.

# CALENDAR

## CONFERENCES 2010

**Mar 22-26 Measurement Science Conference.** Pasadena, CA. Conference and exhibition. Tutorials begin Mar 22, conference begins Mar 24. www.msc-conf.com/msc/index.html.

**Apr 14-16 LAB INDONESIA 2010.** Jakarta, Indonesia. Conference and exhibition. www.lab-asia.com/indonesia.

**Apr 14-16 International Scientific Conference Coordinate Measuring Technique.** Bielsko-Biala, Poland. www.wtp.pl.

**Apr 19-23 Third International Metrology Conference CAFMET 2010**. Cairo, Egypt. African Committee of Metrology / Le Comité Africain de Métrologie (CAFMET), www.ac-metrology.com.

**May 3-6 ESTECH 2010 / IEST 56th Annual Technical Meeting and Exposition. Reno, NV**. Seminars and tutorials in the fields of design, test, and evaluation/product reliability; contamination control; and nanotechnology. www.iest.org

**May 18-20 6th International Competitive Exhibition of Measuring Tools, Testing and Laboratory Equipment Metrology-2010 & 2nd Moscow International Symposium of Metrologists.** Moscow, Russia. www.metrol.expoprom.ru/en.

**May 31 - Jun 4 TEMPMEKO & ISHM. Portoroz, Slovenia.** International Symposium on Humidity and Moisture (ISHM), and the International Symposium on Temperature and Thermal Measurements in Industry and Science. CIPM CCT/WG6 and IMEKO/TC12. www.tempmeko-ishm.org.

**Jun 13-18 27th Conference on Precision Electromagnetic Measurements (CPEM 2010**). Daejeon, Korea. The CPEM is devoted to topics related to the measurement of electromagnetic quantities at the highest accuracy levels. CPEM, Korea Research Institute of Standards and Science (KRISS), secretariat@cpem2010.org, http://cpem2010.kriss.re.kr, cpem2010.pdf

**Jul 11-15 National Conference on Weights and Measures, Inc. (NCWM) Annual Meeting.** St. Paul, MN. www.ncwm.net.

**Jul 12-16 2010 Coordinate Metrology Systems Conference**. Reno, Nevada. www.cmsc.org

**Jul 25-29 NCSL International Conference: 21st Century Innovations in Metrology. Providence, RI.** www.ncsli.org

**Aug 31 - Sep 2 High Resolution X-ray and CT Symposium for High-Resolution Micro- and Nanofocus Computed Tomography. Wunstorf (near Hanover), Germany.** GE Sensing & Inspection Technologies GmbH, tel +49 5031 172-0, fax +49 5031 172-299, phoenix-info@ge.com, www.phoenix-xray.com.

**Sep 13-17 AUTOTESTCON. Orlando, FL**. www.autotestcon.com

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# EDITOR'S DESK

**Amazing Adventures in Metrology (and Physics)**

I have remarked before in this column that when the daily work tasks begin to feel boring (it happens when I'm doing accounting), I take a few moments to look at websites devoted to astronomy, physics or the other sciences and reflect on the exciting projects underway (and of course how important metrology is to those endeavors.) If you don't know where to start, we have a page of science and technology links on our website at www.callabmag.com.

On my latest web journey (www.nist.gov) I found news that NIST and NASA have launched a joint effort to gather enhanced climate data from spaceborne climate observation instruments planned for a group of satellites now under development. The Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission includes a fleet of satellites tentatively scheduled for launch later this decade that will gather data for long-term climate projections. The CLARREO mission will provide an a more accurate climate record of the complete spectrum of energy that Earth reflects and radiates back into space, measurements that should provide a clearer understanding of the climate system.

Meanwhile, from CERN (www.cern.ch), after achieving the world record energy of 1.18 TeV per proton beam last November, the Large Hadron Collider (LHC) took a maintenance break, but the particle beams have started up again as of March 1. It is expected in this next phase that the beams will reach 3.5 TeV per beam. Eventually the hadron beams will reach 7 TeV to allow scientists to study the collision of particles at light speed and better understand the origins of the universe and dark matter, which is causing changes in the universe today. A book has just been published with the collected thoughts and observations of many of the scientists working on the project. *The Large Hadron Collider: A Marvel of Technology*, edited by Lyndon Evans is now available in book stores.

On our own North American shores, the U.S. Department of Energy Fermilab accelerator (www.fnal.gov) located in Batavia, Illinois, has been operating for 10 years now. Fermilab is looking at the same complex questions about matter and the universe as the LHC, and their research has already yielded some very valuable benefits for society along the way. Developments in magnetic resonance imaging first developed for superconducting requirements have been used in medicine as MRIs and PET scans. The technologies of particle physics have provided dramatic advances in cancer treatment. Fermilab physicists and engineers built the nation's first proton accelerator for cancer therapy and shipped it to the Loma Linda University Medical Center, where it has treated some 7,000 patients to date. Relative to x-rays, proton therapy offers important therapeutic benefits, especially for pediatric patients. More than 3,500 patients have received treatment at the Neutron Therapy Facility located at the Fermilab campus.

And on the historic interest side — the Hebrew University of Jerusalem has placed on display for the first time ever, the original manuscripts of Albert Einstein's historic General Theory of Relativity. The manuscript, written in Berlin in 1916, was donated by Albert Einstein to the Hebrew University on the occasion of the University's inauguration in 1925.

Take a moment and cruise the internet and reflect on what we have accomplished and feel proud that metrology is the foundation of it all.

And finally, as you can undoubtedly see, we are suffering from "shrinking page count" syndrome brought on by the bad economy and advertising slowdown. We will try to carry on as best we can, but unfortunately the news and new products sections are suffering. Apologies to the many companies who send us press releases and don't get to see them in print.

As always best regards,

Carol Singer

# CALENDAR

**Oct 5-9 Symposium of the International Confederation of Contamination Control Societies (ICCCS). Tokyo, Japan.** www.soc.nii.ac.jp/jaca/iscc2010/welcome.html

**Oct 18-21 Space Simulation Conference**. Annapolis, MD. Institute of Environmental Sciences and Technology (IEST) and co-sponsored by NASA, AIAA, ASTM, Canadian Space Agency (CSA), and Johns Hopkins University Applied Physics Laboratory (JHUAPL). www.spacesimcon.org.

**Oct 25-28 IEST Fall Conference.** Arlington Heights, IL. Conference and tutorials. www.iest.org

**Oct 31 - Nov 5 25th ASPE Annual Meeting. Atlanta, GA. American Society for Precision Engineering (ASPE),** www.aspe.net.

**Nov 15-18 Eastern Analytical Symposium and Exposition (EAS). Somerset, NJ.** www.eas.org. Deadline for Call for Papers: April 15.

**SEMINARS Online**

**Apr 29 11:00 AM - 12:30 AM (ET) Measurement Uncertainty in Analytical Chemistry**. For registration and conference information: www.cfpa.com. To register, use Priority Code: 520.

**SEMINARS Europe & United Kingdom**

**Jun 9 Measurement Uncertainty Training Course.** Aberdeen, Scotland, UK. TUV NEL Events, tel +44 (0)1355 272858, events@tuvnel.com, www.tuvnel.com/eventarticle.aspx?event_id=217.

**Sep 24-26 Flow Measurement and Calibration: Liquid and Gas.** Munich, Germany. In English language. Held during Munich Oktoberfest. TrigasFI GmbH, tel: +49-8165-64 72 0, info@trigasfi.com, http://www.trigasfi.de/html/en_seminars.htm.

**Sep 27-29 Durchflussmessung und Kalibrierung.** Munich, Germany. In Deutscher Sprache. TrigasFI GmbH, tel: +49-8165-64 72 0, info@trigasfi.com, http://www.trigasfi.de/html/en_seminars.htm.

**SEMINARS USA**

**SEMINARS: Accreditation & ISO/IEC 17025**

**May 24-26 ISO/IEC Standard 17025 Training.** Washington, DC. International Accreditation Service (IAS), alopez@iasonline.org, www.iasonline.org/More/training-Std17025.html.

**May 26-28 Understanding ISO 17025.** Las Vegas, NV. Technology Training, Inc. (TTI), tel 866-884-4338 (866-TTi-4Edu), international 805-845-5050, Training@ttiedu.com, www.ttiedu.com/schedule.html.

**Jul 15-16 Auditing to ISO 17205.** Bloomington, MN. J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/seminars.html.

**Oct 28-29 Auditing to ISO 17205.** Bloomington, MN. J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/seminars.html.

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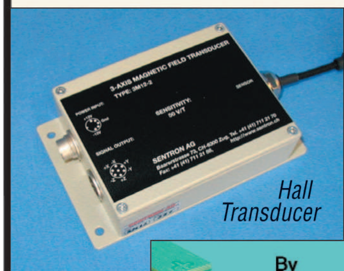
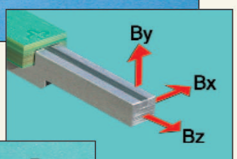
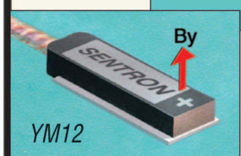
# Measurement & Control

## Magnetic Field

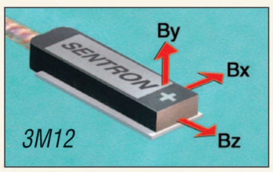

Hall Transducer



3RTP



YM12



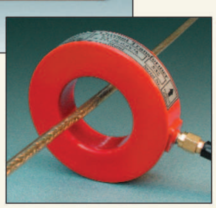
3M12

| Application | Product | Range | Resolution | Bandwidth |
|---|---|---|---|---|
| Linear field sensing. Non-contact measurement of position, angle, vibration, current. Small size, low power. | CSA-1V 1-axis Hall IC, SOIC-8 | ± 5mT | ~ 10µT | dc to 100kHz |
| | 2SA-10 2-axis Hall IC, SOIC-8 | ± 40mT | ~ 50µT | dc to 10kHz |
| High sensitivity and accuracy for low fields. Survey and monitor sites for magnetically sensitive equipment. | MAG-01 1-axis Fluxgate Teslameter | ± 2mT | ± 0.1nT | dc to 10Hz |
| | MAG-03 3-axis Fluxgate Transducer | ± 1mT | ± 0.1nT | dc to 3kHz |
| Linear field measurement. Feedback control. Quality control. Magnet mapping. Unique 3-axis at one point. | YM12 1-axis Hall Transducer | ± 2T | ± 12µT | dc to 5kHz |
| | 3M12 3-axis Hall Transducer | ± 2T | ± 20µT | dc to 1kHz |
| | 3RTP 3-axis Hall Transducer | ± 2T | ± 100µT | dc to 10kHz |
| Hand-held 3-axis for fringe field mapping, quality control, safety monitoring. | 7025 3-axis Hall Teslameter | ± 2T | ± 10µT | dc |
| Precision field measurement and control. Laboratory and process magnets. Analytical instruments. | DTM-133 1-axis Hall Teslameter | ± 3T | ± 5µT | dc to 10Hz |
| | DTM-151 1-axis Hall Teslameter | ± 3T | ± 0.1µT | dc to 3Hz |
| Calibration of magnetic standards and sensors. Very high resolution and long-term stability. | 2026 total field NMR Teslameter | 0.04 to 20T | ± 0.1µT | dc |
| | FW101 total field NMR Teslameter | 1.4µT to 2.1T | ± 0.5nT | dc |
| Precision flux change measurement. | PDI 5025 Digital Voltage Integrator | 40 V.s | ± 2E-8V.s | 1ms to $2^{23}$ms |

Conversion of magnetic flux density (B) tesla to gauss: 0.1nT = 1µG, 100µT = 1G, 1T = 10kG

## Electric Current (isolated measurement)

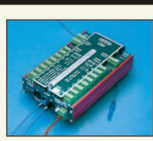
867-400


CT-36

| Application | Product | Range | Resolution | Bandwidth |
|---|---|---|---|---|
| High sensitivity for low currents, currents at high voltage, differential currents. | IPCT Current Transducer | ± 5A | ± 10µA | dc to 4kHz |
| Linear sensor for low-noise, high accuracy, high stability power supplies or amplifiers. | 867-400 Current Transducer | ± 400A | < 4ppm | dc to 100kHz |
| | 866-600 Current Transducer | ± 600A | < 4ppm | dc to 100kHz |
| Instruments for development, quality control, calibration, precision power measurement. | 860R Current Transducer | to ± 2000A | < 5ppm | dc to 300kHz |
| | 862R Current Transducer | to ± 25kA | < 5ppm | dc to 10kHz |
| | 866R 6-channel Current Transducer | to ± 600A | < 10ppm | dc to 100kHz |
| Passive current transformer for rf and pulse current. Low loss, high frequency. | CT Current Transformer | to ± 10kA | to 5V/A into 50 ohm | to 2GHz |
| | ICT Charge Transformer | to ± 400nC | ± 0.5pC | 1µs to <1ps |

## Fiber-Optic I/O


FTR


CNA

| Application | Product | Range | Resolution | Bandwidth |
|---|---|---|---|---|
| Input/Output modules that can be placed locally at the transducer or controlled unit. For high voltage, high noise environments. RF signal transmission. | FTR RS-232-C link | | | 50 to 40 kB |
| | CNA Digital & Analog link | ± 100mV to ± 10V | 16-bit | dc to 30Hz |
| | p2p Digital & Analog link | - 20dBm to + 20dBm | < 25dB for 0dBm | dc to 3GHz |

# CALENDAR

**SEMINARS: Analytical Chemistry**

**Apr 29 Measurement Uncertainty in Analytical Chemistry**. Online Course. Stranaska LLC, www.stranaska.com.

**Nov 15 Metrology in the Analytical Laboratory. Somerset, NJ**. Stranaska LLC, www.stranaska.com. www.eas.org.

**SEMINARS: Certified Calibration Technician Exam**

**CCT Self-Study Course. Online Course**. J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/selfstudy.html.

**Apr 19-23 CCT-501 Metrology for Cal Lab Personnel (CCT Prep).** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**May 10 Calculator Refresher for Certification Exams.** Bloomington, MN. J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/seminars.html.

**May 11-13 Certified Calibration Technician Preparation.** Bloomington, MN. J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/seminars.html.

