Use of a 100 MΩ step Hamon resistor for calibration of pico-ammeters in dc current in the range 100 pA ÷ 100 nA

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Abstract- This paper describes a measurement circuit for the calibration of pico-ammeters in dc current. The system is based on a 100 MΩ Hamon network developed at INRIM to improve the traceability level of the maintained 1 GΩ standard. Besides the Hamon network, the measurement system, presented in this paper, consists of a precision dc voltage source and an electronic circuit used as voltage guard driver.

I. Introduction

Modern pico-ammeters are devices able to conjugate high performances and simplicity of use at reasonable costs. So, they are widely used both as null detectors in experiments such as the realization, reproduction and maintenance of electrical units in dc or in low frequency and as detectors for photomultiplier tubes, in developing systems of semiconductor devices with ionic implantation methods, in mass spectrometers besides for insulation measurements and for characterization of the behaviour of dielectric materials.

The increasing interest in this kind of instruments has induced National Metrological Laboratories (NMI) to extend measurement scales for low currents measure and to organise key comparisons to verify the measurement capabilities of the laboratories. In this paper a calibration method in the range 100 pA÷100 nA based on the use of a dc voltage source and an Hamon network is presented.

Some considerations about the development of the Hamon network, the measurement uncertainties and the results of compatibility test with another measurement method based on the charge of a standard capacitor [1] in the range 100 pA are also reported.

II The 100 MΩ Hamon transfer resistor

The Hamon network project is reported, with full particulars, in [2, 3]. The network is made up of ten resistors, shown in Fig. 1, with low temperature and voltage coefficients. The resistors are connected in series in a structure that works as a support also for the coaxial connectors. The internal assembly of the device is shown in Fig. 2a) and 2b). The main resistors network is guarded by means of an auxiliary series of ten resistors each one with nominal value of 10 MΩ. Each auxiliary resistor is fixed to a main resistor by means of two metal rings and it is also connected to the guarding ring of the triaxial connector. The guarding system is then connected to an external driver.

Fig. 1 – 100 MΩ high voltage resistor used into the Hamon network The resistors are made by a ceramic materials (Terinox®) with interesting specifications of temperature and voltage coefficient. The resistor is drowned in a silicone resin.

The Hamon serial-parallel configuration is fixed by means of a servo-controlled device (Fig. 3). which sets the position of a printed circuit board where the electrical contacts are soldered.

Fig. 2a – Internal view of the assembly of the Hamon network. The image shows the main resistors fixed to a series of coaxial connector .with the auxiliary guard network,

Fig. 2b – The servo-controller moves the board where the electric tracks of the parallel configuration are printed.

III. Measurement setup

Before the use, the Hamon resistor is always calibrated in parallel configuration (10MΩ) by comparison with a 10 MΩ standard using a high precision digital multimeter. Then the measurement circuit is assembled as shown in Fig 3.

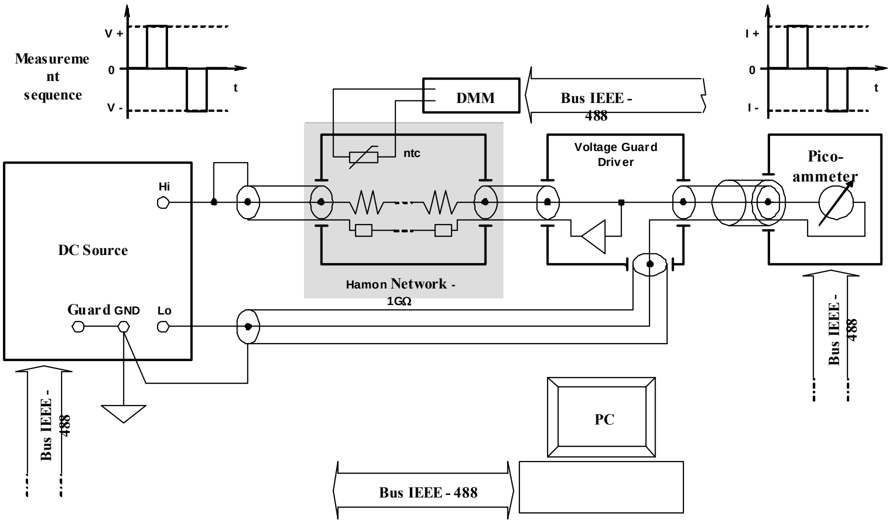

Fig. 3 - Scheme of the measurement circuit for calibration of pico-ammeter.

