20th IMEKO TC4 International Symposium and
18th International Workshop on ADC Modelling and Testing
Research on Electric and Electronic Measurement for the Economic Upturn
Benevento, Italy, September 15-17, 2014

1 Ω–10 kΩ High Precision Resistance Setup to calibrate Multifunction Electrical instruments

P.P. Capra[1], F. Galliana[2], M. Lanzillotti[3]

[1, 2, 3] National Institute of Metrological Research, strada delle Cacce 91, 10135 TURIN – Italy
[1] +39 0113919424, p.capra@inrim.it
[2] +39 011391336, f.galliana@inrim.it
[3] +39 011391315, m.lanzillotti@inrim.it

Abstract – A temperature controlled 1 Ω–10 kΩ Standard resistors setup was developed at National Institute of Metrological Research, (INRIM). The aim of this realization was the involvement of the setup resistors in the traceability transfer process to high accuracy multifunction electrical instruments used in Secondary Electrical Calibration Laboratories or even their use as primary Standards in high level Laboratories or Institutes. The 1 Ω–10 kΩ Standards are formed respectively by two 10 Ω and 100 kΩ parallel connected resistors nets inserted in a temperature controlled aluminium box. Construction details, temperature and power coefficients, stability data and preliminary mid-term use uncertainty budgets of the two setup Standards are given. Their first short time (2 h) stability were on the order of few parts of 10^{-8}. A test to calibrate a multifunction calibrator gave satisfactory results.

I. INTRODUCTION

The need to maintain, compare and use for traceability transfer high accuracy 1 Ω and 10 kΩ Resistance Standards had been felt since some decades by National Metrological Institutes (NMI) [1–5]. High accuracy multifunction instruments as digital multimeters (DMMs) and multifunction calibrators (MFCs), widely used as Standards in Secondary Calibration Electrical Laboratories can be calibrated by means of an “artifact calibration”. This operation requires only few reference Standards: 1 Ω and 10 kΩ Resistance Standards and a 10 V Dc Voltage Standard [6–8]. To transport from National Metrology Institutes (NMI) to Secondary Laboratories only these Standards increases the traceability transfer accuracy as well as the reliability and convenience of the calibration process. For this reason at National Institute of Metrological Research, (INRIM) a temperature controlled 1 Ω and 10 kΩ Standard resistors setup was developed to calibrate and adjust DMM’s and MFC’s. After further satisfactory characterization results, this setup could be also involved as Primary Standard for NMI to avoid thermal enclosures often involved in high accuracy primary resistance Standards as in [3] or specially made as in [9,10]. In addition the setup could act as traveling Standard for high level Interlaboratory Comparisons (ILC’s) as in [1]. A first attempt to realize a thermo-regulated Standard resistor was already made at INRIM with encouraging results [11]. The present realization is an improvement and upgrading of that prototype involving the two main resistance values for the traceability transfer to DMM’s and MFC’s.

II. THE SETUP STANDARDS NETWORKS

The setup involves two resistors nets with Vishay VHA 512 type resistors, selected for their satisfactory tolerance value (± 0.5 %), low temperature coefficient (TCR) less than 1×10^{-6}/°C and long term stability (5×10^{-6}/year as declared by the manufacturer). The resistors were hermetically inserted in an oil filled aluminium cylinder. To develop the 1 Ω Standard resistor ten matched 10 Ω resistors were connected in parallel along with their leads and a manganin strap, chosen instead copper for its lower TCR. The importance to put in oil the 1 Ω resistors net with its connectors is due to the maintaining of the temperature uniformity among the connectors and to reduce ftem’s effects and errors. The 10 kΩ Standard was made with a net of ten 100 kΩ matched and parallel connected resistors. Its parallel connection was made with a manganin strap as for the 1 Ω network.