**May 11-13 Certified Calibration Technician (CCT) Review.** Minneapolis, MN. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 19-21 Certified Calibration Technician (CCT) Review.** Schaumburg, IL. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Sep 13-17 CCT-501 Metrology for Cal Lab Personnel (CCT Prep).** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**SEMINARS: Dimensional and Gage Calibration**

**Precision Dimensional Measurement. Online Course.** The QC Group (formerly QC Inspection Services, Inc.), tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/online/.

**May 4-5 Calibration Training and Hands-On Gage Repair. Houston, TX.** IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**May 4-5 Dimensional Metrology. Westford, MA**. Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**May 4-6 Coordinate Measuring Machine, CMM Training. Minneapolis, MN.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

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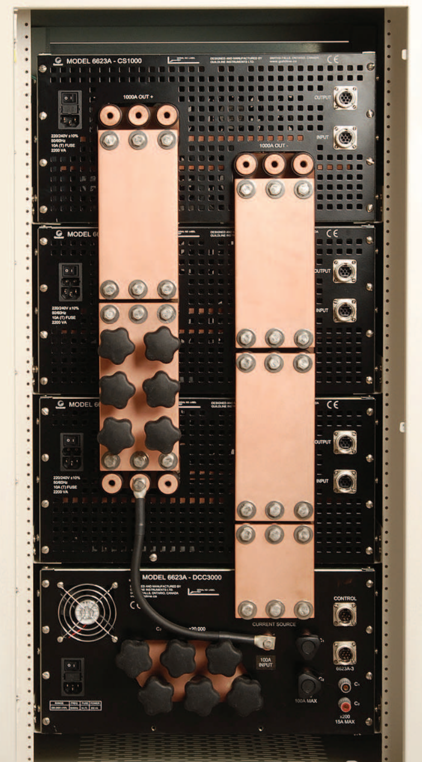



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# CALENDAR

**May 6 GD&T Management Overview. Milwaukee, WI.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 6-7 Calibration Training and Hands-On Gage Repair. Dallas, TX.** IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**May 6-7 Gage Calibration Systems & Methods. Westford, MA.** Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**May 6-7 GD&T Training - Fundamentals. Milwaukee, WI.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 10-11 GD&T Training - Fundamentals. Dayton, OH.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 11-12 Dimensional Calibration Procedures. Las Vegas, NV.** Technology Training, Inc. (TTI), tel 866-884-4338 (866-TTi-4Edu), international 805-845-5050, Training@ttiedu.com, www.ttiedu.com/schedule.html.

**May 13-14 Basic Dimensional Measurement Tools and Methods. Livonia, MI.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 11-14 Integrated GD&T. Westford, MA.** Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**May 12-14 GD&T Training - Advanced Concepts. Dayton, OH.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 18-19 Calibration Training and Hands-On Gage Repair. Cleveland, OH.** IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

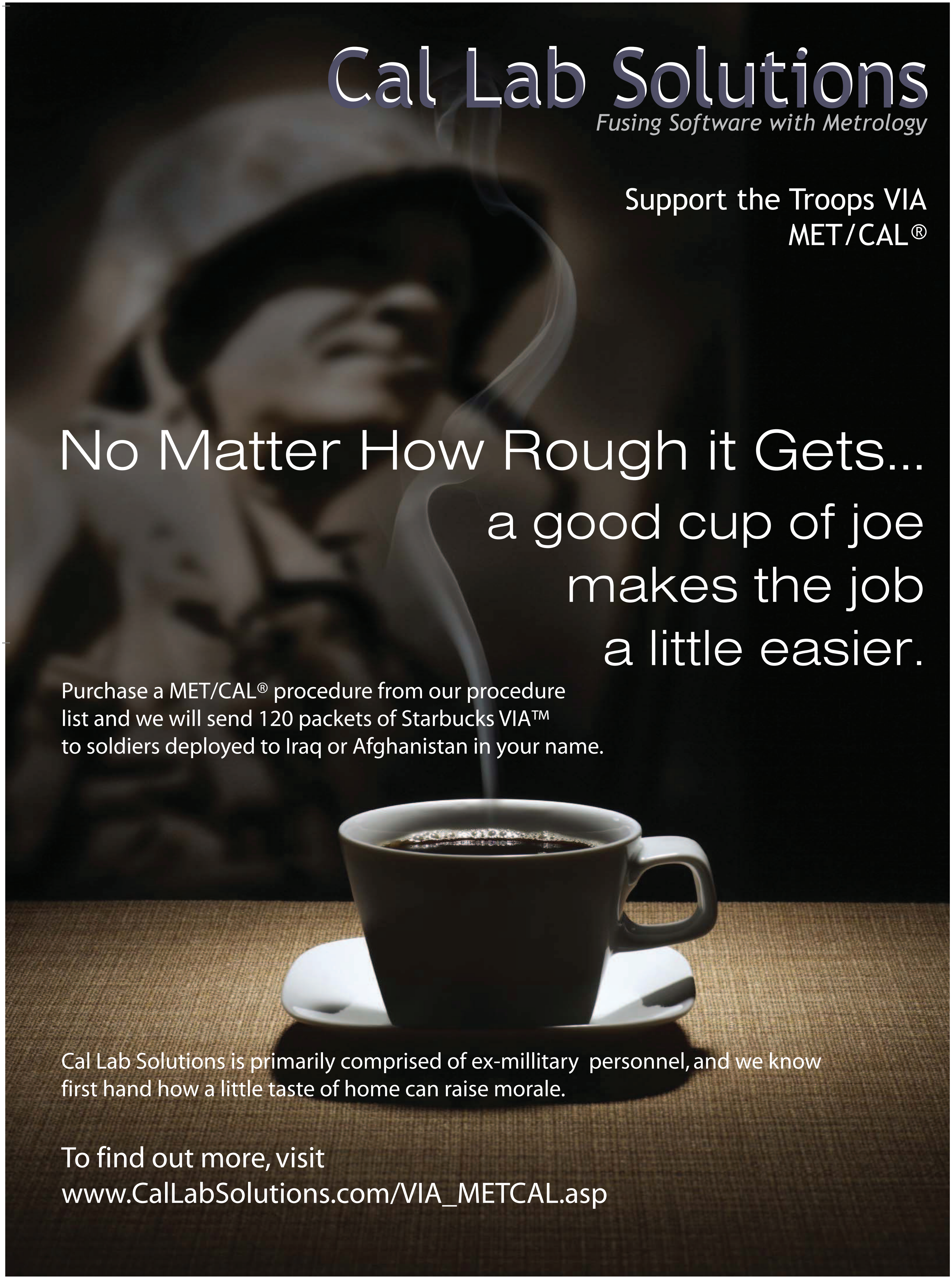
**May 18-19 Dimensional Metrology. Huntersville, NC.** Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**May 20-21 Basic Dimensional Measurement Tools and Methods. Atlanta, GA.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 20-21 Calibration Training and Hands-On Gage Repair.** Schaumburg, IL. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**May 25 GD&T Management Overview.** Livonia, MI. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**May 25-26 GD&T Training - Fundamentals.** Livonia, MI. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.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# CALENDAR

**May 25-28 Integrated GD&T.** Huntersville, NC. Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**Jun 3 GD&T Management Overview.** Atlanta, GA. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 3-4 GD&T Training - Fundamentals.** Atlanta, GA. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 7-8 Calibration Training and Hands-On Gage Repair.** Spokane, WA. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jun 7-8 GD&T Training - Fundamentals.** Rolling Meadows, IL. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 8-9 Dimensional Metrology.** Aurora, IL. Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**Jun 9-11 Geometric Dimensioning & Tolerancing.** Las Vegas, NV. Technology Training, Inc. (TTI), tel 866-884-4338 (866-TTi-4Edu), international 805-845-5050, Training@ttiedu.com, www.ttiedu.com/schedule.html.

**Jun 9-11 GD&T Training - Advanced Concepts.** Rolling Meadows, IL. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 10-11 Calibration Training and Hands-On Gage Repair.** Portland, OR. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jun 10-11 Gage Calibration Systems & Methods.** Aurora, IL. Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**Jun 10-11 Basic Dimensional Measurement Tools and Methods.** Harrisburg, PA. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 14-15 Calibration Training and Hands-On Gage Repair.** Vacaville, CA. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jun 14-16 Basic Dimensional Metrology. Bloomington, MN.** J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/seminars.html.

**Jun 15-17 Hands-On Dimensional Gage Calibration.** Elk Grove Village, IL. Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**Jun 15-18 Integrated GD&T.** Aurora, IL. Mitutoyo Institute of Metrology, tel 888-648-8869, mim@mitutoyo.com, www.mitutoyo.com

**Jun 16-17 Calibration Training and Hands-On Gage Repair.** San Jose, CA. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jun 17-18 Basic Dimensional Measurement Tools and Methods.** Schaumburg, IL. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 22 GD&T Management Overview.** Harrisburg, PA. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 22-23 GD&T Training - Fundamentals.** Harrisburg, PA. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jun 29-30 Calibration Training and Hands-On Gage Repair.** St Louis, MO. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jul 29-30 GD&T Training - Fundamentals.** Minneapolis, MN.The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jul 12-13 Calibration Training and Hands-On Gage Repair.** Blaine, MN. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jul 13-14 Basic Dimensional Measurement Tools and Methods.** Minneapolis, MN. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jul 13-15 Coordinate Measuring Machine, CMM Training.** Minneapolis, MN. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jul 15-16 Calibration Training and Hands-On Gage Repair.** Bloomington, MN. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jul 20-21 Calibration Training and Hands-On Gage Repair.** Detroit, MI. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jul 22-23 Calibration Training and Hands-On Gage Repair.** Toledo, OH. IICT Training & Productions, info@consultinginstitute.net, http://consultinginstitute.net/.

**Jul 22-23 Basic Dimensional Measurement Tools and Methods.** Orange County, CA. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Jul 29 GD&T Management Overview.** Minneapolis, MN. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

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**May 13-14 Electrical Instrumentation Calibration Procedures.** Las Vegas, NV. Technology Training, Inc. (TTI), tel 866-884-4338 (866-TTi-4Edu), international 805-845-5050, Training@ttiedu.com, www.ttiedu.com/schedule.html.

**FDA / ISO 13485 / QSR**

**Contact for Schedule**. FDA Calibration Requirements for QSR and CGMP WorkPlace Training, tel 952-471-8554, www.wptraining.com. Download more information.

**SEMINARS: Flow**

**Apr 27-29 The Americas Workshop. Houston, TX.** TUV NEL Ltd., tel +44 1355 272858, events@tuvnel.com, www.tuvnel.com/content/Training.aspx.

**Sep 27-30 Gas Flow Calibration Using molbloc/molbox.** Phoenix, AZ. Fluke - DH Instruments, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Nov 15-18 Gas Flow Calibration Using molbloc/molbox.** Phoenix, AZ. Fluke - DH Instruments, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**SEMINARS: General Metrology, Calibration Training & Laboratory Management**

**May 3-6 CLM-301 Cal Lab Management for the 21st Century.** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

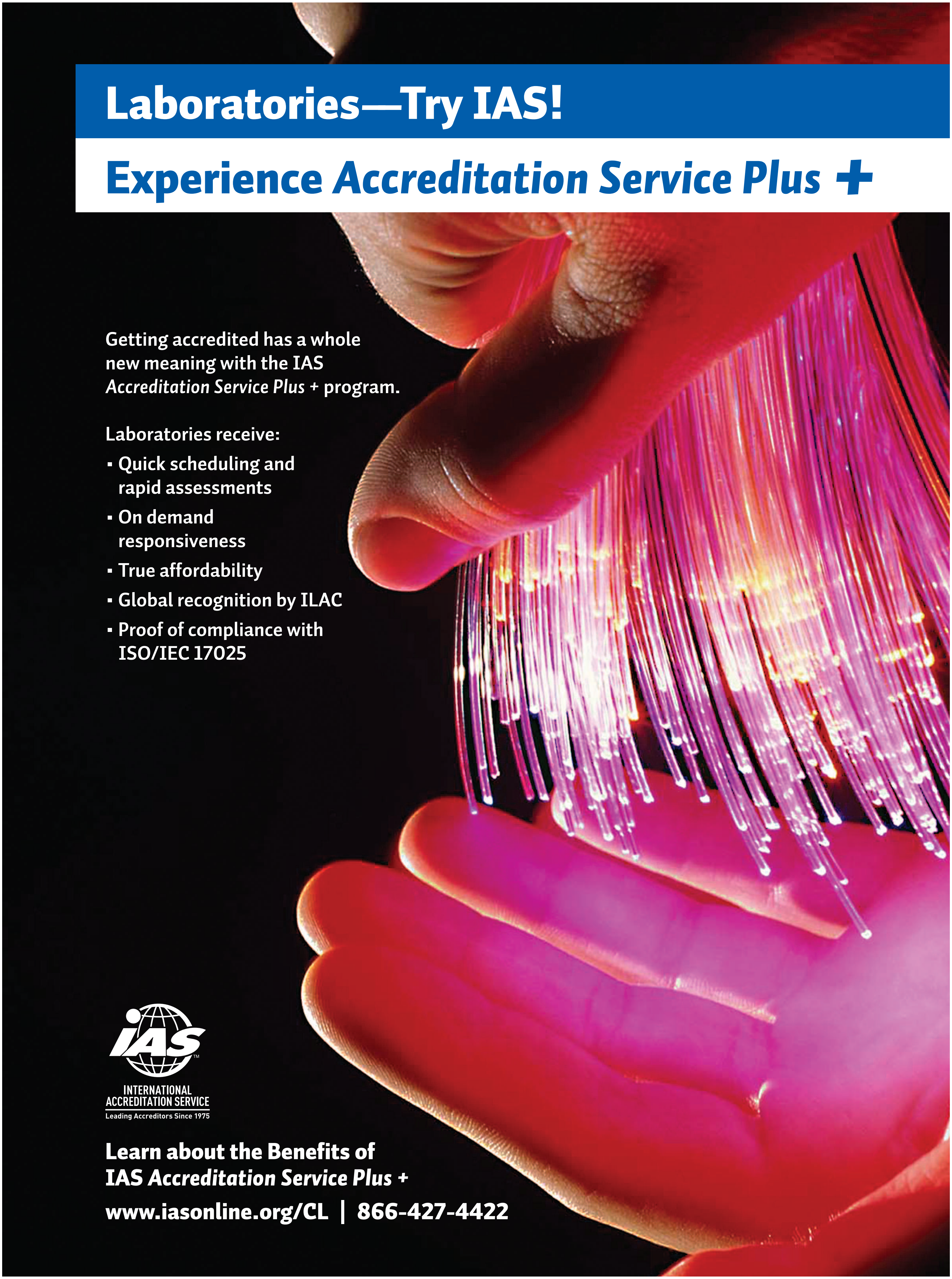
**May 24-25 Calibration Laboratory Operations.** Las Vegas, NV. Technology Training, Inc. (TTI), tel 866-884-4338 (866-TTi-4Edu), international 805-845-5050, Training@ttiedu.com, www.ttiedu.com/schedule.html.

