CAL LAB
THE INTERNATIONAL JOURNAL OF METROLOGY

METROLOGY 101: MILLIMETER WAVE CONNECTOR CARE

2012
OCTOBER
NOVEMBER
DECEMBER

Implementation and Verification of Building-up AC-DC Current Transfer up to 10 A

Faster, Better, Cheaper: New Automated Vacuum Calibration Service at NIST

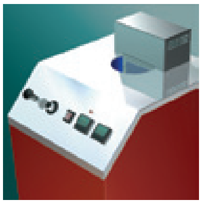
ISOTECH

The World Leader in Temperature Metrology

Thank you for making 2012 our best year yet.

More Nations Choose Isotech Temperature Standards.... Shouldn't You?

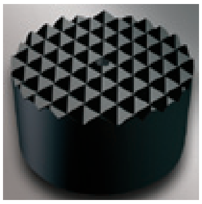
Thermometry Bridges
0.017mk to 0.5mk



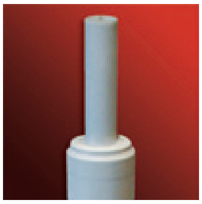
Calibration Baths & Furnaces
-196ºC to 1300ºC

Portable Temperature Sources
-100ºC to 1300ºC

Thermocouple Referencing Systems



Blackbody Sources High Emissivity to 1300ºC



Primary Temperature Standards

Reference Thermometers
0.001ºC to 0.02°C

Isotech North America *(The Americas)*
Web-site: **www.isotechna.com**
E-mail: sales@isotechna.com
Phone: +(802) 863-8050

Isothermal Technology Limited *(Worldwide)*
Web-site: **www.isotech.co.uk**
E-mail: info@isotech.co.uk
Phone: +44 (0) 1704 543830

CAL LAB
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VOLUME 19, NUMBER 4

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FEATURES

DEPARTMENTS

ON THE COVER: The Fluke Calibration Everett Primary Electrical Laboratory wishes you happy holidays—Nicholas Mason, Lead Metrologist, Yvonne Gallardo, Laboratory Analyst, and Jeff Gust, Chief Corporate metrologist share a toast of spiced apple cider in the newly renovated Primary Electrical Laboratory. Over Nicholas' shoulder is the new A40B AC shunt calibration station, which is the U.S. Service location for this product.

CALENDAR

CONFERENCES & MEETINGS 2012-2013

Nov 27-30 80th ARFTG Microwave Measurement Symposium. San Diego, CA. The theme for the 80th ARFTG Conference is in the test and measurements for the rapidly expanding fields of the diverse Wireless Communication applications. http://www.arftg.org.

Nov 28-29 Large Volume Metrology Conference & Exhibition (LVMC) 2012. Chester, UK. LVMC is the premier technical conference in Europe dedicated solely to the use of precision dimensional measurement technology for process improvement for manufacturers. http://www.lvmc.eu/.

Dec 8-10 International Conference on Instrumentation & Measurement, Computer, Communication, and Control (IMCCC 2012). Harbin, China. http://imccc2012.hit.edu.cn/.

Feb 6-7 NCSLI Technical Exchange. Charlotte, NC. The Exchange provides a forum for exchanging ideas, measurement techniques, best practices and innovations with others interested in metrology industry trends. http://ncsli.org/.

Mar 3-4 Southeast Asia Flow Measurement Conference. Kuala Lumpur, Malaysia. http://www.tuvnel.com.

Mar 7-8 METROMEET – 9th International Conference on Industrial Dimensional Metrology. Bilboa, Spain. METROMEET has consolidated as an international reference in the area of Industrial Dimensional Metrology, so it summons international leaders of the sector, to expose the latest advances in the subject and to propose product quality improvements and production efficiency. http://www.metromeet.org.

Mar 18-22 Measurement Science Conference (MSC). Anaheim, CA. To help educate the measurement community during these challenging times, the Measurement Science Conference (MSC) 2013 will focus on presenting concepts that provide the attendee the necessary tools needed in the application of operational excellence in the Metrology organization. http://www.msc-conf.com.

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Correction

In the article "Learning to Apply Metrology Principles to the Measurement of X-ray Intensities in the 500 eV to 110 keV Energy Range" in the Jul-Sep 2012 issue, an error was made in the first sentence regarding accreditation with NIST. The first sentence should read:

"National Security Technologies, LLC (NSTec), Livermore Operations, has two optical radiation calibration laboratories accredited by the National Voluntary Laboratories Accreditation Program (NVLAP) which is the accrediting body of the National Institute of Standards and Technology (NIST), and is now working towards accreditation for its X-ray laboratories."

This correction is meant to distinguish the difference between the two government organizations and is also a requirement of an accredited laboratory to insure that the proper terms are utilized per the NIST Handbook 150, Annex A.

EDITOR'S DESK

Wishing 2012 Adieu!

As I type this letter, the seasons are colliding. The news of a successful return of Space Exploration Technologies' Dragon freighter was overshadowed by hurricane Sandy. The brunt of the storm has yet to hit as I sit at my desk and, sadly, one of the first casualties is the HMS Bounty and two of her crew members off the coast of North Carolina.

After a dry spell of press releases for new products, my inbox is getting inundated with all those new products. They are spilling out on the heels of a number of acquisitions. Even without a business background, I can't help but make a connection—big and medium businesses readjusted themselves and then proceeded forward. For the sake of small business, I hope this will be a positive forward trend. Logically, you'd think a greater push for metrology as technology needs increase would translate into more metrology business, but disappointing conference attendee turnouts this past year conflicted with that line of reasoning. But then there is no indication that proceeding forward is an alternative path… all signs point forward!

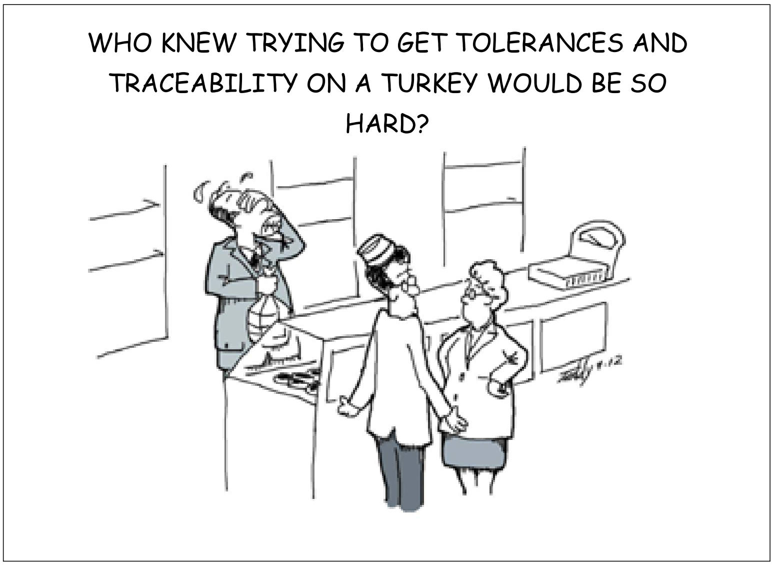
In this issue, Agilent Technologies contributed a Metrology 101 article on connector care for millimeter-wave and N-type connectors. Dr. Halawa was kind enough to share his article with us, "Implementation and Verification of Building-up AC-DC Current Transfer up to 10A." And, the folks in vacuum calibration at NIST contributed a great article detailing implementation of their automated calibration system. We always appreciate great articles that provide specific processes and the reasons why a particular lab chose to go the route they did.

I really am not looking forward to stringing lights around a prickly, dead tree *again*. But, I am very excited for the holidays… the food, the drink, greetings and packages from friends and family, and more food and drink. I hope you are excited too! Dear 2012, do not take offense, but please do step aside because… here comes a new year!

Warmest Regards and Wishes,

Sita

CAL-TOONS by Ted Green teddytoons@verizon.net



SEMINARS: Online & Independent Study

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

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

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

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

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

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

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

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

ISO/IEC 17025 Accreditation Courses. Workplace Training, http://www.wptraining.com/.

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

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

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

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

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

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

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

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

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

Electric Voltage & Current

Voltage Transducers

Provide an Analog Output Signal Magnetically Isolated from the Primary Voltage Circuit

- Full-scale Primary Voltages from ±500V to ±8,000V
- Amplitude Accuracy to ±0.2% at dc
- Amplitude Frequency Response dc to 500kHz (-3dB)

Convert High Voltage Levels in Power Converters to Low Level, Low Impedance Signals that can be Used for Accurate and Safe Test Measurements

LEM CV4

Closed-Loop Hall Current Transducers

Provide an Analog Output Signal Isolated from the Primary Current Circuit

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

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

LEM LF

Closed-Loop Fluxgate Current Transducers

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

- Full-scale Primary Currents from ±60A to ±1,000A
- Amplitude Linearity to ±0.3ppm at dc
- Amplitude Frequency Response dc to 300kHz (-3dB)
- Very Low Noise to <5ppm rms (dc to 50kHz) gives Wide Dynamic Range
- Very Low Sensitivity to External Current Conductors

For High-accuracy Power Measurements over an Extended Frequency Range

LEM IT Ultrastab

Closed-Loop Fluxgate Current Measurement Systems

Very High-Accuracy Current or Voltage Output Signal with Electrical Isolation from the Primary Circuit

Optional Heads, fs Current	600A*	2,000A*	2,000A	5,000A	10,000A	16,000A	24,000A
Lowest fs Current	40A	125A	—	—	—	—	—
fs Current Range Increment	20A	125A	—	—	—	—	—

Very High-accuracy Calibration and Power Measurements

* The 600A and 2,000A fs Heads are programmable by a pre-wired plug.

LEM ITZ Ultrastab

CALENDAR

SEMINARS: Dimensional

Nov 19-20 Hands-On Gage Calibration and Repair Workshop. Minneapolis, MN. http://www.iicttraining.com.

Nov 26-28 Dimensional Measurement Training: Level 1 - Measurement User. Coventry, UK. http://www.npl.co.uk/.

Nov 26-29 Dimensional Measurement Training: Level 2 - Measurement Applier. Telford, UK. http://www.npl.co.uk/.

Dec 3-5 Dimensional Measurement Training: Level 1 - Measurement User. Telford, UK. http://www.npl.co.uk/.

Dec 4-6 Hands-On Gage. Elk Grove, IL. The Mitutoyo Institute of Metrology. http://www.mitutoyo.com.

Dec 6-7 Hands-On Gage Calibration and Repair Workshop. Clearwater Beach, FL (Tampa Area). http://www.iicttraining.com.

Dec 10-11 Hands-On Gage Calibration and Repair Workshop. Atlanta, GA. http://www.iicttraining.com.

Dec 10-12 Dimensional Measurement Training: Level 1 - Measurement User. Coventry, UK. http://www.npl.co.uk/.

Jan 10-11 Hands-On Gage Calibration and Repair Workshop. Minnetonka, MN. http://www.iicttraining.com.

Jan 22-23 Hands-On Gage Calibration and Repair Workshop. Kansas City, MO. http://www.iicttraining.com.

Jan 28-29 Hands-On Gage Calibration and Repair Workshop. Schaumburg, IL. http://www.iicttraining.com.

Feb 12-13 Hands-On Gage Calibration and Repair Workshop. Detroit, MI. http://www.iicttraining.com.

Feb 14-15 Hands-On Gage Calibration and Repair Workshop. Cleveland, OH. http://www.iicttraining.com.

SEMINARS: Electrical

Dec 13-14 Essential Electrical Metrology. Los Angeles, CA. http://www.wptraining.com.

SEMINARS: Flow & Pressure

Jan 28-Feb 1 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. http://us.flukecal.com/Principles-of-Pressure.

Feb 25-Mar 1 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. http://us.flukecal.com/Principles-of-Pressure.

Apr 15-19 Advance Piston Gauge Metrology. Phoenix, AZ.http://us.flukecal.com/training/courses/Pressure-Calibration-Course-Schedule.

CALENDAR

SEMINARS: General

Dec 3-7 Calibration Lab Operations / Understanding ISO 17025. Technology Training Inc. http://www.ttiedu.com.

Dec 10-12 Cal Lab Training; Beyond 17025. Los Angeles, CA. http://www.wptraining.com.

SEMINARS: Mass & Weight

Dec 3 Intermediate Metrology Seminar. Gaitersburg, MD. Sponsored by NIST Office of Weights and Measures. Prerequisite: Basic Metrology seminar. http://www.nist.gov/pml/wmd/5164.cfm.

Jan 28 Volume Metrology. Gaitersburg, MD. Sponsored by NIST Office of Weights and Measures. Prerequisites: Fundamentals of Metrology Seminar AND the Mass Metrology Seminar. http://www.nist.gov/pml/wmd/labmetrology/training.cfm.

SEMINARS: Measurement Uncertainty

Nov 13-15 Measurement Uncertainty Workshop. Fenton, MI. QUAMETEC Institute of Measurement Technology. http:// www.QIMTonline.com.