III. THE THERMOSTATIC BOX

The two resistors nets were put into a box obtained from an aluminum block (Fig. 1). The 1 Ω resistors net was placed inside the box, into a cylindrical space filled with mineral oil to enhance the temperature exchange between the resistors and the box. The resistors net was connected to four binding post connectors on the box cover and fixed with thermal conductive resin. This solution was chosen to make uniform the temperature among the resistor connectors and to reduce the thermal EMF’s (ftem’s) effects. The 10 kΩ resistors net was placed into ten holes in an external ring of the box. The bottom of the box is mechanically connected to a Peltier element (thermoelectric cooling TEC) connected to a radiator. The box was placed in a metallic case filled with polystyrene foam, while the radiator was placed outside the box. The TEC is supplied by a Proportional-Integral-

ISBN-14: 978-92-990073-2-7

Derivative (PID) controller put in another case with the microcontroller and the power supply (Fig. 2).

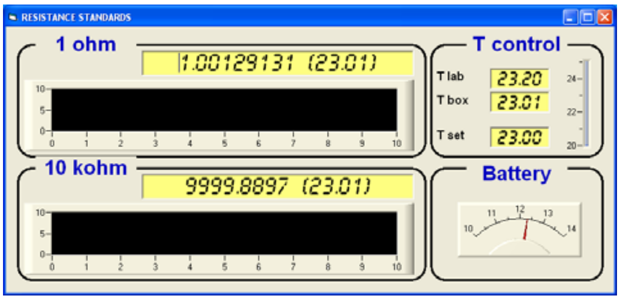
Fig. 1. Aluminium box. The block connected with a TEC and a radiator is shown.

A. Temperature control system

The temperature-control of the box is based on a commercial low noise PID controller with a Negative Temperature Coefficient temperature sensor (NTC). The system can be operate in stand-alone or in pc-controlled mode. In stand-alone mode, the controller checks the box and environment temperatures, the status of the battery and the display.

Fig. 2. Temperature controller system (left) and Standards boxes (right).

Fig. 3 shows the main frame of the program to read and set the temperature of the resistors box, when the controller operates in pc-controlled mode the control program presents a display in which the temperature set point, the environment and the hermetic box temperatures and the last calibration values of the resistors, are shown. By means of a USB-pc connection, it's possible to change the temperature set-point, load the box and laboratory temperatures and store the resistors calibration data on the microcontroller memory.



1 ohm 1.00129131 (23.01)

10 kohm 9999.8897 (23.01)

T lab 23.20

T box 23.01

T set 23.00

Fig. 3. Main frame of the control program of the setup.

The program to control the parameters of the Standards and the firmware of the microcontroller were respectively written in Visual Basic and C.

B Efficiency of the temperature control

Figure 4 shows the 2 h temperature stability of the box, with the temperature controller set at 23 °C. After a transient due to the temperature set point change, the stability is better than 5 mK. The system needs about 30 min to change the temperature in a range of about 3 degree around 23 °C to reach the desired stability in a thermo-regulated laboratory at (23 ± 0.5) °C.

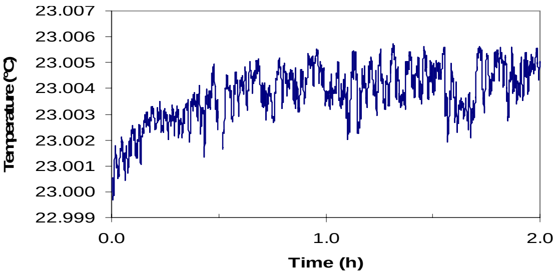


Fig. ***4****. Temperature stability of the box. Initial drift is due to a temperature set-point change.*

IV. EXPERIMENTAL RESULTS

A. The 1 Ω Standard of the setup

The time drift of the 1 Ω Standard is shown in Fig. 5 where the effects of the temperature control and the thermal stabilization between the potentiometric connections can be observed. These measurements were made comparing the Standard with high performance INRIM resistors with a measurement method involving a high precision current comparator bridge [12]. The 2 h measurements spread (measurements Standard deviation) of 4×10^{-8} can be considered at the same level of high performance 1 Ω Standard resistors in oil baths normally used by NMIs. The temperature coefficient (TCR) of the 1 Ω resistors net was evaluated from 22 °C to 24 °C changing the box temperature set point, resulting about 3×10^{-6}/°C.

