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A TEMPERATURE VARIABLE HIGH ACCURACY 10 KΩ RESISTOR

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Abstract

A temperature-variable high accuracy (TVHAR) 10 kΩ resistor has been developed at the National Institute of Metrological Research, (INRIM), in order to transfer the traceability to high accuracy multifunction instruments used in the accredited calibration laboratories. The TVHAR consists of ten 100 kΩ nominal value resistors inserted in a copper block and connected in a parallel configuration. The thermal stability of the copper block is obtained with a temperature controller. In this paper details of the development of the TVHAR and of its thermal behaviour are reported . From preliminary results its relative short-time stability (2h) is on the order of a few parts in 10^{-8}, a negligible temperature coefficient around 23 °C and a power coefficient on the order of -4×10^{-6}/W.

1. Introduction

Some electrical instruments like digital multimeters (DMMs) and multifunction calibrators (MFCs), widely used as standards for precision measurements, are calibrated by means of a particular process called "artifact calibration", which requires only a small number of reference standards: 1 Ω and 10 kΩ resistance standards and a 10 V dc voltage standard [1÷3]. The possibility to transport from the primary laboratory (NMI) to the secondary laboratories only a voltage reference and standard resistors instead of delicate instruments like calibrators increases the accuracy of the traceability transfer and makes the calibration easier and technically convenient.

We developed a prototype of a temperature controlled resistor for using it as standard in all those precision measurements performed in a laboratory at a temperature different from 23 °C (the reference temperature for electrical measurements) or in non temperature-controlled environments. Moreover the possibility to adjust finely the value of this resistor by varying its internal temperature can be useful in some applications in which it is necessary, for example, to balance a measurement circuit.

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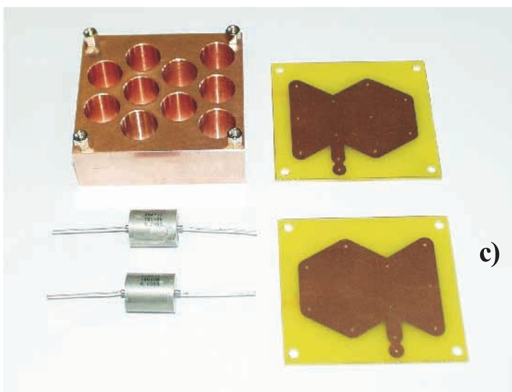
2. Development of the prototyp

Previous experience in realization of high precision resistors based on the principle of connecting several resistance elements in a parallel configuration is described in [4]. Also the TVHAR is composed by ten Vishay resistors of 100 kΩ nominal value connected in parallel, with nominal temperature coefficient +0.6 $\times 10^{-6}$/ °C (from 0 °C to 25 °C); -0.6$\times 10^{-6}$/ °C (from 25 °C to 60 °C), power coefficient 0.75 W at 25 °C.

These resistors are foil type, oil filled, hermetically sealed VISHAY resistors (model no. VHA512) (Fig. 1b). They are fitted in a copper block (Fig. 1a and 3a) which increases the heat capacity in order to reduce the sensitivity of the value of TVHAR to quick temperature fluctuations or temporary over-currents. The block is connected to a temperature collector and a Peltier module (TEC), placed outside the resistor case (Fig. 2). The temperature is controlled by means of a proportional-integrative controller (PI), a hybrid module of Wavelength Electronics HTC series, which needs a small number of external electronic components and uses a 10 Ωk NTC element as sensor and sets the temperature of the block in the range of (18÷28) °C with a stability evaluated as better than 3 mK/h at 23 °C. In the range 21÷25 ∘C of the set point or of the environment temperature the system needs less than 300 mA. In a (23 ± 1) °C controlled laboratory the current drops down to 30 mA. Furthermore, it is possible to use the PI controller to change the temperature of the block in order to trim the resistance value. The 100 kΩ resistors are electrically connected in parallel with two printed boards (Fig. 1c and 3b), while the connections between the TVHAR and the binding post placed on the front panel have low thermal forces.

a)



c)

b)

Fig. 1. TVHA elements: a) copper block used as thermal equalizer b) Vishay resistors VHA512 type, c) printed boards for parallel connection.