Nov 27-28 Estimating Measurement Uncertainty. Boston, MA. The Mitutoyo Institute of Metrology. http://www.mitutoyo.com

SEMINARS: Temperature

Mar 5-7 Infrared Temperature Metrology. American Fork, UT. Fluke Calibration, http://us.flukecal.com/tempcal_training.

Jun 11-13 Principles of Temperature Metrology. American Fork, UT. http://us.flukecal.com/tempcal_training.

SEMINARS: Vibration

Nov 14-16 Fundamentals of Random Vibration and Shock Testing, HALT, ESS, HASS (...). Plano, TX. http://www.equipment-reliability.com.

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

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

Measure Surface Roughness with Your Smartphone

Mahr Federal recently unveiled a revolutionary way to measure surfaces. Mahr Federal introduced a new Android App that lets users measure common surface roughness parameters using their Smartphones and other Android operating system devices. The MarSurf® One App interfaces via Bluetooth with a Mahr RD 18 Drive Unit and probe to measure the most popular roughness parameters, including Ra, Rz, Rmax, Rt, and Rq. Resulting profiles can be zoomed using multi-finger gestures for instant analysis; saved; converted to PDF files; synched; or emailed for display and analysis on other devices such as PCs.

"Using the MarSurf One App with your Smartphone is a very inexpensive, and extremely portable, way to obtain surface roughness measuring capability," said Pat Nugent, Vice President Metrology Systems for Mahr Federal. "The MarSurf One App requires an RD 18 Drive Unit and probe, of course, which come standard with MarSurf M 300 systems. However, by purchasing the RD 18 as a separate unit and using it with the MarSurf One App, the result is a total system that is less expensive than buying an M 300 system."

The MarSurf One App can be downloaded from Google Play for Android. A free demo version is available for 7 days, and the full, licensed version can be purchased via the "buy button" for automatic download. No operator training is required as operational elements follow typical and well-known Android user interface styles. The MarSurf One App uses a standard R-profile filter and measures in accordance with DIN EN ISO 16610-21 (digital phase correct).

Mahr Federal Inc., a member of the Mahr Group, has been providing dimensional measurement solutions to fit customer application needs for over 150 years. The company manufactures and markets a wide variety of dimensional metrology equipment, from simple and easy-to-use handheld gages to technically advanced measurement systems for form, contour, surface finish and length. Mahr Federal is also well known as a producer of custom-designed gages and a provider of calibration and contract measurement services. Mahr Federal's calibration laboratories are accredited to ISO/IEC 17025:2005 NVLAP Lab Code 200605-0 (see our Scope of Accreditation for accredited calibration processes).

For more information visit http://www.mahr.com.

PML Goes to Mars: Far-Out Thermal Calibration

PML physicist Michal Chojnacky (right) demonstrates the method used to calibrate platinum resistance thermometers. At left is sensor designer Chris Albert.

Sometimes the chain of measurement traceability–the unbroken series of links between a calibrated instrument and the official NIST standard – can get pretty long. But 250 million kilometers is remarkable, even for NIST.

That's the current distance between the Curiosity rover on Mars and the temperature labs in Gaithersburg, MD, where the calibration process began for several small but critically important temperature sensors that monitor the rover's power generator.

"They're all hand-made and hand-customized," says Chris Albert of Sensing Devices Inc. (SDI) in Lancaster, PA, who designed the sensors to NASA contractor Teledyne Energy Systems specifications. "Each one has to be calibrated, and each one has to have NIST traceability."

So Albert brought the company's master reference thermometer to PML's Temperature & Humidity (T&H) Group to have it calibrated according to the International Temperature Scale of 1990, the worldwide standard for equipment calibration. For Albert, it was a familiar process. He and his colleagues have been getting calibration services from NIST's thermometry experts for almost 22 years, and Albert has worked with Gregory Strouse, T&H group leader in PML's Sensor Science Division, for 20 of those years.

SDI makes platinum resistance thermometers (PRTs) for applications that range from regulating commercial English muffin ovens here on Earth to monitoring environmental living conditions on the International Space Station.

PRTs work because the electrical resistance of platinum (like various other metals) varies in a linear way with temperature. Measuring the change in resistance is a straightforward and highly accurate way of measuring temperature. The platinum is typically formed into a coil to maximize its resistance per unit length, and covered by protective layers of ceramic and glass. Different PRT designs have different resistance values which can be characterized at two or more well-defined calibration points, usually 0 °C and 100 °C.

Four SDI PRTs, based on three of Albert's designs, are used on Curiosity, and range from 100 ohms to 500 ohms at 0 °C. "The higher the ohmic value," he says, "the easier it is for the electronics to use less power and still get the same precision." The SDI sensors are used to track the temperature inside the rover's Multi-Mission Radioisotope Thermoelectric Generator, which uses thermocouples to convert the heat from radioactive plutonium-238 into about 125 watts of electrical power.

The SDI PRTs, which measure a temperature range from – 200 °C up to 661 °C, had to be made very small to fit the specifications for insertion into the generator. The longest is about the size of a wooden matchstick, and each contains 490 windings of 0.18 mm platinum wire over a 15 mm length. The windings and electrical leads are enclosed in tubes of 99.8% pure alumina ceramic.

When Albert first began working with PRTs, "I had no background in thermometry. NIST trained me back in 1991," he says, "and I've been coming there ever since. That relationship has been, by far, the deciding factor in our being able to satisfy our customer's requirements."

Not that he always knows immediately whether the customer is satisfied. In the case of the rover sensors, "they were designed and sold in 2006 to Teledyne Energy Systems, which was making the rover generator," Albert says, "and of course we moved on to numerous other things and never thought much more about it. Then on Aug. 15 of this year, I got an e-mail from a contact at Teledyne that caught us by surprise. He said something like, 'By the way, thank you, your sensors are working on Mars.' And our reaction was, um, what was that again? I'm glad he included the part number, because we had to look it up."

Source: http://www.nist.gov/pml/div685/grp01/mars-rover-sensors.cfm.

Formation of European Calibration Association

Four years of effort to establish a base for the International Association of Calibration Laboratories in Europe was successfully concluded on Tuesday October 23rd, 2012, when chairpersons of the Czech Calibration Association (CKS) Jiri Kazda, German Calibration Association (DKD) Peter Ulbig, and Slovakia Calibration Association (KZSR) Frantisek Drozda signed an agreement that officially constitutes the European Calibration Association (from this point on referred to as EUROCAL).

EUROCAL aims to become a forum for the coordination and harmonization of cooperation among associations of calibration laboratories, primarily (but not exclusively) from EU countries. EUROCAL is a professional interest group with its main focus on exchange of information and knowledge between national associations in the field of calibration.

A need has been indicated for better representation of calibration laboratories towards the metrology or accreditation authorities. Similarly, the harmonization of local calibration guides shall improve the competitive position of laboratories on an international scale. We believe that EUROCAL will reach the position to address these issues and more.

Membership at EUROCAL is free of charge and is open for any national association, group, club, or other form of calibration lab around Europe. A copy of the EUROCAL agreement, as well as the Accession form and other documents and information are available online at www.eurocal.eu.

Yokogawa Eight-channel Mixed-Signal Oscilloscope

The new Yokogawa DLM4000 is the industry's only eight-channel mixed-signal oscilloscope. Combining the large screen and eight-channel capability of Yokogawa's earlier eight-channel DL7480 oscilloscope with the mixed-signal technology of the company's pioneering DLM2000 Series, the new instrument is ideally suited to test and debug applications in the embedded systems, power electronics, mechatronics and automotive sectors.

The DLM4000 Series is comprised of two models with bandwidths of 350 and 500 MHz and a sampling rate of 1.25 GSa/s (gigasamples per second), expandable to 2.5 GSa/s with interleaving. The inputs can be allocated as eight analog channels or seven analog channels, plus one 8-bit digital input. A future logic-expansion option will offer sixteen additional channels of logic for a total of seven channels of analog input with simultaneous 24-bit digital input.

The new instruments feature exceptionally long memory (up to 62.5 M points per channel and 125 M points in interleave mode), allowing both long recordings and multiple waveforms to be acquired. A history memory function, which does not reduce the oscilloscope's high waveform acquisition rate, allows up to 20,000 previously captured waveforms to be saved in the acquisition memory, with any one or all of them displayed on screen for cursor measurements to be carried out. Waveforms can be displayed one at a time, in order, or automatically played back, paused, fast-forwarded or rewound. The history memory in combination with the advanced waveform search features enable users to capture and see the details of anomalies on individual waveforms when their characteristics are still unknown.

Advanced measurement and analysis features include histogram and trending functions, digital filtering, zoom windows, user-defined mathematics and serial bus analysis.

The instruments incorporate a large (12.1-inch) high-resolution XGA display, and yet are housed in a compact body, which is less than 18 cm deep and weighs just 6.5 kg, similar to smaller 4-channel oscilloscopes. The display is enhanced by a fine grid, high luminance and viewing angle, and on-screen markers with simultaneous display of cursors and automatic parameters. Other features include backlit buttons, additional knobs and jog shuttle, on-screen information in English, German, French, Italian and Spanish languages, two zoom windows with 80:20 or 50:50 zoom/main area split, and a choice of first-cycle or screen average mode for frequency measurement.

The DLM4000 Series comes with a variety of easy-to-configure triggers combining analog and logic inputs such as edge, enhanced and B-triggers. These include dedicated trigger functions for FlexRay, CAN, LIN, UART, I2C and SPI serial bus patterns, as well as the ability to perform simultaneous analyses on two different buses operating at different speeds. This capability is enhanced by the extensive search facilities, allowing the user to look for specific data in the very long memory.

For further information about the eight-channel DLM4000 Mixed-Signal Oscilloscope, visit tmi.yokogawa.com.

Ashcroft Compact Pressure Transducer

The new Heise® Model HPK compact pressure transducer brings renowned Heise® dependability and precision to an affordable, analog output device. Sold under the Heise® brand, the HPK compact pressure transducer combines high durability with unusually high accuracy in a small, stainless steel enclosure.

Available with a choice of pressure and electrical connections, the HPK offers either current or voltage outputs to indicate readings from vacuum through 20,000 psig and absolute ranges to 150 psia. All welded stainless steel construction ensures durability and media compatibility, while an advanced sensor design delivers long term stability and ±0.15% F.S. accuracy. Each Heise® Model HPK pressure transducer is authenticated with a nine-point NIST traceable calibration report.

Product website: www.heise.com.

Bracke Phase Trimmers

Bracke Manufacturing, LLC, a leading manufacturer of RF & Microwave components based in Irvine California, is pleased to announce the release of a new High Performance series of Phase Trimmers with working frequency range from 50 MHz to 18 GHz. The Bracke Manufacturing phase trimmers are designed for applications where phase matching between cables or test equipment is critical to system performance. At elevated frequencies discrete changes in phase can require minute physical adjustment in the length of the electrical path. The phase trimmers enable the engineer or technician to make precise adjustment to the phase without otherwise degrading the signal. These threaded Phase Trimmers offer extremely low VSWR of 1.3:1 thru 18 GHz, low insertion loss, smooth continuous adjustment and come with locking nuts.

The phase shift is accomplished by having a turnbuckle style sleeve having an open interior cylindrical wall surface with opposite open ends of the interior wall surface having threads of equal but opposite pitch. A central conductor comprising of telescoping male and female connectors each having means for connection to one of the center conductors of a coaxial cable. The phase adjustment range is 10 degrees x Frequency in GHz. Impedance is 50 Ohms with an operating temperature range from -40 to +120 C. All Bracke phase trimmers feature bodies made of passivated stainless steel per QQ-S-764 TYPE 303, contacts manufactured with beryllium copper per QQ-C-530 plated gold per MIL-G-45204: TYPE II along with PTFE insulators per MIL-P-19468A. All connector interfaces are per MIL-STD-38 & MIL-39012. The devices have been tested for thermal shock, moisture resistance, vibration and shock.

Bracke Manufacturing, LLC's standard Phase Trimmers are available off the self for immediate delivery starting at $159.95 in quantities less than 25 pieces. Custom phase shifters utilizing other connector types along with direct cable attachment are available typically within 2 weeks or less. For more information, please see our web site www.brackemfg.com or call our customer service or technical departments at 949-756-1600.

PTB Ultra-Low-Noise Preamplifier

The ultra-low-noise preamplifier developed by PTB considerably reduces measurement uncertainties, e.g., for the traceability of impedance standards. This preamplifier is characterized by the fact that selected field effect transistors are connected in parallel at the input; these have the lowest possible noise current and noise voltage values. The circuit is designed in such a way that a stable standby current is generated by the input transistors and also that the drain resistance is increased dynamically. In this way, the noise of the pre-stage can be optimally adapted to that of the main stage. This guarantees very low noise. The optimized feedback network adjusts a stable gain. This novel circuit concept enables the so far unprecedented combination of an input noise voltage smaller than 0.5 nV, an input noise current smaller than 5 fA and an input impedance of 1 GΩ parallel to approx. 100 pF (stated for a noise bandwidth of 1 Hz at a measuring frequency of 1 kHz). A license is available; for further information, visit: www.technologietransfer.ptb.de.

