19th Symposium IMEKO TC 4 Symposium and 17th IWADC Workshop
Advances in Instrumentation and Sensors Interoperability
July 18-19, 2013, Barcelona, Spain

Traceability for Aerosol Electrometer in the fA Range

Dean G. Jarrett[1], Miles C. Owen[2]

[1] *National Institute of Standards and Technology[1], 100 Bureau Drive, Stop 8171, Gaithersburg, MD, 20899,USA*
Tel: +301-975-4240, Fax: +301-926-3972, email: dean.jarrett@nist.gov
[2] *US Army Primary Standards Laboratory, Bldg. 5435 Fowler Rd, Redstone Arsenal, AL, 35898, USA Tel: +256-955-8925, Fax: +256-876-7630, email: miles.c.owen.civ@mail.mil*

Abstract-Described here are the configurations and procedures used to provide traceability to electrical standards for an aerosol electrometer calibration in the range ± 20 fA to ± 40 fA. The technique used here simulated the condition of a current induced when charged particles would flow into the aerosol electrometer's Faraday-cup by replacing the charged particle flow with known source currents. The technique used here was to source known currents over a wider range of ± 1 pA, in addition to the ± 20 fA to ± 40 fA, and subtract the offset (i.e. zero) current measured when charged particles are not flowing into the aerosol electrometer. Linear regression was used to scale from the pA to fA range by determining the slope of the sourced vs. measured currents over both ranges and using the residuals to verify the linearity. Two independent methods, both traceable to electrical standards, were used to source known currents from ± 1 pA to ± 20 fA: a source-meter and a voltage-resistor source using high resistance standards of 100 GΩ or 1 TΩ.

Keywords - aerosol electrometer, standard resistor, current source, charged particles, Faraday cup.

I. Introduction

In recent years, requests have been made of the NIST Metrology of the Ohm project for assistance in providing SI traceability for currents in the nA, pA, and fA ranges for the measurement of photodiode currents, measurement of ionizing radiation currents, and calibration of aerosol electrometers. Internal and external collaborations in recent years have yielded progress on both the sourcing and measurement of the low-currents by using high resistance standards to provide a path for SI traceability from the quantum Hall resistance. NIST experience in design, development, and measurement of high resistance standards has been leveraged to address measurement needs for sourcing and measuring currents in the nA, pA, and fA ranges.

Lack of stability of resistors above 10 GΩ has been cited in the literature [1] as a problem when stable currents smaller than 10 pA are needed for small current measurement. Other groups have used the voltage ramp technique to generate small currents with a reference capacitor and a voltage ramp generator [1, 2] to generate stable currents below 10 pA. Access to well-characterized high resistance standards up to 1 TΩ allowed us to investigate the voltage-resistor source method [3] for this project and compare it to source-meter current sources. Future work may include comparisons to the voltage ramp technique.

II. Setup and Configuration

The aerosol electrometer collects charge by flowing an aerosol of charged particles through a filter that is housed inside of a Faraday cup and connected to an electrometer circuit. Typically, the aerosol particles are conditioned so that each particle carries a single charge of the same polarity, so that the aerosol electrometer correlates the rate of the number of particles collected on the filter to an electric current. When particle-free air is sampled by the aerosol electrometer, the digital readout typically indicates a non-zero current on the order of ± 5 fA, which is attributed to offset errors in the electrometer instrumentation, and this offset current changes from day to day and even within a day. Thus, when measuring aerosols, the signal current resulting from charged particles is first measured along with a second measurement of the offset current for particle-free air. The offset current is then subtracted from the signal current to get the current resulting from the charged particles.

