A PRECISION DC LOW-CURRENT SOURCE FOR CALIBRATION OF ELECTROMETERS IN THE RANGE OF 100 pA TO 1 fA

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Abstract: A precision DC low-current source based on charging a capacitor with a linearly varying voltage ramp was built to calibrate low-current meters in the range of 100 pA to 1 fA. For a calibration of Keithley 6430, the relative expanded measurement uncertainty (k=2) was evaluated to be 16 μA/A ~ 62 mA/A within the current range. In the calibration process, it was observed that the offset current of the capacitors lead to a crucial contribution to the measurement uncertainty.

Keywords: DC low-current, voltage ramp, capacitor, picoammeter

1. INTRODUCTION

The most widely used method for precise calibrations of low-current measurement instruments such as picoampermeters and electrometers is relying on charging a capacitor C by a linearly varying voltage ramp dV/dt. The generating current, $I = C \bullet dV/dt$, is used to calibrate commercial current meters [1, 2]. This capacitor-based low-current source essentially consists of a voltage ramp and a low-dissipation capacitor. In addition to the linearity of the voltage ramp constructed on the basis of operational amplifier integrator, the capacitor plays a crucial role not only in the measurement uncertainty but also in the generation of low-current. Above all, we found that the measurement uncertainty was considerably influenced by the offset current of the capacitor used [2, 3].

In this work, we report the calibration results of commercial low-current meters and test several capacitors to verify the influence of the capacitors on the measurement uncertainty. Finally, we discuss how the offset current of the capacitors is reflected in the measurement uncertainty.

2. EXPERIMENTAL

Figure 1 shows a schematic diagram of the capacitor-based low-current source developed on the basis of the same principle described in Ref. 1. The core element in this setup is an analogue-based voltage ramp generator, in which the non-linearity of a real capacitor in the circuit caused by dielectric absorption and leakage resistance is compensated by an analogue feedback network. The integrator can generate a stable voltage ramp from -12 V to +12 V within 2000 s and therefore has a fixed voltage slope of 9.93 mV/s ± 83 ppm. The variation of the voltage slope required to generate an arbitrary current within the aforementioned range is carried out by a Kelvin Varley divider. In conjunction with a set of metrology-grade capacitors in the range of 1 to 1000 pF, the setup can generate DC current in the range of 1 fA to 100 pA [4].

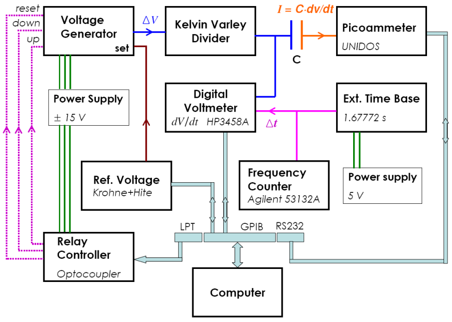

Fig. 1. Schematic diagram of a calibration setup for low-current meters.

3. RESULTS AND DISCUSSION

Figure 2 shows the voltage slope dV/dt of the voltage ramp generator measured using a digital multimeter Agilent 3458A with the ramping sequence (hold, ramp up, hold and ramp down). For a complete measurement cycle, the ramping sequence of hold and up for positive and hold and down for negative current is repeated 20 times, and 25 data points were taken at every ramping step. The inset of Fig. 1. shows an extended view of the ramping-up step in the measurement sequences. In order to eliminate the voltage switching effect, the first five and the last five points were excluded in the evaluation of the mean value and standard deviation.

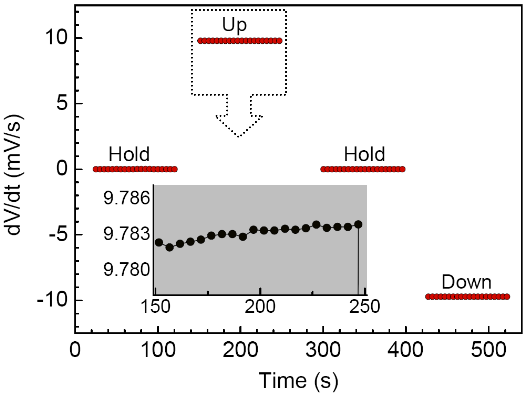

Fig. 2. Voltage slope dV/dt of the voltage ramp generator with ramping sequences, hold, up, hold and down. Inset shows an extended view of the ramping-up step (positive current).