Source: PTBnews, English edition, Issue August 2012.

Mensor CPC8000 Precision Pressure Controller

The New CPC 8000 Precision Pressure Controller is Mensor's highest performance pressure calibrator/controller, designed to automate testing of pressure transmitters, pressure transducers, field pressure calibrators, pressure gauges and pressure sensors of all kinds. Percent of reading uncertainty can be achieved over a wide range with three removable transducers and a barometric reference.

The CPC 8000 has a modern look, a large HD color touch screen, a command set emulation mode, IEEE-488 / USB / Ethernet/ RS-232 remote interfaces, a unique needle valve pressure control system, and quiet operation. Calibration of the removable sensors can be achieved remotely using the optional calibration sled.

The CPC 8000 was designed with the operator in mind. Access to commonly used features and functions is easily achieved through the color touch screen. A choice of 10 languages are available simply by pressing the desired language within the language setup menu.

Operators can automate operation of the CPC 8000 by using an internal sequence application or by programming a command sequence in an external application. Standard Mensor commands, SCPI commands or emulation command sets are available. Company website: www.mensor.com.

Cal Lab Solutions PS-Cal Supports Boonton Sensors

Cal Lab Solutions, Inc., a metrology software and consulting company announces its expanding support of power sensors under its power sensor calibration software (PS-Cal).

Originally developed as a drop-in replacement for the HP 11760S power sensor calibration system software, PS-Cal supports legacy and current Agilent sensors. PS-Cal is designed to perform all of the required tests on power sensors including rho, cal factor, and linearity. Options include support for Anritsu, Tegam, and now Boonton sensors.

PS-Cal is a stand-alone solution, designed for flexibility and expandability. It ships with several test standard routines and allows for additional customized test routines with uncertainty calculations to be easily integrated. For more information visit: www.callabsolutions.com or call (303) 317-6670 (MST).

Rohde & Schwarz ESR EMI Test Receiver

The new R&S ESR test receiver is available in two different models for frequencies ranging from 10 Hz to 3 GHz or 7 GHz to meet the requirements of all users who perform EMC certification on commercial equipment. The R&S ESR covers all commercial standards relevant for test houses and EMC labs used by electrical equipment manufacturers and their suppliers.

The R&S ESR from Rohde & Schwarz is yet another example of the company's technology leadership in the field of EMI test receivers. The test receiver features time domain scan, an FFT-based receiver technology that allows it to perform measurements up to 6000 times faster than other EMI test receivers. Standard-compliant EMC measurements which took hours in the past can now be completed in just seconds, saving users valuable time on the way to obtaining desired results. This measurement method offers great advantages when the DUT can only be operated for short periods for testing.

The R&S ESR opens up totally new analysis capabilities. The spectrogram function seamlessly displays the analyzed spectrum over time and records measurements for up to five hours, allowing developers to detect sporadic interferers. The frequency mask trigger responds to specific events in a spectrum. If the mask is violated, a trigger is activated. The measurement is stopped, and the user can analyze the exact cause and effect of the interferer. The persistence mode allows users to clearly differentiate between pulse interferers and continuous interference. It displays the probability distribution of occurring frequencies and amplitudes in various colors, making it possible to detect interferers that are hidden by broadband signals.

R&S ESR also offers conventional stepped frequency scan so the user can compare with existing results. The test receiver is also a full-featured spectrum analyzer and offers proven tools such as IF analysis and time domain display, e.g. for click rate analysis.

The R&S ESR also scores top marks for ease of operation and its clearly structured touchscreen. The various measurement modes are distinctly separated and users can easily configure complex measurements and automated test sequences directly on the touchscreen.

The test receiver's application spectrum is as versatile as its diagnostics capabilities. The R&S ESR makes it easy to perform acceptance testing (conducted or radiated) in line with EN/CISPR/FCC on modules, assemblies, household appliances, IT equipment, TVs, radios, etc. In the automotive sector, the R&S ESR is ideal for acceptance testing of vehicles and accessories in line with automobile manufacturer guidelines, also for mobile applications thanks to the DC operation option. For more information, visit www.rohde-schwarz.com/ad/esr.

Fluke Calibration 5502A Multi-Product Calibrator

Fluke Calibration, a leader in precision calibration instrumentation and software, introduces the 5502A Multi-Product Calibrator, a multi-functional calibrator that covers a wide range of common workload. The 5502A has the best full range of functions and accuracy in its class.

The Fluke Calibration 5502A features:

- 11 full functions, enabling calibration of 3.5 and 4.5 digits digital multimeters
- 50 ppm dc V accuracy
- ac and dc current to 20A
- Optional oscilloscope calibration to 600 MHz
- Reverse power protection on the output terminals for "mistake proof" protection against common user errors
- Easily transported with an optional rugged carrying case featuring built-in handles and wheels, and removable front/rear access doors for in-situ calibration in almost any environment

The 5502A sources direct voltage and current; alternating voltage and current with multiple waveforms and harmonics; two simultaneous outputs to simulate dc and ac power with phase control, resistance, capacitance, thermocouples and RTDs.

The 5502A can be fully automated with MET/CAL® Plus Calibration Management Software to improve throughput, consistency and productivity. MET/CAL Plus helps meet the requirements for documented processes, procedures and reports mandated by most quality standards.

For more information on the Fluke Calibration 5502A Multi-Product Calibrator, visit: www.flukecal.com/5502A.

Agilent Technologies Handheld Digital Multimeter for Extreme Winter Weather

Agilent Technologies Inc. recently announced the U1273AX OLED handheld digital multimeter, which can operate in temperatures as low as -40 C. Even in such frigid conditions, the new handheld DMM provides accurate results with no warm-up time required.

Although the Agilent U1273AX excels in the wintertime, it remains useful throughout the year with an operating temperature range that extends up to 55 C. Coupling this range with IP54 water and dust resistance, plus a CAT IV/600 V safety rating, creates a robust tool that will help users keep their operations running smoothly in demanding industrial and electrical applications.

When paired with the U1583B AC current clamp, the U1273AX supports current measurements without breaking the circuit under test. The U1583B also functions down to -40 C.

The U1273AX presents 4½-digit resolution on an OLED display that provides crystal-clear readings with a 2000-to-1 contrast ratio and 160-degree viewing angle. Advanced capabilities include a low-impedance mode that reduces ghost voltages from capacitive coupling, and a low-pass filter that eliminates switching noise from motor-drive measurements.

For wireless connectivity to smartphones and tablets, the U1273AX is compatible with the innovative U1177A infrared-to-Bluetooth adapter and the associated remote-monitoring programs that support Agilent's entire line of handheld DMMs. This unique capability enables use of an Android device to wirelessly monitor and control the U1273AX from the warmth and safety of a nearby vehicle or structure.

Information about the U1273AX is available at www.agilent.com/find/U1273AX-pr.

Mitutoyo Quick Vision WLI

Mitutoyo America Corporation announces release of the new Quick Vision® WLI vision measuring machine. Besides an optical vision head, the Quick Vision® WLI also incorporates a white light interferometer (WLI) head. Together these heads enable high accuracy performance of non-contact vision plus non-contact 3D measurement of high aspect-ratio minute form (Z = Sub µm ~ 100µm) functions in a single machine - eliminating the need to move a workpiece from one type of machine to another.

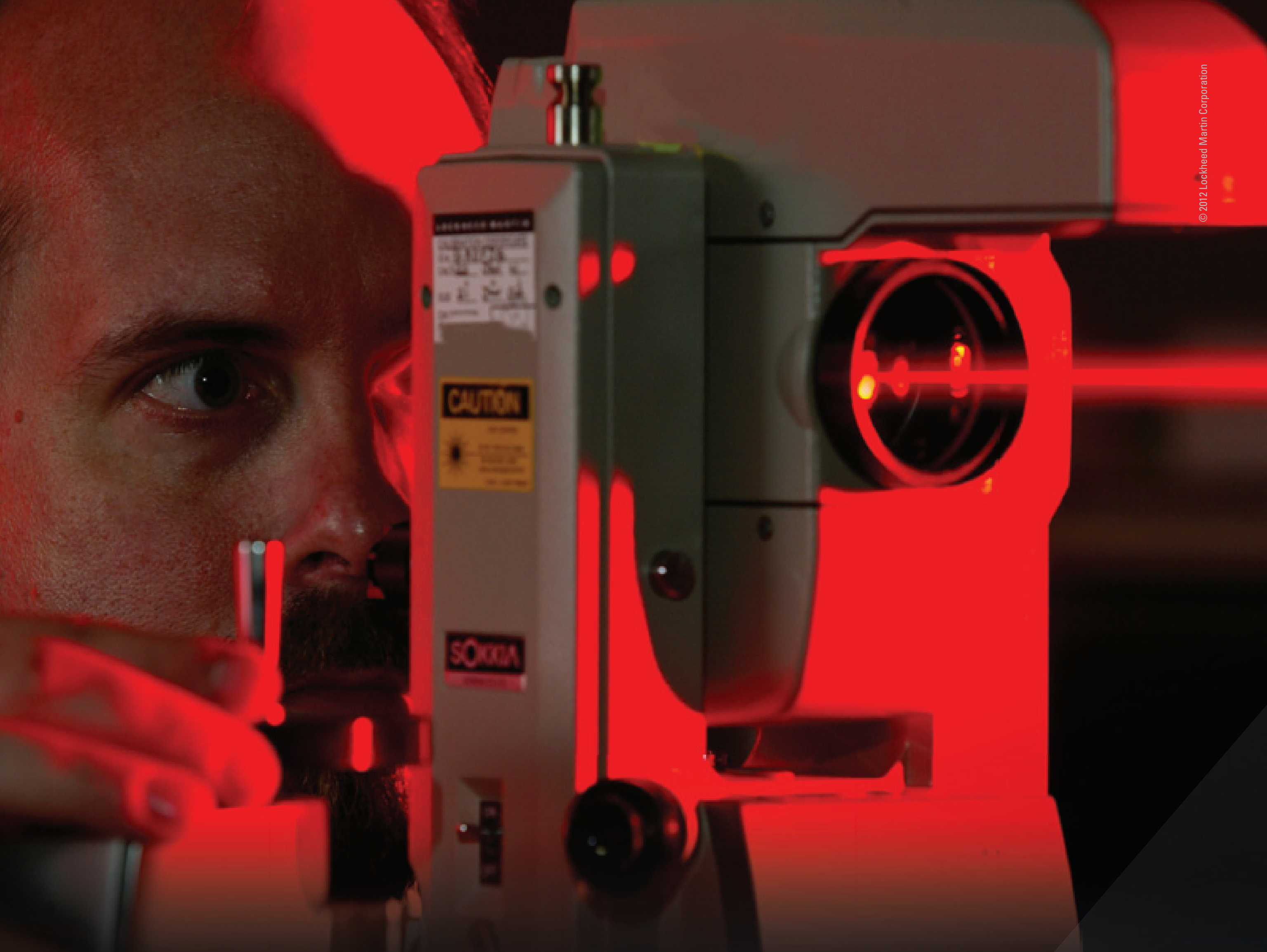
As a result, the Quick Vision® WLI offers a significant throughput improvement for non-contact measurement of items combining both 2D and minute form 3D features in a single workpiece - example subjects could include IC chips and packages, hybrid chassis, lead frames, and many types of precision machined and molded parts.

The Quick Vision® WLI interferometer head splits a beam of white light in two; one beam goes towards a reference mirror and the other beam goes to the workpiece. As the reference objective is moved along the Z-axis, a white "interference ring" is observed on the focus point; analysis of this ring makes it possible to determine the 3D shape of the feature under observation.

The Quick Vision® WLI performs 2D/3D form evaluation using Mitutoyo FORMPAK-QV/FORMTRACEPAK-PRO software which features a refined, intuitive GUI. Results can be displayed in 2D/3D graphics for easy interpretation; a variety of editing and control tools are standard.

In addition, new Quick Vision® WLI 2D/3D non-contact measuring machines can support output to measurement data applications such as MeasurLink®, Mitutoyo's proprietary statistical-processing and process-control program which performs statistical analysis and provides real-time display of measurement results for SPC applications. The program can also be linked to a higher-level network environment for enterprise-wide functionality.

Company website: www.mitutoyo.com.


CAUTION
SOKKIA

Agilent Technologies Large-Scale Active Antenna Calibration and Testing

Agilent Technologies Inc. recently introduced the industry's widest-bandwidth real-time digital downconverter option on the M9703A AXIe eight-channel high-speed digitizer. The new DDC functionality enables faster, more flexible measurements in high-channel-count applications.