To calibrate the aerosol electrometer, a known current was applied to the electrometer conductor housed in the Faraday cup by temporarily attaching a coax lead through the gas port to the stainless steel filter screen where charged particles would normally deposit charge. The coax lead provided an electrical connection by which a

---

[1] Quantum Measurement Division, Gaithersburg, MD. NIST is part of the U.S. Department of Commerce. Official contribution of the National Institute of Standards and Technology; not subject to copyright in the United States. This work was supported by the U. S. Army Test, Measurement & Diagnostic Equipment Activity under agreement number MIPRICO48AP002.

known current could be sourced into the Faraday cup. Figure 1 shows charge collection by the Faraday cup in operational (a) and calibration (b) modes. The calibration curve of the electrometer is well modeled by a linear function with an offset, so that when the offset current is subtracted from the signal particle current, only the slope of the electrometer calibration curve needs to be known with traceability. The slope is not affected by offset errors which would dominate an absolute current measurement in the fA range.

Figure

1. Charged particles (a) or known currents (b) are sourced to the Faraday cup of the aerosol electrometer.

Sakurai and Ehara [4] have described a calibration procedure which uses the slope of the source vs. measured currents to provide traceability in the fA range from calibrated source-meter pA currents. The residuals of a least-squares fit over the pA and fA range was used to evaluate the linearity and provide traceability from calibrated currents at ± 1 pA and ± 0.5 pA to the 20 fA to 40 fA range where the aerosol electrometer measures charged particles. This technique was used for the aerosol electrometer calibration with the addition of voltageresistance sources to provide a second traceability path to electrical standards. A second source-meter was used as a check standard to measure currents provided by the first source-meter and voltage-resistors sources. Figure 2 shows the four configurations of current sources, source-meters, and electrometers used during these measurements.

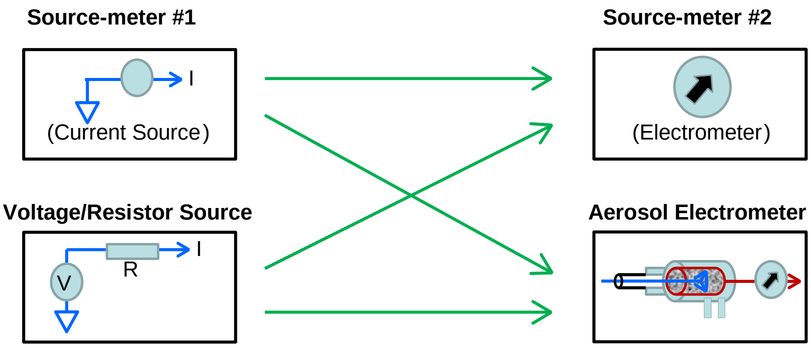

Figure 2. Block diagram of the current sources, source-meters, and electrometers used to provide traceability to electrical standards for the current measurements. The voltage-resistor and source-meter current sources are shown on the left and the aerosol electrometer and source-meter electrometer are shown on the right.

Standard resistors well characterized for temperature coefficient of resistance (TCR), voltage coefficient of resistance (VCR), drift, and settling time [5] have made it possible to configure voltage-resistor sources using programmable dc voltage calibrators and 100 GΩ and 1 TΩ standard resistors. Currents from ± 1 pA to ± 20 fA were sourced using both resistors. Careful attention to shielding of connections and environmental conditions was given. The measurements took place inside a screen room where the temperature was controlled to ± 0.5 °C. All test leads were shielded. The resistors and remote input heads of the source-meters were screened and placed in an insulated box to further suppress variations in temperature. The measurement process was automated to reduce operator induced noise and influence, providing the same timing regardless of which source (source-meter or voltage-resistor) or detector (aerosol electrometer or source-meter) was used. The four configurations all followed the same measurement sequence and were repeated multiple times over the 5 days the measurements took place at NIST.

Short settling times of the resistors allowed the voltage-resistor source measurements to reach steady state in less than 1 minute. All sourced currents used a 120 s hold time followed by 100 measurements at each nominal current. The measurement sequence started with currents in the pA range, followed by the fA range, and finally a closing set of currents in the pA range. The zero was measured before and after each range and when polarity was reversed. Figure 3 shows the current from the voltage-resistor source measured by the source-meter during a set of measurements made in the pA and fA ranges. Nominal currents in the pA range were ± 0.5 pA and ± 1 pA.

