METROLOGY 101: WATCH OUT FOR THOSE THERMOELECTRIC VOLTAGES!

CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

2012
APRIL
MAY
JUNE

Identifying and Avoiding Common Errors in RF Calibration

A Comparison of 12 US Liquid Hydrocarbon Flow Standards and the Transition to Safer Calibration Liquids

Rethinking the Flexible Standards Paradigm

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VOLUME 19, NUMBER 2

www.callabmag.com

FEATURES

DEPARTMENTS

ON THE COVER: CTO, David K. Hamilton of National Test Equipment. is manually checking for noise spur problems on an Agilent E4438C.

CALENDAR

CONFERENCES & MEETINGS 2012

May 8-10 LabIndonesia 2012. Jakarta. Indonesia's 2nd Laboratory Analytical Equipment, Instrumentation and Services Exhibition and Conference. For more information, visit: http://www.lab-asia.com/.

May 9-11 Milestones in Metrology IV. Venice, Italy. The conference trailer on the NMi website gives an initial overview of the new structure, atmosphere and topics of the conference for the markets of Energy, Oil & Gas, Weighing and Traffic. The complete programme will focus on legal metrology, but this scope will be expanded with the introduction of industrial metrology. http://www.milestonesinmetrology.com/.

May 13-16 2012 IEEE International Instrumentation and Measurement Technology Conference. Graz, Austria. "Smart Measurements for a Sustainable Environment." http://imtc.ieee-ims.org/.

May 23-25 MetrolExpo2012. Moscow, Russia. The 8th Moscow International Forum "Precise Measurements - The Basis of Quality and Safety" will be held with specialized exhibition of measuring instruments and metrological equipment (MetrolExpo), to ensure uninterrupted operation of production facilities (PromSafety), commercial energy accounting (ResMetering), means of verification and testing of medical devices (MedTest), and the 4th Moscow International Symposium "Accuracy. Quality. Security." http://www.metrol.expoprom.ru/en/.

Jun 20-22 8th International Symposium on Fluid Flow Measurement. Colorado Springs, CO. During the 8th ISFFM, industrial research laboratories, universities, government laboratories, and industrial field study teams will present information on a wide variety of research and technology topics associated with fluid flow measurement. http://www.isffm.org/.

Jul 16-20 Coordinate Metrology Systems Conference (CMSC). New Orleans, LA. CMSC provides a professional venue where ideas, concepts and theory flow freely among participants. The educational atmosphere encourages attendees to network and learn about the latest innovations in the field of portable 3D industrial measurement technologies. http://www.cmsc.org/.

Jul 29-Aug 3 NCSL International. Sacramento, CA. This year's theme is "The Business End of Metrology Quality and Testing." http://www.ncsli.org.

Sep 9-14 XX IMEKO World Congress. Busan, Republic of Korea. Hosted by the Korea Reaseach Institute of Standards and Science (KRISS), this year's theme for the International Measurement Confederation is "Metrology for Green Growth ." http://imeko2012.kriss.re.kr/.

Sep 10-13 AUTOTESTCON 2012. Anaheim, CA. Sponsored annually by the IEEE, the theme this year is "Mission Assurance through Advanced ATE." http://autotestcon.com.

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

EDITOR'S DESK

A Little Levity

I'd like to give Ted Green a nice big "Hoorah!" for being our toon-contributer. Metrologists really take themselves too seriously sometimes… come on, you know who you are. So, we are very pleased to be able to add a little levity, to the otherwise very heavy subject of precision measurement, in each new edition of Cal Lab Magazine.

If you didn't notice when it first arrived in your mailbox, the April-June issue added several pages in order to squeeze in substantive article contributions. This issue's Metrology 101, "Watch Out for those Thermoelectric Voltages!" by Marty Kidd, is a bit longer than usual, covering the impact of thermoelectric voltages (EMFs) on low-voltage measurements. In a similar vein, Paul Roberts kindly contributed his paper from the Measurement Science Conference (MSC), held in conjuction with ITS9 2012, this past March in Anaheim, CA, on "Identifying and Avoiding Common Errors in RF Calibration."

NIST completed a comparison of results from a dozen government and commercial labs, showing the effectiveness of biologically benign solutions. John Wright of NIST presented their findings at the MSC/ITS9 2012. They want to get the word out that NIST and other flow testing labs are moving away from Stoddard solvent and encourage other labs to follow suit. Cal Lab Magazine was happy to oblige in helping to get the word out by including their work here in our April-June issue.

Finally, our publisher—and software engineer extraordinaire—included his paper, "Rethinking the Flexible Standards Paradigm," demonstrating how automation software must change to accommodate evolving technologies.

Regards,

Sita

CAL-TOONS by Ted Green

Arthur prefers the Measurement Science version

Of Accu-Pressure

SEMINARS: Online & Independent Study

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

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

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

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

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

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

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

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

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

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

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

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

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

Precision Measurement Series Level 1. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

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

Precision Measurement Series Level 1. Workplace Training, tel (612) 308-2202, info@wptraining.com, http://www.wptraining.com/.

Precision Measurement Series Level 2. Workplace Training, http://www.wptraining.com/.

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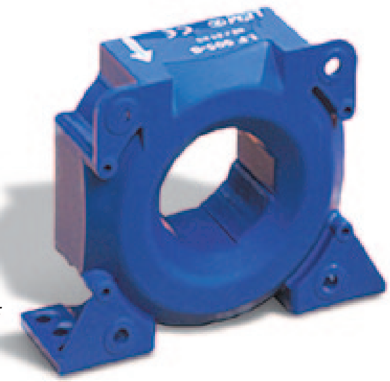

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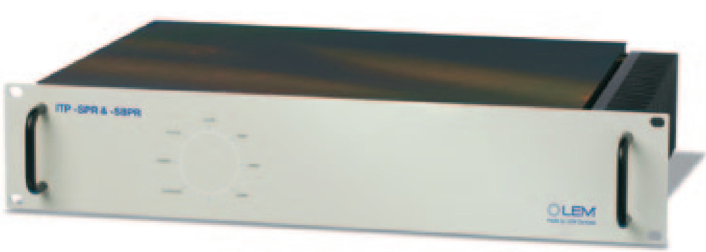
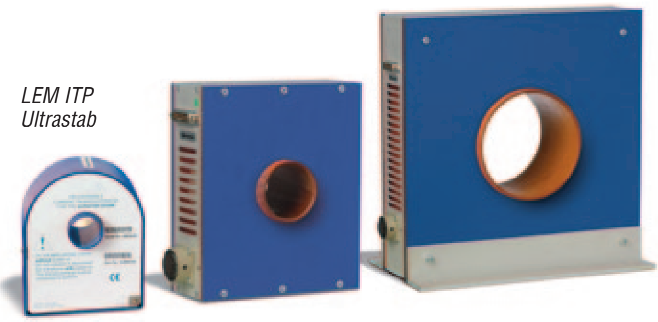
Optional Heads	600A	2,000A	5,000A
Lowest fs Current	40A	125A	2,500A
fs Current Range Increment	20A	125A	125A



Very High-accuracy Calibration and Power Measurements



LEM ITP Ultrastab

CALENDAR

SEMINARS: Dimensional

May 14-17 Dimensional and Thermodynamic Calibration Procedures. Las Vegas, NV. Technology Training Inc., http://www.ttiedu.com/schedule.html.

May 15-16 Dimensional Metrology. Cincinnati, OH. Mitutoyo , http://mitutoyo.com, mim@mitutoyo.com.

May 17-18 Gage Calibration Systems and Methods. Cincinnati, OH. Mitutoyo , http://mitutoyo.com, mim@mitutoyo.com.

May 22-23 Hands-On Gage Calibration and Repair Workshop. Houston, TX. http://www.iicttraining.com.

May 24-25 Hands-On Gage Calibration and Repair Workshop. Dallas, TX. http://www.iicttraining.com.

Jun 7-8 Hands-On Gage Calibration and Repair Workshop. Hartford, CT. http://www.iicttraining.com.

Jun 11-12 Hands-On Gage Calibration and Repair Workshop. Baltimore, MD. http://www.iicttraining.com.

Jun 26-27 Hands-On Gage Calibration and Repair Workshop. Champaign, IL. http://www.iicttraining.com.

Jul 10-11 Hands-On Gage Calibration and Repair Workshop. St. Louis, MO. http://www.iicttraining.com.

Jul 12-13 Hands-On Gage Calibration and Repair Workshop. Kansas City, MO. http://www.iicttraining.com.

SEMINARS: Electrical

May 21-23 Instrumentation for Electrical Test & Measurement. Las Vegas, NV. Technology Training Inc., http://www.ttiedu.com/schedule.html.

Jun 4-7 MET-101 Basic Hands-on Metrology. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Jun 12-14 MET-302 Introduction to Measurement Uncertainty. Seattle, WA. Fluke Calibration, http://us.flukecal.com/training.

Jun 25-29 Grounding, Shielding and Test Procedures for EMI/EMC/ESD. Las Vegas, NV. Technology Training Inc., http://www.ttiedu.com/schedule.html.

Sep 20-21 Essential Metrology for Engineers and Calibration Technicians. Baltimore, MD. WorkPlace Training, http://wptraining.com/.

SEMINARS: Flow & Pressure

May 15-17 Principles and Practice of Flow Measurement Training Course. East Kilbride, Scotland, UK. http://www.tuvnel.com.

CALENDAR

Jun 14-15 Fundamentals of Ultrasonic Flowmeters Training Course. Colorado Springs, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 11-13 Fundamentals of Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

Sep 17-20 Comprehensive Flow Measurement Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

SEMINARS: General

Jun 19 Conducting an Effective Management Review - Webinar. Sponsored by NIST Office of Weights and Measures, details and registration at http://www.nist.gov/pml/wmd/calendar.cfm.

Aug 20-24 Fundamentals of Metrology. Gaithersburg, MD. Sponsored by NIST Office of Weights and Measures. http://www.nist.gov/pml/wmd/5179.cfm.

SEMINARS: Industry Standards

Jun 18 Documenting Traceability and Calibration Intervals - Webinar. Sponsored by NIST Office of Weights and Measures, details and registration at http://www.nist.gov/pml/wmd/calendar.cfm.

Jun 19 Calibration Report Evaluations - Webinar. Sponsored by NIST Office of Weights and Measures, details and registration at http://www.nist.gov/pml/wmd/calendar.cfm.

Jun 26 Practical Methods for Reporting Measurement Uncertainty on a Calibration Report per ILAC - Web Event. Instructor led learning to your desktop, includes 10 hours self-paced elearning prerequisite. Workplace Training, http://www.wptraining.com.

Jun 27 Introduction to ANSI Z540.3 - Web Event. Instructor led learning to your desktop, includes 10 hours self-paced elearning prerequisite. Workplace Training, http://www.wptraining.com.

Jun 12-14 Cal Lab Management; Beyond 17025 Training. Minneapolis, MN. WorkPlace Training, http://wptraining.com/.

Sep 17-19 Cal Lab Management; Beyond 17025 Training. Baltimore, MD. WorkPlace Training, http://wptraining.com/.

SEMINARS: Mass & Weight

Oct 15 - 26 Mass Seminar. Gaithersburg, MD. Two-week, "hands-on" seminar, sponsored by NIST Office of Weights and Measures. http://www.nist.gov/pml/wmd/5192.cfm.

SEMINARS: Measurement Uncertainty

May 8-9 Estimating Measurement Uncertainty. Chicago, IL. http://mitutoyo.com.

May 15-17 Measurement Uncertainty Workshop. Fenton, MI. http://www.QIMTonline.com, click on Public/Private Measurement Uncertainty Workshop/Classes.

CALENDAR

Jun 18 Basic Uncertainty Concepts - Webinar. Sponsored by NIST Office of Weights and Measures, details and registration at http://www.nist.gov/pml/wmd/calendar.cfm.

Jun 25 Introduction to Measurement Uncertainty - Web Event. Instructor led learning to your desktop, includes 10 hours self-paced elearning prerequisite. Workplace Training, http://www.wptraining.com.

Jun 28 Basic Statistics for Metrology with Excel - Web Event. Instructor led learning to your desktop, includes 10 hours self-paced elearning prerequisite. Workplace Training, http://www.wptraining.com.

Jul 17-19 Measurement Uncertainty Workshop. Fenton, MI. Presented by QUAMETEC Institute of Measurement Technology, http://www.QIMTonline.com, click on Public/Private Measurement Uncertainty Workshop/Classes.

Sep 24-26 Measurement Uncertainty Training Course. Loveland, CO. Colorado Engineering Experiment Station Inc., www.ceesi.com.

SEMINARS: Radiometry

Jun 4-8 Radiation Thermometry Short Course. NIST Gaithersburg, MD. http://www.nist.gov/pml/div685/sc/thermometry_course.cfm.

SEMINARS: Temperature

May 15-17 Temperature Calibration Product Training. American Fork, UT. Fluke Calibration, http://us.flukecal.com/training.

Jun 4-8 Radiation Thermometry Short Course. NIST Gaithersburg, MD. 5-day course consists of lectures and hands-on laboratory experiments. http://www.nist.gov/pml/div685/sc/index.cfm.

Jun 12-14 Principles of Temperature Metrology. American Fork, UT. Fluke Calibration, http://us.flukecal.com/training.

Aug 21-23 Infrared Temperature Metrology. American Fork, UT. Fluke Calibration, http://us.flukecal.com/training.

Sep 18-19 ITS-90 Fixed-Point Cell Mini-Workshop. NIST Gaithersburg, MD. http://www.nist.gov/pml/div685/sc/index.cfm.

Sep 18-20 Advanced Topics in Temperature Metrology. American Fork, UT. Fluke Calibration, http://us.flukecal.com/training.

Sep 19-20 Selecting and Using Alternative Thermometers Mini-Workshop . NIST Gaithersburg, MD. http://www.nist.gov/pml/div685/sc/index.cfm.

SEMINARS: Vibration

May 8-10 Fundamentals of Random Vibration and Shock Testing, HALT, ESS, HASS (...). Boxborough, MA. http://www.equipment-reliability.com.

May 30-Jun 1 Fundamentals of Vibration for Test Applications. Las Vegas, NV. http://www.ttiedu.com/schedule.html .

Jul 9-11 Fundamentals of Random Vibration and Shock Testing, HALT, ESS, HASS (...). Boulder, CO. http://www.equipment-reliability.com.

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

Sep 11-13 Seismic Protection of Critical Equipment. Acton, MA. http://www.equipment-reliability.com.

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

Two New Advanced Laboratories Open at NIST Boulder and JILA

Two new advanced laboratory buildings for high-precision science and measurements have officially opened in Boulder, Colo., providing upgraded facilities to support technology innovation and economic growth as well as the training of future scientists.

Federal, state and local government officials, university leaders, and Nobel laureates were among those attending the April 13, 2012, dedication ceremonies and tours at the new Precision Measurement Laboratory (PML) on the National Institute of Standards and Technology (NIST) campus in Boulder and at the new X-Wing at JILA, a joint venture of NIST and the University of Colorado (CU) Boulder. JILA is located on the CU-Boulder campus.

Both new laboratories tightly control environmental conditions such as vibration and temperature, as is required for cutting-edge research with lasers, atomic clocks, nanotechnology and other areas of study at NIST and JILA. Both new buildings also have capabilities for micro- and nanofabrication of custom research devices. The original NIST-Boulder and JILA laboratories were built in the 1950s and 1960s.

Under Secretary of Commerce for Standards and Technology and NIST Director Patrick Gallagher cut the ribbon to officially open the PML, which will house some of NIST's best-known experiments and technologies, including NIST-F1, the U.S. civilian standard atomic clock.

"This laboratory is at the heart of making sure that NIST Boulder has the capabilities it needs to carry out its critical mission," Gallagher said. "The work that's done here is central to the role of NIST. The work done here on atomic clocks, on voltage standards, on quantum computing, on detectors—this is the essence of NIST's role to define and implement a system of measurement to the benefit of the United States. And it's a mission that is as fresh today as it was in 1901 when this agency was first founded. So I think our best is still to come, and it's exciting to know we'll have a home like this in which to do it."