**Jun 28 - Jul 1 MET-101 Basic Hands-On Metrology.** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Aug 9-12 MET-301 Advanced Hands-On Metrology.** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Aug 9 Measurement & Calibration Overview.** Bloomington, MN. J&G Technology, tel 952-935-1108, gmeyer@jg-technology.com, www.jg-technology.com/seminars.html.

**Aug 17-19 MET-302 Hands-On Metrology Statistics.** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.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**Apr 27-28 Estimating Measurement Uncertainty.** Plymouth, MI. Mitutoyo Institute of Metrology, tel 888-648-8869,mim@mitutoyo.com, www.mitutoyo.com

**May 18-20 Measurement Uncertainty Workshop.** Fenton, MI. Presented by QUAMETEC Institute, tel 810-225-8588, www.QIMTonline.com.

**Jul 13-15 Measurement Uncertainty Workshop.** Fenton, MI. Presented by QUAMETEC Institute, tel 810-225-8588, www.QIMTonline.com.

**Aug 5 Measurement Uncertainty Overview.** Minneapolis, MN. The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**Aug 5-6 Measurement Uncertainty Budgets. Minneapolis, MN.** The QC Group, tel 800-959-0632, Training@theQCgroup.com, www.theqcgroup.com/courselist/.

**SEMINARS: Pipette Proficiency & Quality Management**

**May 13-14 Pipette Quality Management Certification.** Westbrook, ME. ARTEL, tel 888-406-3463, tel 207-854-0860, info@artel-usa.com, www.artel-usa.com/news/training.aspx.

**Sep 23-24 Pipette Quality Management Certification.** Westbrook, ME. ARTEL, tel 888-406-3463, tel 207-854-0860, info@artel-usa.com, www.artel-usa.com/news/training.aspx.

**SEMINARS: Pressure**

**May 17-21 Precision Pressure Calibration.** Phoenix, AZ. Fluke - DH Instruments, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Sep 13-17 Precision Pressure Calibration.** Phoenix, AZ. Fluke - DH Instruments, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Dec 6-10 Precision Pressure Calibration.** Phoenix, AZ. Fluke - DH Instruments, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

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### SEMINARS: Software

**Jun 7-10 MET/CAL Database and Reports.** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Jun 14-17 MET/CAL Procedure Writing.** Seattle, WA. Fluke, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

### SEMINARS: Temperature

**Jun 14-15 Principles of Temperature Metrology.** American Fork, UT. Fluke - Hart Scientific, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Jun 16-17 Product Training.** American Fork, UT. Fluke - Hart Scientific, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Aug 2-3 Principles of Temperature Metrology.** American Fork, UT. Fluke - Hart Scientific, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

**Aug 4-5 Advanced Topics in Temperature Metrology.** American Fork, UT. Fluke - Hart Scientific, tel 888-79-FLUKE, www.fluke.com/2010caltraining.

### SEMINARS: Time and Frequency

**May 24-25 GPS: Global Positioning Systems.** Las Vegas, NV. Technology Training, Inc. (TTI), tel 866-884-4338 (866-TTi-4Edu), international 805-845-5050, Training@ttiedu.com, www.ttiedu.com/schedule.html.

### SEMINARS: Vibration / Shock

**Jun 8-11 35th Annual NIST Time and Frequency Metrology Seminar.** Boulder, CO. The Time and Frequency Division of the National Institute of Standards and Technology, http://nistboulder.net/Sem35agenda.htm.

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**NIST Awards $123 Million in Research Development Grants**

The U.S. Commerce Department's National Institute of Standards and Technology (NIST) in January awarded more than $123 million in American Recovery and Reinvestment Act grants to support the construction of new scientific research facilities at 11 universities and one non-profit research organization. With the ultimate research targets ranging from off-shore wind power and coral reef ecology to quantum physics and nanotechnology, the 12 projects will launch more than $250 million in new laboratory construction projects beginning early this year.

The 12 construction project awards, the result of a competition announced by NIST last May, include:

• $15 million to the University of Pittsburgh (Pittsburgh, Pa.) for new laboratories for nanoscience and experimental physics,

• $15 million to Nova Southeastern University Inc. (Fort Lauderdale-Davis, Fla.) for a Center of Excellence for Coral Reef Ecosystem Science research facility,

• $12.4 million to the University of Maine (Orono, Me.) for an Advanced Nanocomposites in Renewable Energy Laboratory,

• $12.3 million to the University of Kansas Center for Research (Lawrence, Kan.) for the new Measurement, Materials and Sustainable Environment Center (M2SEC),

• $11.8 million to the University of Kentucky (Lexington, Ky.) for an expansion of the Center for Applied Energy Research Laboratory,

• $11.8 million to Purdue University (West Lafayette, Ind.) for a Center for High Performance Buildings at the Ray W. Herrick Laboratories,

• $11.6 million to the Georgia Tech Research Corporation (Atlanta, Ga.) for a pilot-scale laboratory for carbon-neutral energy solutions,

• $10.3 million to the University of Maryland (College Park, Md.) for a laboratory for advanced quantum science in the school's new Physical Sciences Complex,

• $8.1 million to the Woods Hole Oceanographic Institution (Barnstable, Mass.) for the Laboratory for Ocean Sensors and Observing Systems (LOSOS),

• $6.9 million to the University of Nebraska – Lincoln (Lincoln, Neb.) for a nanoscience metrology facility,

• $6.9 million to Georgetown University (Washington, D.C.) for The Institute for Soft Matter Synthesis and Metrology, and

• $1.4 million to Columbia University (New York, N.Y.) for an ultraclean geochemistry laboratory at Lamont-Doherty Earth Observatory.

In addition to satisfying the core objectives of the Recovery Act—creating and saving jobs and investment in infrastructure that will provide long-term economic benefits—the projects were chosen on the basis of the scientific and technical merit of the proposals, the need for federal funding, design quality and suitability for the intended purpose, and the strength of the project-management plan.

The new facilities also support research goals of the Commerce Department, NIST and the National Oceanic and Atmospheric Administration (NOAA), including the study of advanced materials, coral reefs, hurricanes, quantum physics, nanoscience and metrology. — *NIST Public Affairs*

### NIST Announces Aluminum Atom Clock

Physicists at the National Institute of Standards and Technology (NIST) have built an enhanced version of an experimental atomic clock based on a single aluminum atom that is now the world's most precise clock, more than twice as precise as the previous pacesetter based on a mercury atom.

In addition to demonstrating that aluminum is now a better timekeeper than mercury, the latest results confirm that optical clocks are widening their lead—in some respects—over the NIST-F1 cesium fountain clock, the U.S. civilian time standard, which currently keeps time to within 1 second in about 100 million years. The new clock keeps time to 1 second in 3.7 billion years.

The aluminum clock is based on a single aluminum ion (electrically charged atom) trapped by electric fields and vibrating at ultraviolet light frequencies, which are 100,000 times higher than microwave frequencies used in NIST-F1 and other similar time standards around the world. Optical clocks divide time into smaller units, and could someday lead to time standards more than 100 times as accurate as today's microwave standards. Higher frequency is one of a variety of factors that enables improved precision and accuracy.

Aluminum is one contender for a future time standard to be selected by the international community. NIST scientists are working on five different types of experimental optical clocks, each based on different atoms and offering its own advantages. — *NIST Public Affairs*

# Practical Aspects of High Resistance Measurements

Ing. Roman Honig
CEO
Measurements International, Europe

We can observe an increased interest in high resistance measurements in the range of MΩ to TΩ. This may be related to recent inter-laboratory comparisons in this area, or to increasing activities in HiPot testing and insulation resistance measurements in industry, which of course requires availability of appropriate calibrated high resistance standards. As there are many metrologists with experience in the low resistance measurements (up to about 100k Ohm) who are now facing the need to extend their range of measurements to higher values, we offer some information that hopefully shall help to make it easier.

***Terminology***

***Isolation resistance*** *– resistance between two points at a measurement circuit – e.g. two conductors at cable, or two terminals. It is the result of a finite value of the resistance of the material which the terminals are mounted on.*

***Leakage resistance*** *– resistance between a particular place of the measurement circuit and ground terminal, respectively the point connected to zero potential.*

***GUARD source*** *– additional active (regulated) or passive (non-regulated) voltage source of VG, used for elimination of influence of insulation or leakage resistances*

***Guard of the resistance standard*** *– additional screening or similar part of the construction of the resistance standard, which is intended to be connected to the guard source* VG

## High Resistance Measurement

There are various methods of high resistance measurement. The most frequently used are either a terraohmmeter for direct reading of the resistance, dual source bridge (DSB) or binary voltage divider (BVD) using the potentiometric method. Regardless of the method used, the high resistance measurement deals with a number of additional effects that have to be taken into account as compared to low resistance measurements. These are namely insulation resistances and leakage effects (although, in the TΩ range these can still influence the measurement if proper care is not taken), but also voltage coefficients of the resistance standards (which may be determined using different voltages for measurement) and the cleanness of connectors, etc.

Although manufacturers of high resistance standards use construction and materials which help limit the insulation and leakage resistance effects, is not possible to eliminate them completely. Therefore, it is necessary to take appropriate care when designing the measurement circuit for high resistance measurements in such a way that allows elimination of these effects as much as possible.

One of the common methods of eliminating leakage effects is through use of a "guard" connection which means that the point where the current leakage may flow is connected to the same potential as the measurement point, so that the leakage current is then minimized or eliminated (as the current flows only when there is a difference in potential).

The following paragraphs discuss in more detail ways to eliminate the effects of insulation or leakage resistances when using a bridge for high resistance measurements based on the binary voltage divider, designed according the Cutkosky principle. Although this particular measurement method is discussed, the solutions or hints shown here are applicable to other methods too and the aim of the article is to show where the problems originate and what one has to take into account in order to achieve good and unbiased results.

To conduct a resistance measurement, two resistors (a known standard and unknown DUT) are connected in series and supplied from the same voltage

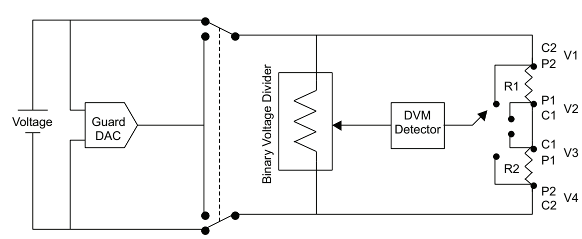


Figure 1. Principle of measurement with binary voltage divider.

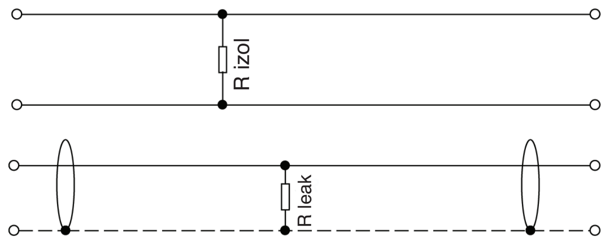


Figure 2. Unshielded two-wire cable (or shielded single wire cable).

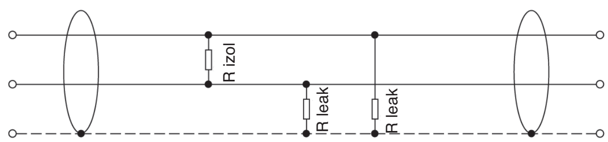


Figure 3. Shielded two wire cable.

source (Figure 1). The voltage is divided at the ratio of the resistors and the individual voltages V1, V2, V3 and V4 at points P2(R1), P1(R1), P1(R2) and P2(R2) are measured by the compensation method, where the measured voltage is balanced with the voltage from the BVD and the DVM acts only as the null detector (high resolution DVM is typically used).

Specific measurement design helps to cancel the influence of the input current of the DVM. The current passing through both resistors is the same, which means that the higher power is dissipated at the resistor with the higher value. The source voltage is considered to be constant during the measurement. The unknown resistance is calculated from the measured voltage ratios and known value of the standard resistor.

Resistors are connected to the bridge using four-terminal connections. If the resistors being measured are two-terminal, the appropriate pairs of terminals at the bridge (P1, C1 and also P2, C2) must be connected together. The bridge construction allows easy and automated switching of the resistor's position at the divider (called a resistance interchange); shown in Figure 13. The voltages measured at points V2 and V3 are sensitive to any leakage caused by the finite insulation of resistors against the ground or common point of the measurement circuit. These leakages are minimized using an isolated guard source that follows the voltage being measured and keeps the guard circuit at the same potential. The resulting leakage current is then practically zero.

The following paragraphs discuss the potential measurement setups and considerations when designing a measurement circuit for high resistance measurements.

## Analysis of Leakage and Insulation Resistances for Various Constructions of Cables and Resistors

### Unshielded Single-Wire Cable

One simple method of resistance measurement uses an unshielded (usually isolated) single wire connection only. Here the insulation properties of the surrounding environment (usually the air) are most important. This connection is acceptable, providing that the configuration of the equipment allows it. Nevertheless, whenever this wire comes in contact with anything (other wires; metal or isolated parts of standards or equipment, or anything else), the mutual resistance of the wire insulation and the touched part starts to play a role. The values are usually changing and hard to define; therefore elimination of their influence is very difficult.

### Unshielded Two-Wire Cable (or Shielded Single-Wire Cable)

The insulation resistance between individual wires or leakage resistance between an inner wire and a shield applies, depending on the insulation material (Figure 2). Use of a shielded wire brings the advantage of elimination of the outside RF noise (e.g. from mobile communication sources), but more importantly, the elimination of leakage current from the inner wire using a guard method sets the potential of the shield to the same level as the potential of the inner wire. This makes the insulation properties of the cable less important; therefore it is possible to use regular, easily available coaxial cables. The same applies to coaxial connectors since they are often used in the construction of precision high resistance standards.