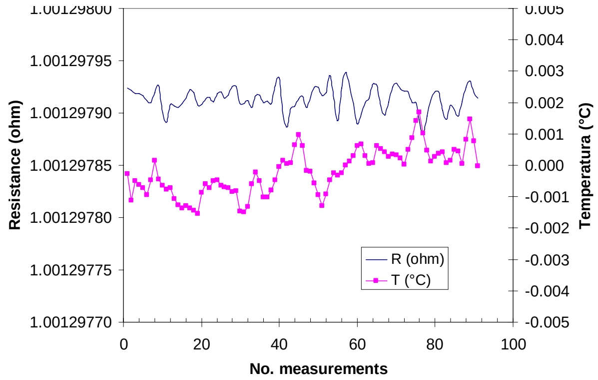


Fig. 5.Measurements on the 1 Ω Standard resistor vs. a 1 Ω high accuracy Standard resistor in oil bath along with the box temperature drift during the test.

B. The 10k Ω Standard of the setup

With same measurement system also the 10 kΩ was investigated. It showed a similar measurements spread (Standard deviation of 5×10^{-8}) although its resistors net is outside the oil bath, but a worse TCR of the resistors net between 22 °C and 24 °C that resulted about 8×10^{-6}/°C.

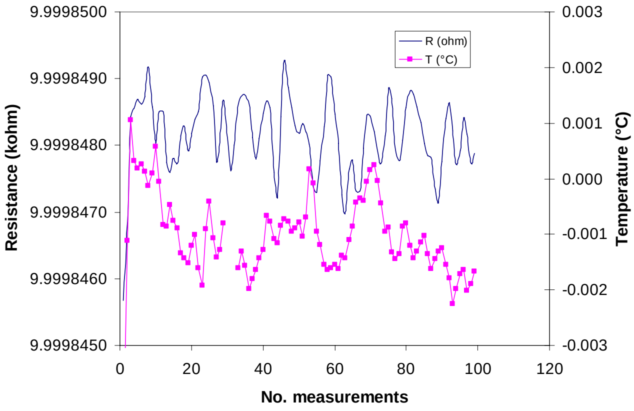


Fig. 6. Measurements on the 10 kΩ Standard at 23 °C set point. vs a high precision 1 kΩ resistor in oil bath along with the box temperature drift during the test.

C. Mid-term stability and power coefficient of the 1 Ω and 10 kΩ Standards

Figures 5 and 6 show the short-time stability of the setup Standards. Their performance have to be compared with top-level Resistance Standards normally used in NMI [13, 14]. Fig. 7 and 8 show the mid-term stability of the two Standards, measured with the same previously mentioned system for about six months since the setup assembly.

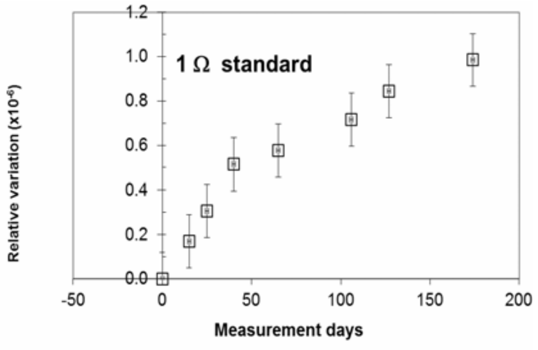


Fig. 7. Time drift of the 1 Ω Standard measured since the setup assembly.

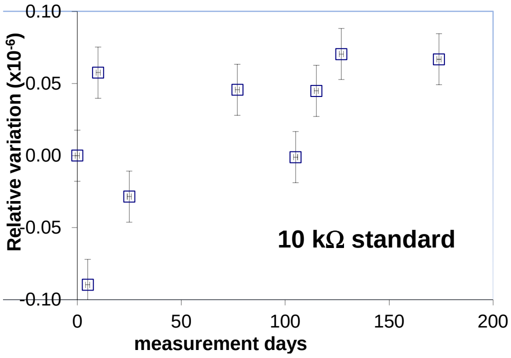


Fig. 8. Time drift of the 10 kΩ Standard measured since the setup assembly.

