Calibration of an Electrometer from 500fA to 100fA

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A method is presented with parameters traceable to the National Institute of Standards and Technology (NIST) to accurately generate and measure a standard DC current in the range of 100fA to 500fA (fA = 10^{-15} Amps). The measurement system consists of a voltage source, 100GΩ (10^{11} Ohms) resistor, multimeter, and digital electrometer. A custom-made Faraday cage is used to improve the signal to noise ratio. Based on Ohm's law, the voltage source and resistor create a calculable current used to calibrate the electrometer. Uncertainties are estimated to be 2% from 500fA to 300fA, and 5% from 300fA to 100fA.

1. System Overview

The system combines a voltage source and a resistor to produce a standard current from 500fA to 100fA used to calibrate the electrometer. A multimeter measures the voltage source. A Faraday cage encloses the resistor and electrometer, while the voltage source and multimeter are located outside of the cage. The electrometer, resistor, and Faraday cage are grounded to the low terminal of the voltage source. Thick, non-insulated copper wires are used to make connections. Using no insulation eliminates certain sources of generated currents, per reference [1]. All measurements are made after at least four hours warm up time in a laboratory maintained at 23^{o} +/- 2^{o}C.

2. Voltage Source and Resistor

A Fluke 5720A calibrator provides a voltage from 10mV to 50mV. This voltage is measured with an Agilent 3458A digital multimeter for maximum accuracy.

The resistor is a Penn-Airborne 100GOhm (10^{11} Ohms) standard calibrated at 50V and 5V traceable to NIST. The value of resistance displays a modest sensitivity to the applied power, with power equal to voltage times current. The resistance at 50V and 5V is measured to four significant digits, with a slight variation in the fourth digit for each case. The system detailed in this paper requires a value of resistance at 50mV and 10mV. Therefore, the resistances measured at 50Vand 5V are rounded to three significant digits to a constant 1.01E+11 Ohms, with a resolution error of 0.005E+11 Ohms included with the calibration errors at 50V and 5V. Furthermore, the voltages and currents measured with this system produce a maximum power of 25E-15 Watts, which should have a minimal effect on the value of resistance.

3. Electrometer

A Standard Imaging MAX 4000 digital electrometer is the unit under test in this calibration. It measures the amount of charge collected over a time interval, which is equal to the electronic current. The electrometer reports values of charge in Coulombs and the sample time in seconds.

Repeated measurements of charge produce a repeatability error, while the error in time is vanishingly small. The input of the electrometer has a triaxial cable connection, while a triaxial to coaxial cable adapter is used for the input of the electrometer, with the low connection grounded to the voltage source low terminal.

4. Procedure

The electrometer and resistor are placed inside of the Faraday cage on foam padding to absorb vibrations. The voltage source and multimeter are placed outside, but very close to, the Faraday cage. Using thick, non-insulated copper wire, the voltage source high terminal is connected to the input of the resistor. The output of the resistor is then connected to the high terminal of the electrometer coax adapter. Finally the low terminal of the electrometer, the ground terminal of the resistor, and the Faraday cage are all connected to the low terminal of the voltage source (see figure 1 below)

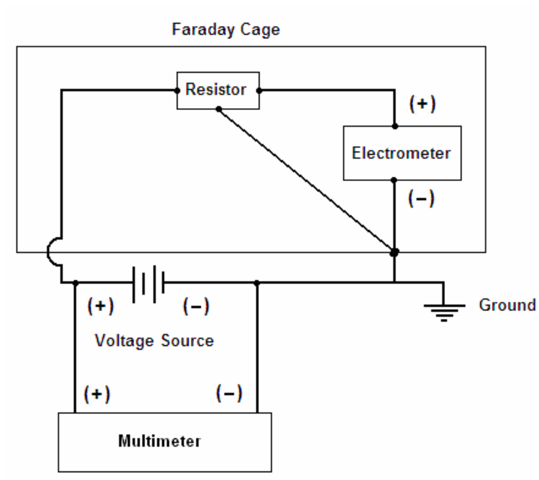

Figure 1: System schematic.

Repeated measurements of current are performed at voltage settings of 50mV, 30mV, and 10mV, corresponding to approximately 500fA, 300fA, and 100fA. The multimeter initially measures the applied voltage, and is then disconnected before making current measurements with the electrometer. Measurements of current are then taken at the above three data points until the values stabilize.

5. Results

The calibration results from three separate days are shown below. The system proves to be repeatable.

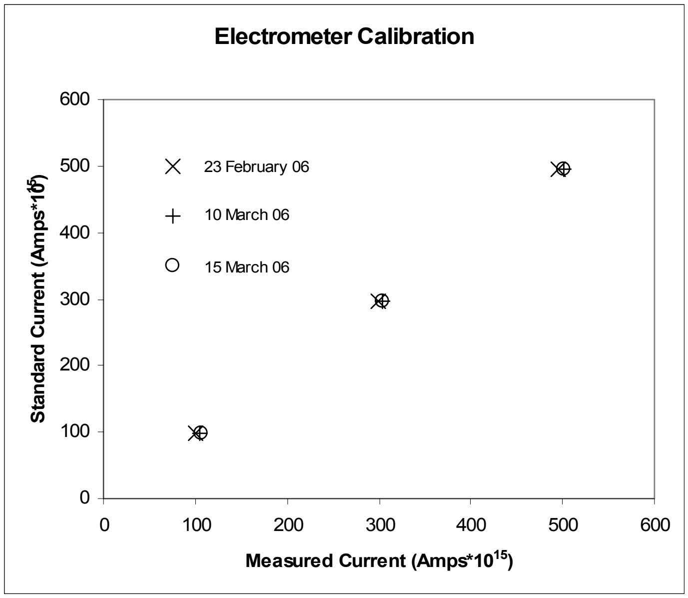

Figure 2: Plot of calibration data.

Next is a table containing the calibration errors from the 15 March data with a k = 2 coverage factor. A linear regression was fit to the data, producing the following equation:

$$y = 1.003x - 0.733 \times 10^{-15}$$

where y is the standard current and x is the electrometer current. Errors of the regression are also included in table 1.

Table 1: Calibration data.

Standard Current	Standard error (k=2)	Electrometer Current	Electrometer total error (k=2)	Linear Regression Accuracy
fA	% reading	fA	% reading	% error
495	1.158	501	4.906	0.019
297	1.158	303	1.798	-0.080
99	1.158	106	1.566	0.111

6. Conclusion

A circuit is presented to perform a NIST traceable calibration of an electrometer from 500fA to 100fA. The system produces a repeatable standard current with approximately 1.2% error. A Standard Imaging MAX 4000 digital electrometer is calibrated with uncertainties of approximately 2% error from 500fA to300fA and approximately 5% error from 300fA to 100fA. The electrometer produces a repeatable and linear output.

7. References

1. J. Yeager and M. A. Hrusch-Tupta ed, Generated Currents, Chapter 2.3.4 in Low Level Measurements 5th Ed, Keithley, 1998, pp. 2.18-2.24.