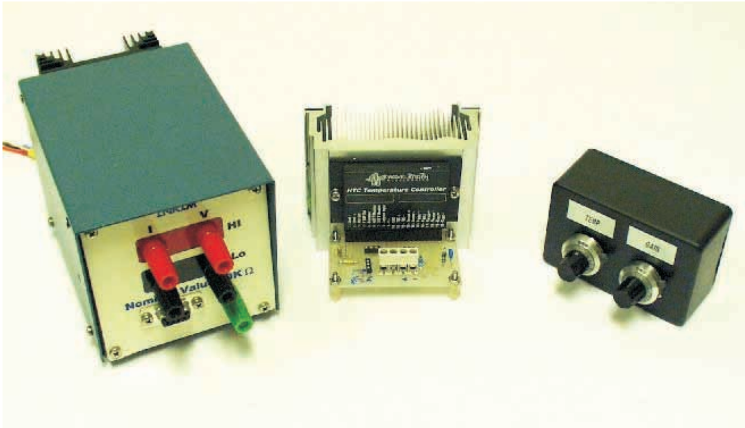


Fig. 2. a) The TVHAR. b) Temperature controller of the TVHAR. c) Potentiometers to set temperature and gain.

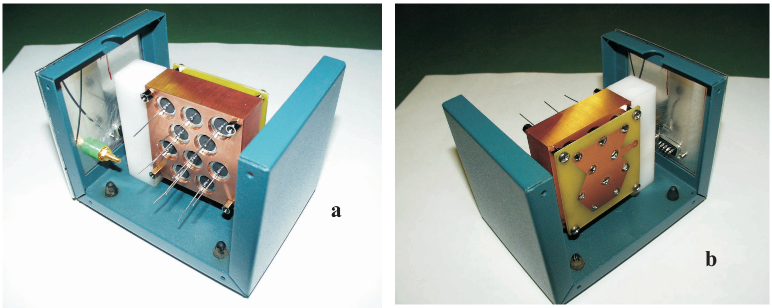


Fig. 3. a) View of the inside of the TVHAR during the building stage. b) External view of the TVHAR during the building stage.

3. Characteristic of the resistor

The main metrological characteristics of a standard are the time stability and the low sensitivity to environment parameters, in particular standard resistors are mainly affected by temperature [5].

In order to evaluate the metrological performance of the TVHAR, several comparisons of this resistor were performed against a 10 kΩ ESI SR104, widely used for its excellent metrological characteristics such as: temperature coefficient -3.4×10^{-8}/ C, $\beta = -2.9\times10^{-8}/^\circ\ C^2$, power coefficient ($< 1 \times 10^{-6}$/W) and drift on the order of 0.05×10^{-8}/year [6]. All the comparisons were performed using a DCC bridge and a

1 kΩ standard resistor, kept in an oil bath, as auxiliary standard, in order to reduce the systematic errors. The aims of these comparisons were the evaluation of long and short-term stability and the thermal behaviour of the TVHAR.

3.1. Long and short-term stability

For the long-term stability several evaluations of the TVHAR resistance value were performed with a rate of about six months and for a period of two years (Fig. 4) and a relative difference of about 5×10^{-7} was found, presumably as consequence of the stabilization process of the TVHAR itself.

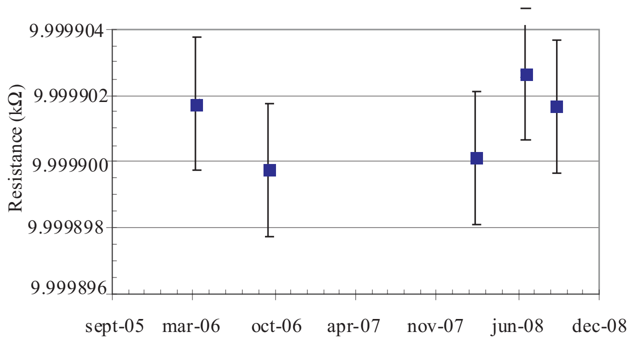


Fig. 4. Long-term stability: determined resistance values of the TVHAR since its assembly in 2006.

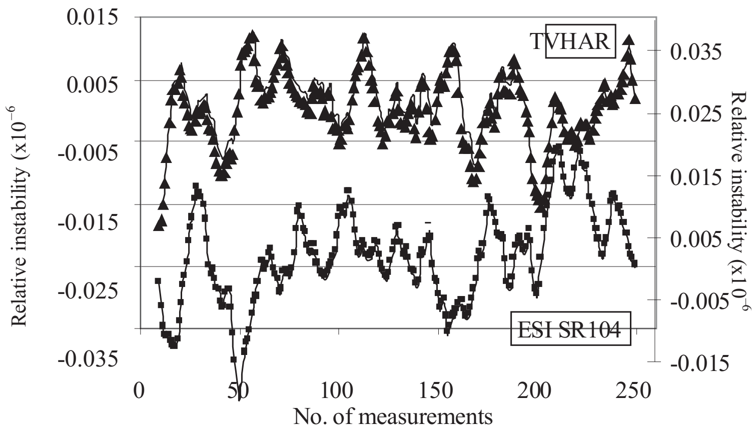


Fig. 5. Short-term stability: comparison of TVHAR and ESI SR104 both in free air against a 1 kΩ transfer standard resistor kept in an oil bath. The measurements were made with a current of 0.3 mA.