Stella Fiotes, NIST's chief facilities management officer, noted that planning, design and construction of the PML required six years of sustained leadership and collaboration to ensure completion on time, within the budget, and with a strong safety record. "This beautiful facility provides a dramatic improvement over the existing facilities located on the NIST-Boulder campus," Fiotes said.

At the JILA ceremony on the CU-Boulder campus, Gallagher said the new X-Wing will deepen and refresh NIST's productive partnership with the university. He noted that JILA supports NIST efforts to promote technology transfer by generating new measurement tools and training young innovators who go on to advance measurement science, found high-tech companies and win Nobel prizes.

"JILA started out, frankly, as a unique experiment 50 years ago, a pioneering partnership bringing together federal scientists and university researchers within the same organization," Gallagher said. "It's been an experiment that has had remarkable success, beyond even the original vision of the founders. It's been so successful, in fact, it has served as a model for all other successful university/government partnerships, not just at NIST, but also at a number of other agencies and universities."

JILA/NIST Fellow and Nobel laureate Eric Cornell, who served as master of ceremonies for the X-Wing dedication, noted that JILA had outgrown its original building. "JILA was a victim of its own success. We really needed to expand, we really needed to modernize, we really needed the X-Wing," Cornell said.

Source: http://www.nist.gov/public_affairs/tech-beat/tb20120417.cfm#labs.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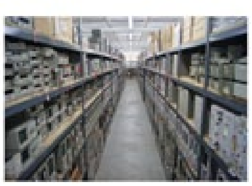
u.s. 1-800-829-4444 canada: 1-877-894-4414 mexico: 1-800-254-2440

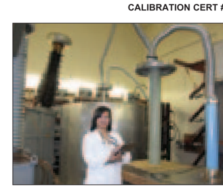
Giga-tronics ASCOR Rackmount/Benchtop Microwave Switching Solution

Giga-tronics Incorporated announced the release of the new Giga-tronics ASCOR rackmount/benchtop microwave switching solution, the Series 8900. The new 8900 microwave switching platform provides the ultimate in scalability and reconfigure-ability:

- Wide variety of Available Relays – While being only 2U tall, the 8900 series is configured to support relays of various sizes from 1×2 up to 1×12 either terminated or un-terminated types. In addition, the 8900 is designed to support two families of relays, one for ultra-high reliability for high use applications, and the other focused on lower use applications at reduced cost.
- Customizable Front Panel - Both the 8901 and the larger 8902 have a removable front panel which can easily be reconfigured to meet the customer's specific requirements. This allows customers to design their own switching system using the relays they need in the positions they prefer.
- Serviceability – Relays can be removed from the front without opening the box. The relays are connectorized on the rear allowing them to be replaced quickly, minimizing meantime to repair (MTTR).
- Switch Closure Counting - The internal firmware keeps track of switch actuation counts on each pole stored in non-volatile memory. This allows the user to compare his actual use to predicted life of the relays allowing him to anticipate failures, or even replace relays near end-of-life before failures occur. In addition, this feature can be used to optimize test procedures to level the number of cycles on each switch position.
- Interfacing – The 8900 family supports GPIB or LAN interfaces allowing the customer to use whichever he prefers.
- Rackmounting options – The 8900 family offers two rackmount options, the first consists of standard rackmount ears that place the faceplate of the switching panel at the front of the rack, making all of the cables and connectors available to the user. The second option is a set of extended rackmount ears which recesses the faceplate of the switching panel back into the rack. In addition, a user-configurable faceplate is provided allowing the user to mount I/O connectors as needed.
- Optional LED Switch Indicators – The 8902 box provides a series of LEDs on the front panel to indicate the closure status of the microwave relays.

Website: http://www.gigatronics.com/.





LeCroy LabMaster 10 Zi Real-time Oscilloscopes

April 24, 2012 LeCroy Corporation announced the extension of the LabMaster 10 Zi product line to 65 GHz from a previously announced 60 GHz. LeCroy uses 8HP SiGe, the most recently available process, to obtain 36 GHz on four channels. LeCroy's 65 GHz model and 100 GHz plans are implemented with LeCroy's patented and proven technology path, DBI. Furthermore, LeCroy's proprietary ChannelSync™ architecture in the LabMaster 10 Zi oscilloscopes permits precise synchronization of up to eighty silicon-based 36 GHz / 80 GS/s channels and up to forty 65 GHz / 160 GS/s DBI channels—with a future 100 GHz upgrade path.

The LabMaster modular oscilloscope architecture separates the oscilloscope signal acquisition function from the display, control, and processing functions. The LabMaster Master Control Module (MCM-Zi) contains the display, controls, ChannelSync architecture, and a powerful server-class CPU. LabMaster 10 Zi Acquisition Modules, provide silicon-based 36 GHz performance with up to 65 GHz on two channels. One LabMaster 10 Zi Master Control Module and one LabMaster 10 Zi Acquisition Module function as a single, conventional four channel 36 GHz oscilloscope, or as a conventional two-channel 65 GHz and four-channel 36 GHz oscilloscope. However, by using ChannelSync architecture, up to twenty LabMaster 10 Zi Acquisition Modules can be perfectly synchronized, thus extending the already unique channel density performance by a factor of twenty to achieve up to eighty channels at 36 GHz and forty channels at 65 GHz.

The LabMaster ChannelSync architecture advantages are numerous. There is a single sample clock and trigger circuit utilized by all acquisition modules to provide the highest acquisition precision possible for up to eighty channels. There is a single display and a single server-class (12-core) central processing unit (CPU) in the MCM-Zi Master Control Module. All acquired channels and processed waveforms from all acquisition modules are displayed in one location for ease of use and understanding of information —just like in a single, conventional oscilloscope.

LeCroy is announcing a 28 Gb/s serial pattern trigger with support for up to 80-bit non-return to zero (NRZ) serial patterns, 8b/10b and 64b/66b symbols, and PCI Express Generation 3.0 protocol. This is in addition to the previously announced 14.1 Gb/s serial trigger with identical NRZ, A LeCroy LabMaster 10 Zi system with four channels at 65 GHz (two acquisition modules) will provide the ability to view two lanes simultaneously using cabled inputs and capture serial data signals with power spectral density to nearly the fifth harmonic, or use eight channels at 36 GHz to capture all four lanes for detailed crosstalk analysis.

To learn more, contact LeCroy at 1-800-5LeCroy (1-800-553-2769) or visit the LeCroy web site (www.lecroy.com).

Beamex® MC6 Field Calibrator and Communicator

Beamex® MC6 is an advanced, high-accuracy field calibrator and communicator. It offers calibration capabilities for pressure, temperature and various electrical signals. The MC6 also contains a full fieldbus communicator for HART, FOUNDATION Fieldbus and Profibus PA instruments. The usability and ease-of-use are among the main features of the MC6. It has a large 5.7" color touch-screen with a multilingual user interface. The robust IP65-rated dust- and water-proof casing, ergonomic design and light weight make it an ideal measurement device for field use in various industries. The MC6 is one device with five different operational modes, which means that it is fast and easy to use, and you can carry less equipment in the field. In addition, the MC6 communicates with Beamex CMX Calibration Software, enabling fully automated and paperless calibration and documentation.

- High-accuracy calibrator for pressure, temperature and electrical signals
- Full multi-bus communicator for HART, FOUNDATION Fieldbus and Profibus PA instruments
- Five operational modes: meter, calibrator, documenting calibrator, data logger and communicator
- Combines advanced functionality with ease-of-use
- Automates calibration procedures for paperless calibration management

For more information and to download related white papers, visit: www.beamex.com.

Ohm-Labs New High Voltage Standard

Ohm-Labs, Inc. has released a new high voltage divider for precision measurement of dc and 50/60 Hz ac high voltage.

The new model HVS incorporates improvements from ten years of manufacturing Park type dividers based on the former Julie Research Labs design (acquired in 2001) and the Sensitive Research / EIS design (acquired in 2010). Both these former models will continue to be supported.

The HVS is modular. 50 MΩ / 50 kV sections may be stacked to increase the measurement range. The low resistor is an Ohm-Labs 1 KΩ resistance standard which may be removed for characterization or exchanged for other ratios.

An innovative guard structure provides high immunity from leakage or ground plane coupling errors. It also provides a secondary metering output, independent of the main divider, for monitoring voltage during tests.

The modular design is rugged and does not require a special transit container.

ISO17025 accredited calibration is included up to 150 kV dc and 100 kV ac (60 Hz rms). Ohm-Labs maintains some of the lowest uncertainties in commercial high voltage calibration.

Please contact Ohm-Labs at 412-431-0640, or visit the website at www.ohm-labs.com for additional information.

NEW PRODUCTS AND SERVICES

New Crystal Engineering 24VDC Loop Power Supply

Crystal Engineering is announcing their latest product to complement their line of field calibration equipment. Convenient, portable power is a common challenge encountered during remote calibrations. The new 24VDC Loop Power Supply, model number 24VDCPS, provides a rugged and dependable, easy to use power source with a low noise regulated output, suitable for use with smart transmitters.

Once activated by the On button, power stays on until disconnected. Users may adjust connections simply by disconnecting and reattaching leads. The Power Hold feature automatically re-activates the circuit when reconnected within 30 seconds.

Bright multi-function icons indicate a powered loop, depleted batteries, and low voltage. Two batteries provide power for up to 14.5 hours. The device works with lithium, alkaline, or NiMH rechargeable AA's, in operating temperatures between -20 to 50°C (-4 to 122°F). The included rubber boot enhances the product's durability, allowing it to survive drops from 6 feet, and provides a convenient attachment point.

Crystal Engineering designed the 24VDC Loop Power Supply to work well with their nVision Reference Recorder and 30 Series Calibrator. It is available with or without test leads.

For more information, visit http://crystalengineering.net/24vdc.

Rohde & Schwarz Compact TV Analyzer

The R&S ETC mid-range, multistandard TV analyzer supports the ISDB-T, DVB-T and DVB-T2 digital terrestrial standards. It provides network operators with a convenient, cost-effective solution for testing their transmitters during commissioning, maintenance and servicing. The R&S ETC is ideal for this task–offering a wide range of functions including spectrum analysis, TV analysis, scalar network analysis and power measurement in a single instrument. It can also be used for network coverage measurements, such as during drive tests.

The compact TV analyzer fully supports the DVB-T2 single and multiple PLP transmission modes. It provides a detailed display of constellation diagrams, channel impulse response, shoulder distance of the OFDM spectrum and MER(k) (modulation error ratio versus OFDM carriers). The R&S ETC has an integrated preselection and preamplifier. This increases both dynamic range and sensitivity.

The core component of the R&S ETC is an FPGA-based demodulator, which demodulates the received signal in realtime and helps to achieve high measurement accuracy. Transducer factors for a given test antenna can be saved in the R&S ETC.

The R&S ETC compact TV analyzer with the R&S ETCView Windows-based PC software is now available from Rohde & Schwarz (http://www2.rohde-schwarz.com/).

NEW PRODUCTS AND SERVICES

Agilent Infiniium 90000 Q-Series Real-Time Oscilloscopes

April 11, 2012 Agilent Technologies Inc. introduced Infiniium 90000 Q-Series oscilloscopes with industry-leading, real-time bandwidth of 63 GHz on two channels and 33 GHz on four channels. The new lineup includes 10 four-channel models ranging from 20 GHz to 63 GHz, all of which are bandwidth upgradeable. These new scopes deliver the lowest noise and have the lowest jitter measurement floor in the oscilloscope industry, ensuring superior measurement accuracy.

At its maximum bandwidth the Q-Series breaks the 60-GHz barrier, with a -3 dB point of 63 GHz. The 33-GHz model allows engineers to simultaneously trigger on and capture signals on all four channels with no compromise. Key capabilities include:

- Direct digitization of M-band signals (60 GHz to 100 GHz).
- Capture of the third harmonic on 28-, 32- and 40-Gbps digital signals.
- Analysis of IEEE 802.3ba 40/100/400-GbE and Optical Internetworking Forum CEI 3.0 signals.
- Measurement of up to four differential channels in a single acquisition.
- Direct measurement of voltage swings larger than 1V.

The 90000 Q-Series allows engineers to take advantage of many years of industry-leading hardware and software advancements in Agilent's Infiniium oscilloscopes to include seamless integration of elements such as:

- Agilent's flexible and innovative InfiniiMax III probing technology for bandwidths up to 30 GHz.
- Compatibility with more than 40 measurement-specific application packages, including jitter, triggering, measurement, analysis tools and full compliance certification test suites.
- The ability to join multiple Q-Series oscilloscopes together to form a system of 40 channels or more.

- InfiniiView software lets engineers analyze data using oscilloscope software on a PC or laptop.
- N2807A PrecisionProbe Advanced software, helps engineers characterize/correct for cables to the full 63 GHz.

The 90000 Q-Series features industry-leading specifications:

- Rise time (<7 ps).
- Noise floor (4.4 mV at 50 mV/div, 63 GHz).
- Jitter measurement floor (~75 femtoseconds).

Additional information is available at www.agilent.com/find/90000Q-Series.

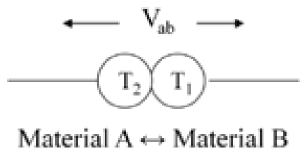
Watch Out for Those Thermoelectric Voltages!

Martin L. Kidd
Fluke Corporation

What are Thermal EMFs?

Thermoelectric voltages (EMFs) are the most common source of errors in low-voltage measurements. Thermal EMFs result from temperature differences within a measuring circuit at junctions between conductors made of dissimilar materials. The magnitude of a thermal EMF generated by a material junction depends on the thermoelectric coefficient of the two materials. For example, when connecting test leads to a voltmeter, at the point where the leads connect to the measurement terminals is a natural point where a thermoelectric voltage is created. The leads are rarely at the same temperature as the terminals when they are connected. Over time they should stabilize to a common temperature point. This time might be seconds, a few minutes, or many minutes or longer. There are many influences over this stabilization time.

Regarding the amount of this voltage, it has two main influences: the different materials that are in contact, which determines the Seebeck coefficient; and the temperature difference between the two materials. Mathematically, the temperature between materials is shown in the equation below.



$$V_{ab} = Q_{ab}\,(T_1 - T_2)$$

Q_{ab} is the Seebeck Coefficient of material A with respect to material B [1].

Paired Materials	µV/°C (Q_{ab})
Copper-Copper	<0.2
Copper-Cadmium/Tin Solder	0.2
Copper-Gold	0.3
Copper-Silver	0.3
Copper-Brass	3
Copper-Lead-Tin Solder	5
Copper-Aluminum	5
Copper-Nickel	10
Copper-Kovar	40
Copper-Copper Oxide	>1000

Table 1. Various Seebeck coefficients Q_{ab} for different materials that might be connected to copper. Copper is the common material used for electrical conductors, so the Seebeck coefficients relative to copper describe the most common conditions that are found in electrical test and measurement applications [1].

You can see from Table 1, copper to copper has the lowest coefficient. Gold and silver are also low, so you often see gold flashed copper in connections. The advantage here is gold does not oxidize as readily as copper. You can see oxidized copper has an extremely high coefficient (1000uV/degree)—so it is important to have clean copper connections. A common soldier connection uses tin/lead solder. Its connection with copper is shown here. At 5uV per degree it has about 25 times the effect as better materials, so a lower thermal soldier such as cadmium-tin soldier is better, having effects similar to the best materials.

How to Avoid EMF Errors

The best measurement practices to minimize thermal EMFs include zeroing the measurement device. It is important to zero the digital multimeter (DMM) to

Figure 1. Small shorting devices are shown here. Specially made circuit boards, supplied with Fluke's 8508A DMM, provide both ohmic and thermal zeros for quick stabilization.

eliminate internal offsets that occur naturally in circuits over both time and changing temperature conditions. The best practice for doing such a zero is to apply both an "ohmic" zero and a "thermal" zero to the DMM. Ohmic zeros have very small actual resistance so the measurement value is truly a zero without any unwanted offsets caused by I times R losses based on the current supplied by the meter and the physical resistance of the shorting device. (For example, milliamps of current through milliohms of resistance create microvolts of unwanted measurement voltage.)