In many multi-antenna applications such as radar, direction-finding and satellite beam-forming, phase-coherent acquisition channels are critical for accurate data acquisition, whether for antenna calibration or channel sounding. Traditional test platforms are generally limited to measurements involving sinusoids, which preclude testing with broader band signals, such as multitone or live signals.

For such complex signals, the exclusive real-time processing algorithm of Agilent's new DDC functionality enables phase-coherent measurements across eight input channels.

With a frequency range of DC to 2 GHz and a sampling rate of 1.6 GS/s, the M9703A-DDC digitizer option provides tuning and zooming capabilities to analyze these signals of interest. The DDC programmable decimation ratio and fine IF tuning allow users to set the bandwidth and center frequency to match the analyzed signal. Real-time decimation allows users to analyze bandwidth from 300 MHz down to less than 1 kHz, reduces the noise level, improves the dynamic range by 3 dB per decimation step, and extends the capture time.

For advanced measurement analysis, the M9703A AXIe high-speed digitizer is compatible with Agilent's 89600 Vector Signal Analysis software, the industry's standard for signal analysis and demodulation.

The M9703A AXIe digitizer, combined with an Agilent two-slot or five-slot AXIe chassis, allows users to easily scale up the number of parallel acquisition channels without the use of switches, reaching up to 40 channels in only 4U of rack-mount space using five digitizers. This enables simultaneous acquisition of data on a large number of channels under dynamic conditions, reducing test and calibration time by days and even weeks, while improving overall test efficiency and cutting costs.

The Agilent M9703A digitizer with the DDC option is also useful in electronic warfare and MIMO applications that need simultaneous wide-bandwidth and high dynamic-range measurements on multiple channels.

More information about product configurations and pricing is available at www.agilent.com/find/M9703A.

Fluke Calibration 7526A Precision Process Calibrator

Fluke Calibration, a leader in precision calibration instrumentation and software, introduces the 7526A Precision Process Calibrator, which combines versatility, precision, and value into a single benchtop process calibrator. The 7526A simplifies calibration of temperature and pressure process instrumentation by incorporating an isolated measurement channel, allowing users to source and measure simultaneously. Easily calibrate RTD and thermocouple readouts, pressure gauges, temperature and pressure transmitters, digital process simulators, data loggers, multimeters and more.

In today's competitive global markets, precise pressure and temperature process control is required to maintain product quality, reduce waste, cut manufacturing costs, and ensure compliance to regulatory standards. The 7526A Precision Process Calibrator puts all the necessary tools for regular process instrumentation calibration into one box.

The calibrator simulates and measures nine RTD and thirteen thermocouple types, accurately measures pressure to within 0.008 percent of reading when combined with Fluke 525A-P Series Pressure Modules, sources and measures dc voltage from 0 to 100 V to within 0.004 percent of reading, sources dc current from 0 mA to 100 mA, accurately measures dc current to within 0.01 percent from 0 mA to 50 mA, and supplies 24 V dc loop power.

For more information, visit: www.flukecal.com/7526A.

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Millimeter Wave Connector Care

Agilent Technologies

Connectors, adapters, and calibration standards in the millimeter-wave frequency range (26 GHz to 70 GHz) are VERY expensive. Although all connectors eventually wear, with knowledge, care, and proper technique, you can easily maximize the accuracy, repeatability, and useful lifetime of coaxial connectors.

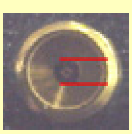
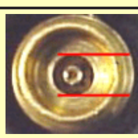
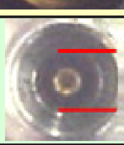
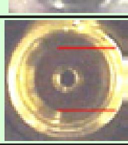
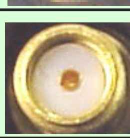
What Mates With What

The outer conductor size of these connectors prevents the mating of incompatible connectors. Connectors in each of the similarly-shaded areas below have the same size outer conductor and therefore can safely be mated together. However, damage to connectors occurs from wear, lack of cleaning, improper connection techniques, and poor handling techniques. When mated, a damaged connector can cause another connector to also become damaged. Therefore, clean and inspect all connectors before mating.

In addition, up to three different grades in each connector type are usually available. Production grade connectors can damage metrology grade connectors when mated.

The first five connector types in the table below use an air dielectric. The name of a connector (ex: 1.85) is determined by the diameter of the air dielectric. This, along with the notes in the following table, is the easiest way to identify these connector types.

Note: SMA is a common and inexpensive connector type, but its lack of precision affects durability and performance, and can cause increased wear when mated with precision connectors. SMA connectors are only rated for a very limited number of connection cycles and should be examined before each use.

Connector Type		Frequency Range	Mates with...	Notes
	**1.0 mm**	To 110 GHz	1.0 mm	Much smaller connector than any of those below.
	**1.85 mm**	To 70 GHz	2.4 mm	The outer thread size of the 1.85 and 2.4 connectors is bigger than SMA, 3.5, and 2.92. This makes the area of the outer conductor mating surface look very large compared to the relatively small air dielectric.
	**2.4 mm**	To 50 GHz	1.85 mm	The 1.85 mm connector that is manufactured at Agilent has a **groove** in the male nut and female shoulder to distinguish these two connector types.
	**2.92 mm**	To 40 GHz	3.5 mm and SMA	These two connectors use the same center pin.
	**3.5 mm**	To 34 GHz	2.92 mm and SMA	
	**SMA**	To 24 GHz	2.92 mm and 3.5 mm	Uses a PTFE dielectric.

Type-N

Although technically not a millimeter-range connector, the Type-N connector is very popular and worth a mention. The high-frequency limit of the Type-N is 18 GHz. With Type-N, the outer conductor mating plane is offset from the center conductor mating plane as seen in the image (Figure 1).

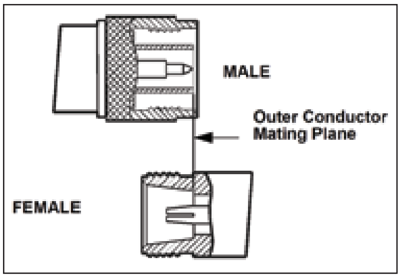


Figure 1. Type N connector.

The mechanical specifications give a maximum protrusion of the female contact fingers from the outer conductor mating plane, and a minimum recession of the shoulder of the male contact pin behind the outer conductor mating plane.

As the connectors wear, the protrusion of the female contact fingers generally increases due to wear of the outer conductor mating plane. This decreases the total center conductor contact separation between the mated pair. Damage to the connectors will occur, and measurement accuracy will deteriorate, when there is a possibility of interference between the shoulder of the male contact pin and the tip of the female contact fingers.

In addition, the Type-N 75 Ω center conductors are smaller than the Type-N 50 Ω connectors. Therefore, the two can never be mated as the male 50 Ω connector will permanently destroy a 75 Ω female connector.

Use Connector Savers

The small size and precise geometry of mmWave connectors means that they are more delicate and more costly than the larger connectors used at lower frequencies. Millimeter-wave analyzers often have male connectors on their front panels to encourage users to semi-permanently attach a female-to-female adapter as a connector saver. Measurement cables and test devices are then attached to the connector saver.

The connector saver can be easily replaced after it becomes worn or damaged with far less cost and down-time than replacing the test port connector on the test instrument.

Be sure to fully inspect the connector saver before connecting to the test instrument.

Because the calibration standards are connected to the connector saver, it should be instrument grade or better.

Inspecting Connectors

Because of the very small and precise mechanical tolerances of mmWave connectors, minor defects, damage, and dirt can significantly degrade repeatability and accuracy. In addition, a dirty or damaged connector can destroy connectors that are mated to it. For this reason, NEVER use a damaged connector.

- Wear a grounded wrist strap having a 1 MΩ series resistor.
- Use a >10X magnifying glass. A trained, naked eye will normally notice defects in a connector, but many times it is necessary to use a magnifying glass to observe more subtle defects such as small fibers, bent pins, and damaged female slotless connectors.
- Inspect BOTH connectors to be mated for the following:

Threads

- The connector nuts should move smoothly.
- All threads should be free of burrs, loose metal particles, and rough spots.
- Damaged threads will usually cause metal flakes to be deposited into other parts of the connector, causing severe damage.

Outer Conductor Mating Surface

- Inspect for deep scratches, evidence of misalignment, or excess torque.
- Deep scratches generally indicate that one or both of the mating surfaces was not clean or has a high spot or burr.
- Any scratch that goes through the plating should be carefully inspected under magnification to see if the scratch has left a high spot of displaced metal. This will damage other connectors.

Center Conductor

- Male pins should be straight and centered appropriately to engage the female contact.
- Female contacts should all be straight and aligned.
- Light burnishing of the mating plane surface consisting of uniform, shallow concentric scratches distributed evenly over the plated surface is normal.

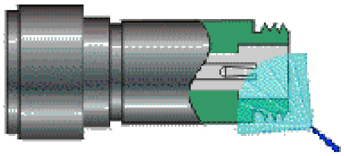
Cleaning Connectors

Safety reminders - When cleaning connectors:

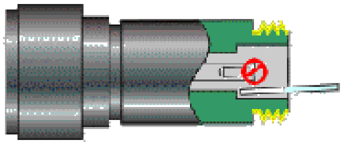
- Always use protective eyewear when using compressed air or nitrogen.
- Keep isopropyl alcohol away from heat, sparks, and flame. Use with adequate ventilation. Avoid contact with eyes, skin, and clothing.
- Avoid electrostatic discharge (ESD). Wear a grounded wrist strap having a 1 MΩ series resistor when cleaning device, cable, or test port connectors.
- Cleaning connectors with alcohol should only be done with the instruments power cord removed, and in a well-ventilated area. Allow all residual alcohol moisture to evaporate, and the fumes to dissipate prior to energizing the instrument.

Procedure

1. Use clean, low-pressure air to remove loose particles from mating plane surfaces and threads. Avoid directing the air directly into the connector, which will force the debris into the connector, but pass air over the end of the connector as you would when blowing a flute. After air cleaning, inspect the connector thoroughly. If additional cleaning is required, continue with the following steps.



2. Moisten - do not saturate - a lint-free swab with isopropyl alcohol. Excellent results can be achieved by using a 1.2 mm toothpick wrapped with a single layer of lint-free cloth.



3. Connectors should be cleaned in a way that will minimize the wicking of the solvent into the connector. Wicking of the solvent causes several problems. It can carry contaminants such as oil and microscopic dirt into the connector structure and affect the RF performance. This places the contaminants where they cannot be easily removed. Solvents in the connector also change the SWR of the connector until the solvent has evaporated. Hold the connector with the mating face down to reduce the wicking effect.
4. Clean any contamination and debris from mating plane surfaces and threads. When cleaning interior surfaces, avoid exerting pressure on the center conductor. Especially avoid the female center conductor as fibers can become trapped in the contact fingers.
5. Let alcohol evaporate, then use compressed air to blow surfaces clean.
6. Inspect the connector. Make sure no particles or residue remains.
7. If defects are still visible after cleaning, the connector itself may be damaged and should not be used. Determine the cause of damage before making further connections.

Gauging Connectors

Because coaxial connector mechanical tolerances can be very precise, even a perfectly clean connector can cause trouble if out of mechanical specification.

Important - Connector Gauge Accuracy
Hand-held connector gauges are only capable of performing coarse measurements on mmWave connectors. This is due to the uncertainties of the measurement versus the extremely precise mechanical tolerances of the connectors. Only special gauging processes performed in a calibration lab can accurately verify the mechanical characteristics of these devices. Therefore, before making pin depth measurements, it is necessary to know the uncertainty of your gauge and the specifications of the connector you are gauging. You may not be able to definitively determine if your connector is within specifications - only to identify gross failures.

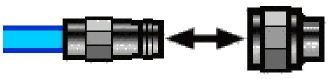
When to Gauge a connector:

- Before you use it for the first time.
- If either visual inspection or electrical performance suggests that the connector interface may be out of specification.
- If someone else uses the device.
- If you use the device on another piece of equipment.
- Routinely: initially after every 100 connections, and after that as often as experience suggests.

Note: Gauge 2.4 mm, 3.5 mm, and SMA connectors more often than other connectors because the center pins can pull out during disconnect.

Making a Connection

1. Wear a grounded wrist strap having a 1 MΩ series resistor.
2. Inspect, clean, and gauge connectors to ensure that all connectors are undamaged, clean, and within mechanical specification.
3. Carefully align center axis of both devices. Push the connectors straight together so they can engage smoothly. The male center conductor pin must slip concentrically into the contact finger of the female connector.