A high precision dc voltage source is applied to the Hamon resistor in series configuration (1 GΩ), in order to form the current source, and to the input of the guarding system. The output of the transfer resistor is connected to the pico-ammeter under calibration through the guard driver circuit and a coaxial adapter. The output of the driver sets the voltage of the low side of the Hamon guard circuit. The common terminal of the pico-ammeter is connected to the low output of the voltage source while

the temperature inside the Hamon standard is monitored by a NTC probe and a 6 digits multimeter.
With the above described setup it's possible to minimize:

- the thermal effects;
- the parasitic and the tribo-electric effects of the cables since the connection between the Hamon standard and the pico-ammeter is very short and rigid;
- eventual disturbs due to the presence of the operator as the whole measurement procedure is automatic.

Fig. 4 - View of the whole measurement system for the calibration of pico-ammeters in dc current

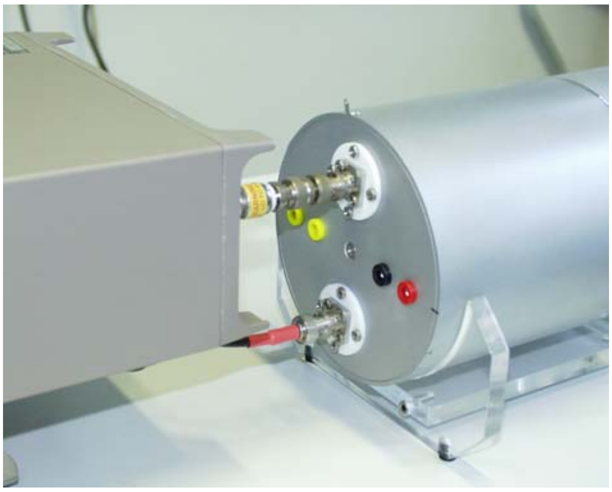

Fig. 5 – Detail of the connection between the Hamon network and the pico-ammeter by means of short adapter

IV. First experimental results

The procedures of pico-ammeter calibration was developed in order to minimise the effect of the temperature and the voltage burden.
The temperature coefficient of the device was measured in the range (16÷ 27) °C showing a value of $3.8\cdot10^{-6}$/C°, better than declared by the manufacturer.
The adopted procedure consists on sequences of measurement of (0, I, 0) A, both for the positive and negative currents. Between the measurements a waiting time of two minutes is needed for the system to exhaust transient phenomena and to achieve the stability of the current. The current measurements are made in the range 100 pA to 100 nA, with the Hamon network as standard resistor and a dc voltage source. The effect of voltage on the resistance of the Hamon network has been measured in the range (50÷250) V resulting negligible. Hence, the calibration of pico-ammeters in different ranges could be performed by using only one resistor.
The described system has been compared with a method based on the charge and discharge of a gas-dielectric capacitor. A current of 100 pA was supplied by both systems and read by the same Keithley 6517 pico-ammeter. Figure 6 shows the values of the positive G+ and negative G- instrument gains measured by the two methods: the dotted and dashed lines represent the values of the positive and negative instrument gains, respectively, obtained by the capacitor-based method, while the squared and dotted points are the same quantities in case of the Hamon-based method. The agreement between the methods resulted better than $4\cdot10^{-5}$.
The measurement of current in ranges higher than 100 pA were done in order to evaluate the noise level and the repeatability, but the comparison with a different method was not performed yet, since the capacitor-based method developed at INRiM is suitable for current values smaller than or equal to 100 pA.