Thermal zeros are short circuits that also have a low physical mass (or thermal mass). This permits a fast thermal equalization between the shorting device and the meter terminals. A low thermal mass enables the temperatures of the meter and shorting device to equalize to a common point and, as a result, have only insignificant thermal EMFs. Remember that any appreciable thermal emf will cause offset voltages. In Figure 1 you can see an example of a large mass shorting bar that is not satisfactory due to its size. Using such a large device would cause a very large delay before proper thermal equilibrium is reached between the terminals and such a large shorting bar. A thermally better shorting device with a smaller mass is also shown for comparison. You can appreciate the mass differences between the two shorting devices.

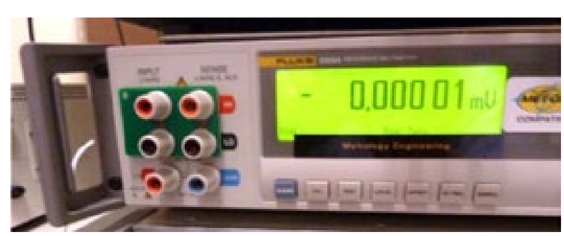
Another best practice recommendation is to use low thermal leads for connection between the UUT and DMM. It is best to use copper wires by itself, or with crimp attached copper lugs as connectors. Alternatively, low thermal solder is good, to attach lugs to wires. It is imperative to clean the connections to remove oxidation. If clean, non-oxidized copper is not practical, use gold flashed copper terminals as this will prevent oxidation and still maintain a low thermal EMF condition. Of course, controlling the environment is important. Keep the ambient temperature constant and avoid sources of heat such as sunlight or exhaust fans. Insulating or covering the sensitive connections is important and is a good practice to use in various situations.

A Demonstration

The following is a demonstration of how you can inadvertently introduce thermal EMF errors when zeroing a High Precision DMM.

The DMM is set to the most sensitive range to easily illustrate the effect. In this case, we set the 8508A reference multimeter to measure DC volts, on the 200 mV range. The filter is enabled and the resolution is set to 7.5 digits for a reasonable speed, yet accurate, measurement setup. The shorting PCB is connected to the input of the meter. This provides a zero condition with an easily usable, quality short, which is supplied with the meter.

For reference, the terminals of the meter are low thermal material—beryllium copper. The shorting PCB uses gold flashed copper on the connection surface, minimizing oxidation problems. It should be noted that the terminals of the DMM are at a higher temperature than room temperature, so there will always be a thermal condition to be aware of. In this case, the input thermals measured about 29 ˚C. Due to the relatively low thermal mass of the shorting PCB the short temperature comes to temperature equilibrium within about a minute. After thermal stabilization a zero is performed on the DMM. Excluding measurement environment noise, over a twenty minute period, the stability of the zero should be six least significant digits in this particular setup.



Now, let's compare how other devices, commonly found in the lab and possibly used to perform an instrument zero, compare to the zero we set with the shorting PCB. One simple test is to take a common test lead, and plug it into the meter so it shorts the high and low terminals with a low resistance 'zero.' You see the measurement on the DMM shows a number much different than the PCB. This is due to the fact the material on the banana plugs is comprised of nickel. It also is at a different temperature. This will create a thermal EMF that is often on the order of hundreds of counts.

Using this technique to zero a measurement instrument is not satisfactory when making measurements with sensitivities in the micro volt or several micro volt levels.

A dual banana plug with a shorting wire between the terminals is often found (and used) in labs.

The problem is not small, as the Seebeck effect between nickel and the copper beryllium terminals of the DMM is very measurable. Also, the thermal mass of the plug is moderately large, so stabilization will take longer than a short with less mass.

This short was found in a box of connection devices in a lab. Could this be a good device to use as a short? The terminals are better than nickel plated terminals, and should exhibit lower thermal EMF characteristics. It should have a very low ohmic resistance, given that the shorting bar is massive and is copper. It has a huge mass, so its thermal mass is also huge. It would require a very long time to thermally settle with the measurement instrument.

Given this short would be at room temperature, and the measurement instrument is several degrees higher than room temperature, the equalization/stabilization time is not practical. The bottom line is this: While this short is an ohmic zero, it definitely is not a zero for a thermal EMF voltage.

Some manufacturers and experienced measurement technicians find that simple copper wire is very satisfactory. This is often called bell wire (a simple wire that has historically been used for telephone connections). When a small solid copper wire is connected to the terminals, you will see this measured zero is very consistent with the performance of the shorting PCB.

The benefit here is both a low Seebeck coefficient and a low thermal mass.

If we re-examine the DMM's measurement zero by reattaching the shorting PCB, the zero should be within 6 LSD once it is settled.

The measured voltage is within 2 counts of the original zero. This confirms the voltages observed with the other shorting devices are EMF related.

Another best measurement practice to minimize thermal EMFs and various offsets is to make multiple measurements using lead reversal techniques. Diagram 1 illustrates an application where a single reference is measured by a DMM [1]. It models the thermal EMF voltage that is caused by different metals involved in connecting the cables to the UUT and DMM with associated temperature differences between the cables and terminals.

The leads are configured in a forward configuration for one measurement and reversed for a second measurement. The equivalent thermal EMF is constant in both cases. Mathematically, the thermal EMF is eliminated through taking half of the difference of the two measurements: $V_{Ref} = (+\text{ Forward} - \text{Reverse})/2$ [1].

There are other offsets which can come into play in such measurements. Also, when you make a null measurement between two standards, there are possibly some common mode signals which cause errors. More thorough reversing techniques will eliminate these errors very effectively. In practice, Fluke switches leads at both the DMM terminals (for forward and reverse conditions), and at the UUT (for positive and negative polarity conditions). Several measurements are taken at each lead configuration.

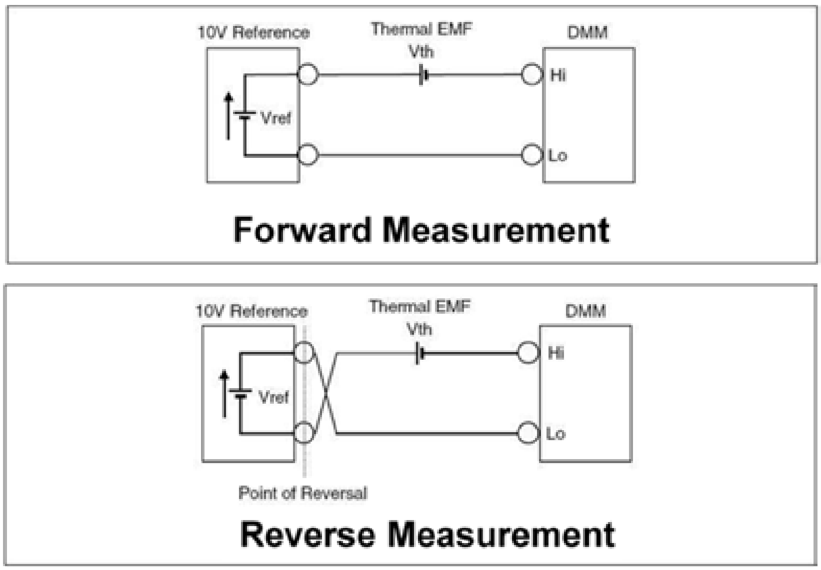


Diagram 1.

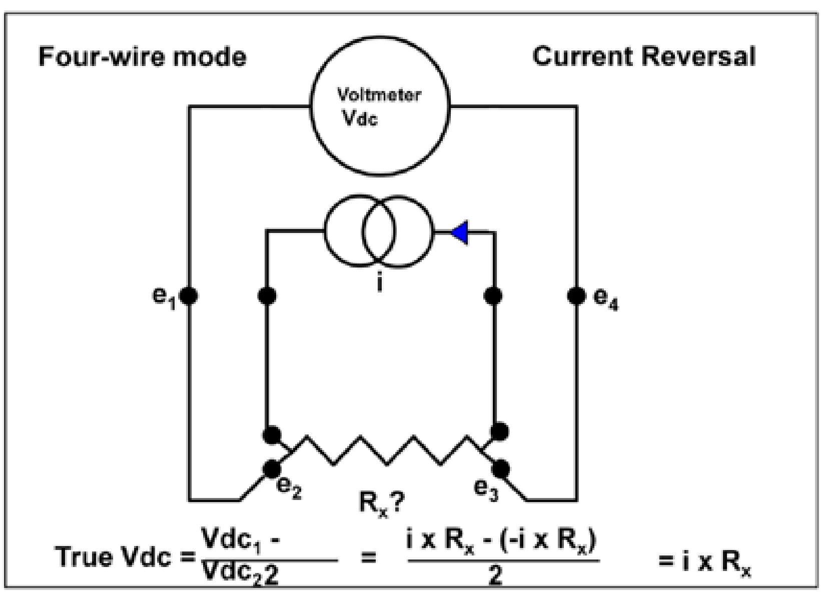


Diagram 2.

Another best measurement practice to minimize thermal EMFs and various offsets is to utilize instrument specific EMF reduction techniques. When measuring resistance with a high sensitivity, or at a low value, the four-wire ohms function is a technique that eliminates the unwanted effect of lead resistance and causing measurement error. Considering how a resistance measurement is done, a DMM usually has an internal precision current source which is used to stimulate the resistance being measured and uses its voltmeter capability to measure the voltage drop across the test resistor. In two wire connection mode, the additional resistance of the test leads can cause an error in the measurement. Making the measuring connection separate from the current source connection eliminates the lead resistance error. However, in the measurement circuit, there are four test lead connections. Each has a thermal EMF and these four thermal EMFs can also cause unwanted measurement errors.

Precision DMMs often have a technique to automatically remove the effects of thermal EMFs. In the 8508A, a technique called "Tru-ohms" can be used to easily remove EMFs. This technique is described in Diagram 2 [1]; it consists of making two measurements and adding the results. The direction of the source current is reversed in these two measurements and the mathematical combination of the two measurements removes the thermal EMF offset. The Tru-ohms method doubles the measurement time (as it takes twice as many measurements of the test resistance), but the thermal EMF errors become a non-issue.

Summary

Thermal EMFs can add unwanted errors to sensitive voltage and resistance measurements. Proper application practices can be used to minimize these errors:

- Use low thermal EMF cables & connections.
- Use proper zero techniques on measurement instruments.
- Use reversal techniques whenever possible.
- Take advantage of EMF limiting techniques found in precision instrumentation.

References

[1] Jack Somppi, "How to Avoid Surprising Errors from Thermal EMFs," Fluke Calibration How To Seminar.

Martin L. Kidd, Fluke Corporation, Everett, WA, martin.kidd@flukecal.com.

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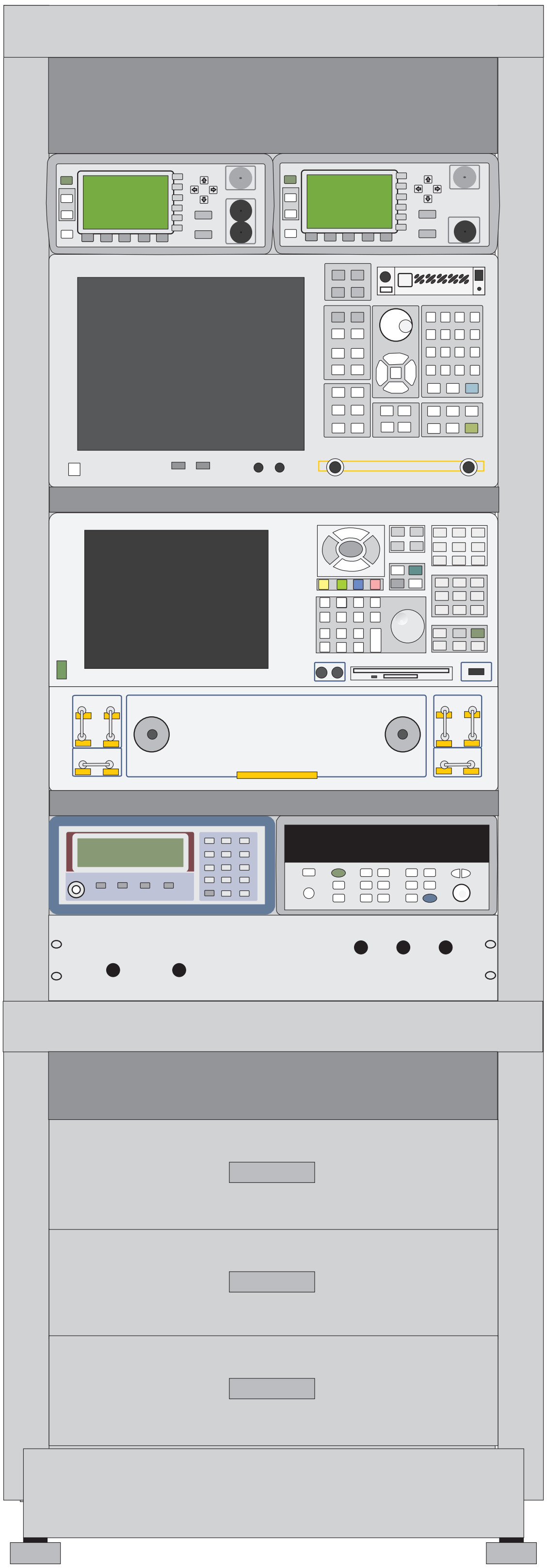

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Identifying and Avoiding Common Errors in RF Calibration

Paul Roberts
Fluke Calibration

There are many potential sources of human and measurement errors in RF calibration. This paper examines five common error sources associated with connectors, cables, and accessories such as adapters, splitters and couplers: their choice, use, maintenance, and application of correction factors and uncertainty contributions.

Introduction

RF and Microwave calibration is one of the most complex fields of metrology, with many potential sources and opportunities for human and measurement errors. While focus is often applied to the technical complexity and ensuring appropriate equipment, procedures and practice are employed, simple basic errors still occur. Common examples are the choice, use and maintenance of cables, connectors and accessories such as adapters, attenuators, splitters and couplers and the application of correction factors and associated uncertainty contributions. This paper examines five common sources of measurement error, how to identify them, and how to avoid them.

The five topics are:

- Choosing and using cables
- Making repeatable connections
- Applying correction factors correctly
- Working with power splitters and dividers
- Minimizing mismatch errors and uncertainties

Choosing and Using Cables

Coaxial cables are common throughout RF and Microwave calibration, representing significant investment as precision cables can be very expensive. Choosing an appropriate cable type is often critical to successfully making accurate, repeatable measurements. Characteristics of the cable, the connectors, and the attachment of the connectors to the cable all contribute. The key characteristics are attenuation; phase shift (delay) and match, and their stability with time; temperature; and flexing/movement of the cable and connectors. Maintaining the cable and connectors in good condition is essential to minimizing errors and uncertainties.

For less demanding applications such as distributing reference frequencies, around the laboratory or between individual instruments within a system, typical general purpose RG58 cable using BNC connectors will suffice (Figure 1). However, these types of cables are not appropriate for metrology applications where signal level or phase accuracy and stability or impedance match is critical. Generally the BNC connector is not appropriate for

Figure 1. General purpose coaxial cables.

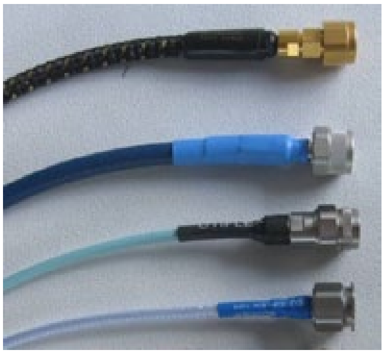


Figure 2. Precision metrology grade coaxial cables.

Figure 3. Phase and level stable cables used for Vector Network Analyzer (VNA) test port connections. VNA test port cables are extremely flexible, maintaining loss/phase characteristics when moved and flexed (extremely expensive).

calibration applications but there are some higher quality BNC connectors available which are typically used with higher grade cables in oscilloscope calibration. The majority of oscilloscopes appearing in the calibration workload have BNC connectors, so use of a BNC connector is unavoidable.

