10 V,1 Ω,10 kΩ high accuracy standard setup for calibration of multifunction electrical instruments and for inter-laboratory comparisons

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Abstract. A temperature controlled 10 V, 1Ω and 10 kΩ transportable setup has been developed at National Institute of Metrological Research (INRIM) for the calibration and adjustment of multifunction electrical instruments as digital multimeters (DMMs) and multifunction calibrators (MFCs) and for high level inter-comparisons. The Resistance Standards are made of two 10 Ω and 100 kΩ resistors nets connected in parallel while the 10 V Standard is an ultra-low noise-drift based reference INRIM developed circuit. The project of the setup started from a previous realization revisiting it and adding a 10 V Standard. The resistors net of the 1 Ω is inserted in oil-bath along with the internal side of its connectors lowering the thermo-electromotive forces (emfs). The three Standards are further enclosed in a thermo-regulated copper enclosure and in an external aluminium case. The setup is also equipped with a high insulation switch to select the desired Standard. Preliminary results (3 h relative stabilities ranging from 5×10^{-8} to 7×10^{-8}) and temperature coefficients are satisfactory to the scope of the realization.

1 Introduction

Multifunction electrical instruments, such as digital multi-meters (DMMs) and multifunction calibrators (MFCs) operating in the five low frequency electrical quantities generally contain many electronic components. The circuit configuration and the values of the components determine the characteristics of the instrument. As the values of these components can vary during the time, instruments require periodic calibration to assure compliance with specifications. Until the advent of the microprocessor, periodic calibration generally required the physical adjustment of components into the instrument. For this process normally were necessary many hours and the employment of several reference Standards to be calibrated elsewhere increasing the calibration costs. Today, internal software corrections have eliminated the need to remove instrument covers to make adjustments in several instruments. Artifact calibration is the process to calibrate an instrument by comparison to a small number of standards assigning values to internally references or parameters. The widely used artifact standards are the 10 V DC Voltage Standard, the 1 Ω and 10 kΩ DC Resistance Standards [1–3]. Following two previous satisfactory attempts [3, 4], at National Institute of Metrological Research (INRIM) a temperature controlled high precision setup involving these three Standards was developed and now is in characterization phase. After the verification of its stability characteristics it could also be employed as travelling standard for high level inter-comparisons (ILCs) as made in the past [5, 6]. Its high performance temperature control allows to avoid the use of especially made thermal enclosures for the circulation of the Standards as [7,8].

2 The setup Standards

The 1 Ω and 10 kΩ are made with two 10 Ω and 100 kΩ parallel connected resistors nets made with ten resistors 10 Ω and 100 kΩ respectively. Details of Standards of similar type can be found in [3]. The 10 V Standard is a Linear LTZ1000 Temperature Stabilized Zener diode based reference visible in the complete circuit of Fig. 3. It is developed at INRIM and projected to operate at 23 °C, utilizing technical details built by means of 3D printer for temperature shield of the integrated at 48 °C, The Zener works over the environment temperature to do an heater inside the TO-5 metal can of the chip. Inside the reference chip a transistor (Qa) is used as temperature sensor and the collector voltage is the set point temperature to the not- inverting input of IC1/2. The net R4-R3 is a divider to set the Qa base voltage. The resulting voltage to the Qa collector fix the temperature of the device to about 50 °C, a good compromise between both the temperature stability in environment controlled laboratory and to the Zener aging effect. The output of IC1/2 close a loop through T1 that controls the heater current. The temperature effect on voltage Zener is compensated with the opposite

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effect of transistor Qb through the loop involving IC1/1. The Zener sense signal is amplified by IC2 in order to achieve an output voltage as close as possible to the nominal 10 V. The output transistor allows the circuit to sink a current of about 10 mA.
The LTZ1000 is mounted on the board shown in Fig. 2, developed following [9].

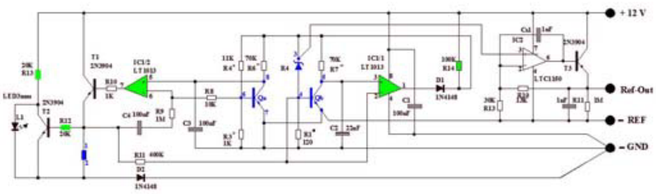

Fig. 1.– Electrical circuit of the Voltage Reference. The Heater is connected to the pins 1 and 2, while the Zener is connected to 3 and 4. Inside the chip there are also two transistors, the first to compensate the Zener temperature coefficient, the second act as a temperature sensor.