Currents in the fA range were from ± 20 fA to ±100 fA at 20 fA steps. Prior to calibrating the aerosol electrometer at NIST, the calibration process was done at the U.S. Army laboratory using the same model source-meter as a current source.

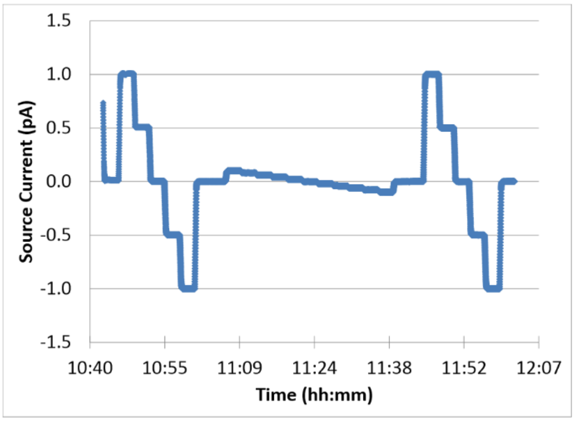

Figure 3. Voltage/resistor source current applied as a function of time in the pA and fA ranges. Zero current applied before and after each range change and current reversal. Current trace shown was measured by the source-meter.

III. Results

The slopes for the measurements for each data set were calculated and plotted for the aerosol electrometer and the source-meter check standard. Aerosol electrometer slopes ranged from 0.9900 to 0.9935 and slopes for the check standard source-meter ranged from 1.0005 to 1.0012. The scatter of the aerosol electrometer slopes was random in that no bias was observed regardless of current source, indicating that the two methods of sourcing current were comparable. The slopes for the source-meter check standard data sets were scattered less and there was a difference of 0.0005 in the slope, dependent upon current source. Figure 4 and Fig. 5 show the slopes for the 12 and 15 sets of measurements for the aerosol electrometer and check standard source meter, respectively.

The residuals of the aerosol electrometer and source-meter check standard were consistent with the variability of the slopes. For the aerosol electrometer, the magnitudes of the residuals of the fit were less than 6 fA and the magnitudes of the residuals for the check standard source-meter were less than 0.5 fA. Figure 6 and Fig. 7 show the residuals from the linear regressions for the 12 and 15 sets of measurements for the aerosol electrometer and check standard source meter, respectively. Zero readings were subtracted to remove the offset current and use the residuals to evaluate the regressions over the pA and fA ranges.

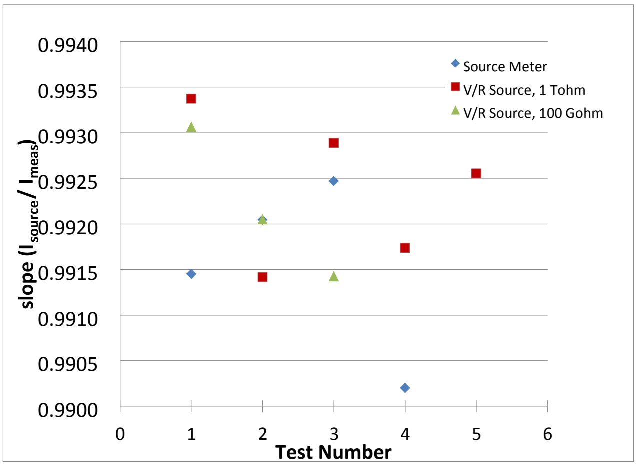

Figure 4. Slopes of the 12 sets of current measurements made by the aerosol electrometer over a 3 day period. Source-meter and voltage-resistor sources (1 TΩ and 100 GΩ) were used to source known currents to the aerosol electrometer. No bias dependent upon the current source was observed.

