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Temperature influence on the frequency response of the Keysight 3458A digital multimeter.

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***Abstract* – This paper describes the procedure and experimental set-up used at CEM to determine the temperature influence on the frequency response of two Keysight 3458A digital multimeters (DMMs) in the Direct Current Volt (DCV) sampling mode. The DMMs were used to digitalize an AC input signal of 0.8 V and 1 kHz provided by an AC source.**

***Keywords* – Analog to Digital Converter, temperature coefficient, aperture time, digital sampling, digitizer.**

I. INTRODUCTION

The Keysight 3458A digital multimeter [1] is widely used in National Metrology Institutes (NMIs) and calibration laboratories as Analog to Digital Converter (ADC) for high-accuracy sampling measurement systems, as electrical power measurements [2]–[3], impedance measurements [4], and voltage [5] and current measurements [6] and it will replace progressively thermal converters and complex coaxial bridges providing much better measurement capabilities and simpler automatic systems. However, metrological grade characterization and a whole understanding of its behaviour are necessary to provide state-of-the-art accuracy.

For instance, characterization of the ADCs is a key point to improve their accuracy and to substitute thermal converters, limited to provide only root mean square (RMS) values so not suitable in presence of dynamic signals, by digital sampling methods.

Nowadays, most of the measurements at National Metrology Institutes (NMIs) and calibration laboratories are performed under static conditions, however most instruments operate under dynamic conditions, where signals vary with time, and their calibration should also be performed in such dynamic conditions. In this situation there is a need for a new traceability chain for current and voltage waveforms, beginning with a Josephson standard as a reference and based on measurements using digital instruments, named digitizers. The European EMPIR project 17RPT03DIG-AC [7], started in May 2018, has as main objective the development of metrological capacity for the transition from analogue to digital measurements for AC voltage and current to enable operation under dynamic conditions.

The Spanish National Metrology Institute (CEM), as one of the participants in the above-mentioned EMPIR project, is interested in the characterization at a metrological level of the 3458A digitizer that is at the moment by far the most employed one.

II. RELATED RESULTS IN THE LITERATURE

Several works regarding characterization of the Keysight 3458A digital multimeter have been published. In [8] some of the dynamic characteristics of this DMM have been assessed: RMS measurement, gain variation with aperture time, hysteresis and integral non-linearity. The characterization of the frequency range from 20 Hz to 400 Hz have been carried out in [9] by means of thermal converters. Evaluation of time jitter and noise performance of the 1 V range at several sampling frequencies and aperture times has been performed in [10] and [11], respectively. There is also a work describing the effect of the 3458A jitter on precision phase difference measurement [12]. The influence of the multimeter synchronization and measurement parameters on the RMS measurements for different frequencies is presented in [13]. The characterization of the amplitude frequency response at different aperture times of the DCV sampling function of the Keysight 3458A using, for the first time, a Josepshson arbitrary waveform synthesizer (JAWS) was also carried out at CEM and published in [14]. A new method for the calibration of digitizers was proposed in [15] using also a JAWS system. Most of this information has been compiled in an excellent book [16].

However, despite the number of research articles in this field, not much attention was paid to the characterization of the temperature coefficient of the DMM.

Recently, a work [17] was carried out at CEM with the aim of characterizing the temperature coefficient of the DCV sampling function of the Keysight 3458A. The paper presented the evaluation of the temperature coefficient of two different Keysight 3458A DMM (DMM_1 and DMM_2) using a 1 V Zener reference. In Fig. 1 the DMM gain error variation with temperature for DMM_2 is plotted as a function of aperture time (T_a) from temperatures ranging from 20 ºC to 26 ºC. The results showed two different temperature coefficients, one for aperture times higher than 100 µs and another for lower values of aperture times. For high frequency sampling, where low aperture times are required, the temperature coefficient is in the order of 10 µV/VºC. It was proved that for the metrological grade characterization of the ADC to be employed in precise sampling measurements, the temperature influence should be included.