The results of the short-term stability evaluation are shown in Fig. 5, where the relative variations of the values of both the 10 kΩ standards are a few parts of 10^{-8}.

3.2. Thermal behaviour

In order to evaluate the temperature coefficient (TC) of the TVHAR, the resistor was placed in an air bath (Fig. 6) with temperature variable in the range 18÷28 °C and stability of 0.01 °C. The TVHAR resistance value, with the temperature controller setting point at (23 ± 0.1) °C, was compared against a 1 kΩ standard kept in an oil bath, at a fixed temperature of (23 ± 0.002) °C. In order to reach a satisfactory stability, the measurements were carried out 24 hours after the setting of each temperature point of the air bath.

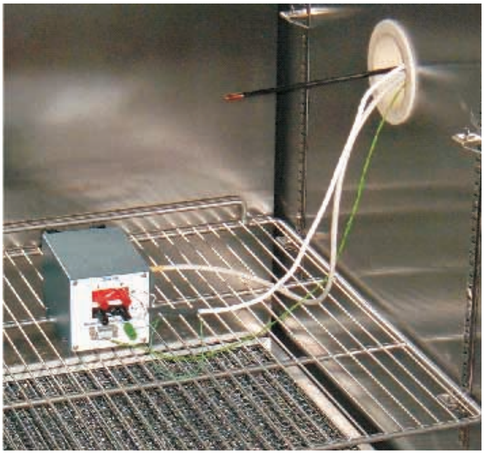


Fig. 6. The TVHAR inside the air bath.

The measurements were evaluated in the range (20÷25) °C. The ratio measurements between the mentioned resistors were evaluated with a DCC bridge and the results are shown in Fig. 7. The TVHAR showed a very stable behaviour in the range 21÷23 °C, due to the effect of the temperature controller. However it has a value change less than 0.2 μΩ/Ω when the temperature changes up to 5 degrees.

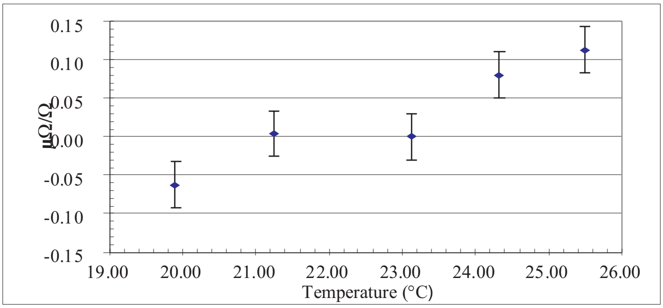


Fig. 7. Relative variation of the TVHAR value with its controller set at 23.0 °C vs. external temperature. The TVHAR was measured against a 1 kΩ standard resistor kept in an oil bath.

3.3. Thermal simulation

The temperature behaviour of the copper block was simulated by means of a finite elements methods. In the simulation a thermal flux of about 0.2 W was applied on the surface where the TEC is normally placed. The analysis shows (Fig. 8) that the gradient of the place of the resistors is less than 0.05 °C.

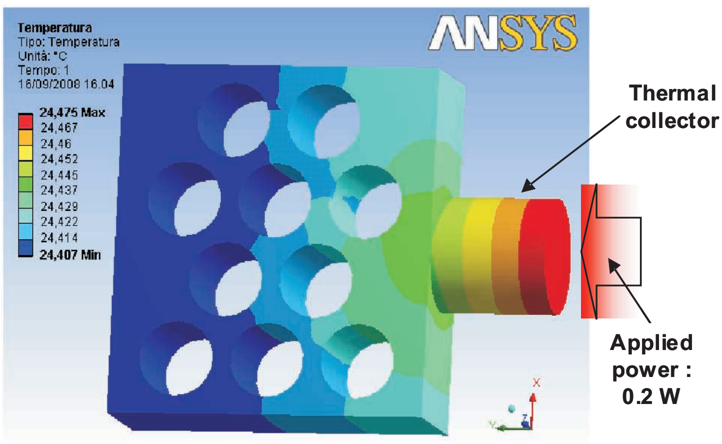


Fig. 8. Simulation of the static behavior of the copper block when the TEC of the temperature controller applies a power of about 0.2W. The thermal gradient showed among the places of the ten resistors is less than 0.05 °C.

3.4. Power coefficient

Preliminary measurements to verify the power coefficient of the resistor were performed. The measurements were carried out with the temperature controller in operation, by comparison with a 10 kΩ resistor with a negligible power coefficient. The obtained results showed a value of -4×10^{-6}/W, suitable for high precision standard resistors.