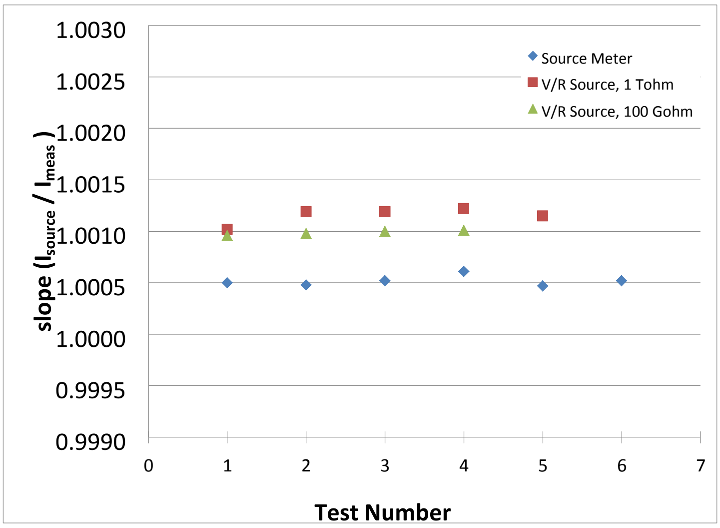

Figure 5. Slopes of the 15 sets of current measurements made by the check standard source-meter over a 4 day period (same days as aerosol electrometer plus one additional day). Source-meter and voltage-resistor sources (1 TΩ and 100 GΩ) were used to source known currents to the check standard source-meter. The scatter of the slopes is less than that for the aerosol electrometer and slope is dependent upon the current source.

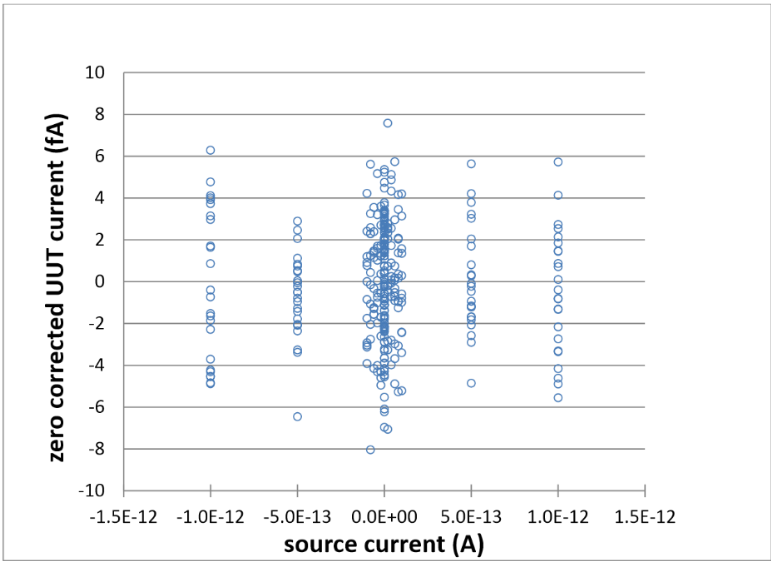

Figure 6. Residuals for the aerosol electrometer measurements from the 12 sets of data where the source-meter and voltage-resistor sources provided source currents over the pA and fA ranges. Zero readings were subtracted to remove the offset current. Uniform distribution of residuals over the pA and fA ranges indicates the regression is linear over the pA and fA ranges.