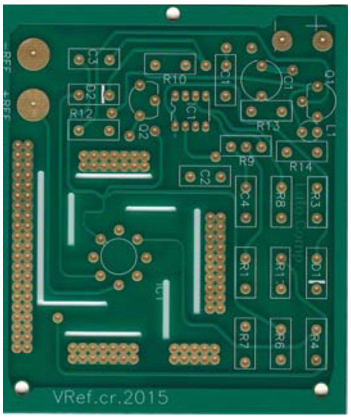

Fig. 2. Bottom view of the double sided pcb of the voltage reference. The tracks has been designed in a tree-wire configuration and the ground is connected in single point. The pads are golden to reduce emfs of the components connections.

The output voltage stability and the short term noise are compromised by thermal contact effects between the Zener pins and the board tracks and other effects related the temperature. The printed board has been designed with a set of solutions to minimize thermal effects. Copper tracks were golden and all welds were made with low emfs alloys. The area around the Zener doesn't contain electrical component so the LTZ1000 is closed inside a shield to minimize air flows effects. The ground lines are kept separate in order to reduce the cross-talk among the circuit stages. The net of the tracks has been designed in a three-wire configuration and the ground is connected in single point.

3. Structure of the setup

A copper box has been developed to house the three standards (Fig.3). The two nets of resistors are maintained inside an aluminum cylinder (in the figure the cylinder on the left) that acts as thermal equalizer. The 1 Ω net is put inside the cylinder and immersed in silicone oil. The net is configured as a four terminal resistor whose connectors are visible in Fig. 3. The second net, to form a 10 kΩ resistor, is placed around the cylinder and not immersed in oil. On the right of Fig. 3 it is possible to see the 10 V reference container and, above, it, the switch is placed. The main board of the voltage reference is housed inside the copper box. It works at 23 °C while the Zener (LTZ1000 is maintained at 48°C with its internal heater system in order to increase the temperature stability). All the signals of the three standards are connected to a low noise and low emfs switch that is managed by an outside micro controller. The switch is based on a set of latching relays connected to the control circuit via electrolytic capacitors. The capacitors both allow the passage of impulse currents to relay excitation and maintaining coils a good isolation dc level. The box of standards and the switch are thermally connected to the rear panel of the shield with a 5 mm thick strip, maintained at a temperature close to 23 °C by means of a Peltier module and a PID controller. The Stability of the whole shield is 0.05 °C, evaluated inside an electrical laboratory operating at a temperature of23 ±0.5 °C. The analogical signals output is a 4 pole Lemo connector inserted in a thermal collector visible in Fig. 4. The collector is thermally connected to the shield. This further temperature control minimizes the effects of emfs and performs a first step of temperature conditioning of the wires connected to the instruments. All the elements of the shield and the lemo are floating in order to define the guarding voltage through the instruments. The image shows also the power supply connector of the voltage reference and a D-type connector used for the temperature sensors and the logic control of the switch.

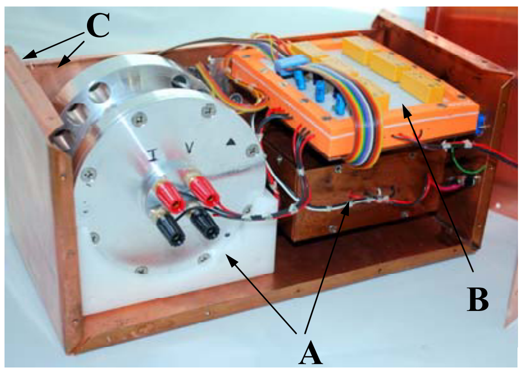

Fig. 3. Internal view of the system. A) voltage and resistors standards, B) switch, C) parts of the shield, the rear part is a 5 mm thick strip thermally connected to the Peltier module.

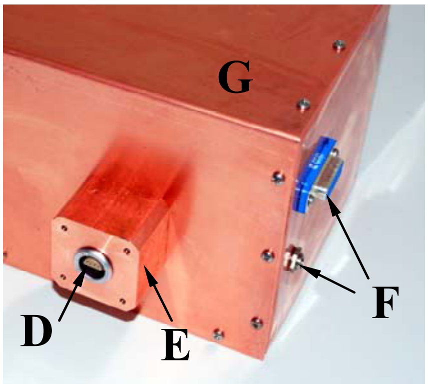

Fig. 4. I/O connectors of the setup. The analogical signals of the standard are available through a lemo 4 pole (D) whose shield is connected to the guard and temperature controlled (E). The power supply and the logical signals are insulated from the shield (F). The external shield (G) of the standards is built with two copper sheets bent and screwed to the back thicker strip.

The copper box is, in turn, inserted in an aluminum case connected to the ground potential. On its front panel, a unique connector, allows to connect the selected Standard to the instrument under calibration.