A few typical examples of metrology grade cables are shown in Figure 2. Unsurprisingly, the improved performance is accompanied by higher costs, typically an order of magnitude more expensive than general purpose cables, with the higher precision cables being even more expensive. These flexible and semi-flexible cables are of the 'level stable' type, where attenuation characteristics are not significantly affected by variations in temperature and flexing. Good practice is to observe a minimum bend radius of around 100mm. Kinked cables will have unpredictable performance and should be discarded to prevent inadvertent use.

Phase stable cable types, as their name implies, also maintain phase (delay) characteristics with time, temperature and flexing. Cable of this type is commonly used as Vector Network Analyzer (VNA) test port cable where good flexibility and immunity to bending and flexing are required (Figure 3).

The manner in which the connector and cable are joined—crimped or clamped—is also important, both electrically and mechanically. Mechanical arrangements differ with connector design, with potential discontinuity of the transmission outer conductor through the termination resulting in variations in transmission line characteristic impedance and therefore contributes to match (mis-match) performance. In a crimped connector, the cable outer conductor is secured by compression between a metal sleeve and the connector body. In a clamped connector, there is a nut and ferrule securing the cable outer conductor to the connector body. Crimping has the potential to add further transmission line discontinuities if the pressure applied to form the crimp distort the cable or connector components. Clamping has the potential for a smoother transition of the transmission line outer conductor, and therefore better match. However, there is opportunity for loosening of the clamping nut with cable movement, etc, degrading the connection impacting attenuation and match performance, potentially in an intermittent fashion. Crimped and clamped terminations have different attributes and users should choose according to their needs.

It is good practice to consider cables much like any other calibrated item within the laboratory. Cables should be included in routine maintenance and calibration schedules and serialized or provided asset tags as a means of identifying individual items. Many higher grade cables are supplied with measured data for attenuation and match and users may make their own measurements (for example, when using VNAs). Regularly inspect cables and connectors for damage and any other degradation that might affect performance, monitoring characteristics, changes; where appropriate, account for the characteristics during use.

Making Repeatable Connections

RF measurements and the associated uncertainty depend on the integrity of the cables and connectors used to interconnect the various instruments and devices involved. Employing best practice is essential in avoiding and reducing uncertainty contributions. Poor performance of coaxial devices and interconnections can be traced directly to problems with out-of- tolerance dimensions, cleanliness, damage or incorrect tightening of connectors. Furthermore a dirty, damaged or out-of-tolerance connector mated to an otherwise good connector can cause it to become damaged, clearly undesirable if the resulting damage is to a connector on a customer's unit or a laboratory standard. Figure 4 shows a damaged N-type connector on one end of a coaxial attenuator, with arrows indicating cracks in the dielectric disc supporting the center contact. Poor and variable alignment of the center contact arising from this damage was ultimately found to be responsible for bad repeatability in measurements made using this device.

It is essential that connectors are inspected for damage and dirt before they are connected to one another every time a connection is made, or at least daily. Connector threads

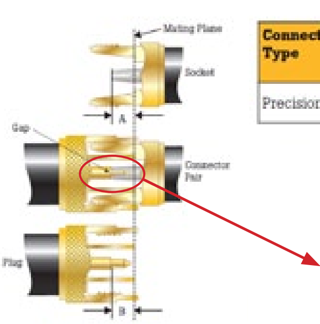
Figure 4. N-type coaxial attenuator connector with cracked center contact supporting disk which caused poor measurement repeatability. The arrows indicate the cracks in the dielectric supporting disc.

and contacts can become dirty from finger oils, airborne contaminants, and from swarf generated in the threads when the connectors are tightened. Dirty or contaminated contacts degrade characteristics of the connecter which can cause undesirable effects, particularly poor repeatability and high/variable VSWR (match). Look for dents, raised edges, and scratches on the mating surfaces. Connectors that have dents on the mating surfaces usually also have raised edges around them and will make less than perfect contact. Raised edges on mating interfaces will make dents in other connectors to which they are mated. An illuminated magnifier or eye glass is very useful, and small wooden cocktail sticks can be used to remove small particles. Any loose particles on the connector surfaces, contacts and threads should be removed using low-pressure solvent-free compressed air. Cans of compressed air for this and other equipment cleaning and maintenance purposes are readily available. Never blow into a connector because moist breath will contaminate the connector even further! Once loose particles are removed, cleaning with a small amount of solvent will remove any attached dirt and contamination. Isopropyl alcohol (isopropanol) is the solvent of choice, applied with a cotton swab or lint free cloth. Care is needed to avoid exerting any force on the connector that might damage or bend the connector pins or sockets. Protective end caps should be used to cover connectors when not in use to prevent contamination or damage by foreign bodies.

Best practice requires that all coaxial connectors fitted on all equipment, cables and terminations should be gauged on a routine basis in order to detect any out-of-tolerance mechanical conditions that may impair the electrical performance or cause connector damage. Coaxial connectors should never be forced together when making a connection, because forcing often indicates incorrectness, damage or incompatibility. Gauge kits for checking the mechanical dimensions for all connector types are available from a variety of manufacturers. Certain dimensions (see Figure 5 for a precision N-type connector) are critical for the mechanical integrity, nondestructive mating and electrical performance of the connector. There are a number of different mechanical specifications for the type N connector and the user should be clear on the mechanical requirement needed for a particular application (precision, general purpose, etc.). Figure 5 shows that the precision Type N connector has the junction mating surface offset from the reference plane to reduce mechanical damage or misalignment when making connections. Also, the inner female pin of the Type N socket connector is of the non-slotted type, to produce characteristic impedance that is independent of the mating pin.

When connecting or disconnecting, avoid misalignment and rotate the connector nut, not the body. Damage can be caused if the mating surfaces rub against each other or the center contacts are twisted. Correct tightening torque will ensure a good connection and avoid damage. Excessive torque can lead to mechanical damage, deformation of the contacts, and result in degraded VSWR. Connectors should be tightened to the manufacturer's recommended torque using a torque wrench. A gentle smooth pressure should be applied directly through the axis until the wrench "breaks" at the correct torque setting. No further pressure should be applied. With torque wrenches, it is possible to get substantially the wrong applied torque by using a twisting action. It is sometimes useful to use a small flat wrench on a connector body to prevent any rotation when making connection. Always make sure that the torque wrench is at the correct setting before use. The torque wrench used should be routinely checked or calibrated. If it is an adjustable type wrench, it should be adjusted to the correct torque settings for the specific connector and clearly marked. If a connector nut has only a knurl and a torque wrench cannot be used the connector should be finger tight. Be aware, it is possible to over-torque a connector by hand tightening if excessive force is used!

Connector repeatability is typically one of the most significant contributors to measurement uncertainty in RF and Microwave calibrations. Connector repeatability is a type A uncertainty contribution, to be assessed and accounted for within the uncertainty budget, by making repeat measurements. To properly account for connector repeatability, it is necessary to make measurements with several connect/disconnect cycles. Furthermore, best practice is to make each repeat measurement with a different connector orientation with three to five orientations covering the full 360°. This ensures potential changes in contact conditions of the mated connectors at different axial



Connector Type	Socket dimension A (inches)	Plug dimension B (inches)	Gap between the mated center contacts (inches)		
			min	nom	max
Precision N	$0.207^{0.000}_{-0.003}$	$0.208^{+0.003}_{0.000}$	0.001	0.001	0.007

The center pin gap represents a change in transmission line inner conductor diameter, resulting in a small mismatch. Ensuring the correct gap minimizes mismatch.

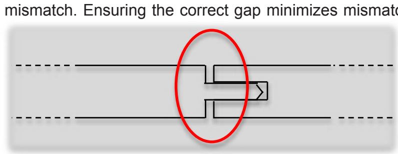


Figure 5. Cross-section of an N-type connector showing the reference (mating) plane and the relevant connector critical dimensions.

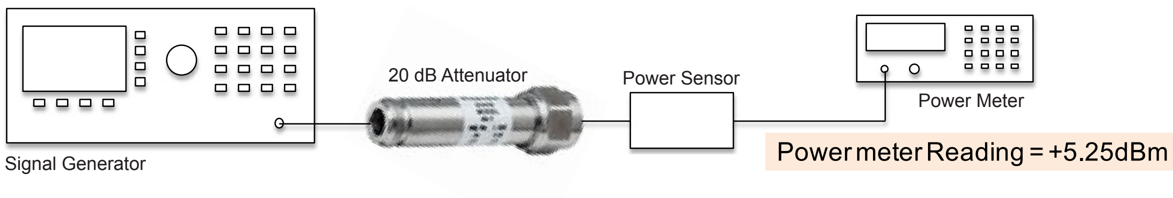


Figure 6. Using a 20 dB attenuator to reduce a signal source output level to within a power sensor range.

orientations and their impact on attenuation, match, etc., are accounted for within the connector repeatability uncertainty contribution.

Applying Correction Factors Correctly

The need to apply correction factors is commonplace in RF and Microwave calibration. Examples would be applying values from a certificate of calibration for standards, or correcting for device/system characteristics derived during measurement, such as adapter insertion loss or splitter tracking error.

Simple human errors may also occur. Incorrect arithmetic and algorithms may be implemented or embedded in automated calculations, such as spreadsheets and software. Mistakes can often go undetected when applied corrections are small. Problems with small values may give apparently believable results, but the results will be in error and any measurement uncertainty estimates will be invalid. Unexpected results are more obvious when large corrections are wrongly applied. It is good practice to test and validate any calculations (including formulae and algorithms in spreadsheets and software) with deliberately large numbers to make the effect of applying correction factors easily observed!

Care is needed to apply 'signed' quantities appropriately and consistently (for example, attenuation values 20 dB or -20 dB). Avoid confusion between 'errors' and 'corrections' usually considered as having opposite signs. The key to avoiding incorrect results is to derive and propagate correction factors consistently. Test algorithms and calculations with values that will clearly demonstrate their correctness or otherwise!

Consider the following simple example of a 20 dB coaxial attenuator, used to reduce the signal level of a source to be calibrated within the range of an available power sensor (Figure 6). Attenuation data from the attenuator's calibration certificate appears in Table 1.

The attenuator could be said to have an attenuation of approximately 19.9 dB, corresponding to an error of -0.1 dB from the nominal 20 dB, which also could be interpreted as requiring a correction of +0.1 dB to be applied to a measurement result (if 'corrections' have opposite signs to 'errors').

In this example, the power meter reads +5.25 dBm, so the signal source power output is nominally (+5.25 + 20) = +25.25 dBm. But the attenuator has an error of -0.1 dB from nominal, so the actual signal source output is 5.25+(20-0.1) = +25.15 dBm. Simply applying (adding) a correction of +0.1 dB to the nominal +25.25 dBm result would give an incorrect value of +25.35 dBm, demonstrating the caution needed to appropriately and consistently propagate and apply calibrated values, errors, and corrections. Note that the certificate of calibration avoids any ambiguity by stating measured values, not 'errors' or 'corrections.'

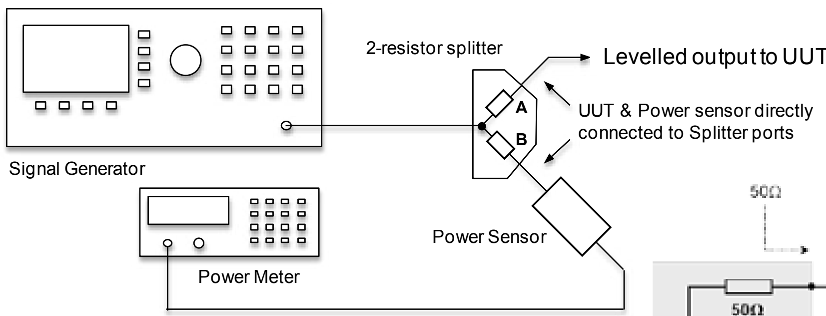
Working with Power Splitters and Dividers

The difference between power splitters and power dividers and their applications are often misunderstood, leading to incorrect choice of device and attendant measurement errors. Both devices may be used to split or combine signals, and sometimes the appropriate choice may be unclear.

The power splitter is often referred to as a "2-resistor splitter." As its name suggests, the 2-resistor splitter is constructed in such a manner as to provide two very well matched impedances close to 50 Ω, between the input and each output port. Figure 7 depicts the typical power splitter application of precision leveling, where a power senor is connected to one splitter output port and the leveled signal appears at the other output port connected to the UUT.

Frequency (MHz)	Attenuation (dB)	Attenuation Uncertainty (± dB)
0.10	19.903	0.003
0.30	19.903	0.003
0.34	19.903	0.003
0.50	19.903	0.003
1.00	19.903	0.003
2.00	19.904	0.003
5.00	19.905	0.003
10.00	19.906	0.003
20.00	19.907	0.003
30.00	19.907	0.003
40.00	19.909	0.003
50.00	19.909	0.003

Table 1. Calibration data for the 20 dB attenuator in the example shown in Figure 6



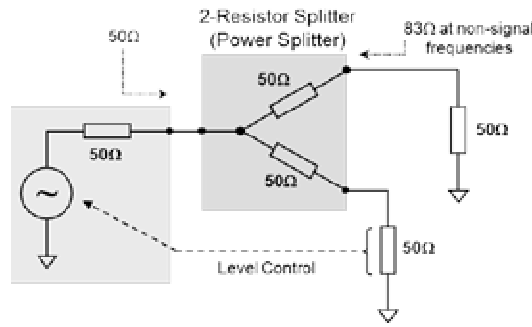


Figure 7. Power splitter (2-resistor splitter) employed for precision levelling.

Feedback from the power meter, either as analog level control feedback, or by computational correction establishes the desired output level at the port connected to the power sensor. As the two splitter resistors are essentially identical, the same level appears at the other port connected to the UUT input. The effect of feedback (analog or computational) is to create a source of precise level from a very good 50 Ω impedance. However, analysis of the network impedances would suggest the output impedance should be 83 Ω. The 50 Ω impedance is only presented at the UUT at the signal frequency due to the feedback control loop, and 83 Ω is presented at all other frequencies. In practice, this is not an issue and power splitters are the appropriate devices when used in this manner for precision leveling applications.

The power divider, often called a "3-resistor divider," is constructed to be the equivalent of three equal (approximately 16.6 Ω) resistors, as shown in Figure 8. In practice, its construction may not be three individual resistors on a substrate, instead having resistive material deposited on the substrate with three connections providing an equivalent circuit corresponding to three resistors. This power divider device may be used for simple power splitting applications, but should not be used for precision leveling applications commonly encountered in calibration applications. Its use is often more common in signal combining applications, as illustrated in Figure 8. Unlike the power divider, it presents 50 Ω at all three ports. In calibration application requiring combining of signals and greater isolation between the sources such as spectrum analyzer intermodulation testing, it is more common to use directional couplers.

In addition to the choice of device, making the connections with the correct physical device orientation is often the cause of errors, for example, when using a power divider. Devices vary in their mechanical layout and packaging, with some having port configuration easier to identify than others. Figure 9 shows one style of power divider device connected for precision leveling where its shape and labeling clearly differentiate the input and output ports.

Figure 10 shows another power divider device connected for this same application of establishing a precision level for spectrum analyzer calibration. However, it is easy to confuse the device port configuration

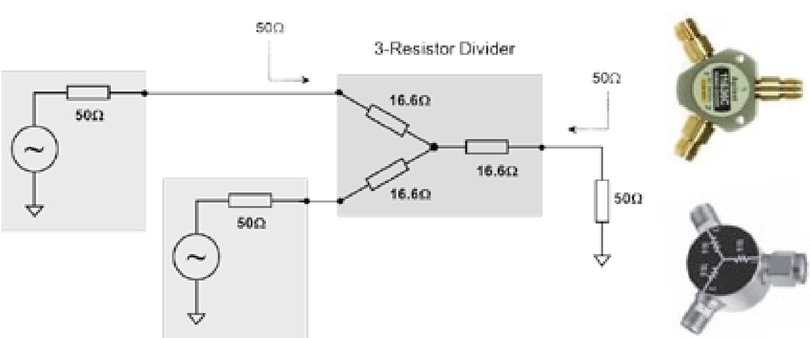


Figure 8. Power divider (3-resistor divider) employed for combining signals from two sources, also showing typical example devices.

