Automatic Calibration of DC Low Level Current at SCL

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***Abstract* — At SCL, an automated system is developed to calibrate DC current sources and meters, including electrometers and femto-ammeters, from 100 pico-amperes (pA) down to 100 femto-amperes (fA). The system comprises an in-house developed control software, a ramping voltage generation circuitry and a precision air capacitor.**

***Index Terms* — Electrometer, current source, current measurement.**

I. Introduction

DC current sources and meters at femto-amperes level are essential for low-level current applications, such as leakage current measurement for electrical/electronic component, current measurement for mass spectrometer, measurements of test probe current in electrochemistry as well as calibration of and precision medical equipment. Conventional method using test current generated by high-valued resistor (i.e. 1×10^9 Ω or above) is not suitable for this application in terms of its levels of precision and accuracy.

SCL has developed an automatic system to calibrate DC current, ranging from 100 pA to 100 fA, based on a precision low level DC current generator (which is composed of a differentiated linear ramping voltage generator and an air dielectric capacitor).

Fig. 1. Calibration System for Low Level DC Current

II. Generation of DC Low Level Test Current

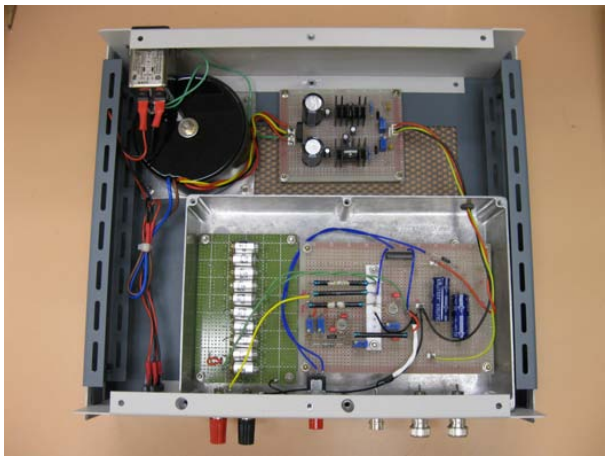
DC current is generated by applying a linear ramping voltage $v(t)$ to the air dielectric capacitor, C.

$$i(t) = c \times \frac{dv(t)}{dt}. \qquad (1)$$

A reliable test current can be generated, if the voltage ramping rate, $dv(t)/dt$, and the capacitance, C, are stable. Major components of the current generation system include:

(i) a linear ramping voltage generator;
(ii) a precision digital voltmeter;
(iii) a programmable voltage source (i.e. a voltage calibrator).

The ramping voltage generator is SCL developed, with ramping rate ranging from ± 0.01V/s to ± 0.1V/s. It is an operation amplifier based circuit (i.e. IC1, C1 and R1) that generates ramping DC voltages, under the control of a programmable voltage source. A feedback circuit (i.e. IC2, R2 to R4) is used to compensate leakage in C1 in order to maintain linearity. Sampling time is controlled by an external triggering signal of 1 Hz square-wave from a precision Function Generator. Ramping rate of the output voltage is measured by a precision digital voltmeter (DVM). The whole system is controlled by the software coded in Visual Basic.



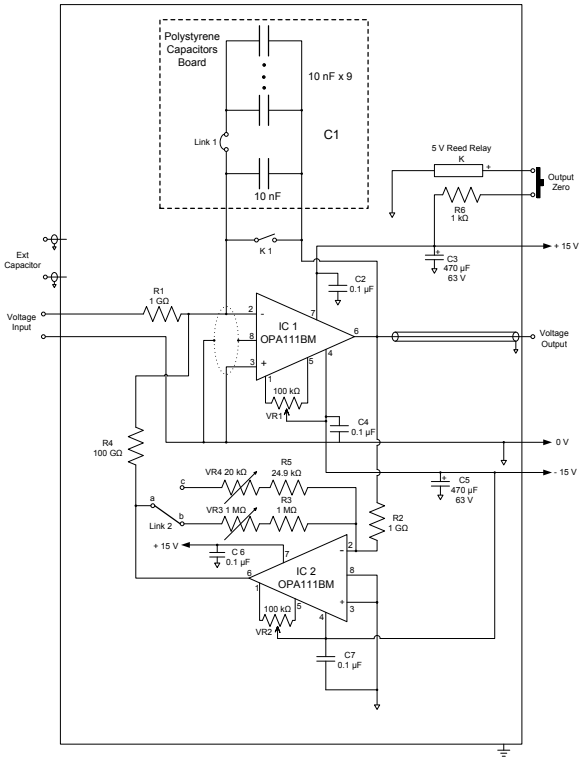


Fig. 2. The Ramping Voltage Generator

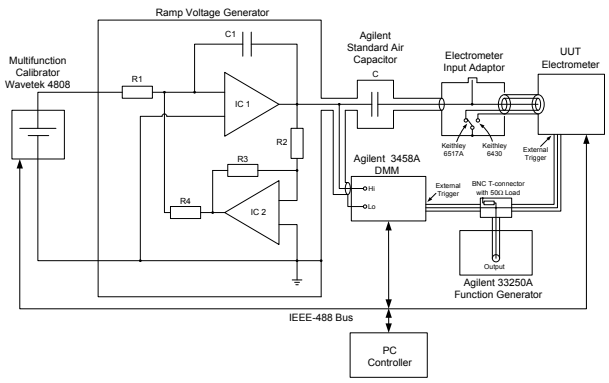


Fig. 3. Schematic Diagram- Calibration of UUT.