### Shielded Two-Wire Cable

The insulation resistance between individual conductors and the leakage resistance between individual wires and the shield applies, depending on the insulation material and cable construction (Figure 3). If the inner wires are used to connect the two-terminal high resistance standard to the bridge, the combination of all leakage and insulation resistances are connected in parallel to it.

Connection of the screen to the same potential as one of the wires will make the problem smaller, but cannot eliminate it – the measurement result will be affected by systematic error at any case. At the other side, this cable can be used for connection of one pair of terminals (e.g. P1 and C1) in the case of four-terminal resistance standards.

In this case the insulation resistance between wires does not play a role, as they are practically shorted inside of the resistor. Leakage to the shield may be eliminated the same way like at case of the single wire shielded cable.

### Unshielded Four-Wire Cable

The insulation resistance between individual conductors depends on the insulation material and cable construction.

Use of such cable for connection of high resistance standards with four-terminal construction means that the combination of the insulation resistances will be connected again in parallel with the standard and the result will be affected by systematic error. This type of cable is not suitable for high resistance measurements connections. In contrast, they offer very good properties when used for low resistance measurements. It is also one of the most frequent errors encountered when people with experience in low resistance measurements start to do high resistance measurement.

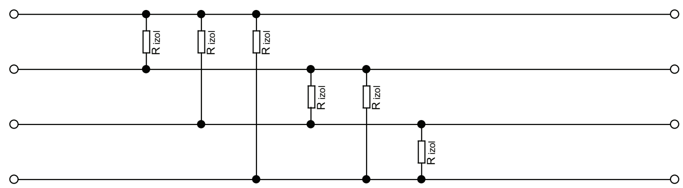


Figure 4. Unshielded four wire cable.

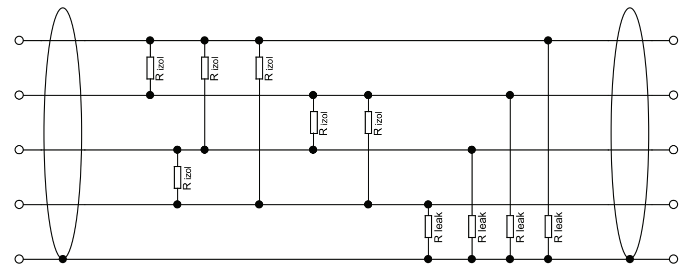


Figure 5. Shielded four wire cable.

**Shielded Four-Wire Cable**

The insulation resistance between individual conductors and leakage resistance between individual conductors and shield applies, depending on the insulation material and cable construction (Figure 5). The same reasons as in the previous case make this type of cable unsuitable for high resistance measurements.

The only exception would be the use of this type of cable for connection of one side of the two resistors with four-wire construction to the BVD bridge – one cable would be used for connection of terminals C1(R1), P1(R1), C1(R2) and P1(R2), while the other will connect to terminals C2(R1), P2(R1), C2(R2) a P2(R2) (see Figure 13 for illustration).

The leakages between wires and shields can be eliminated the same way as single-wire shielded cables. Nevertheless, such a connection requires higher care for connection to individual terminals (do not mix them together) and often represents other difficulties (e.g. very short unshielded parts of cables, making connection of the resistors difficult).

**Two-Terminal Unshielded Resistance Standard**

Only the insulation between terminals applies, if mounted on some insulation material. It then appears to be an integral part of the measured resistor value.

**Two-Terminal Resistance Standard in Metal Shield (e.g. GL 65206)**

The leakage resistance between terminals and the metal shield (Figure 6) are practically connected in parallel to the standard. This may not cause a problem when the terraohmmeter is used for its measurement, but when used with the BVD bridge, the only way to eliminate it is to connect the shield to the guard source, thus maintaining the shield at the same potential as the potential of the point where the voltage is being measured. Any other connection (grounding the shield, or leaving it not connected) will result in measurement errors.

**Four-Terminal Unshielded Resistance Standard (e.g. Tinsley 5685A)**

Insulation resistance among individual terminal pairs (C1, P1 and C2, P2) applies, which will appear as an integral part of the measured resistance value. The possible effect of leakage between the insulation of the terminal board and the metal box of the resistance standard can usually be considered negligible (depending on material used and its cleanness). This additional leakage may apply when the metal container is grounded (e.g. by touching the metal parts of the oil bath). Connecting the container to the guard source would help to eliminate this leakage.

**Four-Terminal Resistance Standard With Metal Shield (e.g. MIL 9331)**

In some resistor construction, insulation resistance between the metal shield and the resistance element occurs, e.g. when the resistance elements are glued to the metal shield. (Figure 7) The situation is therefore practically identical to the previous case except that the most important factor is the insulation of the terminals and the metal shield.

**Two-Terminal Resistance Standard With Metal Shield and Unsplit Additional Guard (e.g. older MIL 9331S)**

This is an old construction of MIL high resistance standards. The insulation resistance of terminals against the additional guard applies and also insulation resistance of terminals against the shield – the outside screen of the BPO terminals is connected with the metal shield (Figure 8). Effects of the insulation resistance against the inner guard are possible; eliminate using the guarding method described earlier. Nevertheless, the insulation resistance of the BPO connectors against the metal shield cannot be eliminated during measurement on the BVD bridge, unless the guard voltage is connected to the outside metal box of the standard too, which of course cannot be grounded at the same time.

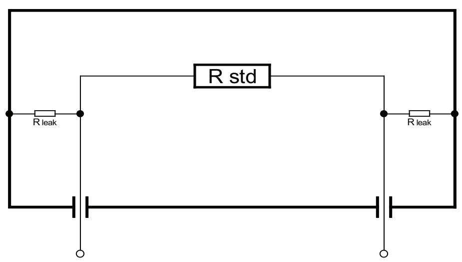


Figure 6. Leakage model of two terminal resistance standard type GL 65206.

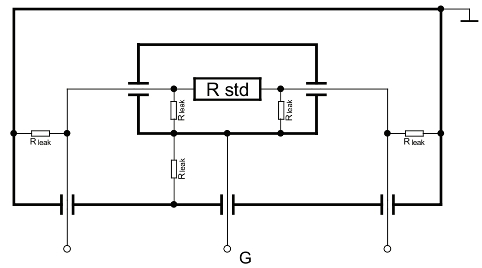


Figure 8. Leakage model of the Two terminal resistance standard type MIL 9331S.

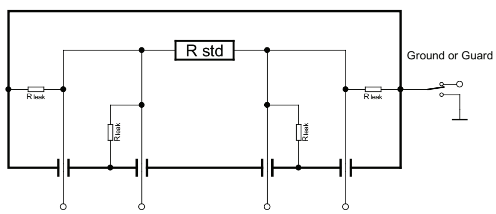


Figure 7. Leakage model of the four terminal resistance standard type MIL 9331.

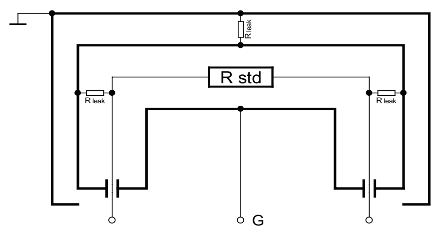


Figure 9. Leakage model of two terminal resistance standard at dual metal shield, e.g. type P4013.

**Two-Terminal Resistance Standard With Dual Metal Shield – Inner Shield Acts As Guard and Holds the Resistance Terminals (e.g. P4013)**

The insulation resistance of terminals against the inner shield applies, as well as the leakage between the inner and outside shield (Figure 9). This construction seems to be very well suited for measurement using the BVD bridge. Leakage between inner guard and terminals is possible. To eliminate use guarding as described above. Outside shield can be grounded and serves as electrical shielding.

**Two-Terminal Resistance Standard With Metal Shield and Additional Split Guard (e.g. MIL 9331G)**

The construction of this type of standard follows the NIST design. The outside part of the N connector is connected with the appropriate part of the inner split guard and is isolated from the shield of the resistance standard (Figure 10). Each part of the inner guard can be connected to a different potential, this improves the elimination of insulation and leakage effects and makes the connection to the BVD bridge easier.

Nevertheless the split guard may need to be interconnected when using other measurement methods like the terraohmmeter, or bridges with passive guard sources. In this case the additional guard terminals represent an advantage and the passive resistive divider can be used to create an appropriate ratio of guard voltages. The leakage resistance between guard and shield is maintained high due to the appropriate construction and materials used. Older units do not have additional guard terminals, which were added in response to customers' comments and as to address some specific applications.

**Two-Terminal Resistance Standard With Metal Shield, Additional Split Guard and Auxiliary Resistance Between Guard Parts (e.g. Ω-Labs)**

The outside part of the BPO connector is connected with an appropriate part of the inner split guard and is isolated from the shield of the resistance standard. The guard parts are connected using an auxiliary resistor of high value (Raux = 100 MΩ) (Figure 11). Insulation resistance occurs between the terminals and guard and at the connectors. The leakage resistance between the guard and shield is kept high through construction. Use of this type of standard is very similar to the previous case. An additional auxiliary resistor eliminates the need for connection guard parts in some applications, and can be also used as part of passive divider in case of the measurement with passive guard source, but only when the resistors of the same value are measured (ratio 1:1).

In addition to the above mentioned common construction of the high resistance standards, there are also standards using a three-terminal configuration, containing a so-called "T" cell, consisting of the two resistors in series and a third connecting their common point and ground (e.g. model GL9337 or older standards from Russia series P4085). These standards actually simulate high resistance values and are usable only with some measurement methods (e.g. with terraohmmeter). Direct measurement of these standards using the BVD Bridge is not possible. It is of course possible to measure the individual resistances of the three resistors inside, or measure series combination of pairs between each pair of terminals and calculate the simulated value of the standard and appropriate uncertainty of such indirectly measured value. However, a detailed description of such calibration procedure is not the subject of this text.

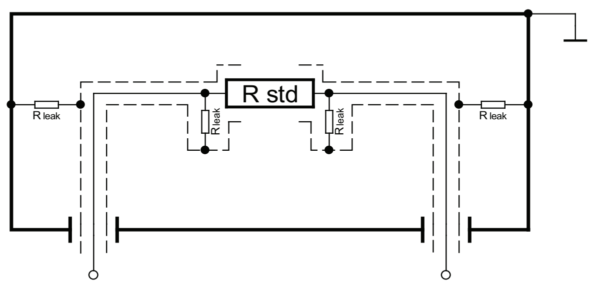


Figure 10. Leakage model of two terminal resistance standard at metal shield with additional split guard, e.g. type MIL 9331G.

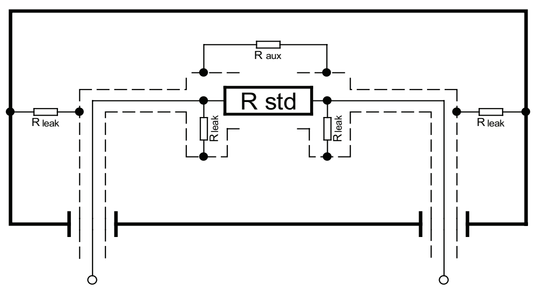


Figure 11. Leakage model of two terminal resistance standard at metal shield with additional split guard and auxiliary resistance between guard parts, e.g. Ω-Labs type.

## Theoretical Calculation of Possible Errors Caused by Leakage

The excellent theoretical analysis of possible errors caused by leakages and their elimination using an active guard source made Tore Sørsdal from the Norwegian National Lab Justervesenet in his article "Current leakage error in calibration when doing potentiometric ratio measurement on two series connected resistors."

The result of his analysis is demonstrated in the simplified schematics shown in Figure 12.

The formulas that apply are:

$$dV_G = V_G - V_S$$

$$I_x - I_S + I_L = 0$$

$$V_E - I_x \cdot R_x = V_S$$

$$I_L \cdot R_L = dV_G$$

$$I_S \cdot R_S = V_S$$

The resulting formula for relative error of measurement of $R_x$ caused by leakage resistance $R_L$ as result of the difference of $V_S$ and $V_G$, which Tore Sørsdal derived is:

$$E_{RxL} = -\frac{dV_G}{V_E} \cdot \frac{R_x + R_S}{R_L + R_x \cdot dV_G / V_E}$$

## Typical Connection to a High Resistance BVD Bridge (Resistors With Split Guard)

A typical connection scheme for two resistors with a split guard is shown in Figure 13. When considering leakage and insulation effects, the following conclusions can be made:

— Terminals P2(R1) and P2(R2) are connected to the H and L terminals of the source, and therefore any leakage or insulation effects at these points are negligible – the low internal impedance of the source will cause the leakage currents, but will not cause any change of the source voltage and therefore will not affect the result of measurements. This means that the shields of cables connected here and appropriate parts of the inner guard of the resistors can be grounded to the ground terminal of the BVD Bridge.

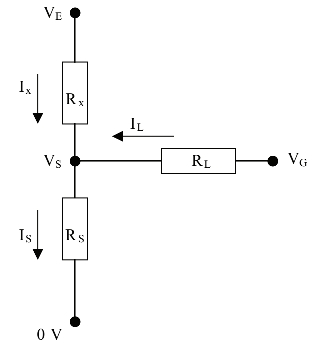


Figure 12. Schematics for calculation of leakage effects on a resistive divider.

On the other side, the terminals P1(R1) and P1(R2) are at high impedance created by measured resistors and therefore any leakage current here through insulation or leakage resistances will cause a problem and will directly affect the results of measurements. Therefore the shields of the cables connected to these points, as well as the appropriate parts of the inner guard of resistors, are connected to the guard source of the BVD bridge to eliminate any possible leakage.

The same applies when using a null detector (DVM) — the shield of its cable as well as the internal guard of the DVM is connected to the guard source of the BVD bridge. (Note that some DVM's have an internal guard connected through a resistor to the Lo terminal – e.g. Datron 1281, and therefore the guarding cannot be used in such units to eliminate leakage when measuring at BVD bridge. It is better to select another DVM as the null detector.)

Insulation resistance between the inner wires of the null detector cable does not apply, as they are at practically the same potential when the balance is reached, not speaking about the fact that this insulation resistance is usually far higher than the internal impedance of the DVM.

This connection configuration is most often used for measurements of the resistance values up to 1G ohm. Measurements of higher values are made using a special measurement setup, where the unknown resistor is connected in parallel with a known standard of the value of 100MΩ or 1GΩ.