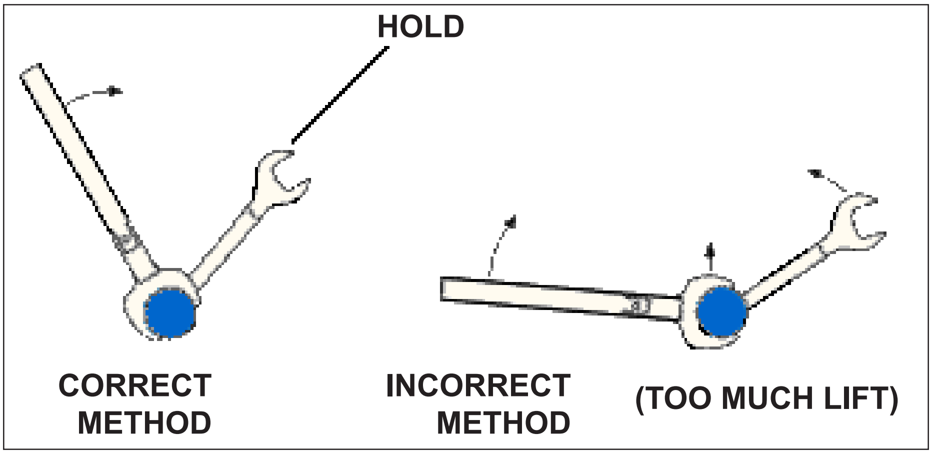
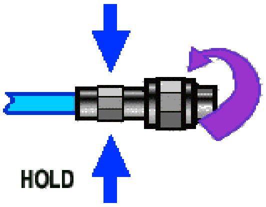
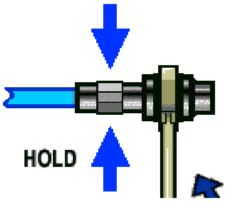


Figure 2.

4. CRITICAL: Rotate only the connector nut - NOT THE DEVICE OR CONNECTOR BODY - until finger-tight, being careful not to cross the threads. Damage to both connectors will occur if the male center pin is allowed to rotate in the female contact fingers.



5. Use a torque wrench to make final connection. Tighten until the "break" point of the torque wrench is reached. Do not push beyond initial break point. Use additional wrench, if needed, to prevent device body from turning.



Using a Torque Wrench

Proper torque on the connector improves measurement repeatability and extends connector life. The tightening torque on connectors has a significant effect on measurements at mm-wave frequencies. Repeatable measurements require consistent torque on all the connections in a setup. A torque wrench avoids damage due to over-tightening and helps connectors achieve their rated lifetimes (refer to Figure 2).

1. Make sure torque wrench is set to the correct torque setting.
2. Position torque wrench, and a second wrench to hold the device or cable, within 90° of each other before applying force.
3. Support the devices to avoid putting stress on the connectors.
4. Hold torque wrench lightly at the end of handle. Then apply force perpendicular to the torque wrench handle. Tighten until the "break" point of the torque wrench is reached. Do not push beyond initial break point.

Separating a Connection

- Support the devices to avoid any twisting, rocking or bending force on either connector.
- Use an open-end wrench to prevent the device body from turning.
- Use another open-end wrench to loosen the connector nut.
- Complete the disconnection by hand, turning only the connector nut.
- Pull the connectors straight apart.

The preceding article is a condensed version of an Agilent Technologies tutorial provided in its entirety at: http://na.tm.agilent.com/pna/connectorcare/Connector_Care.htm.

Agilent also offers a half day connector care training course. Learn more at: http://cp.literature.agilent.com/litweb/pdf/5988-4167EN.pdf or call +1 800 829-4444.

Implementation and Verification of Building-up AC-DC Current Transfer Up to 10 A

Mamdouh. M. Halawa
National Institute for Standards (NIS), Egypt

This paper describes a practical method for implementation and verification of building-up AC-DC current transfer from 10 mA and up to 10 A. A Planar multi-junction thermal converter (PMJTC) at the range of 10 mA was used with a set of coaxial current shunts to build-up the AC-DC current transfer standards for the range from 10 mA to 10 A at frequency range of 10 Hz to 1 kHz. The current level-dependence of the tested ranges at the different frequencies was determined experimentally to evaluate the corresponding corrections of those ranges. The results of building-up AC-DC difference with such corrections, of a 5 A thermal current converter (TCC), were verified by comparing with its calibrated values from PTB, Germany. An expanded uncertainty of less than 27 µA/A and 33 µA/A at 10 A for frequencies of 10 Hz and 1 kHz respectively was achieved in this work.

1. Introduction

Thermal converters (TCs) are the most accurate standards for the transfer of alternating current to the equivalent DC quantities. Single junction thermal converters (SJTCs) are mostly used as thermal current converters because they are easily available [1]. The effective value of an AC quantity is considered equivalent to a DC value when their produced powers, indicated by the output of a TC, are equal at a resistive component (heater) in the TC [2]. Different research work on SJTCs resulted in uncertainties of a few µA/A in the AC-DC current transfer differences [3]–[5]. At present time, thin-film or planar multijunction thermal converters (PMJTCs) are also readily available [6], [7]. They have the advantages of both the low uncertainty of the three-dimensional (3-D) MJTC and the low cost of the SJTC. The PMJTCs provide long-term stability together with high sensitivity and high dynamic range. They are well known for very small AC-DC current transfer differences at audio frequencies.

Commercially available and self-designed coaxial shunt resistors in parallel with the converters were used to extend the current range up to 10 A [9]–[11]. Coaxial shunts have a better frequency behavior than shunts which are not coaxially connected. For currents less than 200 mA, several special metals of low inductance and low temperature coefficient of the resistance are configured in parallel in a star configuration to achieve a stable, low-inductance shunt [1]. Coaxial connectors are usually used at the current input. These standards show very small AC-DC current transfer differences up to 1 kHz, and a very low drift during the measurements. Coaxial shunts for 0.5 A and higher currents are commercially available. Shunts from Holt model HCS 1 with very small inductance are used together with the PMJTC up to 5 A. At 10 mA and 10 A, SJTCs are applied to Fluke A40A shunts.

In practice, AC-DC difference exists at the output of the TC due to its reactive effect to AC quantities. This AC-DC difference can be theoretically evaluated according to the TC's geometry design and the dielectrics among conductors. It can also be determined by comparing the TC against a reference with known AC-DC difference [12]. In the present work, building-up method is employed to step-up current transfer standards at high current values based on a value whose AC-DC differences are known. It is also determined experimentally the level-dependence of the PMJTC used in this method. With necessary corrections, current range in NIS, Egypt is extended to 10 A with those PMJCT and a set of current shunts. To verify this method, a TCC of 5 A was calibrated in PTB, Germany at frequencies from 10 Hz to 1 kHz then compared with the results of this method. Calculations of uncertainty associated with these results are also estimated in details and presented in this work.

2. AC-DC Current Transfer Standards

AC-DC current transfer standards comprise thermal converters used in combination with current shunts. Recently several national institutes built up standards for the current range of 10 mA to 10 A. At NIS, Egypt a PTB-characterized PMJTC is maintained as its 10 mA reference standards. Other different types of TCCs are used to extend the current range up to 10 A with a set of Holt HCS-1 and Fluke A40 primary shunts. The heater resistance of the PMJTC was characterized as about 88 Ω and the nominal input current 10 mA. Fig. 1 shows the building-up of the AC-DC current transfer standards in NIS based on the 10

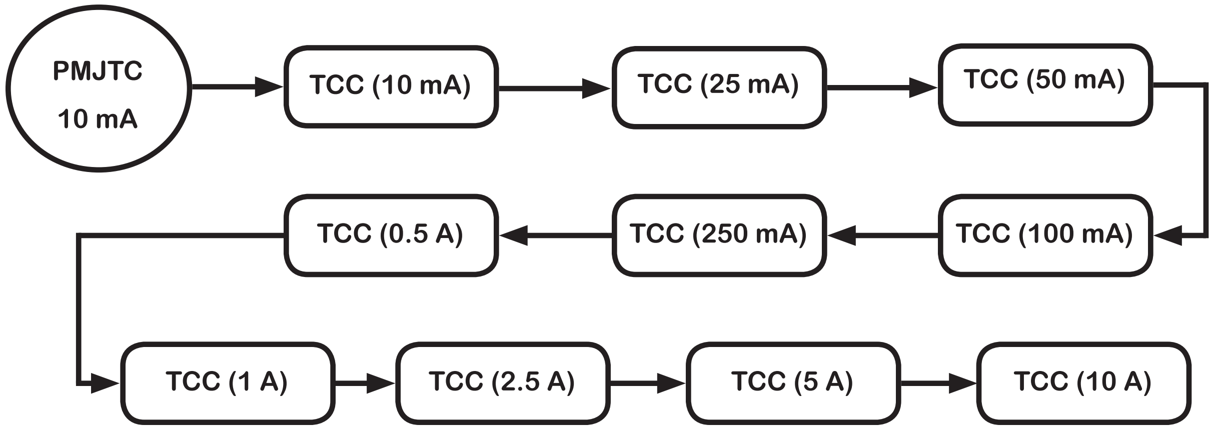


Figure 1. Building-up chain of NIS AC-DC current transfer standards.

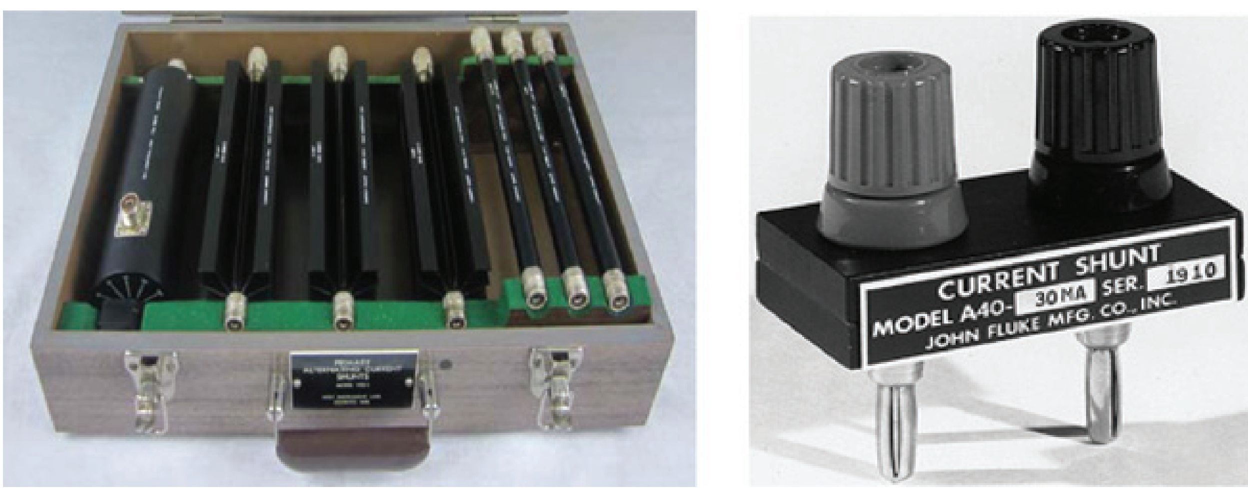


Figure 2. Shunt types used: Holt (model HCS-1) and Fluke (model A40/A40A).

mA reference PMJTC, where arrows indicate the building-up of the measurement traceability from one value (lower, reference standard) to another (unit under test: UUT), the lower values here (≈ 50% of the rated current) are the currents applied for the respective transfers. The UUT is loaded at only half of its nominal input current. It becomes the reference standard at the subsequent steps when it is loaded fully at its nominal input current.

At NIS, from 10 mA to 10 A, two types of shunts are used to build-up the current scale. All shunts are of coaxial design to minimize inductive coupling:

1. Commercially available shunts with coaxial design made by Holt (model HCS-1), (Fig. 2). It is a primary alternating current shunt set consisting of seven separate shunt modules, designed to plug directly into either any Thermal Transfer Voltmeter or true RMS Digital Voltmeter. Each HCS-1 Shunt is a four-terminal resistor providing optimum frequency response well beyond the audio region. Controlled thermal characteristics ensure stable current measurements up to 10 amperes and advanced techniques are employed to minimize inductance and skin effects.
2. Commercially available shunts with coaxial design made by Fluke (model: A40/A40A, accuracy: ± 0.02% at 5 Hz to 100 kHz), as shown in Fig. 2. The A40 Series consists of 12 shunts rated from 10 mA up to 5A. The A40A shunts add 10A and 20A ranges. The A40/A40A allows you to make AC/DC current transfer measurements with the thermal voltage transfer.

The use of shunts of various types and different current steps permits the determination of the current level dependence in the building-up, in which the shunts are calibrated at lower than rated current (≈ 50% of rated current), but are used at rated current.

AC-DC Difference @ 10 mA (100 % of rated current)	6.0 μA/A
AC-DC Difference @ 5 mA (50 % of rated current)	3.1 μA/A
Current level-dependence of the 10 mA TCC at 55 Hz	-2.9 μA/A

Table 1. Current level-dependence of the 10 mA TCC, for example, at 55 Hz.

