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A CURRENT SOURCE FOR CALIBRATION OF LOW-CURRENT METERS

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Abstract: The need for accurate calibration of current meters in the picoampere range is continuously increasing. A traceable current source for calibration of meters in the 100 fA – 100 pA current range is here presented. The source is based on a low-frequency generator ramp generator, which charges and discharges a gas-dielectric capacitor. Current traceability is given by the measurement of voltage parameters with a sampling voltmeter, and by calibration of the capacitor at audio frequency. The source has been employed in the EUROMET.EM-S24 "Comparison of small current sources" supplementary comparison.

Keywords: Current measurement, Calibration, Signal generators.

1. INTRODUCTION

Accurate generation of dc currents below the nA value is of extreme interest for the calibration of current detectors, picoamperemeters, electrochemical transducers and dosimeters for ionizing radiation.

The generation of calibrated currents by using reference voltage sources and high-valued resistors tend to perform poorly below at the pA level. Above the GΩ range, resistors have high voltage, temperature and humidity coefficients, and a low time stability. Furthermore, low-current meters have a voltage burden which is significant for applied voltages at the V level.

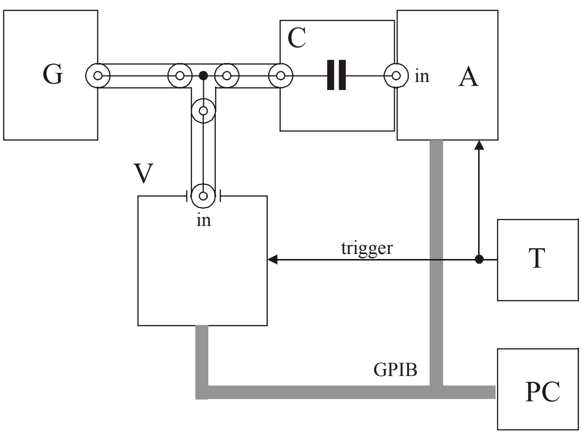

Fig. 1. Block schematics of the experimental setup.

An alternative for generating low current is to apply a slow linear voltage ramp to a differentiating capacitor [1-4]. The following describes an inexpensive implementation of the technique, suitable for the automatic calibration of meters with traceable currents in the 100 fA - 100 pA range.

2. THE METHOD

Fig. 1 shows the block schematics of the source, employed for the calibration of a picoammeter **A**.

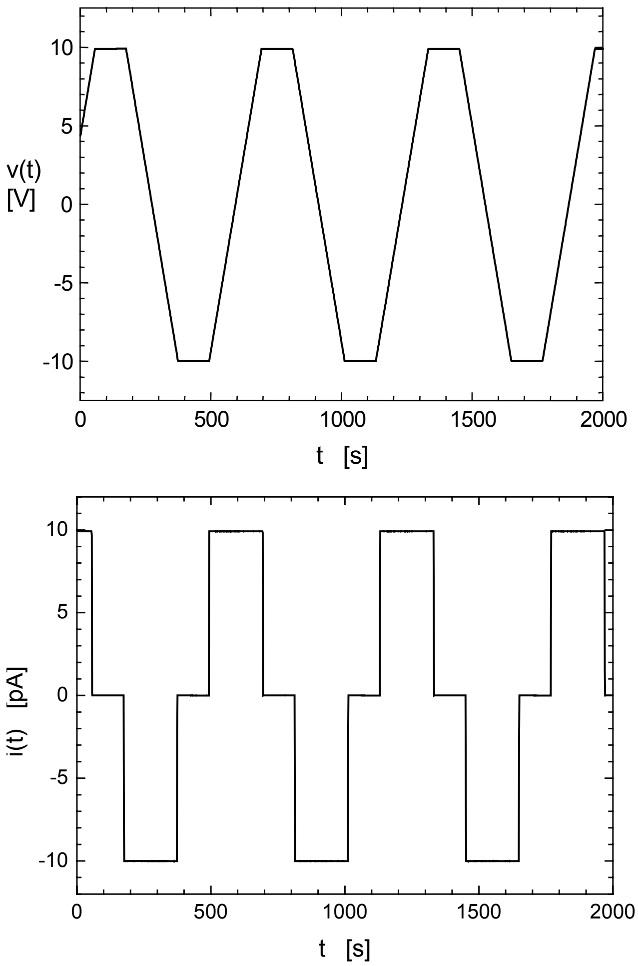

Fig. 2. (top) Voltage ramp $v(t)$ generated by source G, and (bottom) corresponding current $i(t)$ computed from v(t) and capacitor value C.

A ramp generator **G** is connected to a sampling voltmeter **V** and to the high voltage port of a gas-dielectric capacitor **C**. The low voltage port of **C** is connected, directly or with a minimal cable length, to the input connector of **A**. **V** and **A** are triggered by the precision timer **T**. Readings from **V** and **A** are acquired and stored by the personal computer **PC** with an interface bus.