The connection shown in Figure 13 is designed for two resistors with a split guard. When other models of resistors are used, the connection has to be appropriately modified to eliminate as much as possible the leakage and insulation effects. The blank connection scheme may be used to document a particular measurement setup and keep it for future use with the same configuration.

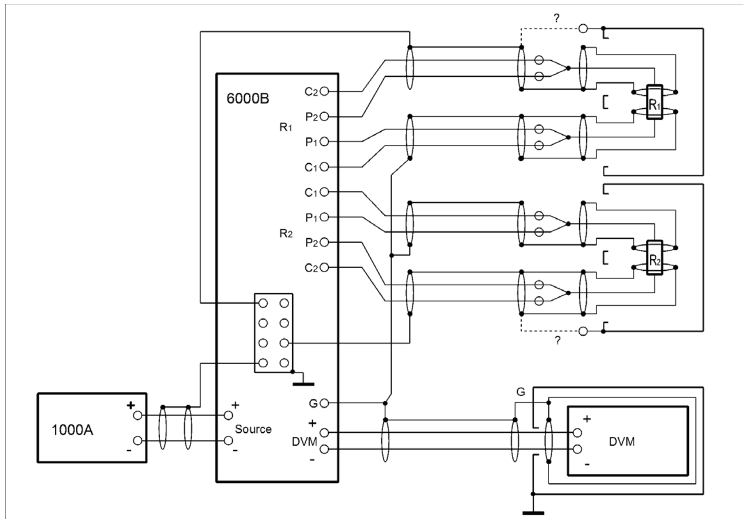


Figure 13. Typical connection to a high resistance bridge (resistors with split guard).

## Connection Design

When designing a particular connection setup for measurement with a BVD bridge, one has to avoid connection of any additional resistance parallel to the measured resistors. This means not using four-wire cables in a typical connection for four-terminal standards, as it is used when the low resistance measurement is made, or avoiding the use of two-wire cable for connection of two-terminal standards. Any resistance that is connected in parallel with a measured resistor cannot be eliminated by any means of guarding or shielding.

It is preferred to use shielded two-wire cables for connection of each pair of terminals P1-C1 and P2-C2 for four-terminal resistance standards. Connection of two-terminal resistance standards is possible using shielded coaxial cable (it is necessary to connect together terminals P1 with C1 and also P2 with C2 at the appropriate input channel of the BVD bridge).

Usually it is recommended to avoid creating any ground loops – therefore all grounding connections should be made to the common point, using grounding bar at the rear panel of the bridge.

The next goal is to design the connection in such a way that it will eliminate or minimize any influence of the leakage or insulation resistances at connection points P1(R1) and P1(R2). Depending on the construction details of the individual resistors (as discussed above) one needs to select connection of the guard source in such a way that it helps isolate the connection points P1(R1) and P1(R2).

As discussed earlier, the best results can be achieved when using the resistors with split guard, connected also to the outside shields of the coaxial connectors (Figure 10) – the voltage VG of the GUARD source is connected to the guard of P1(R1) and the guard of P1(R2) as well as the outside parts of the terminals P1(R1) and P1(R2) and also the shield of the cables connected to these terminals (this is automatically made when using coaxial cables).

The same connection is used for standards with a split guard connected with the auxiliary resistor (Figure 11) – low impedance of the GUARD source will assure that the auxiliary resistor will not cause any problem. This is, of course, only valid for measurements where the guard source is active. If the passive, fixed guard voltage source is used, then the appropriate function of guarding is assured only for measurement of two resistors of the same value and same construction (ratio 1:1).

If the ratio of resistors is different, then the passive divider created from auxiliary resistors will create the wrong guarding voltage and the leakage elimination will not work – it may happen that the results of the measurement in this case will be even worse than if no guarding is used (see Tore Sørsdal's calculation for more understanding).

When connecting the resistors without split inner guard, connect to the guard source. Connection of resistors with a simple shield (two-wire or four-wire connection) is good to connect guard source to this outside shield, but high care must be taken, as the guard voltage will appear at the outside (often bare metal) surface of the resistor! It is necessary to note that high care and specific safety precautions apply when using the guard source – its voltage, which may reach up to 120 V may appear at the metal parts of connectors, shields of cables or even metal parts of the resistor shields. Therefore it is important to never touch any metal parts at the measurement setup when the measurement is running!!!

## Parallel Combination Measurement

As was already mentioned, the BVD bridge is suitable for direct measurements of resistors up to about 1GΩ. Measurement of resistors with values higher than 1GΩ requires a special parallel configuration when the unknown resistor is connected in parallel to the known standard resistor

(Figure 14). The value of the unknown resistor is calculated automatically by the BVD bridge SW from the change of the known value of the standard resistor in the parallel combination. The best results are achieved when the value of the standard resistor is measured first and immediately after this fresh value is used for measurement at a parallel configuration. Any leakage at this type of measurement is, of course, critical and can cause large errors. Proper connection design is really important. This configuration is usable up to 1 TΩ values, although some users have reported successful measurements up to 100 TΩ.

Aside of these detailed discussed effects of leakage and insulation resistances, there are other additional effects that will influence results of high resistance measurements and their uncertainties. We can list for example:

- stability of standards, elapsed time since their last calibration, knowledge of their history and possibility to predict their actual values
- voltage dependence, temperature and power coefficients of the standards, stability of the temperature at the thermostat used, relative humidity of air
- thermal voltages at terminals
- static charges, microphone effects on cables
- correct adjustment of the guard source voltage $V_G$

In order to illustrate some effects discussed in this article, we made a few measurements on the BVD bridge model 6000B from Measurements International. The resistors $R_1$=100MΩ and $R_2$=10MΩ, both MIL model 9331 with a metal shield box and four-terminal connection (Figure 7) were measured in the first experiment. The measurement was made with a source voltage of 10V, so the voltages at the resistors were 9.1V at $R_1$ and 0.9V at $R_2$. Each result was the average of five measured values. In the first case the metal shield boxes were connected to the guard source of the bridge (results marked as guarded in Table 1). The second measurement setup was with metal shields not connected (results marked as floating in Table 1) and finally the metal shield boxes were grounded (results marked as grounded in Table 1). Measurement cables were connected according to the schematics in Figure 13.

Then the resistors $R_1$=1GΩ and $R_2$=100MΩ, both MIL, $R_2$ model 9331 with a metal shield box and four-terminal connection (Figure 7) and $R_1$ model 9331G with metal shield and additional split guard with two-terminal connection (Figure 10) were measured in the second experiment. The measurement was made with a source voltage of 100V, so the voltages at resistors were 91V at $R_1$ and 9V at $R_2$. Each result was the average of five measured values. In the first case $R_1$ was connected according to Figure 13 and the metal shield box of $R_2$ was connected to the guard source of the bridge (results marked as guarded in Table 1). The second measurement setup was with guard connections and metal shield not connected (results marked as floating in Table 1) and finally the guard of $R_1$ and metal shield box of $R_2$ were grounded (results marked as grounded at Table 1). Measurement cables were connected according to the

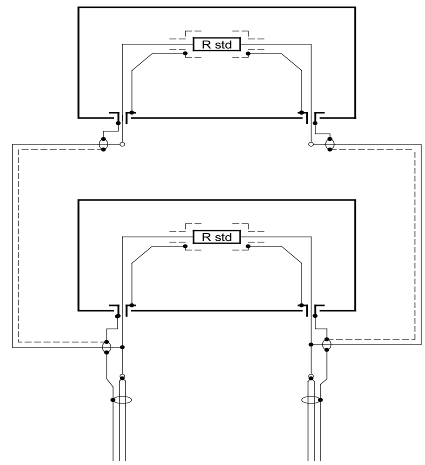


Figure 14. Schematics of connections for parallel combination measurement.

schematics in Figure 13.

It was illustrated that in the case of improper connection setup, the measurement errors can easily reach levels that are higher than the specifications of the BVD bridge.

| 100M/10M | Ratio R1/R2 | R1 Value | Error ppm |
|---|---|---|---|
| **guarded** | 10,00030613 | 100002561,2 | - |
| **floating** | 9,99986849 | 99998184,9 | -43,8 |
| **grounded** | 10,00031374 | 100002637,3 | 0,8 |
| **1G/100M** | **Ratio R1/R2** | **R1 Value** | **Error ppm** |
| **guarded** | 10,00000379 | 1000025991 | - |
| **floating** | 10,00032103 | 1000057716 | 31,7 |
| **grounded** | 9,99990013 | 1000015625 | -10,4 |

## Conclusion

The purpose of this text was to turn the attention to possible difficulties that can be experienced during high resistance measurements, which are not present during low resistance measurements (up to about 100kΩ), where the standard four-wire connection is able to eliminate most of the problems. The possible sources of problems were discussed and several hints for design of appropriate measurement setup for high resistance measurements were offered. It was illustrated that when higher care and appropriate knowledge is not used for measurement connection design, the results will be most likely affected with systematic errors caused by improper elimination of leakage and insulation effects. The author hopes that proper analysis of connection may help to improve measurement results and help to make high resistance measurements easier and more correct.

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# Some Factors That May Affect the Calibration Accuracy of Universal Testing Machines

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The calibration of universal testing machines using calibrated force transducers (load cells) is very important for industry and research institutions in any country in the world. Some factors may affect the calibration results considerably. This study concerns the effect of some important factors related to the force measurements. The calibration of material testing machines does not only contain the calibration of the test forces, which is investigated in this paper, but also the calibration of other important quantities. This study deals with the effect of the curve fitting equation of the load cell used in calibration, the permissible error of the machine, the rotation of the load cell, the repeatability and reversibility effects. This work reveals that if the previous factors are not taken into consideration, erratic calibration results will be obtained. The experimental results of this study show that the calibration error may reach ± 0.4% due to the linear approximation of the load cell curve fitting. The results show also that the error may exceed ± 2.25% and ± 2.5% for each of the repeatability and the reversibility effects respectively.

## Introduction

Standard specifications cover procedures for the force verification, by means of force transducers, of tension or compression, static or quasi-static testing machines [1, 2]. The verification of the universal testing machine is generally performed onsite at the place of the installation the testing machine. The class of force transducer shall be equal to or better than the class for which the testing machine is to be classified [3]. The calibration shall be carried out for each of the force ranges used and with all force indicators in use. Any accessory devices (e.g. pointer, recorder) that may affect the force measuring system shall, where used, be verified. The present study is not concerned with the details of the calibration procedures. It is only concerned with some important factors which may affect the calibration results. The influences of such factors on the calibration accuracy will be presented.

## Metrological Characteristics of Testing Range

Table 1 shows the maximum permissible values for the different relative errors of the force-measuring system and for the relative resolution of the force indicator, which characterize a testing machine range in accordance with the appropriate class [1].

| Class of machine range | Maximum permissible value % | | | | |
|---|---|---|---|---|---|
| | Relative error of | | | | Relative resolution |
| | accuracy | repeatability | reversibility | zero | |
| | q | b | v | $f_0$ | a |
| 0,5 | ± 0,5 | 0,5 | ± 0,75 | ± 0,05 | 0,25 |
| 1 | ± 1,0 | 1,0 | ± 1,5 | ± 0,1 | 0,5 |
| 2 | ± 2,0 | 2,0 | ± 3,0 | ± 0,2 | 1,0 |
| 3 | ± 3,0 | 3,0 | ± 4,5 | ± 0,3 | 1,5 |

Table 1. Characteristic values of the force measuring systems.

## Evaluation of Some Factors That May Affect the Calibration Results

### Influence of Linear Approximation

The result of the calibration curve of the force transducer is given by first, second or third degree polynomial equations [4, 5]. For simplicity, some laboratories make a linear approximation for the force transducer responses. Using a linear polynomial equation may introduce erratic calibration results for the calibration machine. Figures 1 – 4 show the relative deviation (RD) of the fitted results by first, second and third degree polynomial from the experimental calibration results, for different transducer types with different capacities. The relative deviations are calculated from the following equation:

$$R.D. = \frac{x_{fit} - x_{\exp}}{x_{\exp}}.100 \qquad (1)$$

Where $x_{fit}$ is the response of the standard force transducer which is estimated from the curve fitted polynomial and $x_{exp}$ is the response of the reference force transducer when it was under calibration (experimental

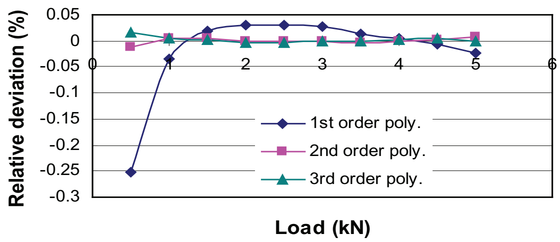


Figure 1. Relative deviation for different fitted polynomials equations of 5 kN load cell.

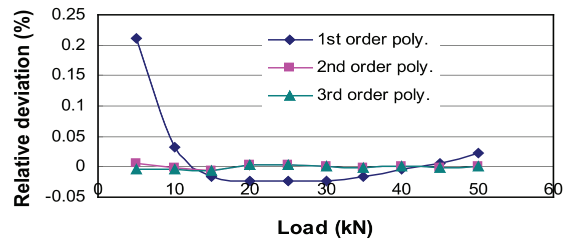


Figure 3. Relative deviation for different fitted polynomials equations of 50 kN load cell.

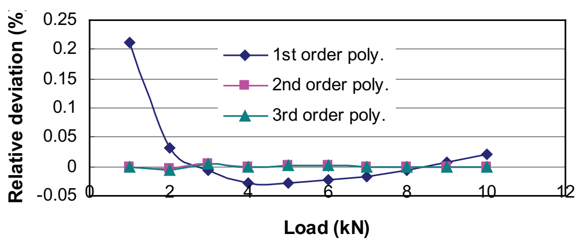


Figure 2. Relative deviation for different fitted polynomials equations of 10 kN load cell.

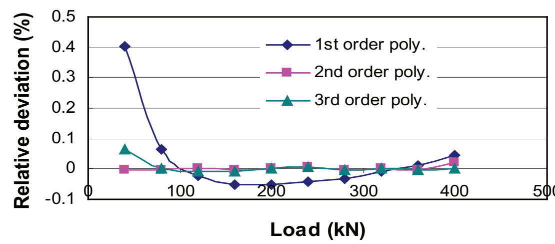


Figure 4. Relative deviation for different fitted polynomials equations of 400 kN load cell.

value) which represents the reference force transducer response under the true applied load. The four figures above show the response of four standard load cells with capacities of 5, 10, 50 and 400 kN respectively.

