Automatic Calibration of Linearity in High Precision Digital Multimeters

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ABSTRACT—**This paper proposes a method for measuring the linearity of high precision digital multimeters using a self-calibrating resistive divider. The measurements are carried out automatically via a computer that manages a scanner and the voltmeter under test by means of a control program. This program drives the selected sequence of steps that go from 10% to 100% of the range, in steps of 10%.**

Key words – Analogue to digital converter, resistive divider, uncertainty, measurements, integral linearity.

I. INTRODUCTION

It is very important and useful, for the laboratories, to know the response of the linearity of high precision digital multimeters (DMM). Calibrations of these equipments are usually done in few points for each range, usually near the beginning and the end of the scale (e.g. at 10% and 100%), and for the remaining intermediate points it is assumed the linearity manufacturer specification. This project investigates the linearity of a high precision multimeter model Agilent 3458, 8½ digits [1]. This type of multimeter has linearity specifications that reach values in the order of 10^{-7}, which is not simple to test. One verification method is through the use of Josephson standards [2], [3], but not all laboratories have one. Another possibility, which is followed in this paper, is the use of resistive divider [4]. These dividers should be calibrated and this paper describes a fully automatic calibration method that does not require any other standard.

There are several definitions for the linearity of a DMM. One of them is the departure of a straight line calculated by least-squares fit to the true values [2]. Others use a similar definition than calibration errors [3]. However, linearity errors are different than calibration errors. In the latter, all sources of errors are included, that is offset, scale error and linearity errors. To separate linearity from the others, offset and scale errors must be removed. In this way, the definition of integral non-linearity (INL) takes into account only the deviation from the ideal slope once offset and scale errors were corrected. Then, any linearity error curve that represents this error versus the voltage must have zero value at zero voltage and full scale voltage. This definition is used in this paper.

II. DESCRIPTION OF THE METHOD

The development of this project uses a resistive divider of ten 100 Ω Vishay resistors with another divider in parallel to provide guard potentials for each output of the main divider as shown in Fig. 1 and Fig. 2 [4]. The set of resistors is immersed in a container with mineral oil to provide thermal stability, in order to reduce about 0.1 K the ambient temperature variations during the period each test lasts (about 4 hours). The temperature is measured by means of a thermistor and a 6 ½ digit multimeter. In addition, a low thermal emf (50 nV) 10-channel-scanner is used for measurements. As power supply, a voltage standard model Fluke 732B [5] of 10 V is connected at the input. It is remarkable the high stability of the source for the maximum current (10 mA). This allows covering ranges up to 10 V on the DMM. Upper ranges require the use of a calibrator as the source.

The measurements are carried out automatically via a PC through a program developed in LabView language [6]. The program drives the sequence of selected steps. These steps include measurement of the full voltage, partial voltages and null voltages, at both polarities. It also takes measurements of

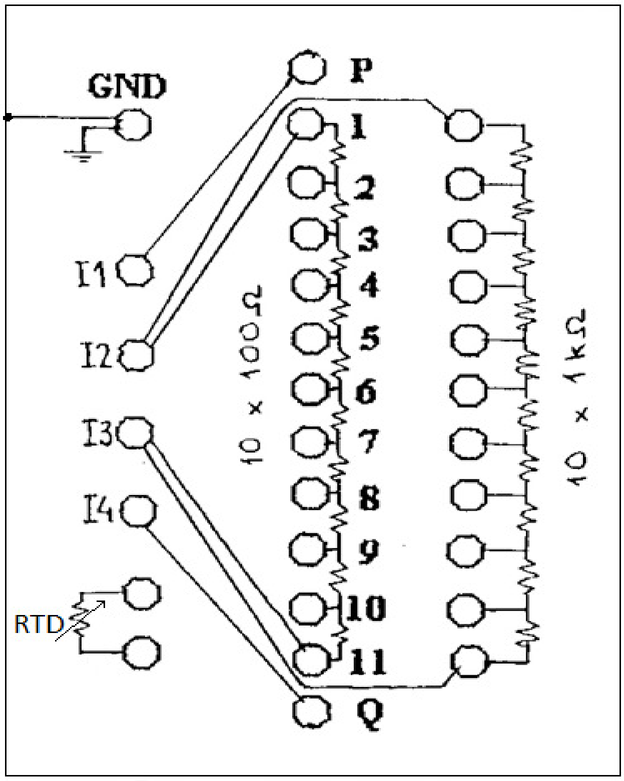

Fig.1. Resistive divider circuit.

the temperature of the divider to correct resistor temperature variation.

All these measurements are recorded by the program in different files. Additionally, the program makes the calculations and plotters.