The drifts of the two setup resistors are different. Starting from the setup assembly date, the 1 Ω showed an increasing exponential drift (considered as mid-tem stability) of 1.0×10^{-6}. The 10 kΩ Standard showed a lower drift at six months of 2.0×10^{-7} as the resistors involved for its net were stored for several years granting to this Standard a better stability. This result is in agreement with resistors manufacturers suggestion that long-term resistors drift is defined only after a suitable stabilization period. The power coefficients of the two Standards were evaluated measuring them vs high stability standard resistors with the system with the current comparator bridge resulting 1.7×10^{-6}/W and 2.7×10^{-6}/W respectively for the 1 Ω and 10 kΩ Standards. the 1 Ω power coefficient allows to measure this Standard at currents up to 100 mA.

D. Temperature coefficients with the activaction of the temperature controller

To investigate the temperature behavior setup Standards with their temperature controller set at 23°C, in the temperature range of electrical calibration laboratories, (23 ± 1) °C, the Standards were measured, after suitable stabilization, at (22, 23 and 24) °C in a settable temperature laboratory to evaluate their temperature coefficients around 23 °C. These coefficients are reported in Table 1.

Table 1. Temperature coefficients of the setup Standards

Standard	α_{23} ($\times10^{-7}$ °C^{-1})	β ($\times10^{-7}$°C^{-2})
1 Ω	5.5	1.0
10 kΩ	0.6	1.4

D. MFC's calibration and adjustment results

A high performance MFC was calibrated and adjusted with the setup Standards and a with 10 V Zener DC Voltage Standard. This process allows to the MFC to self-assign new values to its all internal references. The attitude of the setup Standards to calibrate the MFC was verified by means of two tests: with the first one the measurement differences of the MFC's 1 Ω and 10 kΩ internal references values were measured vs. high stability 1 Ω and 10 kΩ INRIM Standards before and after its calibration and adjustment process. These differences resulted negligible and unvaried after the calibration process. This first test showed that the calibration and adjustment process with the setup Standards don't cause any systematic measurement error in the process. With a second test the setup Standards were compared vs. the same 1 Ω and 10 kΩ INRIM resistors by means of a high performance DMM, showing 0.5×10^{-6} and 0.2×10^{-6} relative differences. These values can be considered negligible as only due to the short-time stability and repeatability of the DMM. Both these first tests confirmed the suitability, technical correctness and reliability of the setup Standards for artifact calibration as they don't introduce any systematic error, besides to state a very high stability of the MFC 1 Ω-10 kΩ internal references.

IV. UNCERTANTY EVALUATIONS

A. Setup 1 Ω and 10 kΩ resistance Standards Calibration uncertainties

The two setup Standards are periodically calibrated in the INRIM Resistance Laboratory in terms of the INRIM 1 Ω primary group of Standard resistors referred to the recommended value $R_{K\text{-}90}$ of the Von Klitzing constant respectively with expanded uncertainties of 1.7×10^{-7} for the 1 Ω and 1.2×10^{-7} for the 10 kΩ.

B. Setup 1 Ω and 10 kΩ resistance Standards mid-term use uncertainty

The use uncertainty can be defined as the best uncertainty that the Standards can assure in the time period between two calibrations. In Table 2 and 3 preliminary uncertainty budgets of the use uncertainty of the two Standards are given. It was assumed to use the setup resistors as Resistance Standards for 90 days (mid-term period) without recalibration.

Table 2. 1 Ω mid-term use uncertainty.

Source	type	1σ ($\times10^{-7}$)
calibration	B	0.85
drift	B	2.9
ftem	B	negl[1]
Temperature dépendance	B	12
power dependence	B	0.02[2]
Total RSS		12.4

Table 3. 10 kΩ mid-term use uncertainty.

Source	type	1σ ($\times10^{-7}$)
calibration	B	0.61
drift	B	0.6
Temperature dependance	B	1.2
power dependance	B	1.4[2]
Total RSS		2.0

For a 95% confidence level the mid-term use uncertainties of the setup Standards are about 2.5×10^{-6} and 4.1×10^{-7} respectively for the 1 Ω and 10 kΩ. These uncertainty budgets could be updated as uncertainty components, due to possible pressure, humidity and transport effect have to be investigated and eventually added. Nevertheless, for MFC's and DMM's calibration, the use uncertainty should be better as it can be considered in the uncertainty budget a lower drift component as artifact calibration normally is performed after few days from the calibration of the Standards at the NMI.