If we call $v(t)$ the voltage applied by generator **G**, and $i(t)$ the current entering **A**, then $i(t) = C\,\mathrm{d}v/\mathrm{d}t$. If $v(t)$ is a continuous piecewise linear function, to each slope k of $v(t)$ a stable current value I_k flows in **A**. Looking at Fig. 2, a symmetric trapezoidal waveshape for $v(t)$ permits the calibration of two current points (during the ascending and descending linear ramps) and two offset points (when a stable voltage is mantained). A continuos repetition of the waveshape permits repetated measurements, which are usually affected by noise.

2. THE GENERATOR

A suitable generator for the voltage ramp of Fig. 2(top) must have an excellent linearity, stability and low noise; battery operation is preferable to reduce interference. Since no commercial product satisfy these requirements, a suitable generator has been purposely developed.

Fig. 3 shows a simplified schematics of the generator.

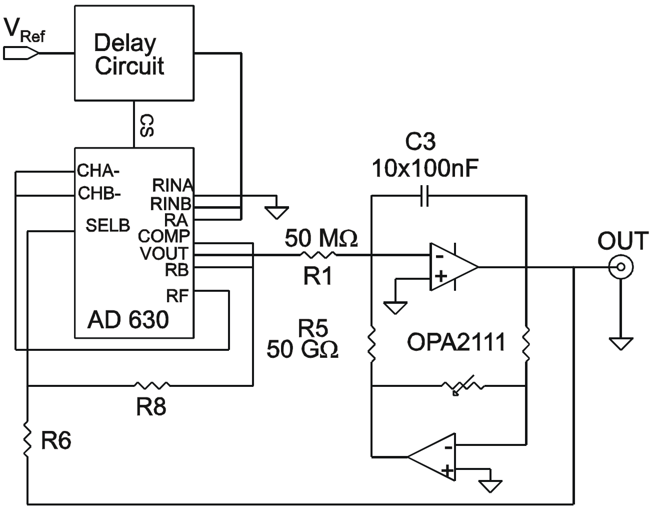

Fig. 3. Simplified electrical schematics of the generator G.

A voltage reference V_{Ref} is chopped by a delay generator, and enters a balanced squarewave modulator (Analog Devices AD630); the voltage output is transformed in a small current with resistor R1; such current has a shape similar to the final current of Fig. 2(bottom). The current enters an integrator (Burr-Brown OPA2111 and capacitor C3). The integrated signal, shown in Fig. 2(top), is available as output, and drives also the modulator threshold.

Losses in C3 cause small deviations of the ramp linearity. To compensate the effect, a feedback current generated by second section of OPA2111 and a resistor network is added to the integrator input; the network is trimmed until a linear ramp is obtained.

Voltage ramp extends to ±10 V in 200 s, i.e. a slope of 100 mV/s; horizontal steps have a duration of ≈120 s. When a variable reference is chosen, the voltage slope can be varied, and non-decadic current values obtained.

It is necessary to use a high-quality gas-dielectric capacitor for **C**, in order to minimize losses and dielectric absorption. Several capacitors have been tested: Agilent 16380A series (C=1, 10, 100, 1000 pF), General Radio 1404 series (Available standards C=10, 100, 1000 pF, we tested 100 and 1000 pF models), General Radio 1403-K (C=1 pF), Sullivan (various models). All capacitors are calibrated against the Italian mantained national standard of capacitance, by substitution with a Andeen-Hagerling 2500A automatic capacitance bridge, at the frequency of 1 kHz.

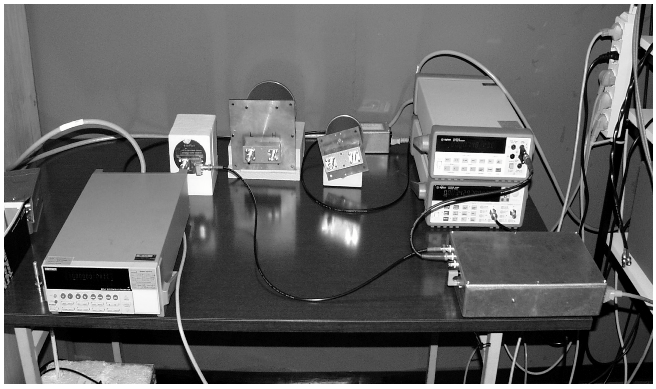

Fig. 4. A photo of the experimental setup. (left) current meter to be calibrated. (center) gas-dielectric capacitors of variuos values. (right, front) the current source developed. (right, back) sampling voltmeter and frequency meter.

V is a Agilent Tech. 34401 digital multimeter (6½ digits, accuracy specification 0.4 mV on the 10 V scale. The accuracy of **V**, which is specified for DC voltage, has been checked for a variable voltage ramp against a more accurate sampling voltmeter, Agilent mod. 3458A). Both **V** and **A** are triggered simultaneously by **T**, a purposely built digital synthesizer with a frequency of 950 mHz calibrated against IEN timescale. Data are acquired via GP-IB or serial interface driven by a LabWindows/CVI C program.