The figures show that the second and third degree polynomial give more accurate results than the first degree relation. This conclusion is coincided with ref. [5]. The figures showed very close fitted values to the corresponding experimental results. For the linear relation, the fitting errors may reach 0.4% (as shown in Figure 4). It is worth to mention that the fitting error due to the linear approximation will consequently lead to classify the machine calibrated to worse grade than it deserves as well as increase the uncertainty of the calibration results.

**Permissible Error Effect**

The result of a calibration according to ISO 7500-1 permits the accuracy error q to lie within the mentioned values in Table 1, according to the class of the machine. This means that, if the errors do not exceed one of the mentioned values of q in Table 1, the machine can be classified as the corresponding class for the q value. These errors are often not corrected after the calibration of the testing machine. This does not mean that there is no error for the calibrated machine. For accurate results, corrected values have to be used, otherwise a corresponding uncertainty value have to be added to the calibration result.

**Rotation Effect**

The design of precise force transducers used in calibration of the universal testing machines is rotationally symmetrical. This requirement applies to the mechanical body as well as to the arrangement of the strain gauges. If it is assumed that the characteristic values are identical, in the case of axial and central loading of the force transducers, all strain gauges would therefore have to exhibit the same measurable changes of the electrical resistance [6]. This is not the case in practice. The manufacturing tolerances on the dimensions and the bonding position of the strain gauges result in the strain gauges being subject to slightly different mechanical stresses. In addition, the universal testing machine, which is under calibration, does not exhibit ideal rotational symmetry. When force is applied in homogeneities and tolerances of the components and material of the machine, this always results in inclinations or shift of the axis of the machine. Three possible situations are presented in Figures 5-7.

Figure 5 shows a universal testing machine which inclines under load. Figure 6 represents a transducer positioned on an oblique plate of the calibrated machine. Figure 7 illustrates a machine that has a center of the upper compression platen that does not coincide with the center of the force axis. A combination of all these effects may occur and causes erroneous calibration results. To minimize this effect, it is necessary to rotate the force transducer during calibration about its axis taking the average value for these positions instead of using only one position during the calibration.

To show the rotation effect, two machines with capacities

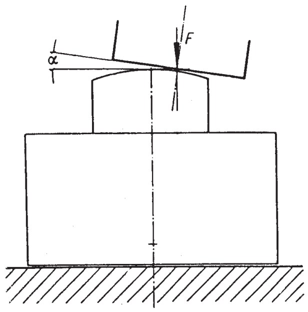


Figure 5. A universal testing machine with inclined application of the force.

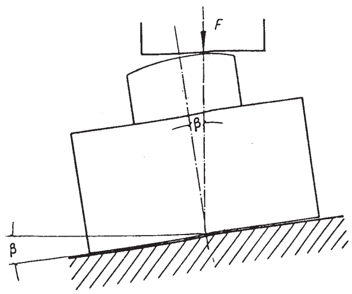


Figure 6. A universal testing machine with inclination of the bearing surface.

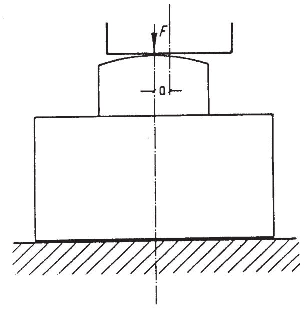


Figure 7. A universal testing machine with parallel displacement of the axes.

of 100 kN and 400 kN were calibrated. The standard force transducers used in the calibrations were rotated at three different position angles at the center of each machine: 0°, 120° and 240°. Figures 8-10 represent the relations between the different position angles and the relative deviations at some calibration points. The relative deviations were calculated from the following relation:

$$\text{Relative deviation} = \frac{x - \bar{x}}{\bar{x}} .100$$

where x is the transducer response at any position and $\bar{x}$ is the average response for the three positions.

The three figures show sinusoidal relationships between the position angle of the transducer and the relative deviation. The three figures show also that considerable errors may be introduced in the machine calibration results if the rotational effect is ignored. The figures reveal that these errors may exceed ± 0.5 %.

**Repeatability Effect**

One of the most important factors that may affect the calibration results is the repeatability effect. For the sake of simplicity, one series calibration may be taken. Of course this may give misleading results since the random error in this case will not be taken into consideration. In order to evaluate the effect of repeatability under the same conditions, two different calibration series are taken. The statistical range or the standard deviation for the calibration results may be estimated. As all of the previous affecting factors, the size of the error depends on the state of the machine under calibration. Figures 11 and 12 show the repeatability errors for two different machines. The repeatability error in each machine is determined from the following equation:

$$\text{Repeatability error} = \frac{x_{max} - x_{min}}{\bar{x}} .100$$

where $x_{max}$, $x_{min}$ are the maximum and the minimum responses of the force transducer used under certain load respectively and $\bar{x}$ is the average response of the two series.

The two figures show that, the values of the repeatability error varied depending on the class of the machine. The

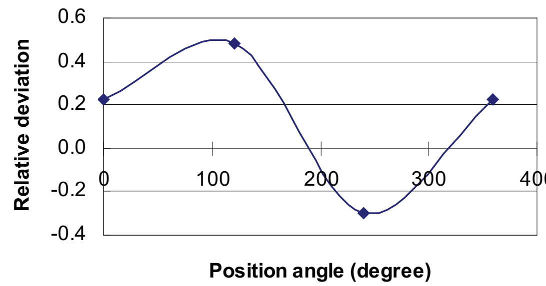


Figure 8. Relative deviations for different position angles at 30% of the 100 kN machine capacity.

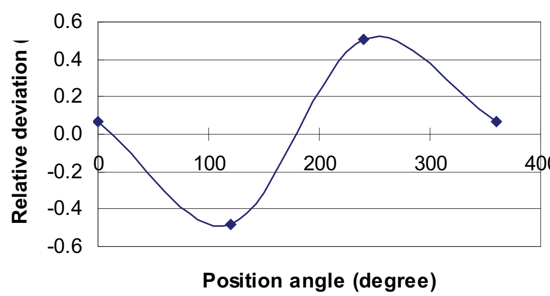


Figure 9. Relative deviations for different position angles at 50% of the 400 kN machine capacity.

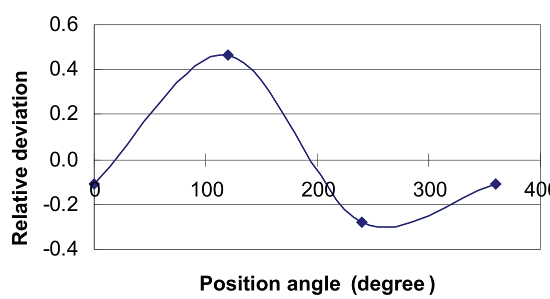


Figure 10. Relative deviations for different position angles at 100% of the 100 kN machine capacity.

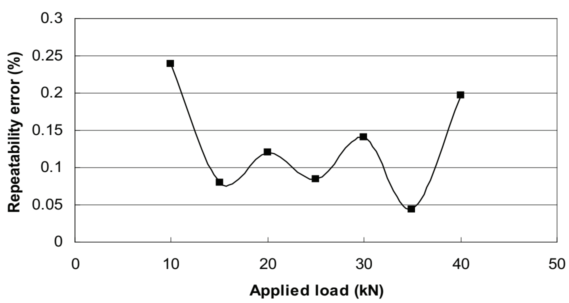


Figure 11. Repeatability error for a 50 kN universal testing machine.

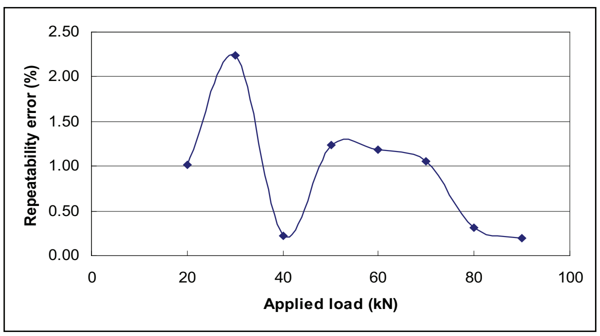


Figure 12. Repeatability error for a 100 kN universal testing machine.

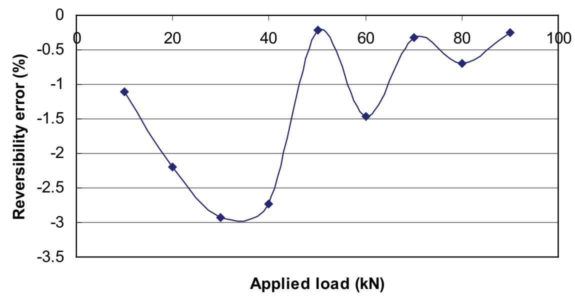


Figure 13. The reversibility error for a 100 kN universal testing machine.

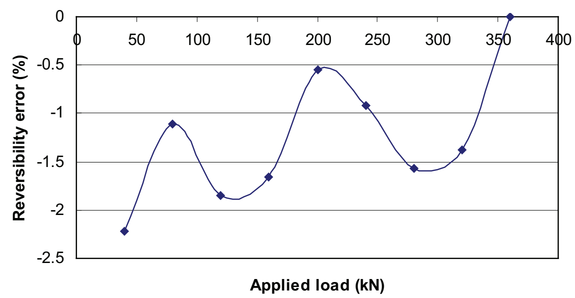


Figure 14. The reversibility error for a 400 kN universal testing machine.

value of the repeatability error for the 50 kN machine varies from 0.04% to 0.24% (Figure 11), where as it varies from 0.2% to 2.24 % for the 100 kN machine (Figure 12).

**Reversibility Effect**

Many force applications require performing force in both increasing and decreasing modes. Of course, it is expected that the behavior of the universal testing machine will be different at these two modes. For example for the machines with hydraulic systems, the friction effects depend mainly on the direction of motion between the internal cylinder surface and the oil seal. Whereas, the machines with mechanical systems, the machine behavior will depend on the nature of the contact areas of the power screws and the driving nuts. For accurate measurements with that type of applications, the universal testing machines have to be calibrated in both increasing and decreasing modes at the same discrete levels force, first with increasing force levels and then with decreasing force levels. Figures 13 and 14 show the reversibility error of two hydraulic machines with capacities of 100 kN and 400 kN respectively.

Where the reversibility error is calculated from the following equation:

$$\text{Re}\,versibility\ \text{error} = \frac{\mathrm{x}_i - x_d}{x_i}.100$$

where $x_i$ is the transducer response with the increasing mode and $x_d$ the transducer response with the decreasing mode.

The two figures show that the reversibility error may exceed ±2.5%. This means that the true applied force value corresponding to a certain nominal force value at the machine scale is different when the load is applied in increasing mode rather than in decreasing mode.

## Conclusion

The calibration of universal testing machines is one important requirement of the accreditation of any material testing laboratory. Some important factors have to be taken into consideration during the calibration process. These factors affect the accuracy of the calibration. The linear approximation of the force transducer response used in calibration may introduce an error that may reach 0.4%. It is very important to make the suitable corrections according to the calibration results, even if the error does not exceed the machine class error; otherwise, the error has to be added to the uncertainty value.

To minimize the error due to the machine eccentric load application, it is necessary to rotate the force transducer during calibration about its axis. This type of error may exceed ± 0.5%. In order to minimize the random error, one extra calibration series has to be repeated at the same conditions as the first series (at the same transducer position). The random error of any machine depends on the class.

This study reveals that the repeatability error may exceed ± 2.25 %. Many force applications require performing forces in both increasing and decreasing modes. In such case, it is important to calibrate the universal testing machine in the two modes (increasing and decreasing). This study shows that the reversibility error may exceed ± 2.5 %.

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# Pressure-Indicating Film Characterization of Wafer-to-Wafer Bonding

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Wafer-to-wafer bonding has become an enabling semiconductor technology in industries such as 3D packaging, MEMS, MOEMS, and SOI. In a typical wafer bonding process, two flat substrates are permanently joined (bonded) to one another by applying precise combinations of physical pressure, temperature, and/or voltage (Figure 1). Each of the above factors is set depending on the substrate materials being bonded, and the control of these parameters is crucial to a successful, high-quality, high-uniformity manufacturing process.

Of the three major parameters in a bond recipe, voltage and temperature are readily measurable within a wafer bonding chamber using common electronics and thermocouples. Pressure, on the other hand, is measured in the tool as the total amount of force exerted over the pressure column. This measured force is then used to calculate the average pressure, assuming perfectly flat pressure plates.

In practice, the pressure plates are often non-ideal, or they may have degraded over time. This leads to potential pressure variations which would not be detected with control software alone. Such poor distribution of pressure can lead to unbonded wafer areas, cracked wafers, or even premature wear of the pressure plates.

The significance of a uniform applied pressure in a bonding process depends largely on the specific materials being bonded. For example, in an anodic bonding process, silicon is bonded to glass (typically Pyrex®) by applying a large electric field (e.g. 1000V) at elevated temperatures (e.g.>300 C). At such temperatures, sodium impurities in the bulk of the normally insulating glass becomes mobile (Figure 2), thus making the glass much more conductive. When a high voltage is applied to the anode (hence the name anodic bond) in this state, the sodium ions move towards the anode, leaving oxygen ions at the bond interface. The reaction between silicon and oxygen then forms a very strong $SiO_2$ bond.

What is relevant to our discussion is the fact that the applied voltage also creates a very large electrostatic force on the bond stack, which assists with the bonding process. Because the magnitude of the electrostatic pressure is generally sufficient for a full bond, physically applied pressure is neither critical nor required for this type of bond process.

However, in an eutectic/thermocompression bonding process, two arbitrary substrates are bonded together using thin intermediate films that are often metallic alloys (Fig. 1-3). A common bond metal for silicon is Au-Si eutectic bond with a eutectic temperature of 363°C. In this bond, the silicon surface is placed in contact with Au deposited on the other substrate, and the stack is brought in contact to a temperature just beyond the eutectic point for a short time to allow the alloy to form.