III. Calibration of Unit-under-Test (UUT)

UUTs (e.g. electrometer and femto-ammeters) are calibrated by the test current generated as follows:

Step 1: Generation of DC ramping voltage, V

Voltage, V, is generated based on the programmable voltage source output, V_{in}, $R1$ and $C1$.

$$V = \frac{V_{in} \times t}{R1C1}. \tag{2}$$

Ramping rate is determined by measuring the voltage values by the system DVM at intervals of 1 s (through a 1 Hz triggering signal from the frequency counter). The ramping voltage is:

$$\frac{dV}{dt} = \frac{V_{t(n)} - V_{t(n-1)}}{t_{(n)} - t_{(n-1)}}. \tag{3}$$

Where $V_{t(n)}$ and $V_{t(n-1)}$ are voltage at $t_{(n)}$ and $t_{(n-1)}$ respectively.

Step 2: Generation of Low Level DC Current

The instantaneous value of the test current, $I_{t(n)}$, is:

$$I_{t(n)} = C \times \frac{dV}{dt} = C \times \frac{V_{t(n)} - V_{t(n-1)}}{t_{(n)} - t_{(n-1)}}. \tag{4}$$

Where C is an air type capacitor of value 1 pF, 10 pF, 100 pF or 1000 pF depending on the test current.

For a period from t_o to t_m, the test current is:

$$I_{avg} = \frac{\sum_0^m I_{t(n)}}{m}. \tag{5}$$

Step 3: Determination of Error in the Meter Reading

The UUT's meter instantaneous reading error is determined as:

$$E_{t(n)} = \frac{I_{meter\_t(n)} + I_{meter\_t(n-1)}}{2} - C \times \frac{V_{t(n)} - V_{t(n-1)}}{t_{(n)} - t_{(n-1)}}. \tag{6}$$

The entire calibration process is software controlled. Ramping voltage, test current, UUT readings and meter errors are displayed for real-time monitoring.

TABLE I
CALIBRATION AND MEASUREMENT CAPABILITIES (CMC) ACHIEVED

	Quantity	Expanded Uncertainty*
Generation of DC test current	100 pA	10 fA (0.01 %)
	100 fA	0.10 fA (0.1 %)
Calibration of UUT meter	100 pA	11 fA (0.011 %)
	100 fA	0.30 fA (0.3 %)

Note *: coverage factor, k, equal to 2 at 95% C.L.

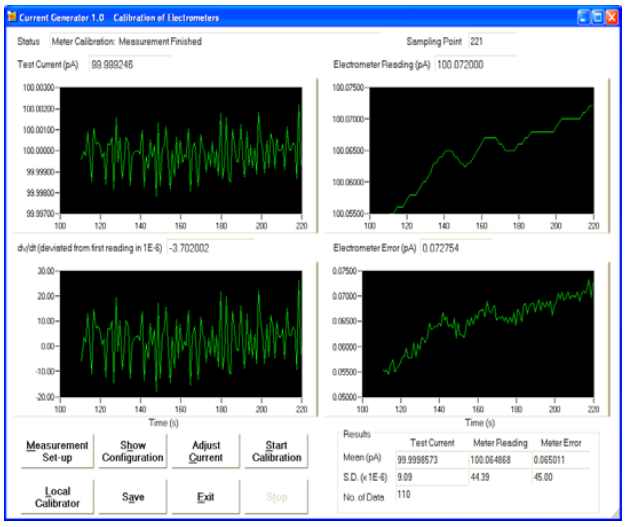


Fig. 4. Real-time Display of Measurement Results

IV. Conclusions

A Low Level DC Current Generation and Measurement System for calibration of electrometers, femto-ammeters and some precision medical equipment has been developed at SCL. SCL has been accredited to perform calibration of low level DC current from 100 fA to 100 pA with measurement uncertainties of 0.3 fA to 20 fA at 95 % confidence level.

References

[1] Nick E. Fletcher, *et al*., "New Capability for Generating and Measuring Small DC Currents at NPL," *IEEE Trans. on Instrum. and Meas.*, Vol. 56, No. 2, pp.326 – 329, April 2007

[2] Luca Callegaro, *et al.,* "Techniques for Traceable Measurements of Small Currents,", *IEEE Trans. on Instrum. and Meas.*, Vol. 56, No. 2, pp.295 – 298, Apr 2007

[3] Luca Callegaro, *et al.,* "A Current Source for Picoammeter Calibration," *IEEE Trans. on Instrum. and Meas.*, Vol. 56, No. 2, pp.1198 – 1201, Apr 2007