Measurement and Reproduction Small DC Currents by means Electron Multiplier

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***Abstract* — This paper describes device based on the method of measurement and reproduction ultra-small dc currents by counting electrons using the electronic multiplier (EM).**

***Index Terms* — Ultra small DC current, electronic multiplier, electron.**

I. Introduction

In 2007, the Consultative Committee for Electricity and Magnetism (CCEM), recommend to the use fixes the elementary charge as peer exactly $1.602\ 176\ 53 \cdot 10^{-19}$ A·s [1].

Since 1991, in the Russian Federation reproduction and storage unit of DC carried through state primary standard unit of DC (GET 4-91) in the range (100 aA – 1 nA); 1 mA; 1 A [2]. At the same time the basis of equipment used for reproduction and current measurements in the range of 100 aA – 1 nA put an electrometric method providing uncertainty at the level $(5\cdot10^{-2} – 2\cdot10^{-4})$.

In the mass spectroscopy to determine the composition of substances is used method of counting charged particles by means of devices containing a photomultiplier or channel electron multiplier.

The same principle may be used for electron counting, to allowing make measurement of currents up to 1 aA, as well improve the accuracy of reproduction and measurement of currents in the range of 100 aA – 1 pA.

Solution of this problem is carried through measurement of current and frequency the electron charge leaning on equation:

$$i = e\cdot f \quad (1),$$

where: e – charge of electron,

f – the frequency output pulse (EI).

This equation defines the physical meaning unit of current, "1 A - is current, at which the through the transverse-section per 1 second pass in the 1 C the charge". While the frequency output pulse f (EI) determines the number of electrons in measured circuit.

Since the amplitude of impulse is not included the basic measurement equation, stability amplification factor EM does not affect the measurement result [3].

The proposed device for measuring and reproducing dc current is based on the principle of electron counting by electron multiplier (EC), which operates at room temperature.

In [3] electron counting carried out by means EM with an amplification factor gain of about 10^8. The measured dark current does not exceed 1 electron per second.

II. Block Diagram of Devices and Description of it Work

Block diagram of the device for measuring and reproducing the DC to implement a method of counting electrons is illustrated in figure 1.

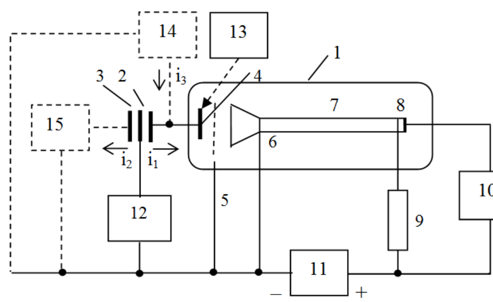

Fig. 1. Device for measuring and reproducing the direct current.

1 – vacuum part of the device for measuring current and reproducing (vacuum balloon); 2 – capacitor C_{B1}; 3 – capacitor C_{B2}; 4 – cathode of electron-emitting; 5 – control grid; 6 – cathode of electron multiplier; 7 – electron multiplier; 8 – anode of electron multiplier; 9 – bias resistance; 10 – pulse counter; 11 – power source of electron multiplier; 12 – measure of linearly variable voltages; 13 – source of ultraviolet radiation; 14 – calibrated standard of current; 15 – calibrated ammeter; i_1 – reproducible unit of DC (measured current); i_2 – reproducible reference for the certification current measuring; i_3 – the measured current of standards for certification and the current calibrators.

In the mode current measuring device works as follows: calibrated standard 14 delivers the current that runs between the cathode 4 and the reference electrode 5. The voltage between the cathode 4 and the reference electrode 5 is set automatically and the measured current source is independent of the external load.

As a result of the voltage between the cathode and the reference electrode stays constant. Thus, the cathode emission is proportional to the measured current.

Direct current (provided a cathode 4) passes through the reference electrode 5 and feeds electron multiplier 7. Each electron gives an impulse, which is released at the output electron multiplier 7. Then he supplied to a pulse counter 10.

When using the gilded cathode necessary to use an ultraviolet irradiation source 13 to operate the device in a predetermined range of currents.

Reproduction DC carried by the known formula:

$$i = C \cdot du/dt, \qquad (2)$$

where, C – rechargeable capacitance;

du/dt – linearly varying voltage.

Linearly varying the voltage applied to the input (middle) electrode, charges the reservoir 2 and 3, where rate of voltage change du/dt proportional to reproducible current. At $C_{B1} = C_{B2}$; reproducible currents i_1 and i_2 are equal.

In the device current reproducible i_1 measured by the manner described above in real time, a reproduced at the same time current i_2 is used for certification reference SI (electrometers) or for other purposes.

III. Estimated uncertainty Budget

Number of impulses proportional strength of measured current, can be measured with frequency meter uncertainty of no more than $1 \cdot 10^{-7}$. Electron charge e is known with uncertainty $2.2 \cdot 10^{-8}$ (CODATA adjustment from 2010).

Consequently, the measurement and reproducing current uncertainty will mainly be determined by other sources, as can be seen from the table 1.

Table 1

№	Source of uncertainty	Uncertainty value	Current measuring range
1	Electron charge	$2,2 \cdot 10^{-8}$	1 aA - 1 pA
2	Measurement of frequency	$1 \cdot 10^{-7}$	
3	Instability of dark current ЭУ	$2 \cdot 10^{-1}$ - $2 \cdot 10^{-2}$	1 aA - 10 aA
		$3 \cdot 10^{-3}$ - $3 \cdot 10^{-4}$	100 aA - 1 fA
		$4 \cdot 10^{-5}$ - $4 \cdot 10^{-6}$	10 fA - 100 fA
		$5 \cdot 10^{-7}$	1 pA
4	Leakage current	$2 \cdot 10^{-1}$ - $2 \cdot 10^{-2}$	1 aA - 10 aA
		$3 \cdot 10^{-3}$ - $3 \cdot 10^{-4}$	100 aA - 1 fA
		$4 \cdot 10^{-5}$ - $4 \cdot 10^{-6}$	10 fA - 100 fA
		$5 \cdot 10^{-7}$	1 pA
5	Shot noise in a band 0,01 Hz	$6 \cdot 10^{-2}$ - $2 \cdot 10^{-2}$	1 aA - 10 aA
		$6 \cdot 10^{-3}$ - $2 \cdot 10^{-3}$	100 aA - 1 fA
		$6 \cdot 10^{-4}$ - $2 \cdot 10^{-4}$	10 fA - 100 fA
		$6 \cdot 10^{-5}$	1 pA

Fluctuations of ionization current and ill-defined capacities can be taken into account when processing the results of measurements.

Ionization current fluctuations are not constant and depend on many factors (solar activity, getting into the input circuit of cosmic high-energy particles, X-rays, etc.). Since, with good screening, many of such noise can be greatly suppressed, but residual noise have pronounced in the form of a 5 - 10 current pulses within 30 min. Then the processing of measurement results (according to need) can be excluded, or taken into account.

As for the error due to inequality capacitances when reproducing current, it is possible to determine amendment by measuring the current twice, by the relocation of the capacitors. By installing a capacitor C_{B1} in place of the capacitor C_{B2}, and the capacitor C_{B2} in place of the capacitor C_{B1}.

VI. Conclusion

Uncertainty budget reveals that the device based on the EM allows expanding range of current measurement and reproduction with improving accuracy to the level up 1 aA at room temperature.

References

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