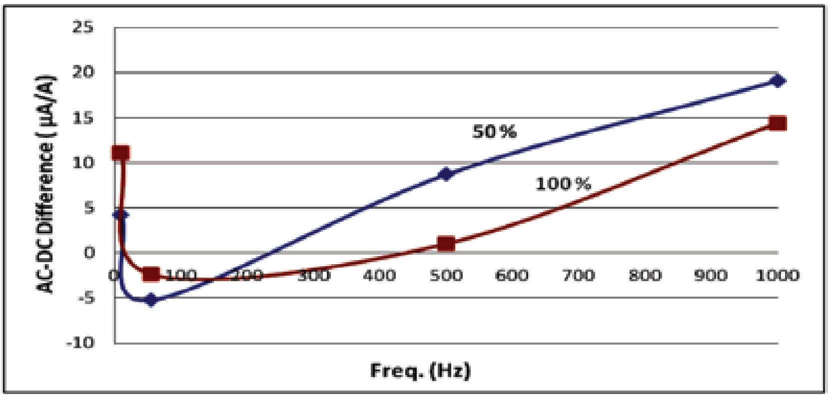


Figure 3. AC-DC difference of 10 mA TCC at 50% and 100% of the rated current.

	Current level-dependence corrections (μA/A)			
Range	**10 Hz**	**55 Hz**	**500 Hz**	**1 kHz**
10 mA	6.9	2.8	- 7.7	- 4.7
25 mA	3.5	- 17.9	- 12.5	- 14
50 mA	- 4.1	- 11.9	- 0.8	-12.7
100 mA	0.2	- 7.6	- 6.4	- 6.8
250 mA	- 8.5	- 8.2	- 0.2	6.2
0.5 A	- 1.4	- 2.8	- 0.8	- 14.8
1 A	-7.8	- 3	- 3.6	- 22.6
2.5 A	- 0.2	5.2	- 9.3	- 0.1
5 A	0.7	0.5	0.5	3.6
10 A	0.2	12.3	18.2	6.2

Table 2. Current level-dependence corrections of the building-up process.

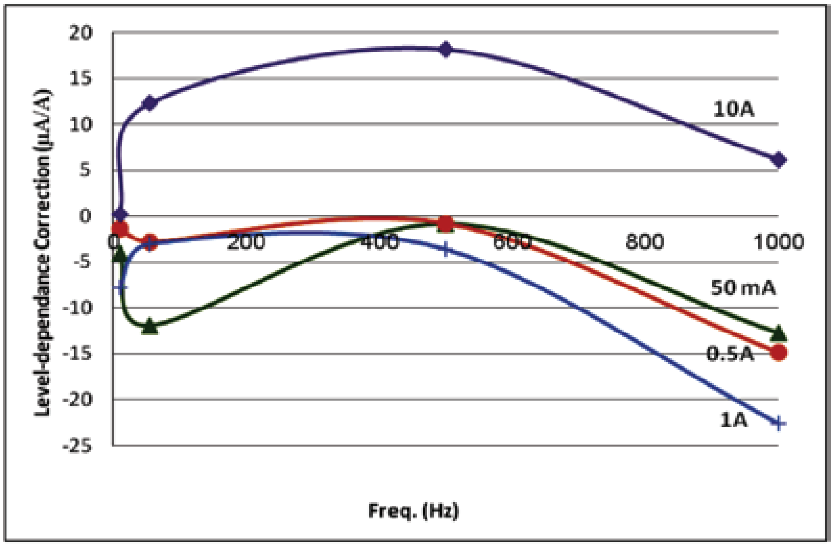


Figure 4. Variation of the level-dependence correction, for example, of 50 mA, 0.5A, 1A and 10 A.

3. Measurement of Level-Dependence of TCCs

Self-heating is assumed to be the cause of current level dependence of the AC-DC difference in shunts. This leads to the approach to measure current level dependence using a shunt with negligibly low self-heating as a standard [13]. This level dependence is, of course, taken into account when determining the AC-DC differences of the CTTs set at the different frequencies.

In the present work, two TCCs (PMJTC and Holt) were loaded at both full and half of their nominal input current (10 mA) to evaluate their current level-dependences. The Holt TCC (UUT) was first connected in series with the reference converter (PMJTC) and its AC-DC differences were measured at the full signal (10 mA). Then the UUT was connected in parallel with a similar one (2nd UUT) (or a precise resistor) having the same rated current and then connected in series with the reference converter (PMJTC). The AC-DC difference of the UUT was measured another time against the reference converter (PMJTC). With this configuration, the injected current of 10 mA from the system fully flows through the reference converter (PMJTC), hence the conditions at the reference converter (PMJTC) remain unchanged, while only half current (~ 5 mA) flows through the UUT. The results from the two tests were compared and the current level-dependence of the UUT was then determined at 55 Hz, for example, as listed in Table 1. Fig. 3 shows the results of the 10 mA TCC. It can be seen that the AC-DC difference of the 10 mA TCC decreases with halved injected current.

As illustrated in Fig. 3, the change in the AC-DC differences are 6.9, 2.8, 7.7 and 4.7 μA/A at 20, 55, 500 and 1000 Hz respectively. Compared with the usual low uncertainties (a few μA/A) of the AC-DC differences for this type of calibrations, these changes are significant and corrections

Freq.	Results of AC-DC Difference, μA/A		Deviations, μA/A	
	Building-up Method	**PTB Calibration**	**Without level-dependence correction**	**With level-dependence correction**
10 Hz	17.5	28	-9.8	-11.5
55 Hz	2.7	-0.8	4	3
500 Hz	9.7	-8.3	18.5	17
1 kHz	2.6	-14.3	20.5	16.9

Table 3. Comparison between building-up method and PTB calibration for TCC at 5 A.

need to be made at each step when building-up current ranges, as listed in details in Table 2. For instance, Fig. 4 shows the variation of the current level-dependence of the 10 mA TCC at 55 Hz.

4. Verification of the Building-up Method

The results of building-up AC-DC differences method with such corrections, of a combination of the tested TCC and a shunt at 5 A, were verified by comparing with the calibrated values from PTB. A comparison between the two results (building-up method and PTB calibration) is tabulated in Table 3. Fig. 5 shows the deviations for this comparison with and without current level-dependence corrections. It can be seen that the deviation (~ 20 μA/A) at 1 kHz is close to the expanded uncertainty (~ 30 μA/A) at this frequency.

On the other hand, Table 4 reports the proficiency testing results of the comparison between the two results (PTB calibration results and building-up results at 5A). Proficiency testing is the determination of the performance by means of comparing and evaluating calibrations by two or more methods in accordance with predetermined

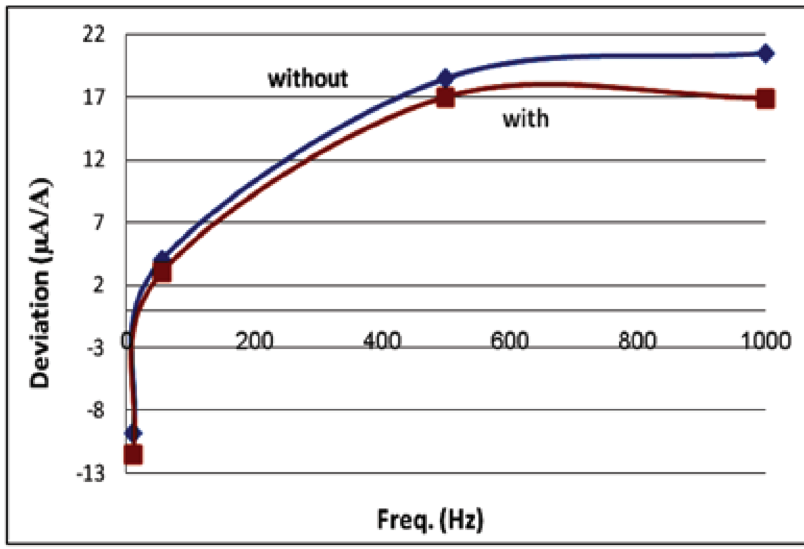


Figure 5. Comparison of AC-DC difference at 5A between the building-up method and PTB calibration (with and without level-dependence corrections).

conditions [14]. The performance of the building-up results of 5 A at the four frequencies against the PTB calibration results, (as the reference values) is judged using the equation of:

$$E_n = \frac{|X_L - X_R|}{\sqrt{U_L^2 + U_R^2}} \quad (1)$$

Where:

X_L = the value as measured by the compared method.

X_R = the value as measured by the reference method (algorithmic).

U_L = the expanded uncertainty of the compared method.

U_R = the expanded uncertainty of the reference method.

Note: En ratio (or En number) should be between -1 and + 1 (or $|En|$ <1). (The closer to zero the better.)

Referring to the values of E_n listed in Table 4, it has been noted that En values are less than 1 for all measuring points. This means that the building-up results are competent, reliable and satisfactory.

Freq. (Hz)	Building-up Results (μA/A)		PTB Calibration Results (μA/A)		$\lvert E_n \rvert$ Ratio
	AC-DC Difference	**Expanded Uncertainty**	**AC-DC Difference**	**Expanded Uncertainty**	
10	17.5	25.2	28	15	0.40
55	2.7	30.3	-0.75	15	0.10
500	9.7	29.5	-8.3	15	0.55
1000	2.6	30.5	-14.3	15	0.50

Table 4. En Ratio of the comparison between PTB and Building-up results at 5 A.

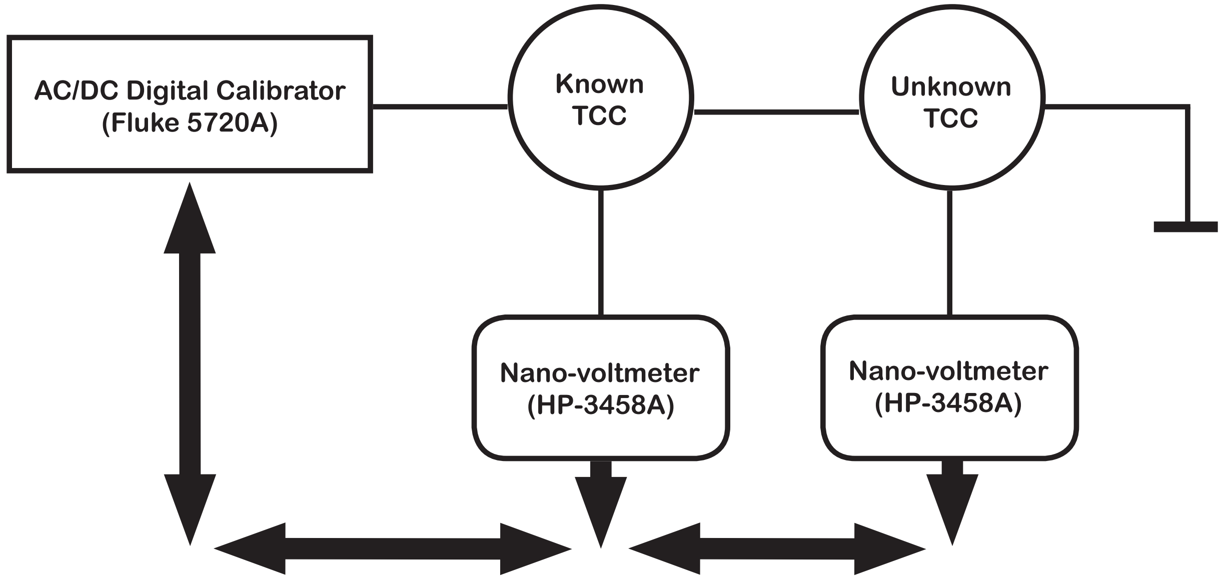


Figure 6. Measurement setup for AC-DC current transfer difference measurements.

5. Calibration Setup

The comparison of thermal current converters (TCCs) is made with the methodology of integrated calibration system, which applied at NIS, Egypt [15], (Fig. 6). The two TCCs to be compared are connected in series. The AC and DC current is supplied by the AC / DC current calibrator. The input current is fed into the TCCs by coaxial cables. This construction may avoid any AC current leaving the circuit through any leakage impedance [1]. In addition, the housings of the two TCCs are usually at low and high potential [8]. As there are small differences at high frequencies depending on the potential of the "known" and the "unknown," all measurements are repeated with the potentials interchanged and the results are averaged [16].

In this type of calibration, the sequence for the measurements is AC, DC+, AC, DC-, AC with a time delay of about 60 seconds and 90 seconds for the SJTCs and PMJTCs respectively (after switching and before reading the two nanovoltmeters) [1]. Averaging of the output emfs of this sequence for AC and DC results is nearly perfect drift compensation. Taking the differences of the output voltages at AC and DC using a digital nanovoltmeter performs the measurement of AC-DC differences. The standard deviation of the mean of 14 measurements is usually about 2.5 μA /A. It increases to about 6 μA /A only at 1 kHz. Table 5 lists the final results of AC-DC difference recorded for the building-up method in this work.