Fig. 4 shows a picture of the experimental setup which is the implementation of the schematics corresponding to Fig. 1; note the compactness of the ramp source.

4. EXPERIMENTAL

Fig. 2(top) show a typical voltage ramp $v(t)$ sampled by V when the source is operated. In fact, $v(t)$ is sampled at a fixed rate T (the trigger interval); the current $i(t)$ is computed with the discrete-time expression

$$i(t_k) = \frac{v(t_k) - v(t_{k-1})}{T}$$

and shown in Fig. 2(bottom). At the same time, a measurement sample $i_m(t_k)$ is acquired from **A**. Fig. 4 shows an expanded view, for the positive ramp, of the current i(t) and of the corresponding readings $i_m(t)$ of the meter. The effect of residual non linearity of the voltage source (on i(t)) and of the capacitance loss (on $i_m(t)$) can be observed.

Several alternative data treatment procedures can be employed to take into account these effects: the rationale is an average of positive and negative offsets and a linear fit of the error $\Delta=[i_m(t) - i_m(t)]$ to V=0. An effort is now being made to find the procedure giving the lowest uncertainty.

Several tests of the current source have been conducted by calibrating a picoamperemeter (Keithley mod. 6517) on current values of 100 fA, 1 pA, 10 pA and 100 pA. The results on 10 and 100 pA calibration points have been compared with more conventional measurements performed with a dc voltage source and high-value resistors, and show a good consistency.

In march 2006, the Istituto Nazionale di Ricerca Metrologica (INRIM) partecipated [5] to an international intercomparison (EUROMET.EM-S24: "Comparison of small current sources"), involving 11 European national laboratories and organized by Physichalisch-Technische Bundesanstalt (PTB, Germany). The travelling standards to be calibrated were two current meters (Keithley mod. 6430 and PTW UNIDOS E dosimeter); the current source presented has been employed to participate in the comparison. The comparison will finish in 2007 and the report (if positive) will permit to validate the source, the method, and will permit INRIM to issue CMCs for the Mutual Recognition Arrangement (MRA) between National Metrology Institutes.

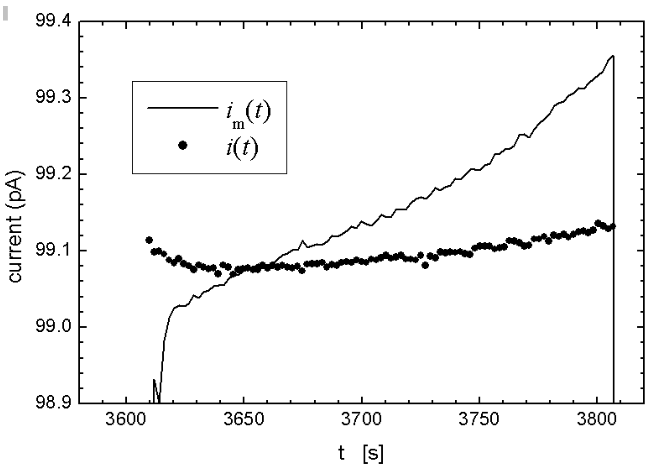

Fig. 4. An expanded view of calculated i(t) current (continuous line) from G, and the corresponding readings $i_m(t)$ (dotted line) from the meter A, during a positive voltage slope.

4. PRELIMINARY UNCERTAINTY BUDGET

The uncertainty of the current source comes from several contributions, main are listed below:

- Capacitance calibration (5 ppm), temperature coefficient (4 ppm/K), ac-dc difference (see later);
- Voltage reading (35 ppm);
- Triggering timing (1 ppm);
- Leak current compensation ($2 \cdot 10^{-5}\, I$ + 10 aA)
- Noise (strongly dependent on meter under calibration).

A preliminary uncertainty evaluation is shown in Tab. 1: the evaluation regards only systematic (type B) uncertainty, and repeatability (type A), strongly dependent on the noise of the picoammeter under calibration, must be added; however, the uncertainty obtained is well below typical specifications of meter accuracies.

I	$U_B(I)$ $(k=2)$
100 fA	13 aA (1.3×10^{-4})
1 pA	48 aA (4.8×10^{-5})
10 pA	420 aA (4.2×10^{-5})
100 pA	4.2 fA (4.2×10^{-5})

Tab. 1. Preliminary uncertainty assignement for the current generated by the source described. Only type B evaluation have been considered.

5. CONCLUSION

A current source designed for the calibration of low-current meters in the 100 pA – 100 fA current range has been constructed and characterized. The current uncertainty permits the calibration of even the most accurate commerical meters present on the market. The source is simple, portable and based on low-cost electronics and equipment typically present in most electrical metrology calibration laboratory, where it could be efficiently employed.

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