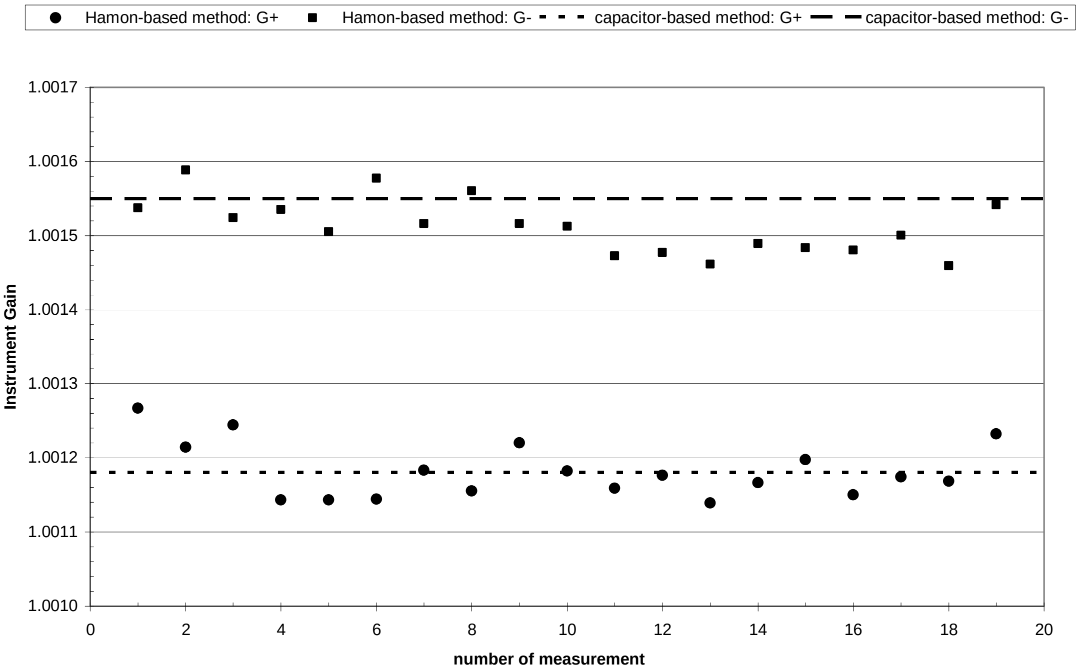

Fig. 6 - Results of compatibility test between the Hamon network-based method and the capacitor-based method: the lines represent the values of the positive and negative instrument gain obtained by the capacitor-based method, while the squared and dotted points are the same quantities in case of the Hamon-based method.

V Uncertainties budget

The main uncertainty components of the method can be due to:

- calibration of the Hamon standard in parallel configuration;
- short time instability of the same standard;
- temperature and voltage effects on the resistor;
- effects due to voltage burden;
- calibration of the dc voltage source;
- accuracy specifications of the voltage source.

The current *I* to be read by the pico-ammeter can be given by the following:

$$I = \frac{(V + v_1 + v_2)}{(R + r_1 + r_2)} \tag{1}$$

Where:

- V is the dc voltage supplied by the voltage source;
- v_1 is a corrective factor to consider the possible error due to the accuracy specifications of the dc voltage source;
- v_2 is a corrective factor to consider the possible error due to the input voltage burden of the pico-ammeter;
- R is the resistance value of the Hamon resistor in series configuration;
- r_1 is a corrective factor that considers the variation of R due to the instability f the temperature of the laboratory;
- r_2 is a corrective factor that considers the variation of R due to the voltage coefficient of R.

Hence the standard uncertainty (1σ), according to [5], can be given by:

$$u_c^2(I) = (\frac{1}{R})^2 \cdot [u^2(V) + u^2(v_1) + u^2(v_2)] + (-\frac{V}{R^2})^2 \cdot [u^2(R) + u^2(r_1) + u^2(r_2)] \qquad (2)$$

and the expanded uncertainty for a confidence level of about 95,5 % (2σ): $\boldsymbol{U}(I) = 2 \cdot u_c(I)$ (3)
In Table 1 evaluated relative uncertainties for the considered measurement range are reported.
Table 1: Relative uncertainties of the system for calibration of pico-ammeters

100 pA	$4{,}2 \cdot 10^{-4}$
1nA	$4{,}7 \cdot 10^{-5}$
10 nA	$1{,}9 \cdot 10^{-5}$
100 nA	$2{,}1 \cdot 10^{-5}$

VI Conclusions

At INRIM a measurement setup for calibration of picoammeters in dc current in the range (100 pA ÷ 100 nA) was developed, using simply a commercially available dc voltage source and a home.-made guarded Hamon network with guard driver. The encouraging results obtained with this measurement setup lead us to continue to improve and to extend the capabilities of this measurement method. In particular, future aims/development of this work could be the measurement of the input voltage burden of the picoammeter, as the value declared by the manufacturer is presumably worse than the effective one. At the moment, the uncertainties budget in the 100 pA range is predominantly affected by this value. Furthermore, another Hamon network with ten 10 GΩ resistor could be built to extend the capability of this method down to fA.

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