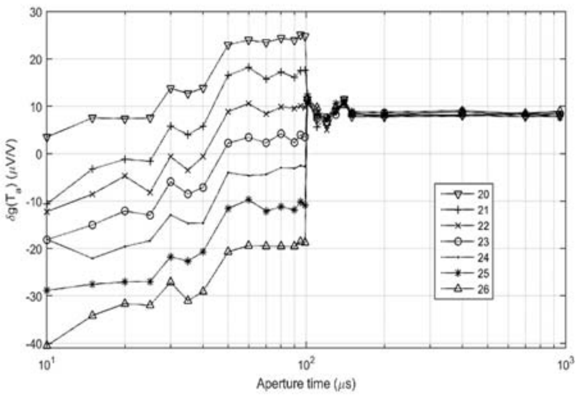

Fig. 1. DMM_2 gain error due to temperature coefficient as a function of aperture time for different temperatures.

As this temperature evaluation was carried out only for a DC input signal, it is necessary to extend the study to an AC input signal, to confirm that a similar behavior is obtained for the evaluation of the DMM temperature coefficient in its operation conditions.

In this paper, we describe the results, procedure and experimental set-up used at CEM to evaluate the temperature influence on the frequency response of the DMM in the DCV sampling mode under an AC signal application.

III. DESCRIPTION OF THE METHOD

To evaluate the temperature coefficient of the 3458-A as a function of aperture time for different temperatures in DCV sampling mode using an AC input signal, two different digital multimeters (DMM_1 and DMM_2) have been employed. As it can be seen, both DMMs under characterization are placed in a climatic chamber and connected to a computer by GPIB interface. The schematic diagram and the experimental set-up inside the climatic chamber are shown in Fig. 2 and Fig. 3, respectively. The climatic chamber employed was the VC3 7034 model manufactured by Vötsch with the possibility of temperature and humidity control. A preliminary evaluation of thermal stability and uniformity of the climatic chamber was carried out to assure the temperature working conditions.

The DMMs were used to digitalize an AC input signal of 0.8 V and 1 kHz provided by a Fluke 5720 multifunction calibrator.

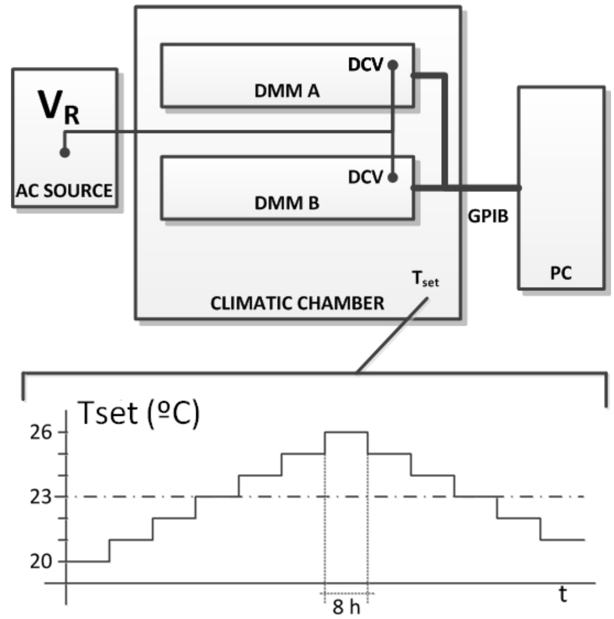

Fig.2. Schematic for two DMM temperature coefficient evaluation using an AC input signal.

Temperature in the chamber, set-point temperature (T_{set}), was setting from 20 ºC to 26 ºC in steps of 1 ºC. In order to guarantee that the multimeter internal temperature is stable during the measurements each temperature step was maintained for eight hours. Measurements are carried out twice for the same temperature, first increasing temperature from 20 ºC to 26 º and then decreasing temperature from 26 ºC to 20 º so that the AC source stability could be evaluated and compensated.

A software application was developed to control the simultaneous measurements of two different DMMs that are configured for digitizing. Moreover, samples were read and stored together with the internal temperature of both DMM.