The offset current caused by a device-under-test (DUT), voltage ramp and a capacitor due to an incomplete discharge can be eliminated by subtracting the null current measurement (hold step) from the measured current [4].

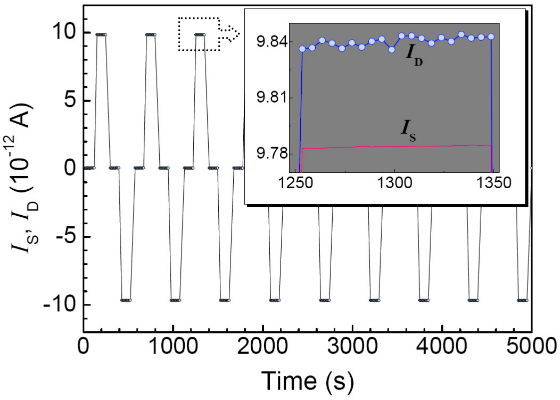

Fig. 3. Generated source current I_S (solid lines) and measured current I_D (open circles) by a DUT (Keithley 6430). Inset shows an extended view of the current source I_S and measured current I_D.

Figure 3 reveals an example of calibration results obtained using an electrometer Keithley 6430. The source current of 10 pA was produced using a gas-dielectric gap capacitor of 1 nF (General Radio 1404-A). The measured current I_D (open circles) is larger than that of the generated source current I_S (solid lines) due to the offset current of the capacitor as shown in inset of Fig. 3.

A detailed uncertainty analysis shows that the type A uncertainty is strongly dependent on the DUT and leads to main contribution to the total measurement uncertainty budget. The contributions to type B uncertainty are as follows: the capacitor (calibration uncertainty, temperature dependence, ac/dc deviation, and leakage current), the voltmeter (readout uncertainty and the linearity), and the time base, the voltage ramp and the DUT (voltage burden and bias current). Therefore, the type A uncertainty obtained by a DUT, Keithley 6430, lies between 1.6×10^{-5} at 100 pA and $6.2 \text{x} 10^{-2}$ at 1 fA [4].

To verify the influence of the capacitors used on the generation of low-current, several capacitors have been tested: General Radio (GR) 1404 series (10 pF, 100 pF, 1000 pF), GR 1403 series (1 pF, 10 pF, 100 pF, 1000 pF), homemade KLR capacitors (10 pF, 100 pF) and homemade fused silica capacitors (10 pF, 100 pF). The GR 1404 series and the KLR capacitors use dry nitrogen in sealed enclosure, whereas the GR 1403 series and the fused silica capacitors are unsealed. The calibration results obtained using the same ramp generator but different capacitors mentioned above are in good agreement within the measurement uncertainty and independent of the type and dielectric materials of the capacitors. However, we found several times increased uncertainty of the source current produced by using the sealed GR 1404 series capacitors. The measurement uncertainty increases nearly one order of magnitude from $3.9 \text{x} 10^{-4}$ to $4.9 \text{x} 10^{-5}$, although the same capacitor was used.

Indeed, the capacitors significantly influence not only the generated current but also the uncertainty of the measured current. A substantial difference between the two measurements lies in the offset current of the capacitor used. In fact, the offset current in the optimal discharged capacitor was in the level of 10 fA, whereas the offset current was considerably higher (in the level of sub-picoampere) in the case of the poor uncertainty. In addition, the discharging process of the capacitor with low offset current was monotonous, whereas the discharge rate of the capacitor with the higher offset current was not simple monotonous function of time. Accordingly, it is clear that the short term drift of the offset current caused by the discharge of the capacitor cannot be completely eliminated by the subtraction method. Therefore, it is important to notice that the offset current of the capacitors should be monitored prior to calibration of low-current meters.

4. SUMMARY

A precision low current source has been developed on the basis of charging a capacitor with a voltage ramp. A detailed analysis of the uncertainty indicates that the current source can be used for calibration of commercial electrometers with an uncertainty of 10 μA/A at 100 pA and 2.8 mA/A at 1 fA. For the precise calibration of low-current meters, the offset current of the capacitors should be carefully considered.

5. REFERENCES

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