4. Resistance triming

A particular feature of the developed resistor is the possibility to vary finely its value acting on its temperature controller. An example is reported in Fig. 9 in which the controller is firstly set at 23.0 °C, then moved down to 22.2 °C, maintained at this temperature for 90 min, returned and maintained at 23.0 °C for about 30 min, then moved up to 23.8 °C, maintained at this temperature for again 90 min, and finally returned at 23.0 °. The figure shows that the value of the resistor was respectively increased and decreased by about 0.5×10^{-7} with respect to its value at 23.0 °C due to the two induced changes of its internal temperature. The standard deviation of the measurements performed during this temperature cycle was also determined and summarized in Table 1.

Table 1. Standard deviation of the measurements on the 10 kΩ in a temperature cycle of (23 ± 0.8)°C (see Fig. 8).

Temperature (°C)	Time (min)	Std. dev. of the meas ($\times10^{-8}$)
23.0	30	2.1
22.2	90	1.7
23.0	30	2.0
23.8	90	1.5
23.0	30	1.5

It is possible from Table 1 that TVHAR presents an instability on the order of about 2.0×10^{-8} evaluated in the first 30 min after the set point change. Moreover it is possible to see from Fig. 9 that the value of the resistor at 23 °C returned at a level of better of 1.0×10^{-8} after both temperature changes. Fig. 10 reports the behaviour of the TVHAR in a wider temperature change. Also in this case the standard deviations of the measurements performed on the resistor at each temperature are ofthe same order of those of Table 1.

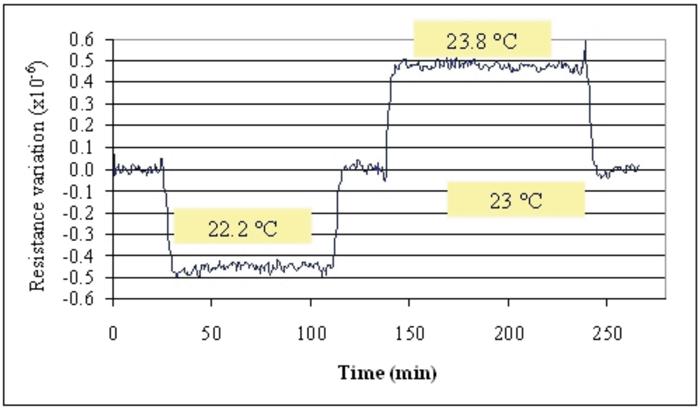


Fig. 9. Behaviour of TVHAR vs. temperature changes induced by its controller of the same order under and above the reference temperature of 23 °C.

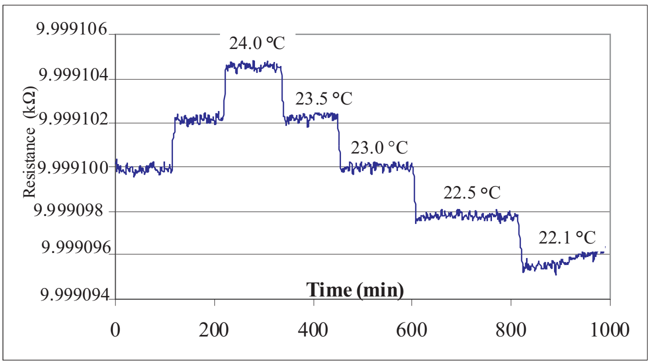


Fig. 10. Behaviour of TVHAR vs. temperature changes induced by its temperature controller.

It is possible to change the value up to 7×10^{-6} with a temperature change of about 10 °C around the normal set point of 23 °C.

5. Conclusions

The paper shows the development of a 10 kΩ standard resistor suitable for various applications. Its short time stability is equivalent to a high performance standard resistor while its temperature controller improves its use both as travelling and reference standard. We are performing other measurements for better determination of its long time stability and its power coefficient. With the stability and the possibility to trim finely the value of the TVHAR, it can be also involved to test experimental measurement equipment like current comparator bridges and potentiometric circuits. The determination of the transport effects could be evaluated by a inter-laboratory comparison. Future aims of this work could be the possibility to perform a series of thermal cycles of stabilization either before the use either periodical (weekly for example) to observe the behaviour of the resistor during a long time. Some reviving techniques with moderate thermal cycles could improve the technical specifications of the standard. This analysis will also allow us to perform an artificial ageing of the resistor to see the thermal effects of daily use of such temperature variations of the laboratory, during transport. Another improvement could be the addition of a digital system that reports the calibration data, the internal temperature of the standard and the resistance value evaluated on the basis of its time drift and of the set temperature.

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