Temperature control is obviously a critical parameter here, but it is not the focus of this discussion. Given a fixed temperature, if too much pressure is applied, the eutectic alloy could "spill out" into unwanted regions and cause short circuits. Conversely, too little pressure would typically result in weakly bonded or unbonded regions. And in practice, both spill outs and unbonded regions are often found on the very same pair of substrates due to pressure and/or temperature non-uniformities. Therefore, the characterization of applied pressure

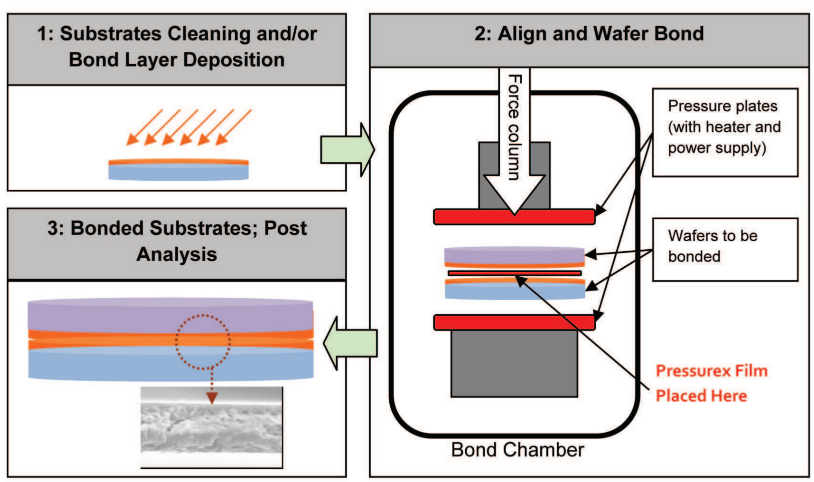



Figure 1. Wafer bonding process illustration.

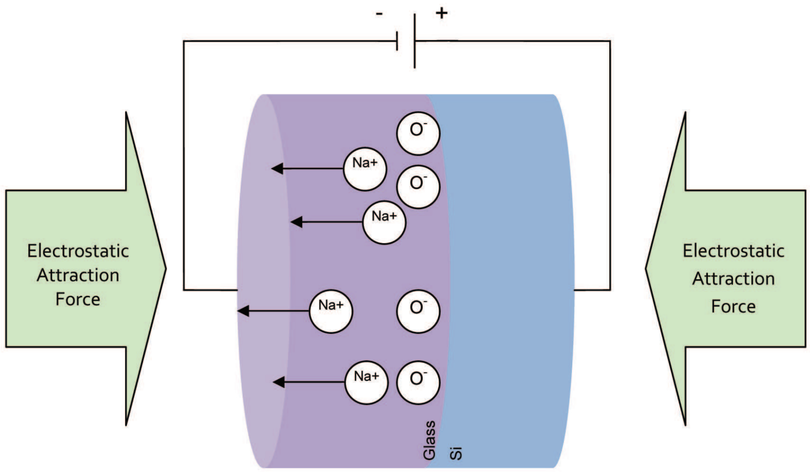



Figure 2. Anodic bonding process illustration.

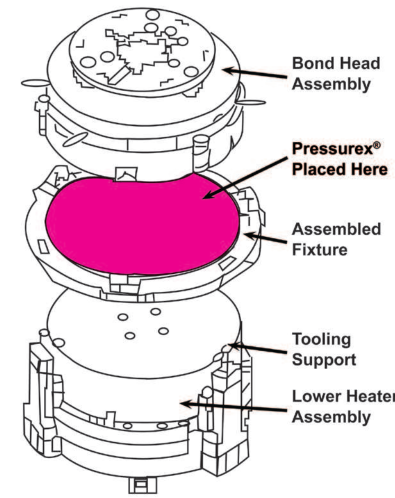



Figure 3. Magnified image of a wafer bonding fixture shows Pressurex sensor film in place.

would be an important aspect of such bond processes to achieve a high yielding bond.

Pressurex® film, developed by Sensor Products Inc., is one of the most direct and economical ways to detect and correct such pressure variations. The thin flexible film measures pressure from 2 - 43,200 PSI (0.14 - 3,000 kg/cm2).

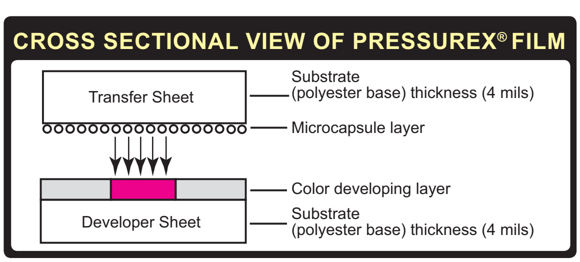
Pressurex® is a Mylar based film that contains a layer of tiny microcapsules. The application of force upon the film causes the microcapsules to rupture, producing an instantaneous and permanent high resolution "topographical" image of pressure variation across the contact area.

When placed between contacting surfaces of a wafer bonding fixture, it instantly and permanently changes color directly proportional to the amount of pressure applied. The precise pressure magnitude is easily determined by comparing color variation results to a color correlation chart (conceptually similar to interpreting Litmus paper). The film's thickness is 4 or 8 mils, which enables it to conform to tight spaces. It is ideal for invasive intolerant environments and tight spaces not accessible to conventional electronic transducers.

By running a bond recipe, with the pressure set to 4 bar on an appropriate grade of pressure film, a direct imprint is formed. Figure 4a shows an image of Pressurex Micro® sensor film 2-20 PSI (0.14 – 1.4 kg/cm2) taken from a 6″ diameter bonding tool with poor pressure uniformity. Analyzing the pressure distribution with the Topaq Tactile Force Analysis System®, this image is transformed into a color coded pressure map in Figure 4b, revealing a donut shaped high pressure ring (>10 bar) with relatively little pressure applied at the center. The line scan [Figure 4c] further elaborates these pressure inconsistencies.

A series of adjustments to the pressure column of the bond tool were then made, and the pressure uniformity was checked each time by running the same bond recipe on the same range of pressure film. The resulting series of images are shown in Figure 5, which confirms that the adjustments have been made and the actual pressure is more uniform. Note that after the adjustments, the pressure film analysis shows an offset from the intended recipe pressure of 4. By using properly calibrated pressure film, the offset can be corrected. Similarly, it can also be used to match processes across multiple bond tools.

In addition to troubleshooting the pressure distribution, the same pressure film can be used as a tool performance log in manufacturing practices such as six-sigma statistical process monitoring. Cost savings will inure to users of pressure indicating film through decreased scrap rate and increased time efficiency. There are also specific benefits that are distinct to each type of bonding application:




**1. Metal Eutectic Bonding**

Key benefits provided: Prevents the eutectic alloy from spilling out into unwanted regions and causing short circuits which given a fixed temperature can occur if too much pressure is applied. Conversely, minimize weak bonded or un-bonded regions which can occur if too little pressure is applied. The pressure

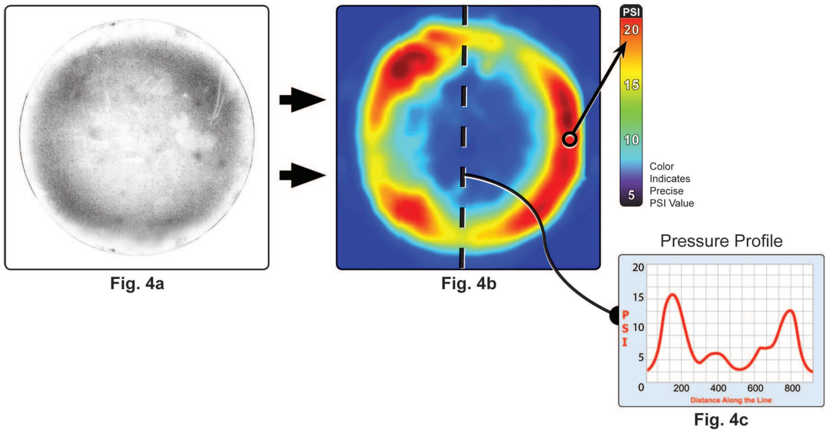



Figure 4. Bond tool images show pressure inconsistencies.

film reveals both the magnitude and distribution of pressure across the bonding platen and part minimizing the potential of too much or too little pressure.

Film grade recommended: Ultra low (28 to 85 PSIi)

**2. Anodic Bonding**

Key benefit provided: Reveals whether the top and bottom plates are in uniform contact.

Film grade recommended: Ultra low 28 - 85 PSI (2 - 6 kg/cm2)

**3. Fusion Bonding**

Key benefit provided: Minimizes trapped air pockets in between the bonded substrates which on certain applications can be caused by non-uniform applied pressure.

Film grade recommended: Ultra low 28 - 85 PSI (2 - 6 kg/cm2)

**4. Metal Diffusion Bonding**

Key benefit provided: Greatly minimize un-bonded wafer sections since the wafer won't bond at all if the forces are too low.

Film grade recommended: Super low 70 - 350 PSI (5 - 25kg/cm2)

**5. Glass Frit Bonding**

Key benefit provided: Ensures hermetic seal is formed around the device which will not occur if pressure is too low. Prevent the glass frit from flowing into the device area which can occur if pressure is too high.

Film grade recommended: Ultra low 28 - 85 PSI (2 - 6 kg/cm2)

**6. Polymer Adhesive Bonding**

Key benefit provided: Minimizes voids caused by polymer thickness non-uniformity. While this is not a direct problem related to the amount of pressure, pressure non-uniformity can exacerbate the problem.

Film grade recommended: Ultra low 28 - 85 PSI (2 - 6 kg/cm2)

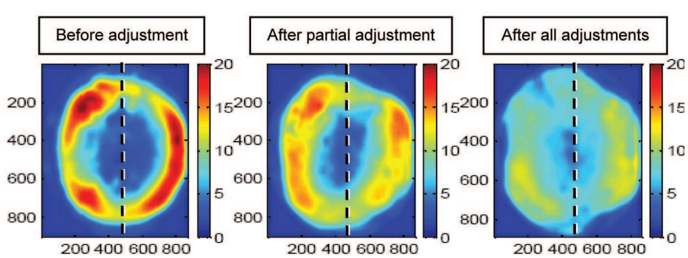



Figure 5. Bond tool images show improvement to the pressure uniformity as captured by Pressurex Pressure Indicating Film.

## Conclusion

In summary, Pressurex® is a quick and direct research tool that provides a snapshot of the pressure distribution of a bond tool at room temperature. Through calibrated post analysis, it also provides a method to compare processes and tools in manufacturing.

*About Micralyne Inc.*

*Micralyne is one of the largest independent MEMS foundries in the world. As a MEMS industry innovator and leader, Micralyne has a reputation of offering unparalleled MEMS product development and commercial volume MEMS manufacturing. With core competencies in MEMS micromachining, thin film deposition, and MEMS assembly & test capabilities, Micralyne develops and manufactures MEMS technology for the communications, energy, life sciences, and transportation markets. http://www.micralyne.com*

*About Sensor Products Inc.*

*Headquartered in New Jersey, USA, and established in 1990, Sensor Products Inc. is a world leader in the manufacture and distribution of tactile pressure indicating solutions. Their customized and off-the-shelf products are installed within all of the Fortune 500 industrial companies as well as thousands of smaller manufacturing firms. Their sensors are used in applications as diverse as tire testing to semiconductor manufacturing and from R&D labs to space missions. Additionally, Sensor Products Inc. provides in-house and on-site stress and pressure mapping analysis and consulting, as well as a variety of regional technical seminars. http://www.sensorprod.com*

## References

1. U. S. Patent No. 3,397,278, Wallis and Pomerantz, "Field Assisted Glass-Metal Sealing", Jour, of App. Phys. , Vol. 40, No. 10, September, 1969,
2. Bonding in Microsystem Technology, Jan A. Dziuban, Springer 2006

# Test Sieve Weaving Uncertainty

Dr. Graham Rideal
Managing Director
Whitehouse Scientific Ltd

Jamie Storey
Laboratory Manager
Whitehouse Scientific Ltd

The variations in apertures during weaving have been recognized for some time and are written into international standards. For example the ISO standard for a 180 micron sieve states that the mean size can vary between 172 and 188 microns. For the highest precision weavers, there is no problem in falling within, and in most cases, exceeding, these tolerances. However, a major and recent concern is the emergence of new weavers who, although they comply with the mean aperture size and wire count, have a very wide range of aperture sizes. Calibrating woven wire meshes, especially when used in test sieves, has therefore never been so important.

Considering the automatic weaving loom was invented more than 300 years ago, it is surprising how many people still think that all the apertures in a woven wire mesh are exactly the same size. The fact is, it is virtually impossible to produce wires with a zero diameter tolerance and then lay them in a high speed loom into perfectly replicated square apertures.

The variations in apertures during weaving have been recognized for some time and are written into international standards. For example the ISO standard for a 180 micron sieve states that the mean size can vary between 172 and 188 microns, while 95% of the apertures should be less than 207 microns. But the maximum size for a single aperture can be as high as 227 microns.

## The Good, the Bad and the Ugly

For the highest precision weavers, there is no problem in falling within, and in most cases, exceeding, these tolerances. However, a major and recent concern is the emergence of new weavers who, although they comply with the mean aperture size and wire count, have a very wide range of aperture sizes (Figure 1). The only sieve medium where apertures are virtually identical is the electroforming process where sizes are replicated to within a few microns (Figure 2). Calibrating woven wire meshes, especially when used in test sieves, has therefore never been so important.

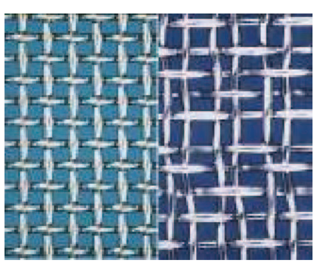
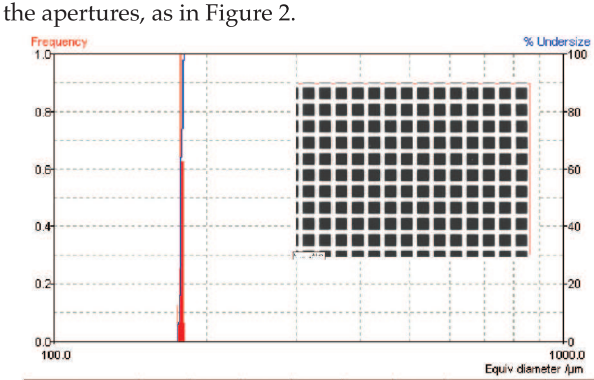


Figure 1. Identical meshes? The above have the same wire count and mean aperture size (Courtesy of G Bopp).