Figure 9. An example of a power splitter employed for precision levelling in a spectrum analyzer calibration application where the device shape and labelling help to easily identify its port configuration.

Figure 10. A power splitter correctly configured (left) and incorrectly configured (center) for precision levelling. On the right, a direct connection from the levelling head of an RF Reference Source.

and reverse the source and power sensor connections as shown in the center of Figure 10. This confusion is reportedly a common mistake made with this particular style of splitter device because the incorrect connection appears to offer opportunity to more easily support the power sensor when the setup is made close to the edge of the bench. Mistakes can be avoided and measurement errors reduced by employing an RF Reference Source. The RF Reference Source delivers an accurate input directly to the UUT via a leveling head without need for a power sensor and splitter (the Fluke 9640A), as shown in Figure 10 above.

Minimizing Mismatch Errors and Uncertainties

Along with connector repeatability as discussed previously, mismatch errors are one of the most significant contributions to errors and uncertainties in RF & Microwave calibration. Mismatch error depends on the source and load match:

$$\textit{Power Error} = \left\{1 - \frac{1}{\left(1 \pm |\Gamma_S||\Gamma_L|\right)^2}\right\} \times 100\%$$

where Γ_S is the source reflection coefficient and Γ_L is the load reflection coefficient. The reflection coefficient Γ (gamma) is a vector quantity, however often only its magnitude |Γ| is known from a scalar measurement. Reflection coefficient, return loss and voltage standing wave ratio (VSWR) are all related measures of match, with VSWR probably being the most commonly used, where:

Reflection coefficient $\rho = |\Gamma| = \frac{VSWR - 1}{VSWR + 1}$

Return loss $= 20 \log |\Gamma|^{-1}$

It is evident that the quality of the source and load match both contribute to the mismatch error, and also that if either one is very good (close to the ideal 50 Ω, with VSWR approaching 1.0:1) the impact of the other being relatively poor is reduced. This latter effect can be exploited in practical measurement situations to reduce mismatch errors by deliberately inserting a device with good match characteristics (low VSWR). The device, an attenuator, often referred to as a “masking pad” or “matching pad” is inserted at the point where doing so will bring the greatest benefit—at the point where the match is worst or most variable. In this instance, the purpose of the attenuator is only match improvement and not signals level reduction. (Note that the term matching pad is also used for impedance conversion pads, used to convert between 75 Ω and 50 Ω, and these are different devices.)

An appreciation of the mechanism of mismatch error reduction can be obtained by considering Figures 11 and 12. Figure 11 depicts the reflection of a proportion of the signal at the interconnection of a source and load device where a mismatch occurs. When the masking pad is inserted, as shown in Figure 12, the reflection travels through the masking pad twice. Therefore, the magnitude of the reflection is reduced by twice the pad attenuation value, thus reducing the effect of the otherwise poor match.

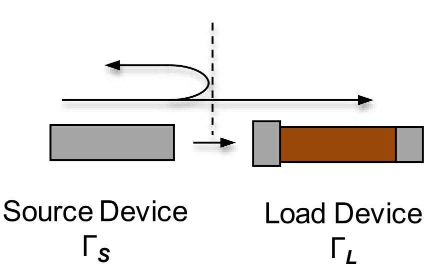


Figure 11. Reflection occurs at the mismatch between source and load.

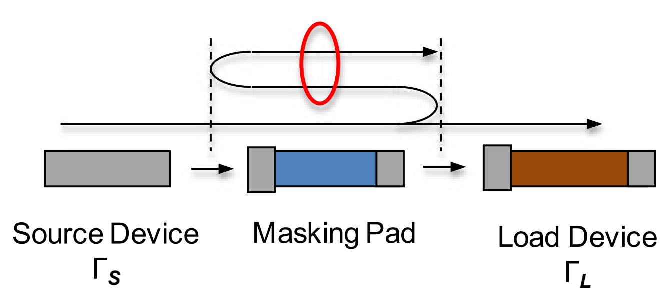


Figure 12. The reflection travels twice through the masking pad inserted between source and load.

Inserting attenuation, thus reducing signal level, can negatively impact measurements. Signal levels move closer to the noise floor or require higher input levels, which place greater demands on signal source output capability. However, relatively small value pads (3 dB or 6 dB) are generally sufficient to significantly improve match conditions and reduce mismatch errors with only moderate and generally tolerable signal level reductions. It is relatively easy to obtain attenuator devices with good match performance. However, there can be a limit where the masking pad match may not be good enough to provide significant improvement over the match provided by the source and load connected directly if they are also well matched devices.

Most commonly, the masking pad technique is used to improve match of active devices such as output match of a signal source or input match of a measuring device. The output or input is directly from/to an active device with no passive circuits or attenuator to better define matching conditions. The masking pad should be placed at the end of any interconnecting cable, furthest away from the signal source, such that it 'masks' the match of both the generator and cable. Another common application is switched step attenuators, which may be permanently fitted with masking pads at their input and output to ensure the various attenuator stages work into a constant well defined match. Frequently, the entire attenuator and masking pad combination is submitted for calibration as a single unit.

Conclusions

Five common sources of error in RF & Microwave calibration have been discussed along with hints and best practice guidance to identify and avoid them. Mistakes, measurement errors, and uncertainties can be eliminated or minimized by following best practice:

- Use appropriate metrology grade cables and connectors.
- Regularly inspect cables connectors and adapters for damage, cleanliness and compliance with mechanical specifications (gauging).
- Ensure connectors are correctly stored, handled, and tightened with correct torque.
- Derive and apply correction factors in a consistent manner.
- Test any and all calculations, algorithms (manual, in paper procedures and embedded in software and spreadsheets) with numeric values that will make obvious any mistakes and incorrect implementations.
- Use power splitters for precision leveling applications. Power dividers may be more appropriate for signal combining applications.
- When using splitters and dividers, pay close attention to device physical input and output configurations.
- Masking pads (attenuators) can significantly reduce the impact if poor match (high VSWR) devices on mismatch errors and uncertainties.

The topics have been treated in a practical back-to-basics manner avoiding, where possible, any detailed mathematics. However, references are provided where further detail may be obtained.

References

1. "The ANAMET Connector Guide," available from www.npl.co.uk.

2. Fluke Application Note "RF Calibration Best Practices Guide: Coaxial Connectors," document 2649664 A-EN-N, available from www.flukecal.com.

3. Aeroflex datasheet "Power Splitters and Dividers," available from www.aeroflex.com/weinschel.

4. Agilent Technologies Application Note "Differences in Application between Power Dividers and Power Splitters," document 5989-6699EN, available from www.agilent.com.

5. Fluke Application Note "Calibrating attenuators using the 9640A RF Reference," document 4015975A A-EN-N, available from www.flukecal.com.

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This paper was previously presented at the Measurement Science Conference (MSC), on March 22, 2012 in Anaheim, CA.

A Comparison of 12 US Liquid Hydrocarbon Flow Standards and the Transition to Safer Calibration Liquids

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During 2010 and 2011, NIST piloted a 12-laboratory comparison of hydrocarbon liquid flow calibration standards spanning the range 3.8 L/min to 38 L/min. The laboratories were in mutual agreement within the expected 0.3% uncertainty, which is approximately half as large as the differences measured in a similar 1988 comparison. The transfer standard (a pair of turbine flow meters in series) introduced an uncertainty of 0.17%* into the comparison. The comparison protocol used methods that were developed during international comparisons including: using uncertainty weighting to generate a best fit comparison reference curve, using statistical criteria to remove discrepant results from the fit, assessing and including in the data analysis the uncertainty contributed by the transfer standard, and reporting a standardized degree of equivalence between the participants. Several laboratories used mixtures of propylene glycol and water (PG + W) instead of Stoddard solvent (the commonly used surrogate for jet fuel) because the PG+W mixtures are safer and cheaper to manage environmentally. This comparison and other studies show that there is no significant difference in the calibration results between Stoddard solvent and a PG + W mixture with the same kinematic viscosity. Therefore, NIST is changing its calibration fluid to PG + W and encourages other laboratories to do the same.

* All uncertainties are approximately 95% confidence level (k=2) unless otherwise stated.

Introduction

The aerospace industry and the US Department of Defense measure fuel consumption in jet engine test stands and in other applications using turbine meters that are periodically calibrated against reference standards. The end users require flow measurements with uncertainties < 0.5% and the test uncertainty ratio of 3 to 1 through multiple calibration layers imposes low uncertainty demands on the reference standards (< 0.1%). Calibration laboratories maintain their traceability, proficiency, and understanding of the behavior of the flow meters over wide ranging operating conditions so that they can assist the end users in correctly using flow meters to achieve their required uncertainties. Some labs conduct periodic comparisons with NIST by sending their check standards (usually turbine meters) to NIST for calibration. This is a valuable element of quality assurance, but it does not compare secondary or tertiary labs directly. Hence it is also valuable to periodically send a transfer standard to a large number of participants to confirm that the traceability hierarchy is functioning well and that there is the desired degree of equivalence between calibrations from all of the labs. The last time such a comparison was conducted for this sector was 1988 [1].

During the last decade, national metrology institutes (NMIs) such as NIST conducted key comparisons to demonstrate that they meet their uncertainty claims. Flow key comparisons are organized by the Bureau International des Poids et Mesures and its NMI members in the Working Group for Fluid Flow (WGFF). These international comparisons have developed a body of knowledge and consensus about comparison methodology. Some examples are:

- Publication of the Guidelines for CIPM Key Comparisons [2] which formalized aspects of planning and conducting a comparison such as: the selection and number of participants and using an agreed upon protocol that covers (1) the schedule, (2) instructions for operating the transfer standard, (3) reporting results (including uncertainty), and (4) communication issues such as keeping results confidential, resolution of anomalous results, and the review of draft reports before dissemination.
- Papers on processing comparison data, particularly Cox's The Evaluation of Key Comparison Data [3], which documents the calculation of the key comparison reference value (KCRV), its uncertainty, and degrees of equivalence (differences) between laboratories. Cox recommends two methods for calculating the KCRV: 1) an "uncertainty weighted average"* of the participants' results or 2) in case of statistically discrepant results (outliers), the median.
- The Working Group for Fluid Flow developed specific recommendations for comparisons that use flow meters as transfer standards. They include thorough preliminary testing of the transfer standard to determine its sensitivities to environmental and installation variables and the uncertainty it contributes to the comparison [4]. If a transfer standard is sensitive to the fluid temperature (or other variables), this must be identified and quantified before the comparison begins. Otherwise, differences introduced by the sensitivity of the transfer standard to environmental and installation effects will be incorrectly interpreted as lab-to-lab differences. Another idea adopted by the WGFF is to fit a curve to the participants' flow meter calibration data and to calculate differences of each lab from this "comparison reference curve" [5].

The present comparison of labs that calibrate flow meters for hydrocarbon liquids intentionally exploited the experience gained during prior international comparisons. In the following sections we will describe the reference and transfer standards used, the working fluids, details of the comparison data analysis, and the results of the comparison.

The Reference and Transfer Standards

All of the comparison participants used volumetric piston provers as the reference flow standard, similar to the NIST 20 L piston prover shown in Figure 1 [6]. A variable speed motor pushes a piston through a cylinder of known diameter, driving the calibration fluid through connecting piping to the meter under test. The position of the piston (and hence the volume of liquid pushed out of the cylinder) is measured with optical encoders (20 μm resolution) that are attached to the piston shafts. Valves in the connecting piping are automatically switched to maintain flow in the positive direction through the meter under test even though the piston alternates direction when it reaches the cylinder ends. To avoid cavitation at the meter under test, the entire system is placed under pressure by an external gas source. Pressure and temperature sensors allow corrections for storage effects, such as changes in the mass of the liquid in the connecting piping due to changes in liquid density over time.

* Using the inverses of the squares of the participants' uncertainties as weights gives greater significance in the comparison reference value calculation to laboratories with lower uncertainty.

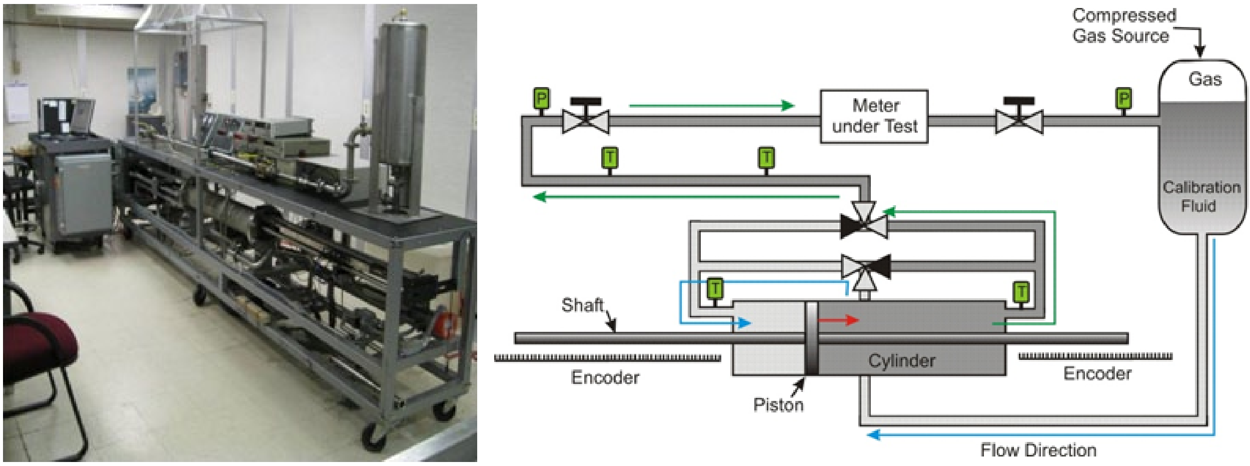


Figure 1. The NIST 20 L piston prover. Flow directions in the schematic are shown for the piston travelling from left to right. The T and P symbols represent temperature and pressure sensors.

The transfer standard for this comparison was two 1.3 cm nominal diameter dual rotor turbine meters installed in series. A plus-sign-shaped flow straightener was installed in the approach tube upstream of each turbine meter. Each participating laboratory recorded the sum of the dual rotor frequencies from the output of the manufacturer's signal conditioner. The protocol called for: (1) testing of the transfer standard at three nominal flows (3.8 L/min, 12 L/min, and 38 L/min), (2) reversing the order of the flow set points, and (3) reversing the order of the two meters (configurations 1 and 2). Steps (2) and (3) were used to evaluate hysteresis, installation effects, and reproducibility. Five data points were collected at each flow set point and meter configuration, resulting in 120 data points for each of the two turbine meters. Approximately halfway through the comparison, one of the turbines (SN 5644) was damaged by a piece of debris in the flow and it was replaced by a new turbine (SN 5852). One of the original two turbines (SN 5643) functioned well throughout the entire comparison.

Laboratory	Liquid	Kinematic Viscosity (mm^2/s)	*U* (flow) or *U* (PS) (*k* = 2, %)
NIST	SS, PG + W	1.22	0.07
Air Force Primary Standards Lab	SS	1.29	0.05
Arnold Air Force Base	PG + W	1.2	0.05
Hill Air Force Base	SS	1.32	0.05
Robins Air Force Base	SS	1.24	0.05
Tinker Air Force Base	SS	1.3	0.05
Army Primary Standards Lab	SS	1.28	0.043
TMDE Support Center Corpus Christi Army Depot	SS	1.27	0.06
Navy Mid-Atlantic Regional Cal Center	SS	1.23	0.08
Flow Dynamics, Inc.	SS	1.31	0.04
Flow Technology, Inc.	SS	1.26	0.036
University of Tennessee Space Institute	PG + W	1.26	0.06 to 0.19

Table 1. Summary of comparison participants. Laboratory name, reference standard liquids (SS = Stoddard solvent, PG + W = propylene glycol and water mixture), its nominal kinematic viscosity at the temperature of the measurements, and the approximately 95% confidence level uncertainty for flow measurement reported by each participant are shown.