V. CONCLUSIONS

The characterization on the 1 Ω–10 kΩ setup Standards, as well as the test to calibrate and adjust a MFC showed positive results. Only the 1 Ω Standard TCR is not yet completely satisfactory. Nearest work will be the improvement of the temperature control to improve the 1 Ω Standard TCR. After this further improving, it could be concluded that the setup 1 Ω and 10 kΩ resistance Standards are suitably act for artifact

---

[1] This component can be considered negligible as the temperature between the resistors net and its connectors is maintained uniform.

[2] Power dependence uncertainty component was evaluated considering the maximum possible applied power difference between INRIM calibration and Secondary Laboratory utilization of the Standard [13].

calibration and eventually as Reference Standards for maintaining the Resistance Unit in top level Laboratories, and NMIs. From the economic point of view the cost related the development of the setup described in the paper was of the same order of two commercial type 1 Ω and 10 kΩ Standard resistors as this setup was a research prototype one. Its cost could significantly be lower if its construction was made by a resistance Standards manufacturer. Future aims of our research will be the investigation of the setup resistance Standards transport effect to better define their use uncertainty for artifact calibration and a stability comparison with 1 Ω and 10 kΩ top level Standard resistors actually available in NMIs and Secondary Laboratories. Other aims will be the evaluation of their humidity, pressure and transport dependence to to verify their attitude as traveling Standards for high level inter-laboratories comparisons as well as an improvement of the thermal control stability at a level of 1 mK.

AKNOWLEDGEMENTS

The authors wish to thank F. Francone, and D. Serazio for their disposability and competence in the development of the mechanical details of the thermostatic box.

REFERENCES

[1]F Delahaye et al, “Report on the 1990 International Comparison of 1 Ω and 10 kΩ Resistance Standards at the BIPM”, Metrologia, 29 pp. 153–174, 1992.

[2]B.J Pritchard: “Fabrication of reference Standard 1 ohm resistors from Evanohm S alloy” Proc. of Prec. El. Measur. Conf. CPEM, pp. 290–291, 1990.

[3]T.J Witt, D. Reymann, D. Avrons, “An accurate 10 kΩ Resistance Standard”, Proc. Prec. Electr. Measur. Conf. CPEM , pp. 129-130, 1990.

[4] \A.C.Grossenbacher, ”Development of a precision one ohm resistance Standard” Proc. of Prec. El. Measur. Conf. CPEM , pp. 50–51., 2002.

[5]G. Boella, P.P. Capra, C. Cassiago, R. Cerri, G. Marullo Reedtz, and A. Sosso, “Traceability of the 10-kΩ Standard at IEN”IEEE Trans. Instr. Meas., Vol. 50, No. 2, pp. 245–248,2001.

[6]Fluke Corporation, Calibration: Philosophy in Practice, Second Edition.

[7]G. Rietveld, “Artifact calibration: An evaluation of the Fluke 5700A series II calibrator ", Rep. ISBN 90-9\013\322-4, 1999.

[8]G .Rietveld, "Artifact calibration - The role of software in metrology" Proc. of NCSL Workshop Symp., 1996.

[9]B. Rolland, R. Goebel, N. Fletcher, “A Transportable Thermo-regulated Enclosure for Standard Resistors Proc. of Prec. Electr. Measur. Conf. (CPEM), pp. 378–379, 2012.

[10] Kwang-Min Yu, Mun-Seog Kim, Po Gyu Park, Kyu-Tae Kim: “Realization of quantum Hall resistance Standards at KRISS based on a cryogenic current comparator “,Proc, of Prec. Electr. Measur. Conf. (CPEM), pp. 629–630, 2010.

[11]P.P. Capra, C. Cassiago, F. Galliana, M. Astrua, “A temperature variable high accuracy 10 kΩ resistor”, Metrol. Meas. Syst. V16, No. 1, pp. 183–191, 2009.

[12]] P. Mac Martin, L. Kusters, A Direct–Current–Comparator Ratio Bridge for Four–Terminal Resistance Measurements, IEEE Trans. Meas IM–15 (5) (1966) 212–220.

[13] Fluke 742 A Series Instruction Manual, Rev. 1, 4/89, September 1989.

[14] ESI SR104 Transportable Resistance Standard, User and Service Manual.