## Microscopy Analysis

The two main methods of measuring the apertures in wire meshes are microscopy and the more recent method of glass microsphere standards. In microscopy and image analysis, wire spacings and wire diameters are measured, but more advanced systems can measure the dimensions of individual apertures and plot either the minimum or maximum size of the apertures, as in Figure 2.




| % Undersize | 3.0 | 5.0 | 10.0 | 25.0 | 50.0 | 75.0 | 90.0 | 95.0 | 97.0 |
|---|---|---|---|---|---|---|---|---|---|
| Size /µm | 175.2 | 175.2 | 176.4 | 177.1 | 177.7 | 178.3 | 179.0 | 179.0 | 179.6 |

Figure 2. Image analysis of a 180 µm electroformed sieve.

## Challenge Testing

In the challenge test method of measuring aperture size, the mesh is calibrated by "challenging" the surface with a narrow size distribution of glass microspheres.

Although any method of shaking the standards over the mesh can be used for apertures above about 50 microns, for complex 3-dimentional twills and very fine meshes, a sonic method of fluidizing the glass microspheres is essential to ensure efficient transport of the particles through the mesh.

The maximum aperture sizes can be determined either by analyzing the beads passing through or by simply weighing and using a calibration graph supplied with the standard.

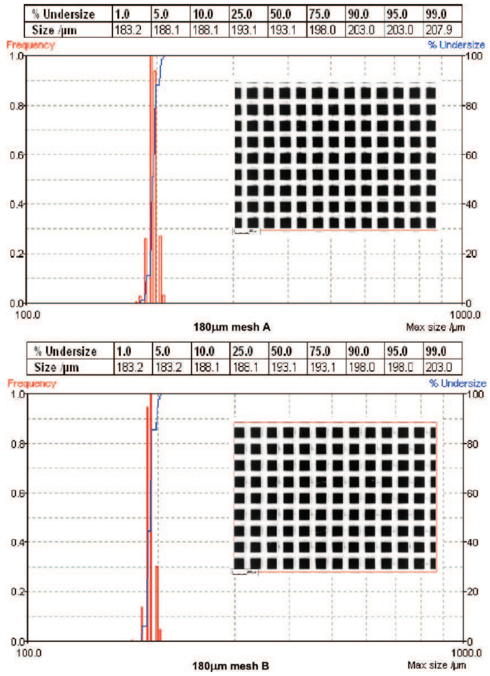



Figure 3. Mean aperture sizes do not discriminate between good and bad meshes. D95% is a more sensitive measure.

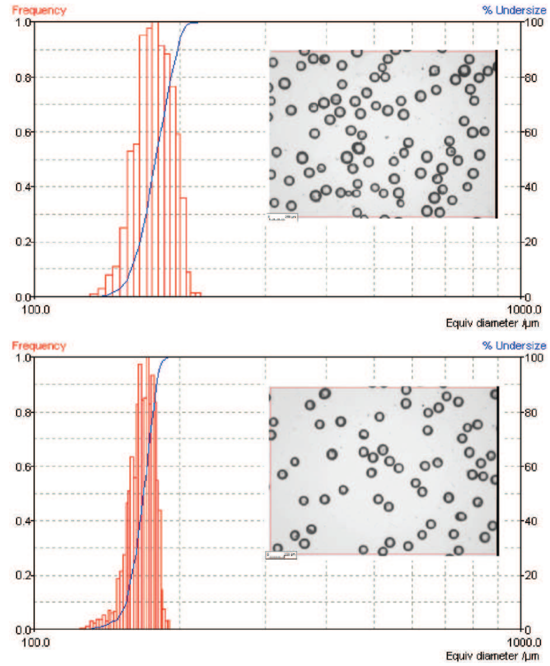



Figure 4. Size of calibration standard before and after passing a 108 micron mesh (B).

## Mesh Size or Performance

As shown in Figure 1, both mesh count and mean aperture size would fail to distinguish between a good and bad mesh. However there would be a considerable difference in performance because of the presence of such large apertures.

The two nominal 180 micron meshes in Figure 3 have the same mean aperture size, but mesh A has larger apertures than mesh B, with 95th percentiles (D95) of 203 and 198 microns respectively.

When the meshes are challenged with a glass microsphere standard using the sonic challenge test, mesh A had a cut point of 193 microns while mesh B had a cut point of 185 microns.

Measuring only the mean aperture size is not, therefore, a good measure of the performance of a sieve or filter as it is the larger apertures that determine cut point.

## Defining Cut Point

The end point in the sonic challenge test is when there is no further significant weight loss in the fluidized microspheres. The weight of beads passing is used to calculate the cut point, but by measuring the size of the beads passing, the gravimetric method can be related directly to the maximum apertures in the mesh.

Figure 4 shows that the 97th percentile (D97) has decreased from 202 microns in the standard to 182 microns in the filtered beads.The 182 microns compares very closely with the 184 microns obtained from the gravimetric method.

So the sonic cut point is defined as the 97th percentile of the calibration beads passing a sieve or filter. This result confirms other experiments on a range of meshes.

It should be noted that this definition only applies to the Whitehouse Scientific narrow size range of calibrating microspheres. Broad distribution glass beads or non-spherical powders may give different answers.

## Conclusion

Assessing a woven mesh by mesh number (number of wires per inch) or mean aperture size is not sufficient to discriminate between good and bad meshes because sieving/filtration efficiency is dependent on the larger mesh apertures. Furthermore, a microscopic method cannot be used on complex weaves where light cannot pass through.

This research has shown that the end point in sieving or the cut point in the filtration process is determined by the 97th percentile of the aperture sizes. Both microscopic analysis of the calibrating beads passing and the sonic cut point give very similar results, but the challenge test has the advantage of being able to be performed at high speed in the analyst's own laboratory without the need for any specialized microscopic equipment.

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info@whitehousescientific.com

### Fluke Introduces Power Standards

*MSC Booth # 23,24,25,42,43,44*

Fluke Corporation has introduced new, more accurate electrical power standards designed to deliver stable, precise reference power and energy for use in calibrating electrical measurement equipment. The new Fluke 6105A and 6100B Electrical Power Standards provide the stability and accuracy required by users including national measurement institutes, instrument service and calibration firms, electronics manufacturers, power utilities and standards laboratories.

Choosing between a 6100B or 6105A depends on the user's accuracy requirements. Both models meet all accuracy requirements of power quality testing to the IEC 61000-4 series of standards. The 6100B can also be used to type test 0.1 percent to 2 percent energy meters, while the 6505A has the highest accuracy available for calibrating and type testing secondary standard energy meters and Watthour meters.

The Fluke 6105A provides all the functionality of the 6100B, with even better accuracy to match that of the best measurement devices for sinusoidal waveforms. The 6105A Electrical Power Standard is specifically designed to provide the accuracy required to verify the performance of secondary standards such as the Radian Research RD and RM range, the Zera EPZ303 and COM 3003; also the MTE (EMH) K2006, Calport 300, SRS PRS PWS and PTS series products.

Few systems can match the 0.007 percent (66 ppm) one-year energy accuracy provided by the 6105A for sinusoidal waveforms. Waveforms with high harmonic distortion are also delivered with similar accuracy traceable to national and international standards.

A Microsoft Windows® user interface makes the 6100B and 6105A easy and simple to operate. In addition, the 6100B and 6105A can be operated under remote control.

Fluke Corporation, tel 800-760-4523, fluke-info@fluke.com, www.fluke.com/6105.

### New Full Immersion Probes from Hart Scientific

*MSC Booth # 23,24,25,42,43,44*

The Hart Scientific Division of Fluke Corporation has introduced new full immersion platinum resistance thermometer (PRT) probes designed to perform in extreme environments. The Hart Scientific 5606 and 5607 Full Immersion PRTs are designed to perform in "full immersion" applications where both the transition junction and the lead wires must withstand temperatures covering the entire operating range of the probe. Such applications can include calibration or validation of sensors used in laboratory or bio freezers, walk-in refrigerators, autoclaves, ovens, stability test chambers, furnaces or incubators.

The Hart Scientific 5606 has a temperature range of -200 °C to 160 °C, while the 5607 has a range of 0 °C to 450 °C.

The 5606 is only 2 inches (50 mm) in length with a sheath diameter of 1/8 inch (3.1 mm). Since it can be fully immersed over its entire temperature range, users need not worry about calculating minimum immersion depth and can immerse the entire probe, transition junction, and lead wires in either non-corrosive liquids or dry mediums.

Hart Scientific (A division of Fluke Corporation) toll free 1-800-GET-HART (1-800-438-4278) or 801-763-1600, info@hartscientific.com.

### Rotronic Introduces HygroGen2 Humidity and Temperature Generator

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Visit www.rotronic-usa.com for more information.

### Veriteq Instruments Announces Online Demo for ViewLinc™

*MSC Booth #47*

Veriteq Instruments has released a new online demo of the latest iteration of their monitoring, alarming and reporting system for temperature and humidity in controlled environments — viewLinc™. The demo is accessible online at http://www.veriteq.com/landing-pages/viewLinc_demo_request.htm.

Designed for monitoring and alarming temperature, humidity and other critical parameters in quality controlled environments, viewLinc is the only system of its kind to ensure continuous, gap-free data for records that must comply with stringent guidelines in industrial and critical manufacturing.

The 5-minute demo gives a brief overview of viewLinc's basic functions, including the ability to generate and deliver reports automatically. Other features include: browser-based interface and site-licensing, realtime view of multiple environments and trends from remote locations, flexible alarm management via text/email to PC, cell phone, pagers and more.

Unlike other monitoring systems, viewLinc ensures against lost data with three discrete recording methods:

- Independent memory in each data logger
- Back up to the host PC
- Automatic file transfers

For further information contact: Chuck McFarlane at 800-683-8374 (NA only) or email cmcfarlane@veriteq.com.

### Mensor Introduces CPC 6000 Transducer

What is 0.01%intelliscale-50 ? It is an abbreviated way to express a percent of reading uncertainty for CPC 6000 transducers. "0.01%" indicates that the transducer has an uncertainty of 0.01% of reading; "-50" indicates that the percent of reading uncertainty applies to the portion of the range above 50%. "0.01%Intelliscale-50" also has a 365 day recommended calibration interval. These qualities increase the accuracy, extends the calibration interval and lowers the total number of ranges required, thus reducing the cost of ownership by extending the "up-time" and decreasing the yearly re-certification cost.

For more information, please contact the Mensor Sales Department at 512.396.4200 or via email at sales@mensor.com.

### GEC Instruments Offers Ultra High Accuracy Temperature Measurements with Thermocouples

GEC Instruments has developed unique instrumentation for making ultra high accuracy temperature measurements with thermocouples. Multiple channel thermocouple scanners are available with as many as 94 input channels in a single enclosure. Combined instrument errors, including voltage measurement error, thermocouple reference junction error, and conformity to ITS-90 reference functions, are usually less than 0.015 °C.

Each GEC thermocouple scanner is accompanied by a versatile and powerful software package for display, plotting, logging and retrieval of data. The software includes a calibration wizard that enables a two point systems calibration of the instrument and attached thermocouples against a precision temperature reference, thus reducing the contribution from thermocouple wire error and normally providing a measurement accuracy of 0.05 °C or better within the calibrated range.

GEC instruments, tel 352-373-7955, info@gecinstruments.com, www.gecinstruments.com.

### ASL U.S. Announces F252 Precision Thermometer

Precision thermometry manufacturer ASL has upgraded its market leading range of AC bridges with the launch of the F252 as a successor to the highly popular F250. Thanks to further advances in technology, ASL has now replaced the F250 with the F252, which is the fastest commercial AC Bridge of this precision class and faster than any DC bridge of similar specification.

It boasts accuracy to within ±0.01ºC (full range) and resolution of 0.001ºC (0.0001Ω) with a resistance range of between 0 - 400Ω. It is also the first AC Bridge to be launched with "smart probe" capability.

The F252 also comes with two channels as standard, but four and six channel variations are available with each channel able to work with up to 72 user-defined probes so providing spot on calibration. The F252 also offers single, differential and alternative measurement modes.

The F252 is capable of measuring temperature ranges to meet ITS90, CVD, EN60751 & IEC751 standards and results are delivered via a LCD backlit display with large numeric, statistical or graphical information. It also comes with USB interface as standard, but optional RS232, IEEE or LAN interfaces are also available.

In Canada contact techniCAL at www.technical-sys.com or call 1-86-MEASURE-1 (1-866-327-8731)

### GE High Performance HART® Communicator Is Also A Calibrator

The hand-held DPI 620 advanced multifunction calibrator from GE Sensing & Inspection Technologies now incorporates full HART® capability, making it the only combined HART communicator and calibrator currently on the market. The rugged and compact instrument, which is weatherproofed to IP 65, incorporates the latest application software and contains a complete library of registered HART device descriptions to support more than 1000 sensors. Upgrades may be simply downloaded free-of-charge, from the GE Sensing & Inspection Technologies website. Offering so many functions and features within one portable instrument, the DPI 620 has application in the oil and gas, power generation, utilities and process industries, as well as in the laboratory and on-plant.

Features new to HART communicators include an integral 24V loop power supply to energize HART devices and loops and a menu-selectable 250 ohm loop resistor, rather than a separate physical resistor, for use when a device is not connected or the loop is switched off.

For more information please visit:www.gesensinginspection.com

### Michell Instruments Announces SF52 Dew-Point

***MSC Booth #7***

Michell Instruments is pleased to announce the new SF52 with a Dew-Point Temperature range of -40 to +140º F. Communication is by 4-20mA or voltage signal for either dew-point or absolute humidity with <3.6º F accuracy <1.8º F annual stability. The SF series is contained within a rugged housing of less than 1.1" diameter, and provides operating pressures up to 300psig. The ½" NPT port contains a flush filter disc to minimize flow disturbance and is extremely easy to install.

The SF52 is very competitively priced and ideal for OEM's in a wide range of dew-point and moisture measurement applications.

For further information, please contact Gary Werner at Process Measurement & Controls, tel 203-792-8686, fax 203-743-2051, gwerner@pmc1.com, web Site: www.michell.com/us/rh /

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