Calibration Liquids Used

Today, most laboratories that calibrate turbine meters for jet fuel applications use Stoddard solvent* as a surrogate fluid because it is less flammable and toxic than jet fuel, however, it still presents fire and biological hazards. Recently, Arnold Air Force Base Calibration Laboratories and NIST replaced Stoddard solvent with biologically and environmentally benign mixtures of propylene glycol and water. The Army Primary Standards Laboratory is also studying PG + W as an alternative calibration liquid [7]. A mixture of approximately 7% by weight (or volume) propylene glycol in water matches the kinematic viscosity of jet fuel at 21 °C (approximately 1.2×10^{-6} m^2/s) and pure propylene glycol has a kinematic viscosity of approximately 50×10^{-6} m^2/s, which matches the middle of the range of hydraulic oils at 21 °C. Propylene glycol ($C_3H_8O_2$) is commercially available, "generally recognized as safe" by the Food and Drug Administration, and is an ingredient in many consumer products such as cosmetics and food. Calibration laboratories that replace Stoddard solvent with mixtures of propylene glycol and water will (1) reduce inhalation danger to workers, (2) eliminate fire danger, and (3) decrease the cost of disposal of hydrocarbon liquids. NIST calibrations of turbine meters using flows of many mixtures of propylene glycol and water agreed with NIST's Stoddard solvent calibrations within 0.02% [8]. These results validated the theory for the dependence of turbine meter calibrations on the fluid properties density and viscosity. NIST's theory for turbine meters also incorporates the effects of bearing friction and fluid drag. In addition, it correlates data spanning a 200:1 flow range with liquid mixtures spanning a 42:1 kinematic viscosity range. Based on these results, the consensus of a NIST Workshop held in September 2011 was that where practical, NIST and other calibration laboratories should transition from Stoddard solvent to propylene glycol and water mixtures in their calibration services.

Data Processing

The calibration results were reported using the dimensionless Strouhal (St) and Roshko (Ro) numbers. In this comparison the Strouhal number was defined as:

$$St = \frac{\pi f D^3}{4Q_{MUT}} \qquad (1)$$

where Q_{MUT} is the actual volumetric flow at the meter under test (i.e. the reference flow measured by the participant), D = 1.3 cm is the diameter of the flow meter, and f is the sum of the two rotor frequencies from the meters under test. The Roshko number was defined as:

$$Ro = \frac{f D^2}{\nu} \qquad (2)$$

where υ is the value of liquid kinematic viscosity (i.e., density divided by dynamic viscosity) at the fluid's temperature and pressure. The diameter in Eqns. (1) and (2) was corrected for thermal expansion, but these corrections were insignificant (0.01% or less)**.

The three flow set points for the comparison were selected in the viscosity independent range of the turbine meters [8]. Preliminary testing at NIST identified the viscosity independent range of each turbine meter at $Ro > 5 \times 10^4$.

NIST used a best-fit polynomial to obtain comparison reference curves (CRCs) for each turbine meter. Only data for each turbine meter in the upstream position was used to obtain the CRCs and in most of the comparison analysis. The data were fitted using three different options (see Figure 2): (1) using equally weighted data from the participants (including NIST) at the three flow set points, with discrepant results removed, (2) using uncertainty-weighted data [$1/U^2(St)$ where $U(St)$ is the expanded uncertainty of the Strouhal number] from the participants at the three flow set points, with discrepant results removed and (3) using equally weighted data from NIST alone, including both preliminary and post-comparison testing to check the transfer standard stability [3]. (Note that the numerous data used to obtain the "NIST only" fit are not shown in Figure 2, only the averages from one run of the protocol that was used as the NIST comparison data.) The largest difference (0.08%) between the three versions of best fit curves occurred at the medium flow set point for the replacement turbine meter, SN 5852 (see Figure 2C insert). The uncertainty-weighted fit to all participants (option 2) was used as the comparison reference curve for all three turbine meters.

A polynomial in log (Ro) was used to fit the calibration curves:

$$St_{CRC} = a_0 + a_1 \log(Ro) + a_2 \log(Ro)^2 + a_4 \log(Ro)^4 \qquad (3)$$

The coefficient a_4 was zero for two of the turbines (SN 5644 and 5643) but a nonzero value was necessary to obtain an acceptable fit to the data for the replacement turbine (SN 5852). Also, because of the unusual shape of the SN 5852 calibration curve, an extra set of NIST data (distributed over a wider range than the comparison flow set points) was added to the fitting process, shown as "NIST extra" in Figure 2C. This produced a better fit at the endpoints of the comparison flow range. Once the comparison reference curves for the three turbines were established, the results of the comparison were analyzed by examining the percent difference between each participant's results and the CRC.

* MIL-PRF-7024E Type II, a light mineral oil.

** Several presentation methods for turbine calibration data are available. Here we use Strouhal versus Roshko numbers, but the K factor = f/Q_{MUT} versus f/υ is also commonly used as is the Reynolds number for the abscissa. All would have worked equally well in this comparison. Strouhal versus Roshko numbers have the advantage of being dimensionless and accounting for thermal expansion effects on the meter dimensions (not a significant effect here). While the Reynolds number is dimensionless, the Roshko number has the advantage that it does not require Q_{MUT} and hence avoids an iterative process when the calibrated turbine meter is used to measure flow.

Uncertainty of the Strouhal Number

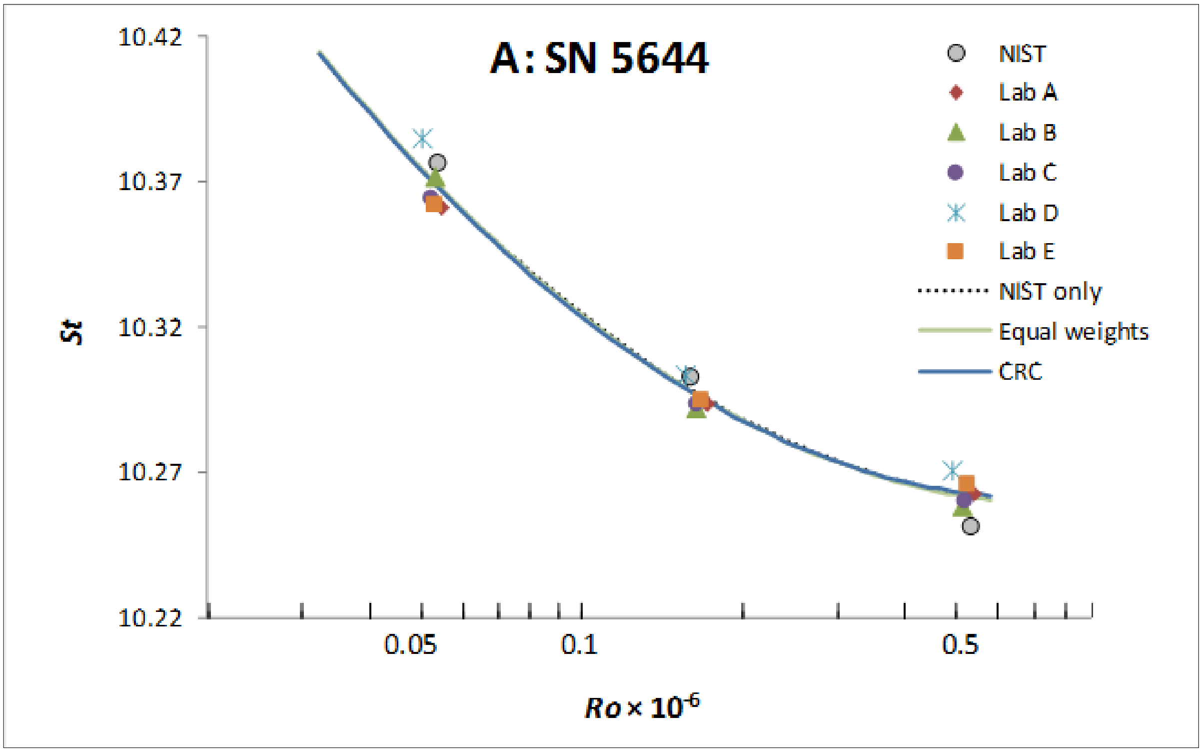
The uncertainty of the Strouhal number values reported by each laboratory are necessary inputs for the comparison data processing. They are used for performing chi-squared tests to eliminate outliers from the CRC calculations, for the weighting in calculating the CRC, and for calculating the uncertainty of the CRC [3]. In this comparison, the uncertainty components related to the transfer standard were similar in magnitude to the largest primary standard uncertainty, leading to a large and nearly constant value for the uncertainty of the Strouhal number for all participants (0.15% to 0.19%, k = 2). This resulted in approximately equal significance for each participant in the uncertainty-weighted best fits.

The expanded uncertainty of St was calculated using the formula:

$$U^2(St) = U^2(PS) + U^2(S) + U^2(v) + U^2(f) + U^2(T) \quad (4)$$

where the variable names and how they were determined are:

1. $U(PS)$ is the expanded uncertainty of the participant's primary standard. These values were reported by each lab (see Table 1) and ranged between 0.036% and 0.19%. $U(PS)$ does not include the reproducibility of the meter calibration data from the comparison.
2. $U(S)$ represents the calibration stability of the transfer standard over the course of the comparison. This value was determined by doubling the standard deviation of the residuals of best fit curves for all NIST preliminary testing at the set point flows over the 2 year period of the comparison. $U(S)$ was 0.1%, 0.14%, and 0.1% for SN 5644, SN 5643, and SN 5852 respectively. We also studied the ratio of the upstream and downstream meter frequencies in order to check that the two turbines maintained calibration stability while in use at the participating labs and found similar variability. This component also covers the uncertainty due to irreproducibility in the participant labs.
3. $U(v)$ is the expanded uncertainty in St due to kinematic viscosity effects. Participants used either Stoddard solvent or propylene glycol and water mixtures that varied in kinematic viscosity between 1.20×10^{-6} m²/s and 1.32×10^{-6} m²/s. A NIST evaluation of turbine meters used for Stoddard solvent and PG + W mixtures determined that the fluid change introduced an expanded uncertainty of 0.02% within the viscosity-independent range of a turbine meter [8]. This sub-component was root-sum-squared (RSS) with a second sub-component, resulting from uncertainty in the kinematic viscosity values used by each lab. This second sub-component



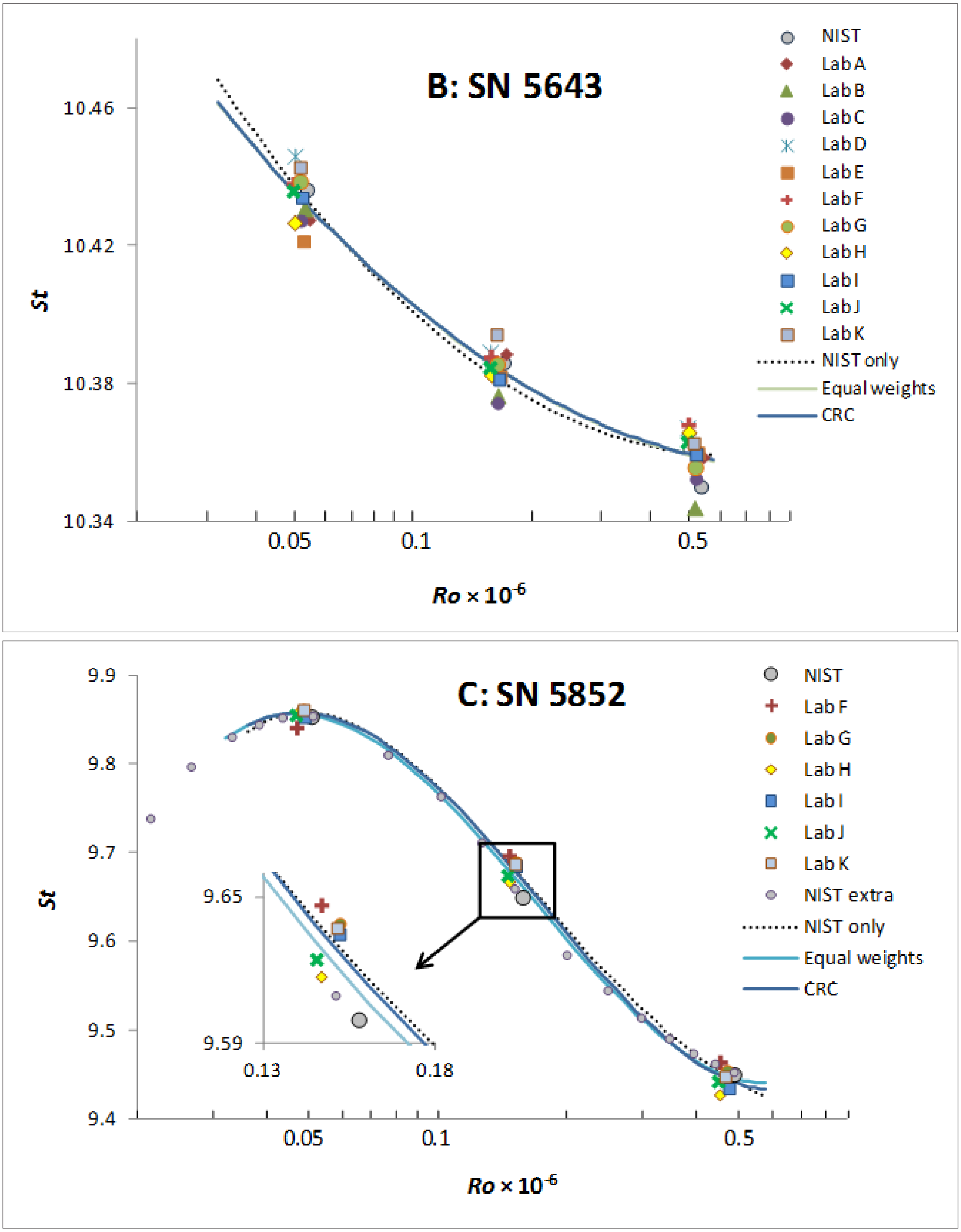


Figure 2. Best fit comparison reference curves for the 3 turbine meters and the data used to obtain them. Three versions of best fit curves are shown, but uncertainty-weighted fits to all participants were used as the comparison reference curve (CRC). Note that the "equal weights" curve is not visible in panels 2A and 2B because it is covered by the CRC. The insert in panel 2C shows two clusters of data separated by 0.3% at the medium flow.