6. Uncertainty Analysis

At each step in building up the current transfer values as listed in Fig. 1, measurement uncertainties of the determined AC-DC differences are estimated by taking into account of the following influence quantities:

1. Repeatability of 14 measurements in same conditions, (U_A).
2. Uncertainty of the reference standard (Reference TCC in each step), (U_{B1}).
3. Uncertainty of the DC signal provided by Fluke 5720 calibrator, (U_{B2}).
4. Uncertainty due to level-dependence corrections for each step, (U_{B3}).
5. Rounding-up resolution of the nano-voltmeter readings, (U_{B6}).

For instance, the values of uncertainty contributions for 25 mA and 10 A at 55 Hz are given in Table 6 and Table 7 respectively. Table 8 lists the expanded uncertainty for the building method starting from 10 mA and up to 10 A for the four different frequencies (10 Hz, 55 Hz, 500 Hz and 1 kHz). In addition, Fig. 7 shows the behavior of the typical measurement uncertainty (at approximately 95% level of confidence, $k = 2$) of the determined AC-DC differences through this process. Fig. 8 shows also, for example, the results of the AC-DC Difference associated with the expanded uncertainty ($k = 2$) for 10 mA TCC.

	AC-DC Difference, µA/A			
Range	**10 Hz**	**55 Hz**	**500 Hz**	**1 kHz**
10 mA	11.1	- 2.4	1	14.4
25 mA	- 35.5	4	15	- 7.5
50 mA	26	5.5	- 10.4	15.6
100 mA	- 19	10.5	12.4	0.2
250 mA	10.6	11.2	5.6	23.4
0.5 A	1.5	- 10.6	- 1.9	- 7.8
1 A	2.3	13	1.9	11.1
2.5 A	7.6	-6.3	5.4	-2.5
5 A	-50.5	-22	38	82.5
10 A	47.6	23.6	-38.4	-84

Table 5. Final results of the building-up method from 10 mA to 10 A.

No	Symbol	Due to	Contribution, ppm
1	U_A	Repeatability of 10 measurements in same conditions	1.2
2	U_{B1}	Uncertainty of the reference standard ($TCC_{ST.}$)	0.5
3	U_{B2}	Uncertainty of the DC signal provided by Fluke 5720 calibrator	4
4	U_{B3}	Uncertainty of the level-dependence corrections	4.3
5	U_{B6}	Rounding-up resolution of the nano-voltmeter readings	0.3
Standard Uncertainty			6
Expanded Uncertainty (*k* = 2, confidence level ≈ 95 %)			**12**

Table 6. Uncertainty budget of 25 mA TCC, for example, at 10 Hz.

No	Symbol	Due to	Contribution, ppm
1	U_A	Repeatability of 10 measurements in same conditions	1.8
2	U_{B1}	Uncertainty of the reference standard ($TCC_{ST.}$)	1
3	U_{B2}	Uncertainty of the DC signal provided by Fluke 5720 calibrator	4
4	U_{B3}	Uncertainty of the level-dependence corrections	15.8
5	U_{B6}	Rounding-up resolution of the nano-voltmeter readings	0.3
Standard Uncertainty			16.3
Expanded Uncertainty (*k* = 2, confidence level ≈ 95 %)			**32.8**

Table 7. Uncertainty budget of 10 A, for example, at 55 Hz.

	Expanded Uncertainty, *k* = 2, (µA/A)			
Range	**10 Hz**	**55 Hz**	**500 Hz**	**1 kHz**
10 mA	9	9	9.5	10
25 mA	12	12.6	13.5	14
50 mA	14.4	21.3	16.5	17
100 mA	16.8	23	19	20
250 mA	18.8	24.5	21.5	22.5
0.5 A	20.6	26	23.5	25
1 A	22.2	27.5	25.5	27
2.5 A	23.8	29	27.5	29
5 A	25.2	30.3	29.5	30.5
10 A	26.6	32.8	31	32.5

Table 8. Typical measurement uncertainty of the built up AC-DC Difference at NIS.

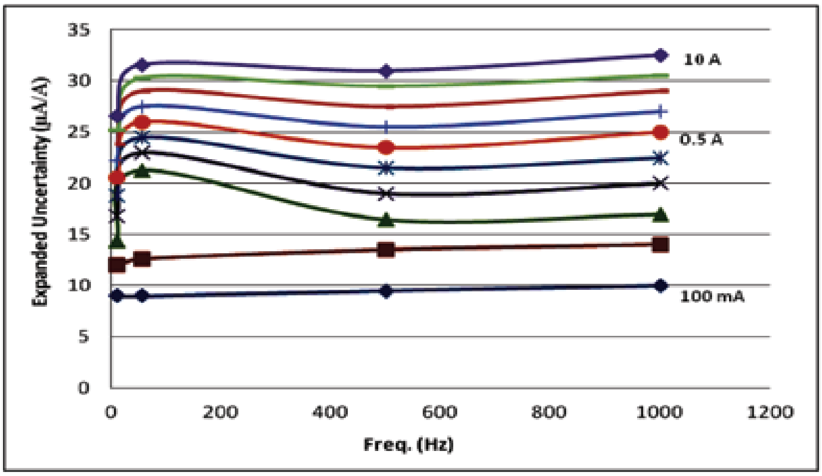


Figure 7. Measurement uncertainty Behavior of the Built up AC-DC Difference at NIS.

7. Conclusion

The current shunts ranging from 10 mA to 10 A have already been used as AC-DC transfer standard with excellent performances in the frequency range of 10 Hz -1 kHz. A combination of these current shunts and a calibrated 10 mA PMJTC is used to build-up a scale of current transfer standards from 10 mA up to 10 A at 4 different frequencies: 10 Hz, 55 Hz, 500 Hz and 1 kHz. Using the PMJTC and the shunts accompanied with a rigorous uncertainty budget resulting in smaller uncertainties than stated before, the measurement range for AC-DC current transfer difference measurements could be extended to 10 A. The uncertainties of this method are suitable for the calibration of the most accurate TCCs and determination of their AC-DC differences. In total, the expanded measurement uncertainty (k = 2) for 10 mA and 10 A at 1 kHz could be estimated around the value 10 µA/A and 32.5 µA/A respectively.

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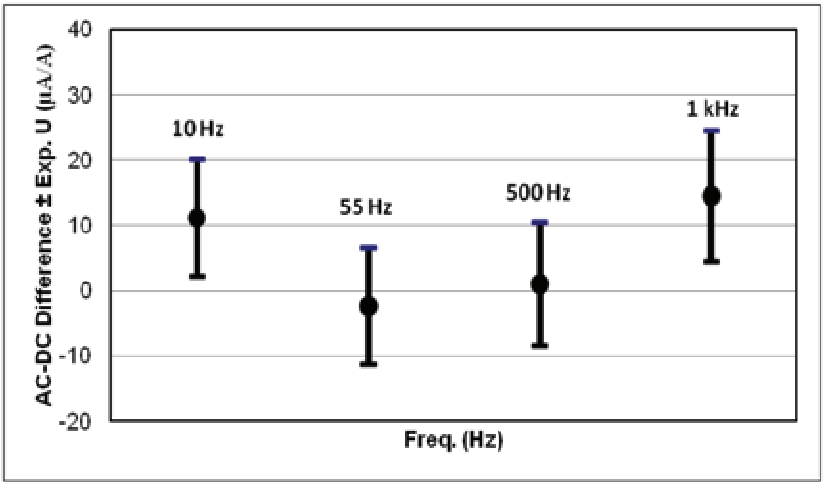

Figure 8. AC-DC Difference Associated with Expanded Uncertainty of 10 mA TCC.

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Faster, Better, Cheaper: New Automated Vacuum Calibration Service at NIST

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National Institute of Standards and Technology (NIST)

In today's fast-paced world and ever-expanding quality assurance requirements, the National Institute of Standards and Technology (NIST) has developed a system to fill the need for faster, better, and cheaper low pressure calibrations (0.65 Pa to 130 kPa). This has been achieved by using the advantages of an *automated calibration* system. This new system has resulted in reduced turnaround time (*faster*), lower costs for customers and NIST (*cheaper*), and provides broader access to direct traceability from NIST standards (*better*). The enabling technology is a combination of commercially available computer-controlled systems, a NIST-developed high-accuracy transfer standard, and intelligent software allowing all the parts to work together as an automated calibration system. While this article is specific to vacuum calibrations, automation of calibration service delivery is a general concept that can be used by other metrology labs to enable delivery of *faster*, *better* and *cheaper* calibration services.

Introduction

In the vacuum business, less is more – except when it comes to accuracy. Industries that depend on high-quality, carefully monitored vacuum for sensitive processes such as microchip fabrication, as well as researchers in numerous technology fields, defense R&D work, and academic science, require high-precision sensors calibrated to authoritative standards.

But until recently, getting direct traceability to NIST for vacuum gauges has been a time-consuming and relatively expensive process. Calibrating an atmospheric range to vacuum customer gauge against one of the primary pressure standards (that is, one of NIST's Ultrasonic Interferometer Manometers, or UIMs) usually takes about fifty hours of data-acquisition, followed by several days to complete a report. The customer's cost ends up being around $5000 with a turnaround time of approximately eight weeks. That excludes many potential customers without the requisite time or money. Now, however, even small businesses and labs can take advantage of a new, fully automated calibration service to obtain direct NIST traceability at a cost of less than $1000.

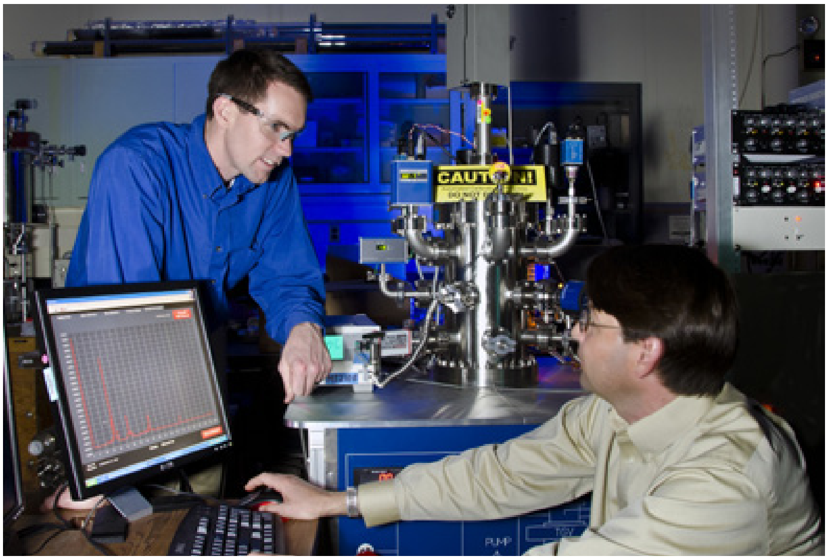

Figure 1. Vacuum Comparison System (VCS) can calibrate up to 10 customer gauges connected to the vacuum chamber shown above.

The new service relies on a transfer of the SI unit the pascal (Pa) from the manually operated UIM primary standard to a fully automated vacuum comparison standard. This automated standard is the key to providing extremely accurate and stable calibrations while reducing turnaround time and customer cost. This system simultaneously calibrates up to 10 gauges of different types, providing automated calibrations that are faster, better, and cheaper.

Faster: Benefits of Automation

Development of the new Vacuum Comparison Standard (VCS) was focused with automation as the key goal. NIST designed and built the VCS from the ground up with the idea that everything would be computer controlled (Fig. 1). Automation provides many advantages, but the prominent benefit to NIST customers is reduced turnaround time. A faster calibration results in less down time for customers and their process lines. However, for NIST, an automated vacuum calibration system required a significant investment and planning and was created with calibration service development (internal) funds designated for improving the delivery of NIST calibration services. For NIST, an automated calibration service reduces work-load and frees up staff time for other important R&D work. To perform a calibration, the system (Fig. 2) must be capable of achieving multiple pressures and comparing the reading of the transfer standard to the devices under test (customer gauges). The VCS utilizes multiple components to achieve each pressure with the set point accuracy achieved by using a mass flow controller, throttling gate valve, and computer controlled solenoid valves in tandem. The mass flow controller can vary the flow rate of gas into the system or can be pulsed to let small volumes of gas into the system. The throttling gate valve is capable of millions of steps and is connected to a high vacuum turbomolecular pump able to evacuate the system to $2x10^{-6}$ Pa (1.5×10^{-8} Torr). For pressures closer to atmospheric, a valve and small diameter orifice (2.5 mm) are used to flow gas into the vacuum chamber. As seen in Fig. 2, the system was designed with a backup manual gas handling system for research or other projects.