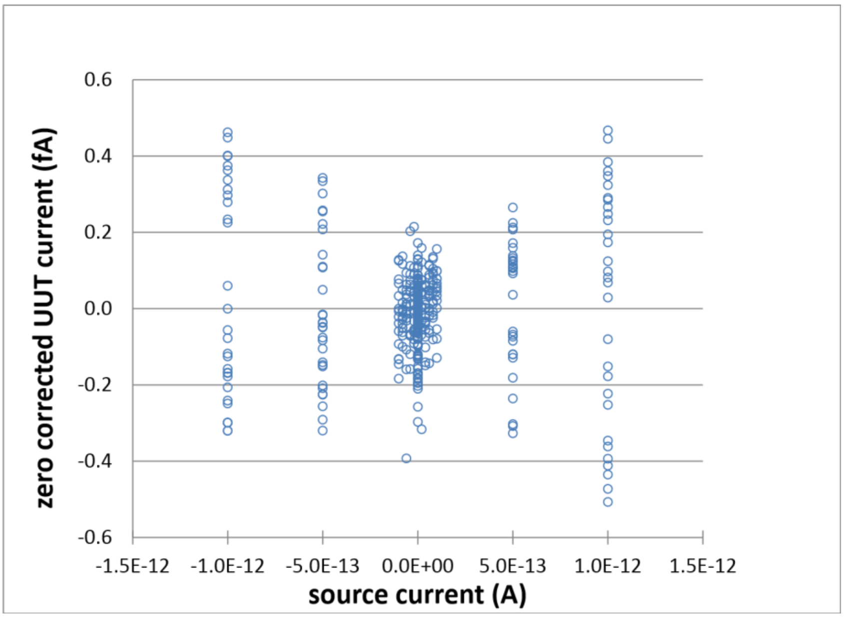

Figure 7. Residuals for the check standard source-meter measurements from the 15 sets of data where the other source-meter and voltage-resistor sources provided source currents over the pA and fA ranges. Zero readings were subtracted to remove the offset current. Magnitude of the scatter is an order of magnitude less than what was observed for the aerosol electrometer. The increase in scatter in the residuals for higher source current magnitudes has been attributed to the difference in slopes for the two types of current sources used for these measurements.

IV. Conclusions

The linearity of the aerosol electrometer response to current sourced from the voltage-resistor source or sourcemeter is sufficient to provide traceability to measurements in the 20 fA to 40 fA range from known currents generated at the pA level with an expanded uncertainty ($k=2$) of 0.1 % with the voltage-resistor source and 0.8 % with the source-meter.

The U.S. Army Primary Standards Laboratory (APSL) aerosol electrometer calibrated by the method described here has since participated in an international comparison of eight aerosol electrometers from Europe, Asia, and North America [6], measuring aerosol concentrations from 1,000 particles/cm^3 to 10,000 particles/cm^3. Particles ranging from 20 nm to 100 nm diameter were used during this comparison. These particle concentrations and sizes will generate currents in the 3 fA to 30 fA range. The traceability for fA currents described here will be used to support the APSL aerosol electrometer in this international comparison.

References

[1] T. Bergsten, K.-E. Rydler, O. Gunnarsson, G. Eklund, and V. Tarasso, “A Novel Precision DC Current Source in the pA Range,” *CPEM 2010 Conf. Digest*, June 13-18, 2010, Daejeon, South Korea, pp. 123-124.

[2] G.-D. Willenberg, H. Tauscher, and P. Warnecke, “A traceable precision current source for currents between 100 aA and 10 pA”, *IEEE Transactions on Instrumentation and Measurement*, vol. 52, pp.436-439, 2003.

[3] P. Sipilä, R. Rajala, P. Kärhä, A. Manninein, and E. Ikonen, “Calibration of Current-to-voltage Converters for Radiometric Applications at Picoampere Level,” *Proceedings NEWRAD*, Oct. 17-19, 2005, Davos, Switzerland, pp. 223-224.

[4] H. Sakurai and K.Ehara, “Evaluation of uncertainties in femtoampere current measurement for the number concentration standard of aerosol nanoparticles”, *Meas. Science and Tech.*, vol. 22, no. 2 024009, 2011.

[5] R. F. Dziuba, D. G. Jarrett, L. L. Scott, A. J. Secula, “Fabrication of High-Value Standard Resistors,” *IEEE Trans. on Instrum. and Meas.*, Vol. 48, No. 2, April 1999, pp. 333-337.

[6] “Comparison of aerosol electrometers,” Ref. 1244, http://www.euramet.org/index.php?id=tc-mcprojects&no_cache=1&ctcp_projects[cmd]=details&ctcp_projects[uid]=1017, 2013.