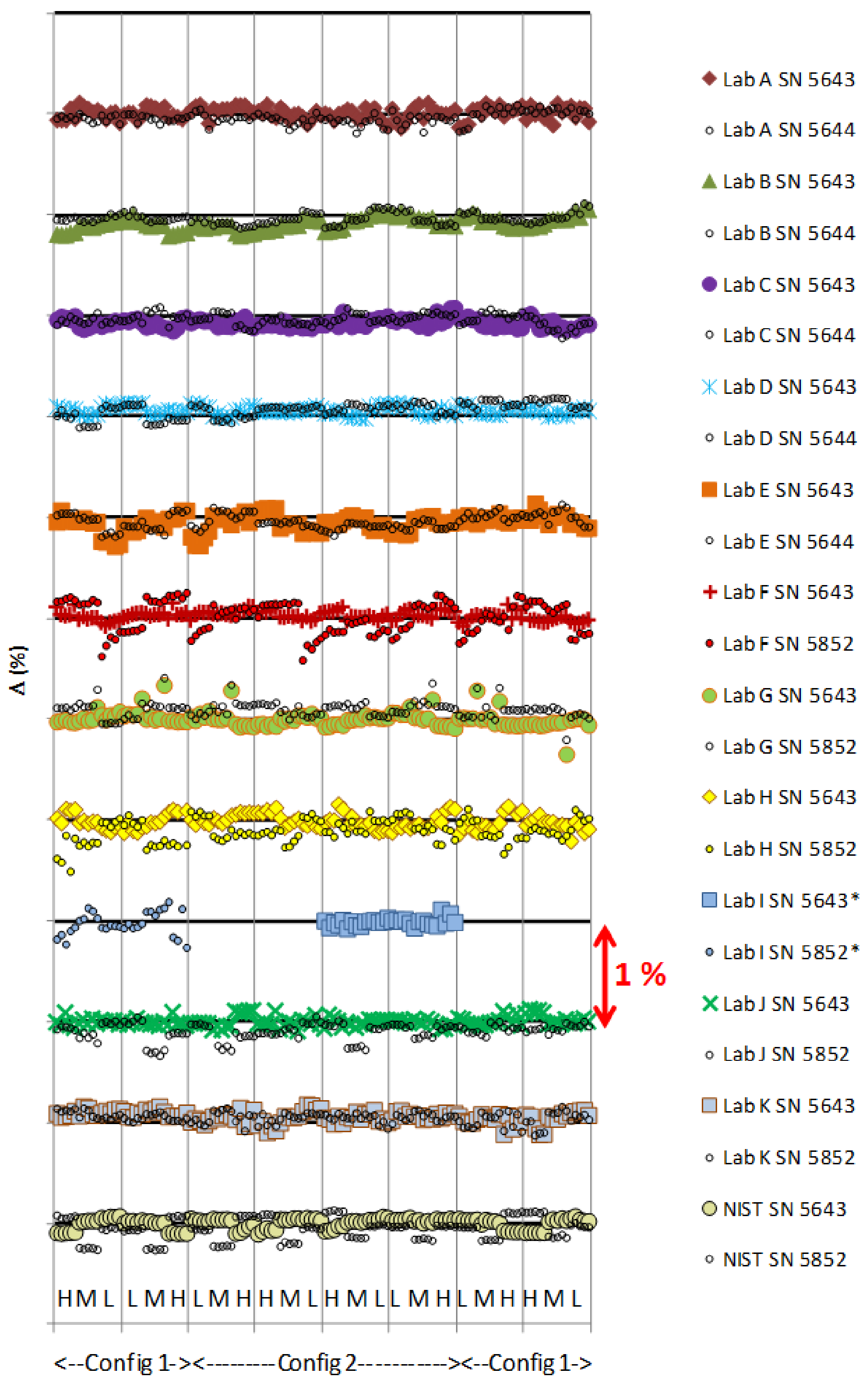


Figure 3. Data for both turbine meters collected by each participant for all configurations (upstream or downstream positions).
*The data from Lab I were not collected with 2 meters in series.

was determined by calculating the slope of the *St* vs. *Ro* plot for each meter at the 3 comparison flows and assuming a 4% expanded uncertainty in the reported v values due to either (1) temperature measurement uncertainty or (2) problems with the systems used to determine the relationship between v and T. The uncertainty in *St* introduced by a 4% uncertainty in v varied between a negligible value (where the calibration curves are flat) to 0.1 % for SN 5852 at the medium flow set point. Using the worst case of 0.1 % for the second component, the root-sum-square of the two $U(v)$ sub-components rounds to 0.1%.

4. $U(f)$ and $U(T)$ are the uncertainties due to frequency and temperature measurements respectively and both are negligible in this comparison. In a few cases, there were obvious problems in frequency measurements and these data points or sets were re-measured or removed. The effects of temperature uncertainties via thermal expansion corrections are negligible (<0.01% for 6 °C) and the effect of temperature on kinematic viscosity was included in $U(v)$ above.

Combining these components leads to an expanded, 95% confidence level $U(St)$ of 0.15% to 0.19%, depending on the participant and turbine meter considered. Combining the components $U(S)$ and $U(v)$ gives an expanded uncertainty due to the transfer standard of 0.14% to 0.17%.

Comparison Results

Figure 3 shows the data processed for the comparison. The y-axis shows the difference from the CRC in percent (Δ), with each participant's results offset by an integer multiple of 1% so that the data for different labs do not overlap. The x-axis is a time series of the 120 individual points as measured in the protocol. The x-axis is labeled with both the configuration (1 or 2, i.e. which meter is in the upstream position) and with the flow set point (low=L, medium=M, and high=H). Configuration 1 is the arrangement with either SN 5644 or its replacement, SN 5852 in the upstream position. Configuration 2 is the arrangement with SN 5643 in the upstream position.

NIST testing at the conclusion of the comparison showed that the pressure drop through the transfer standard was large, and unless the meters were calibrated at pressures > 480 kPa, incorrect, low *St* values were measured at the downstream turbine, probably due to cavitation. The data affected by this problem was either removed or additional testing was done at higher pressures to remove this source of error from the comparison results. One participant re-tested because of interference between the two turbine meter outputs in their data acquisition system. Lab I could only test one meter at a time because of data acquisition limitations.

Figure 4 presents the comparison results as standardized degree of equivalence, E_n, in which the difference between each participant and the comparison reference curves (Δ) is normalized by the uncertainty expectations for the difference:

$$E_n = \frac{\Delta}{U(\Delta)} \tag{5}$$

where $U(\Delta)$ is the $k = 2$ uncertainty of the difference between a participant result and the CRC [3]. By this measure, E_n values between -1 and 1 indicate that a participant is in agreement with the comparison reference curve within uncertainty expectations. All points for all labs fall within this bound for SN 5643. Two labs have $|E_n| > 1$ for SN 5852. The figure uses data from Figure 3, for each turbine meter when it was tested in the upstream position, i.e. configuration 1 for SN 5644 or SN 5852 and configuration 2 for SN 5643. Each point in Figure 4 represents the average of the 20 individual data points at the low, medium, and high flow set points, labeled as, L, M, or H, respectively.

Discussion

One of the two turbine meters was damaged and replaced about half way through the comparison. Using data from the meter that worked throughout (SN 5643), all participants had $|E_n| < 1$ (within uncertainty expectations) for all 3 flow set points and the largest difference between any two labs was 0.27%; given the ability of the transfer standard and protocol to resolve differences, the participants met their uncertainty claims. For SN 5852, two labs had $|E_n| > 1$ and the largest difference between any two labs was 0.39%. Two of the three $|E_n| > 1$ points were due to results for SN 5852 at the medium flow falling in two clusters separated by 0.3% (see Figure 2C). Since these lab-to-lab differences are not found for the other meter (SN 5643), they can be attributed to SN 5852 and not the laboratory reference standards. In fact, there is a noticeable increase in the range of E_n values for the replacement turbine meter relative to the other two turbines (see Figure 4). The lab-to-lab differences measured in this comparison are approximately half as large as those measured in the 1988 comparison [1].

The ability to discern differences between the participating labs was hampered by uncertainty components related to the transfer standard: (1) long term calibration stability (0.1% to 0.14%) and (2) kinematic viscosity effects (0.1%) which are large compared to some of the uncertainties of the primary standards reported by the participants (0.036% to 0.19%). The long term calibration stability of the transfer standard was assessed using (1) repeated calibrations performed at NIST before, during, and after the comparison, (2) the variance of the meter output frequency ratios when tested in series by each participant, and (3) the range of points in the northeast to southwest direction in Youden plots [9]. All three approaches gave similar results,

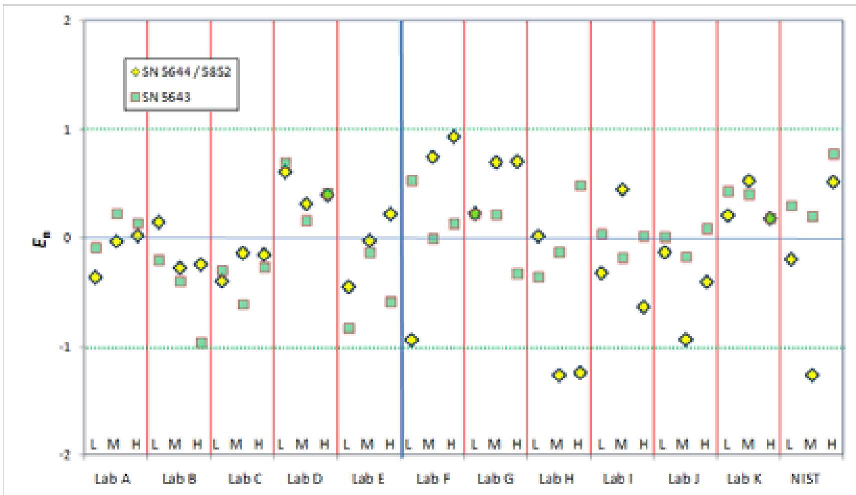


Figure 4. Standardized degree of equivalence for each meter while in the upstream position at the 3 flow set points (low=L, medium=M, and high=H). The vertical line between Labs E and F indicates the change from turbine SN 5644 to SN 5852.

0.1% to 0.14%. A more stable transfer standard is required to evaluate the uncertainty statements of participants in future studies.

Most of the comparison participants used Stoddard solvent, a surrogate for jet fuel, as the test liquid. Several participants instead chose mixtures of propylene glycol and water with the same kinematic viscosity as jet fuel because it is biologically and environmentally benign. Recent theoretical and experimental studies at NIST [8] conclude that the calibration results are effectively the same for either liquid. The results of this comparison are consistent with that conclusion: there was no significant difference between the labs using PG + W and those using Stoddard solvent. Some concerns remain about the long-term effect of exposing 440c stainless steel turbine meter bearings to water solutions, and NIST is now conducting experiments on this topic. To date, we have found that keeping bearing exposure to water to a minimum and drying the meters after calibration with successive ethanol washes is sufficient to prevent corrosion. Where practical, NIST and other laboratories are currently transitioning from Stoddard solvent to safer water-based solutions.

Acknowledgements: The financial support for this study by the Department of Defense Physical/Mechanical Calibration Coordination Group under Project Number 585 is gratefully acknowledged.

References

[1] Mattingly, G. E., "A Round Robin Flow Measurement Testing Program Using Hydrocarbon Liquids: Results for First Phase Testing," NISTIR 88-4013, September 1988.

[2] *Guidelines for CIPM Key Comparisons*, Committee International des Poids et Mesures, March 1999, updated October 2003, www.bipm.org.

[3] Cox, M. G., "The Evaluation of Key Comparison Data," *Metrologia*, 39, pp. 589 to 595, 2002.

[4] Wright, J. D., "Uncertainty of the Critical Venturi Transfer Standard Used in the K6 Gas Flow Key Comparison," FLOMEKO proceedings, Johannesburg, South Africa, September 2007.

[5] Dopheide, D., Mickan, B., Kramer, R., Hotze, H.-J., Vallet, J.-P., Reader-Harris, M., Shaw, J.-H., and Park, K.-A., "Final Report on the CIPM Key Comparisons for Air and Nitrogen Conducted in November 2004 / June 2005 CCM.FF-5b, Metrologia, 2006, 43, Tech. Suppl., 07008.

[6] Johnson, A. N., Crowley, C. J., and Yeh, T. T., Uncertainty Analysis of NIST's 20 Liter Hydrocarbon Liquid Flow Standard, FLOMEKO proceedings, Taipei, Taiwan, October 2010.

[7] Ball, J. M., Turbine Flow Meter Calibration Using Nonhazardous, Nonpolluting Fluid Mixtures to Simulate Fuels and Lubricants," *Cal Lab*, Jul Aug Sep 2011, pp. 32 to 36.

[8] Pope, J. G., Wright, J. D., Johnson, A. N., and Moldover, M. R., "Extended Lee Model for the Turbine Meter and Calibrations with Surrogate Fluids," *J. Flow Meas. and Instrum.*, 24, 2012, pp. 71 to 82.

[9] Mattingly, G. E., "Flow Measurement Proficiency Testing," in *Flow Measurement: Practical Guides to Measurement and Control*, 2nd edition, D. W. Spitzer editor, ISA, 2001.

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Rethinking the Flexible Standards Paradigm

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In many of today's software projects, developers are challenged with the task of designing interchangeable standards architecture into their metrology based applications. Currently, many developers see an oscilloscope as an oscilloscope and believe that all oscilloscopes are created equal, and are therefore interchangeable; at the same time, any oscilloscope manufacturer will tell you their oscilloscope is different with special features requiring non-standardized sets of commands to implement those special and specific features. Consequently, developers write their code to implement special and unique features in what was designed to be a generic driver. Cal Lab Solutions took a step back to re-evaluate the problem and all the solutions. We came up with a software design methodology that allows the user to incorporate non-standardized features of complex standards while maintaining a highly flexible interchangeable instrumentation model. This paper will demonstrate how a process centric model allows greater flexibility over the generic command centric model.

Overview

Software design at its core is an abstraction of reality. Software projects succeed or fail based on the architecture and how the developers approach the problem they are designed to solve. A software design based on a solid abstraction is more likely to succeed having an extended lifespan, reusability, and flexibility; whereas a bad abstraction most likely will result in a poor software solution leading to a weak and fragile final product. This paradigm holds true for the metrology related software solutions.

Designing flexible and robust software solutions is no easy task. There are countless hours spent at the drawing board. Ideas are vetted; models are designed, evaluated, and thrown away. Through a lot of trial and error, a solid design appears. And when the design appears, it is so elegant it looks intuitive; and you are left asking yourself why we didn't do this in the first place.

Through this process, we stumbled upon a design model that solves the problem on complex instrumentation, as well as functions cross-platform, by making a slight alteration to the paradigm behind the underling concept of flexible standards.

Background

For years I have attended conference reading papers and watched presentations rehashing the same old interchangeable standards paradigm. Despite dynamic changes in the design of instrumentation, the industry still thinks of equipment and flexibility in terms of equipment classification, as if all instruments fall neatly into some form of generalization. Much of the industry's automation software is based on these assumptions; idiosyncrasies of the equipment classification type are written into the calling code, limiting the flexibility of the software.

The assumption that an instrument will fall into some kind of general classification is flawed; and history demonstrates how problematic this assumption can be. For example, when I came into calibration in the late 1980's we had a DC Voltage Standard, an AC Voltage Standard, and a set of standard resistors. Today, all of those instruments are wrapped up into one instrument called a multi-function calibrator. Looking at the historical evolution of instruments in general, as an instrument peaks in measurement accuracy, manufacturers start adding capabilities and instruments then morph into something else, creating entirely new instruments.

With today's increased computing power, Moore's Law allowed products to morph and hybridize at an ever increasing pace [1]. Today we have oscilloscopes with a built-in arbitrary waveform generator, hand-held digital multimeters that output current and pulses, and even oscilloscopes with fully functional spectrum analyzers built in. And this is just the beginning!

Built-in Complexity

Each time an instrument adds capabilities, it increases its operational complexity. This leads to increased complexity in the instrument's remote operation command structure. This forces developers to write wrappers, patches and Band-Aids adding unwanted complexity to the software.

Another change in complexity we are seeing is in the communication mechanisms. For more than two decades, GPIB has been the dominate medium used for communication. Today, many instruments have several options with it comes to communication, each with its own level of complexity.

Modular Instruments

We are also starting to see a larger number of modular instruments. In the not too distant future, they will become a predominate part of the instrumentation we will be supporting. Tomorrow's instruments will be a conglomeration of the sub-components, assembled in the modular hardware section, and designed to solve a specific set of measurement problems. Manufacturers are already offering built to order configurations of instruments, but a modular architecture gives them much greater flexibility.

Modular instrumentation provides manufacturers with some very distinct advantages: it allows them to right-size an instrument to the customers' unique requirements; manufacturers are better able to balance cost vs. measurement requirements—where traditional instruments would typically have more features than required for many applications; it allows them to go to market faster, because the underlying hardware is flexible—can be easily configured and reconfigured; then, user defined interface allows the manufacturer to customize the instrument to the measurement needs.

The impact of this migration to modular instrumentation on metrology will be just as significant, causing some major disruptions in many of the software systems we are currently using. The first major disruption will be that many manufacturers are not investing in the development of a command language to control the instrument. Manufacturers instead rely on software drivers in order to communicate with the instrument; because there is no command language, software solutions designed using a database of commands will no longer work. Developers will then have to create a patch to their software in order to communicate with the manufacturer's drivers.