The equipments that integrate the project are selected from the computer through a GPIB bus which commands the scanner and the two multimeters. The sequence of measures consists of several steps. Initially, the self-calibration of the divider is made at ratios 10:8, 10:6, 10:4 and 10:2, taking the resistors in pairs. There are 5 pairs, 1-2 to 9-10 resistors. In a second stage, the relations 10:7, 10:5, 10:3 and 10:1 are determined using single resistor comparisons. The ratio 10:9 is not measured. This is because the amount of channels (10) of the scanner is not enough to cover all decade ratios. A new scanner with more channels will be used in the future. Specific measurement sequence is:

1. Measurement of the voltage drop of each adjacent pair of resistors with direct and reverse polarities, calculating the average voltage of both.
2. Measurement of the above step in the opposite direction, in order to eliminate effects of drift of influence factors.
3. Temperature correction of the calculated ratios, using previously calculated temperature coefficients for each resistor.
4. Calculation of ratios 10:8, 10:6, 10:4 y 10:2.

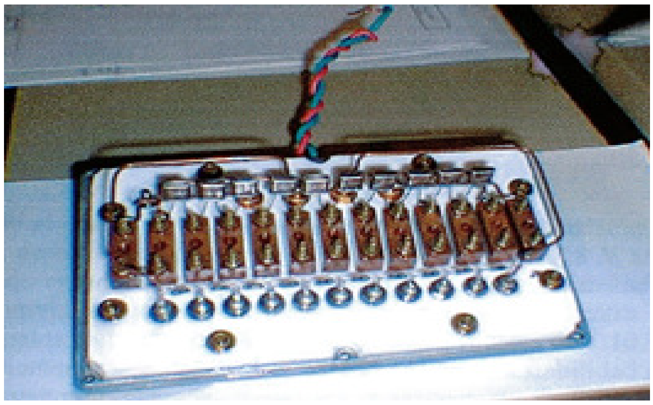

Fig. 2. Internal view of the resistive divider.

5. Repetition of the previous sequence to determine the ratio 2:1 from each pair of adjacent resistors.
6. Calculation of ratios 10:7, 10:5, 10:3 y 10:1.

Although the voltmeter under test is used for these comparisons, it measures similar values so that the ratios between them are not affected by any error of the instrument, including its non-linearity. In this way, it is possible to self-calibrate all mentioned ratios of the divider.

After the self-calibration procedure, linearity errors of the DMM are measured using the following steps.

7. Measurement of the total voltage of the divider Vt. DMM indicated output: Vit
8. Measurement of zero voltage (short circuit at the input of the DMM). DMM indicated output: Vio
9. Measurement of the voltage, Vc, to be calibrated.DMM indicated output: Vic
10. Temperature correction of the used divider ratio r_c.

The linearity error *e,* expressed in volt, is calculated as

$$e = Vt\left(\frac{Vic - Vio}{Vit - Vio} - r_c\right) \qquad (1)$$

III. UNCERTAINTY

Many factors affect the uncertainty of this method.

A. Temperature. Resistors have low thermal coefficients, in the order of 10^{-6} K^{-1}. However, this is a significant value compared to the expected accuracy, so that temperature variation cannot be neglected. The divider is placed in a thermal block to get a temperature stability of 0.1 K, leading to a possible ratio variation in the order of 10^{-7}. To reduce this factor, the thermal coefficient of each resistor was determined and results are corrected by this factor. In this way, the uncertainty due to this effect is reduced about 3 times, leading to 3×10^{-8} with a cover factor 1.

B. Thermoelectric EMF. These voltages appear in the connections between the divider and the scanner, inside the scanner and at the voltmeter connections. The scanner generates this type of emf due to its relay contacts. Total compensation of this factor influence requires polarity reversal of the voltage source. At present state of the project, this is not performed. Polarity changes are made by the scanner itself so that its own emf cannot be compensated. In a second phase of the project, the supply polarity will be reversed. The scanner emfs are under 50 nV. Two relay contacts are involved in each measurement. This leads to an uncertainty contribution of 4×10^{-8} with a cover factor 1. A study of the thermoelectric emf of the system will be conducted, replacing the Agilent 3458 by a nanovoltmeter.

C. DMM offset. As a short circuit is made at the DMM input before each measurement to know the offset of the instrument, the influence of this factor can be neglected.

D. Stability of the power supply. The stability of the source together with the stability of the DMM was measured during the time required for the calibration of one point. This was better than 0.1 μV that represents an uncertainty contribution of 1×10^{-8} with coverage factor 1. This uncertainty source is included in type A.

E. Type A uncertainty. Standard variation in short time is around 1×10^{-8} with a cover factor 1.

Test results will be included in the final paper.

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