3.1. The temperature control

The temperature controller of the complete system is based on a hybrid proportional-integrative (PI) commercial circuit. This system, designed for laser stabilization, drive, through an H bridge output configuration, a Thermoelectric Cooler Peltier (TEC) using a 10 kΩ NTC thermistor as sensor. The PI temperature set point is defined by a voltage dc between 0 and 3.6 V provided by a DAC controlled with a microcontroller witch acts also as interface to the pc. The temperature of the complete system is measured with a platinum 100 Ω thermometer. A less accurate temperature is also possible with a digital electronic thermometer connected to the microcontroller. Both the thermometers are placed near the TEC copper collector.

3.2 The reference output

By means of the switch it is possible to select and obtain at on the four output terminals, the two resistance values and the reference dc voltage value alternatively. The switch configuration has been designed in order to fit with the input terminals of MFCs and DMMs. Figs 6 and 7 show the behaviour respectively of the two Resistance and of the DC Voltage Standards at the output four terminals with the setup temperature controller set at 23.0 °C. The measurements shown in the graphs concern a few hours of measurements, typical period due to the process for the calibration of a multifunction instrument.

Fig. 5. Hybrid PID circuit of the temperature controller. The temperature sensor is a 10 kΩ, NTC while the output is connected to a Peltier module.

The temperature stability of a calibration laboratory is normally within ± 1 °C, in this condition the stability of the reference is enough to achieve the best specification reported on the datasheet of high end instrument.

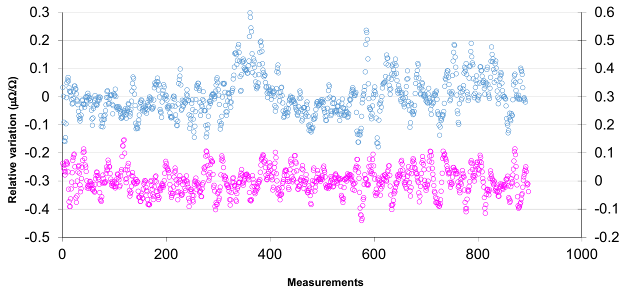

Fig. 6. Stability of the resistance standards, 10 kΩ (upper)and 1Ω (lower). The measurements showed a stability, evaluated as relative standard deviations, respectively of 7×10^{-8} and 5×10^{-8} evaluated during three hours of measurement.

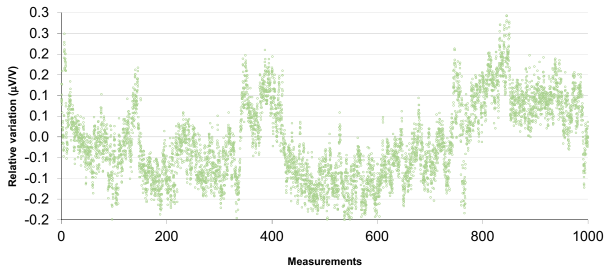

Fig. 7. Stability of 10 V standard, with a relative standard deviation of 6×10^{-8} during about three hours of measurement.

To evaluate the temperature coefficient (TCR) of the three Standards the entire setup of Fig. 3 was placed inside a climatic chamber with the possibility to change the temperature between 21 and 25 °C. Plot of Fig. 8 shows the behaviour of the 10 V and of the 10 kΩ. Their TCR are respectively 1.0×10^{-7}/°C and 3.0 $\times10^{-8}$/°C. This means that, when the setup temperature controller is active, granting an internal temperature stability of about 0.05 °C, the effect due to temperature instability on these standards can be considered negligible.

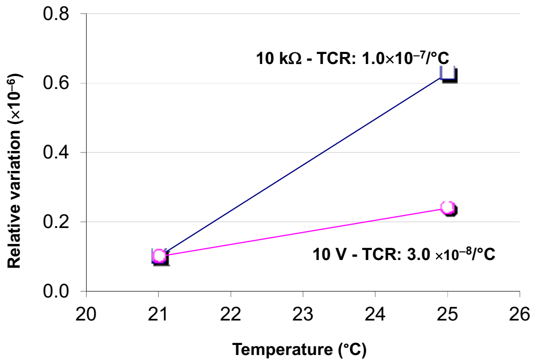

Fig. 8. Relative variation of the 10 kΩ and of the 10 V vs. temperature.

The 1 Ω resistor shows instead a TCR of about 2.0 $\times10^{-6}$/°C and requires a resistors net to compensate it.

Conclusions

From preliminary characterization results the setup Standards seem suitable to the aim of the realization. In particular the short-term high stability of the Standards and the satisfactory temperature dependence (particularly of the 10 V and of the 10 kΩ) fit to the need of calibration and adjustment of multifunction electrical instruments. Future aims of this work will be an evaluation of the mid-long term stability of the setup Standards, the transport effect, calibration and use uncertainties.

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