Where the Model Breaks

The examples cited above demonstrate some weakness in the architectural designs being implemented in several software solutions currently on the market. Despite solving many of today's measurement problems, without extensive rewrites, solutions using the generic command centric model will become more and more difficult to support and maintain as the underlying design principles of instruments changes.

Concerns arise when looking at many of today's flexible standard models. First, as complexity of the command syntax increases, a simple model of inserting a value into a formatted string will be problematic as instruments morph. This model lacks the fundamental flexibility required to adjust for programmatical variations in the instrument's implementation. One prime example of a complex instrument available today is the Agilent E4440A. This instrument has several modes of operation, and thus the complexity of a simple reset now takes several commands and queries.

Another concern is error checking and error handling. When a simple command syntax replacement is being used, there is often no implementation of error handling. Each instrument has drastically different implementations of error handling so it becomes very difficult to compress into simple commands. Furthermore, proper error checking should include, at a minimum, both range checking for measurement validation, in addition to verification the instrument is properly configured with no configuration errors. These errors must also be passed back to the calling environment so they can be handled properly.

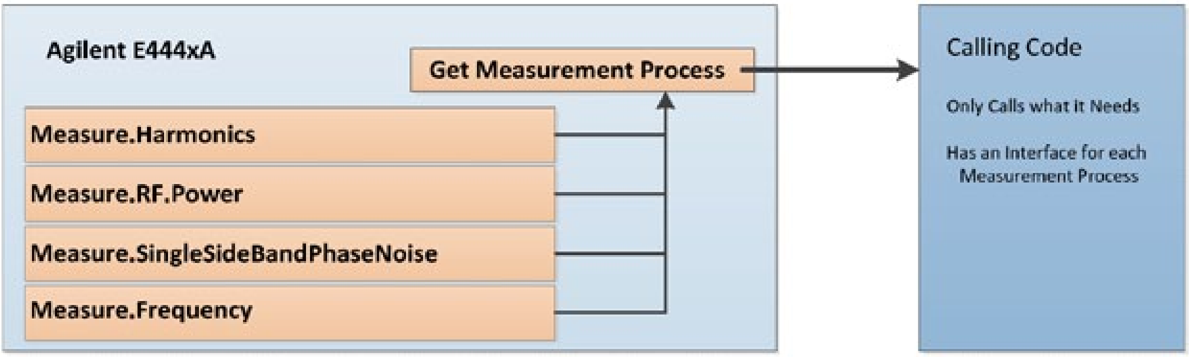
Eventually the command replacement model will become obsolete, as instruments move from a command based control model to a driver based model. As instruments change to modular based instruments, very complex instruments using desktop computer power with Distributed Component Object Models (DCOM) command languages will no longer dominate instrument control. Program control of instruments will become very specific and tightly coupled to the drivers provided by the manufacturer. Solutions on the market today will require a middleware tool or a patch to bridge the incompatibility.

Rethinking the Paradigm

First we need to rethink the concept of instrument interchangeability. With instruments increasingly hybridized to increase their features, the concept of a generic instrument class driver, with commands stored in data, no longer functions. This presented a problem and forced us back to the drawing board, where we threw everything out and rethought the model from scratch. We discovered a driver model that allows us greater flexibility, one that can withstand the changes in technology and hybridization of instrumentation. By understanding and utilizing the principles of Object Oriented Programming (OOP) [2], we broke our software structure down into core reusable pieces of code. When we looked at an instrument from the perspective of a collection of metrology functions, not a device type, we discovered that model was very solid and very flexible [3]. And keeping with OOP, our abstraction matched reality, allowing us to mimic in software what manufacturers were doing in hardware. Because when you think about it, they are just adding measurement capability.

Measurement Process Model™

We came up with the Measurement Process Model™, which allows us to create a series of very small drivers for any given instrument and providing a standard methodology of assembling them into a hybridized instrument driver. As shown in the figure below, the Get Measurement Process allows the calling procedure



to laterally ask the driver if it supports the measurement functions it needs. If the driver does not support a measurement function, the calling procedure is not able to use that instrument.

The abstraction shows that each of the measurement functions in the driver represents a contract defining the specific operations and interaction between the calling procedure and the instrument driver. The calling procedure explicitly knows how to use the measurement driver though it has no idea of the specific implementation.

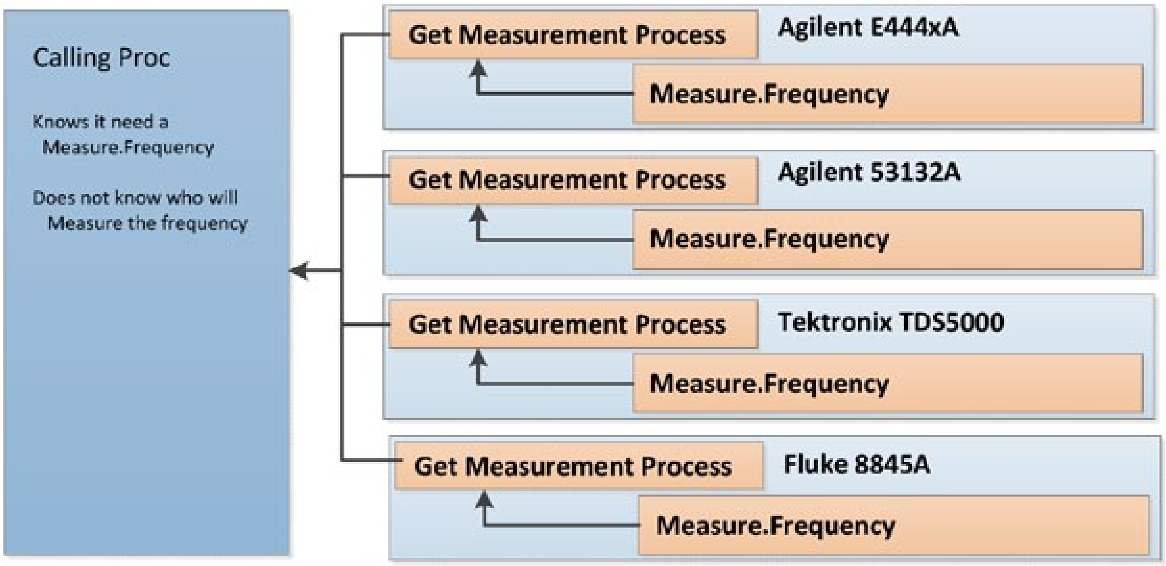
When you look at it from the calling code, you can see the power of this new paradigm by changing our focus from an instrument classification basis to a measurement process model. We gain greater flexibility by not limiting standard substitution to a single instruments classification. Now we can use a wider range of instruments capable of implementing the required measurement process.

Cross Platform Compatibility

In theory, when a concept is sound, it will work in multiple software tools and cross-platform. So far, the implementation has been proven to be very robust in the Microsoft®.Net and Fluke's MET/CAL® platforms.

Microsoft® .Net Implementation

The Microsoft® .Net model proves most flexible, since it is an Object Oriented Programming environment, allowing us to take full advantage of features like interface and inheritance. Microsoft® .Net has a very structured interface which helps the developer fully implement an interface in a driver, taking advantage of the power and flexibility of the Measurement Process Model™.



The calling procedure has passed complete control of the measurement process to the driver. This provides the greatest flexibility in instrumentation, drivers can now become instrument specific and are able to implement processes that allow them to take full advantage of their specific measurement operations.

The sample interface below becomes the contract between the calling code and the implementation in the driver. Notice the interface is very simple and very abstract. This becomes the contract between the calling procedure and the driver. The calling procedure can only call the functions defined in the interface and the driver must implement every one of the functions.

```
Public Interface iDC_Volt_Meter
  Inherits iInstrument

  ' Meter Operations
  Sub Reset()

  ' Meter Measurements
  Function MeasureDCVolts(ByVal ExpectedValue As Double) As Double

  ' Instrument Uncertainties
  Function GetInstUnc(ByVal Value As Double) As Double

End Interface
```

The driver below must implement the interface per the contract. You can see how the HP 34401A Driver implements several interfaces including the interface listed above.

```
Public Class HP_34401A
  Inherits CLS_DriveBaseClass

  Implements iDC_Volt_Meter
  Implements iAC_Volt_Meter
  Implements iDC_Current_Meter
  Implements iAC_Current_Meter
  Implements i2W_Ohm_Meter
  Implements i4W_Ohm_Meter
…………
  Public Function MeasureDCVolts(ByVal ExpectedValue As Double) _
           As Double Implements iDC_Meter.MeasureDCVolts
    ' Check the Routing Button
    Me.CheckFrontTerm()

    Me.Write("CONF:VOLT:DC AUTO,MIN")
    Me.OPC()

    Return Me.ReadSettled()
  End Function

Public Function GetInstUnc(ByVal Value As Double)
          As Double Implements iDC_Meter.GetInstUnc
    'Uncertainties Based on 1 Year Specifications
    ' Percent of Reading + Percent of Range

    Select Case Value
      Case Is <= 0.1
        '0.0050 %of Reading + 0.0035 %of Range
        Return (Value * 0.00005) + (0.1 * 0.000035)
      Case Is <= 1
        '0.0040 %of Reading + 0.0007 %of Range
        Return (Value * 0.00004) + (1 * 0.000007)
      Case Is <= 10
        '0.0040 %of Reading + 0.0007 %of Range
        Return (Value * 0.00004) + (10 * 0.000007)
      Case Is <= 100
        '0.000045 %of Reading + 0.000006 %of Range
        Return (Value * 0.000045) + (100 * 0.000006)
      Case Is <= 1000
        '0.0045 %of Reading + 0.0010 %of Range
        Return (Value * 0.000045) + (1000 * 0.00001)
      Case Else
        Return 4.99E+39
    End Select
```

Not shown in these programming samples is the code implementing the Get Measurement Process. Microsoft® .Net includes a feature called Reflection, allowing the code to interrogate on object extracting its interfaces. However, in our implementations we have explicitly written the Get Measurement Process function.

Fluke MET/CAL® Implementation

Implementing this Measurement Process Model™ in MET/CAL® is a little more difficult, but not impossible. The Fluke MET/CAL® platform is not an Object Oriented Programming environment, so the programmer will have to pay closer attention to what he or she is doing to insure each driver implement is 100% of the interface. The interface will then have to be defined and maintained in support documentation.

A Sub Procedure in MET/CAL® is a script, so it cannot be instantiated, used and then unloaded. It has limited support for local variables as well as static variables and data storage. But, none of these limitations prevent us from implementing the Measurement Process Model™.

Notice in the MET/CAL® driver below, we are supporting all the key features of the interface above. We have a specific call for the reset command as well as the Measure. Volts.DC. There are only a few specific differences in the implementation. In the VB.Net implementation above, we perform two calls—one for the reading and the other for the uncertainty—whereas in the MET/CAL® implementation, we do it all in a single measurement call and automatically return the uncertainties.

```
Cal Lab Solutions                              MET/CAL Procedure
=============================================================
=====================
INSTRUMENT:        CLSD-Measure.Volts.DC             (34401A Front)
DATE:              2010-12-01 15:24:57
AUTHOR:            Cal Lab Solutions
REVISION:          $Revision: 5 $
ADJUSTMENT THRESHOLD:  70%
NUMBER OF TESTS:     4
NUMBER OF LINES:     127
#============================================================
=====================
 STEP   FSC    RANGE NOMINAL       TOLERANCE    MOD1       MOD2
3  4 CON
 1.001  JMPL       Reset                  (find(S[30], "Reset",1)>0)
 1.002  JMPL       Measure.Volts.DC   (find(S[30], "Measure.Volts.DC",1)>0)

 1.003  DISP       Error Calling the Procedure..
 1.004  END
 1.005  EVAL   CLS

#============================================================
=====================
 2.004  LABEL      Reset
 2.005  IEEE       [@34401]*RST[D299]*OPC?[i!]
 2.006  JMPL       End
 2.007  EVAL   CLS

#============================================================
=====================
 4.001  LABEL      Measure.Volts.DC
# Set the Defaults
# Get the Volts
 4.002  IF         (Find(S[30],"Volts=",1)>0)
```

```
 4.003  MATH       L[11]=Sub(S[30],find(S[30],"Volts=",1),1e3)
 4.004  ELSE
 4.005  DISP      Error: Expected Voltage required.
 4.005  DISP      CLSD-Measure.Volts.DC (34401A Front)
 4.006  MATH       S[31]="Value= 99e39  Unc= 0";MEM=99e39
 4.007  END
 4.008  ENDIF

# Check Range
 4.009  IF        L[11]>1.1e3
 4.010  DISP      Error: Voltage exceeds meter limits.
 4.010  DISP      CLSD-Measure.Volts.DC (34401A Front)
 4.011  MATH       S[31]="Value= 99e39  Unc= 0";MEM=99e39
 4.012  END
 4.013  ENDIF

# Check the Input Terminals
#========================================
 4.014  LABEL      SetInput
 4.015  IEEE      [@34401]ROUT:TERM?[I$]
 4.016  IF        ZCMPI(MEM2, "REAR")
 4.017  DISP      Set the 34401A Front\Rear Input to Front
 4.018  JMPL       SetInput
 4.019  ENDIF

# Configure the Input
#========================================
 4.020  IEEE      [@34401]CONF:VOLT:DC [L11],MIN;*OPC?[i!]

# Settle the Reading
 4.021  IEEE      [@34401]READ?[I]
 4.022  IEEE      [@34401]READ?[I]
 4.023  IEEE      [@34401]READ?[I]

 4.024  IF        abs(MEM)>1e30
# If overranged then go to AutoRange
 4.025  IEEE      [@34401]CONF:VOLT:DC AUTO,MIN;*OPC?[i!]
 4.026  IEEE      [@34401]READ?[I]
 4.027  IEEE      [@34401]READ?[I]
 4.028  IEEE      [@34401]READ?[I]
 4.029  ENDIF

# Set Uncertainties
#=================================
 4.030  LABEL      SetTol
 4.031  MATH       L[1]=ACCV("HP 34401A","Volts", MEM)
 4.032  MATH       S[31]="Value= "& MEM &" Unc= "&L[1]
 4.033  MATH       S[31]=S[31]&"Volts= "& MEM &" VoltsUnc= "&L[1]

……………………………………………..

#=================================
 4.049  LABEL      End
 4.050  END
```

Note that our MET/CAL® implementation only implements a single measurement process at a time. We did this because scripting languages become very cumbersome to debug as they increase in complexity. Also notice at the top of the procedure we are at revision 5, meaning it only took five edits to write, test, and fully debug this code.

Conclusion

Though it seems obvious and appears to be a very simple course correction, in hindsight the Measurement Process Model™ presents a very innovative approach to solving the flexible standards problem. The fundamental underlying concept is simple: write the code you need as you need it, and then add it to the instrument driver after testing. We've shown fallibilities of the instrument classification driver model and how an alternative method can make our code run more efficiently.

History has shown us the natural evolution of hardware; how manufacturers will continue to add measurement functionality to gain a competitive edge. Newer computers, modular instruments, and communication innovations will repeatedly challenge our implementations and software solutions. We can choose to patch them each time or simply rethink the paradigm. In the end, the instrumentation is changing, and software solutions will have to change to keep pace.

References

[1] "Moore's Law and Intel Innovation," <http://www.intel.com/about/companyinfo/museum/exhibits/moore.htm > (accessed March 12, 2012).

[2] Shalloway, Alan and Trott, James, *Design Patterns Explained*, 2 ed. (Addison-Wesley, 2005).

[3] Michael Schwartz, "Using Fluke MET/CAL® to Implement a Flexible Measurement Driver Model with Expanded Measurement Uncertainties, Error Checking and Standard Flexibility," NCSLI 2011 Workshop & Symposium, National Harbor, MD, August 21-25, 2011.

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This paper was previously presented at the Measurement Science Conference (MSC), on March 22, 2012 in Anaheim, CA.

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