The computer software ties all automated actuators and sensor components together to achieve target pressure set-points, collect data, and monitor system health. A screen shot of the software developed by NIST personnel is shown in Fig. 3. The system software was designed to interface with RS-232/485, GPIB, DeviceNet, or analog (0 V to 10 V) signals for collecting data and was designed to accommodate all common gauge data output interfaces. The software controls all components of the gas handling system described above and is capable of setting pressures and collecting gauge data through the range of 0.65 Pa ($\approx 5 \times 10^{-3}$ Torr) to 130 kPa (≈1000 Torr or 1.3 atm). The system is capable of achieving a pressure, allowing the system to stabilize, and taking a pressure reading in 5 min to 10 min. For comparison, the UIM takes 30 min to 45 min per data point. Overall, the automated system results in a factor of four reduction in turnaround time.

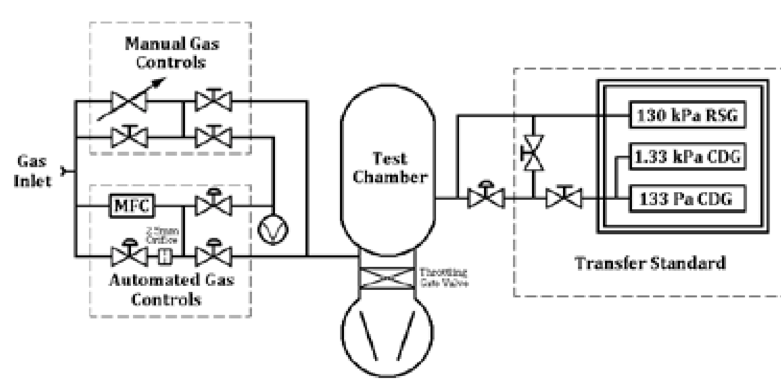

Figure 2. Schematic of calibration system and temperature controlled transfer standard.

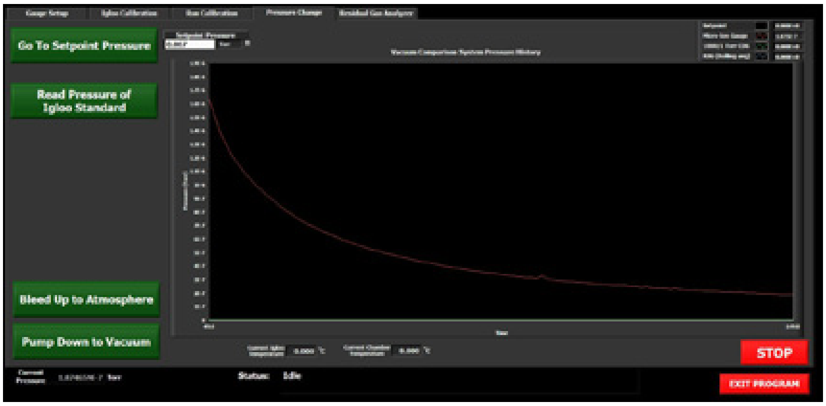

Figure 3. Custom software.

Better: Improved Transfer Standard

NIST maintains UIMs as primary standards that have the lowest stated uncertainty in the world [1, 2], but most commercial transfer standards do not have the resolution/accuracy/stability to fully utilize this advantage. Over the past 10 years, NIST has developed a portable Transfer Standard Package (TSP) which can disseminate pressure at significantly lower uncertainties than commercially available transfer standards [1, 3]. Although higher than the UIMs, the TSP uncertainty is sufficient to calibrate 90 % of commercial gauges. At the heart of this standard is a set of two Capacitance Diaphragm Gauges (CDGs) along with a Resonance Silicon Gauge (RSG) enclosed in a temperature controlled enclosure, shown in Fig. 4. By using the TSP on the VCS system, NIST controls the traceability chain and passes on these low uncertainties directly to the customer.

The crucial advantage of the NIST TSP is the ability to exploit the advantages of both gauge types. CDGs offer unbeatable resolution at lower pressures (typically 1 part in 10^6 of full scale range), but are subject to up to 0.5 % uncertainty (k=2) due to long term stability (drift uncertainty). However, the short term stability (< 8 hours) is excellent (less than 0.01 %). RSGs offer drift uncertainties of 0.01 % (k=2), but don't have the resolution or low full scale ranges of CDGs. Because of these characteristics, it is possible to calibrate the CDGs just before use and wind up with a very low uncertainty measurement. The software takes advantage of this by performing a pre-calibration adjustment to correct the CDG drift against the RSG. This is an entirely automated and in-situ self-calibration to adjust the CDG calibration function just before customer data is collected. The CDG calibration function is gauge dependent and is usually a second to fourth order fit and while overall shifts of this function do occur in time (drift), most CDG drift can be accounted for because the shape of the function is usually very stable. The TSP is recalibrated against the UIM regularly to reassess the calibration function over time.

Additionally, both CDG and RSG gauges see significant noise reduction by placement in a temperature controlled enclosure and ensuring they remain fixed (level). For temperature control, NIST implemented a commercial portable cooler with a built in Peltier heating/cooling unit. By using a feedback loop with a Platinum Resistance Thermometer (PRT) and a NIST designed electronics circuit, the temperature in the enclosure is controlled to ±10 mK (in the operating environment). The cooler is mounted to a flat plate which is leveled to within 100 μRad. By ensuring the gauges are calibrated and leveled in the same manor, the random component of uncertainty is below 0.01 % (k=2) at the lowest pressure and is negligible at higher pressures. The overall calibration uncertainty of the new vacuum comparison standard system is plotted in Fig. 5. The calculated uncertainty shows a marked improvement over a commercial heated CDG and is shaped more like the UIM uncertainty (which it is directly calibrated against). This indicates that the VCS's uncertainty is dominated by the UIM calibration uncertainty. In contrast, the commercial CDG uncertainty is limited by the long term stability and random noise of the

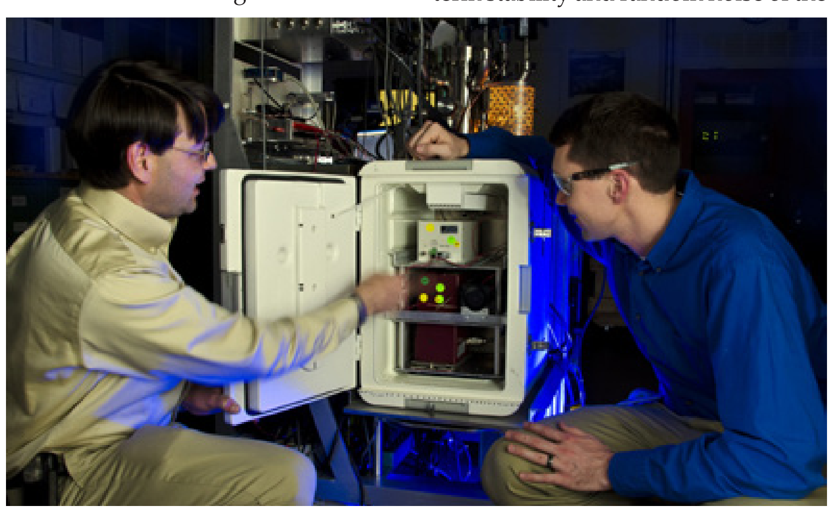

Figure 4. The Transfer Standard Package (TSP) is key to the high accuracy (low uncertainties) produced by the VCS system.

device. Although the uncertainty is not as low as a calibration against the primary standard, the uncertainty of the VCS is significantly improved over other automated transfer standards.

Cheaper: Cost Savings Passed to NIST Customers

The greatest advantage to implementation of an automated calibration system is the reduction in staff time required for a calibration which directly translates into lower costs for the customer. The VCS was designed to be self-sufficient where the calibration staff will only need to attach the gauges, configure the software, and initiate the calibration. The software will run the automated self-calibration routine and complete the calibration unattended or even overnight (when there is often less noise due to vibrations). Overall a reduction in staff time results in savings to NIST which results in a lower calibration cost being passed on to customers. Additionally, customers may also see cost savings due to reduction in down time as a result of gauges having a quicker turnaround time.

Maintaining low uncertainties and lowering calibration costs for the new service has enabled NIST to reach out to a new customer base. These customers may have wanted direct NIST traceability, but couldn't afford the full UIM calibration. Others may have devices that don't have the resolution or accuracy to make use of a UIM calibration, but now may be able to obtain direct traceability at a significantly reduced cost. More gauge types can be accommodated such as new combination gauges or high accuracy digital thermocouple (vacuum) gauges. In general, an increase in customers reduces the total overhead cost of maintenance for the system. Finally, the VCS is designed to be versatile. The system can be used as a test bed for multiple different research applications and projects by providing a system which automatically sets pressures, has multiple access ports, and includes a high quality standard. By maintaining one system that accomplishes many goals we have reduced maintenance costs and expanded capabilities of the lab. Overall these combine to provide calibration service that is one-fifth the cost!

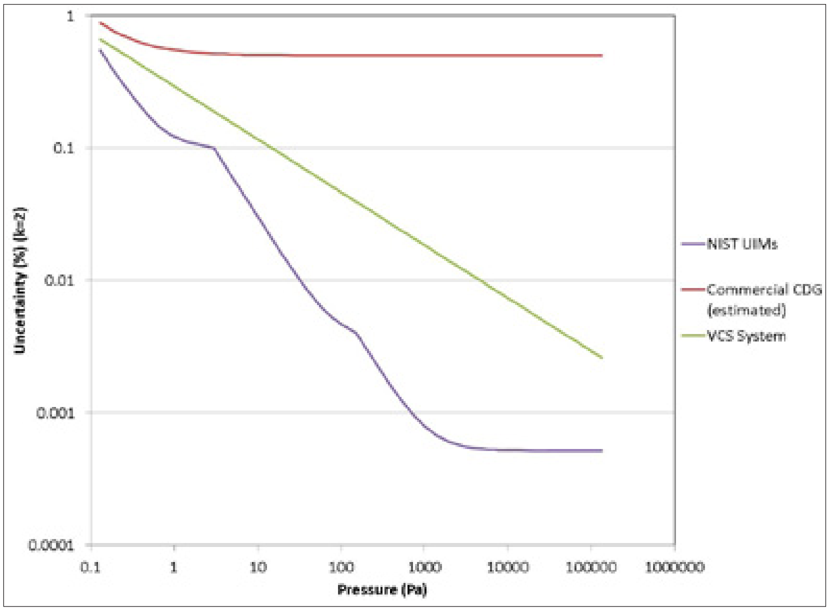

Figure 5. Plot of Uncertainties vs. Pressure (*k*=2).

Conclusion

In a world where time is money, automated calibration is crucial to any calibration facility. But essential to meeting uncertainty goals is the development and evaluation of a stable transfer standard that can be used in an automated process. NIST's VCS required development of a new transfer standard package, automated test-chamber, and custom software to provide a service at one-fifth the cost and a factor of four improvement in turnaround time. This automated calibration system decreases staff time required for calibrations with the resulting lower calibration cost expanding the accessibility of calibrations to a new customer base that includes small businesses and start-ups. Overall, one thing is certain: "Automated calibration *is* progress."

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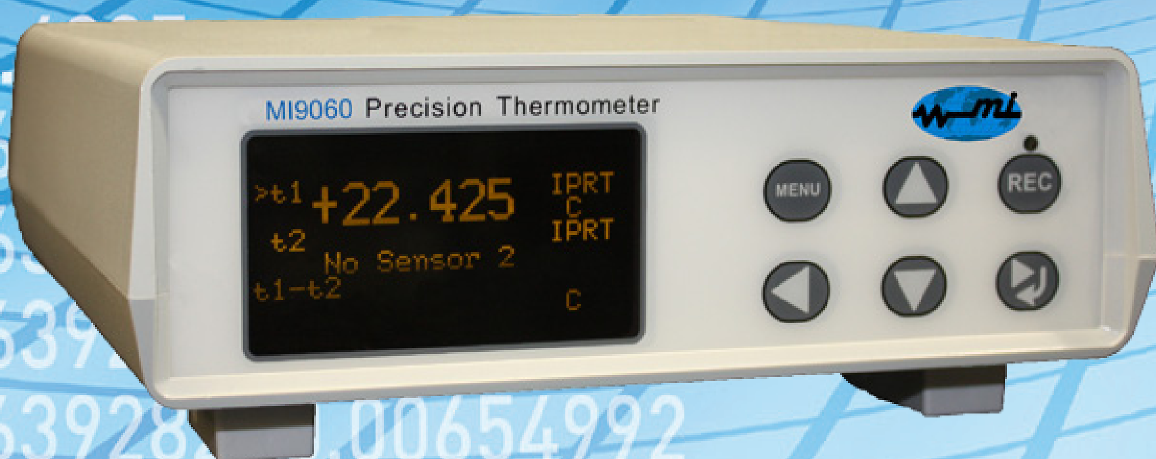

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