Fig.3. View of the set-up for the evaluation of temperature influence on the frequency response of two DMM in the DCV sampling model.

IV. RESULTS AND DISCUSSIONS

The multimeter gain factor as a function of aperture time, $g(T_a)$, was evaluated for a set of temperatures and aperture times. The aperture time was configured from 10 µs to 300 µs in a cyclical way, so once the last value (300 µs) reached the first (10 µs) was configured again, repeating the set of aperture times until the end of the temperature step.

The sampling frequency provided by the DMM internal timer was configured at 2788.4 Hz.

For each measurement, 2557 samples in DCV sampling mode were obtained, stored in the DMM memory and read by GPIB at the end of the acquisition together with the DMM internal temperature.

At each aperture time T_a, five iterations of each configuration were performed.

Therefore, for each measurement, at each T_a and each T_{set}, the measured value V_M is the average of the acquired samples, and the DMM gain error as a function of aperture time $\delta g(T_a)$ was obtained from Eq. (1) as the deviation of the measured value V_M from the AC source reference voltage, V_R..

$$\delta g(T_a) = \frac{(V_M - V_R)}{V_R} \cdot 10^6 \quad (1)$$

The results obtained by the above mentioned procedure using an AC reference input has been evaluated. Figures 4 and 5 show, for DMM_1 and DMM_2, respectively, the gain error curves $g(T_a)$ for the set-point temperatures.

From figure 4 and 5, it can be stated that a similar behaviour to that found employing a DC voltage reference has been obtained. It is also clear that two different temperature coefficients arise, depending on the aperture times considered being higher or lower than 100 µs. For the high accuracy stage (aperture times higher than 100 µs) the temperature influence is negligible whereas in the high speed stage (aperture times lower than 100 µs) it is import and should be considered in the metrological grade DMM characterization. This behaviour is a consequence of the ADC switch between 10 kΩ and 50 kΩ inputs at 100 µs [18].

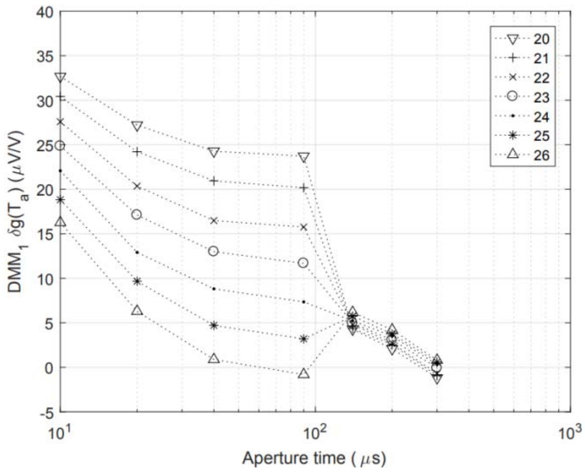

Fig.4. DMM_1 gain error curves for the set-point temperatures between 20 ºC and 23 ºC.

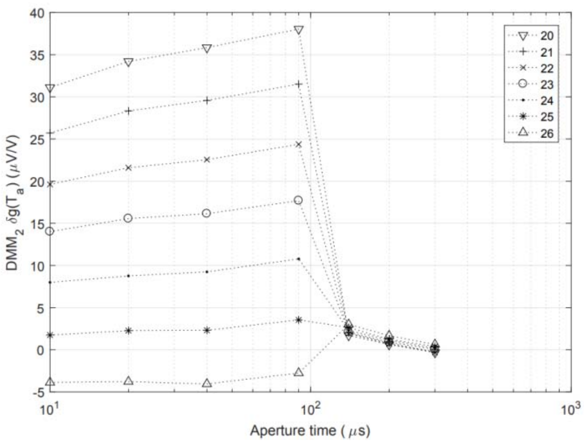

Fig.5. DMM_1 gain error curves for the set-point temperatures between 20 ºC and 23 ºC.

After data processing, an estimation of temperature coefficients for each DMM has been done plotting the gain error values as a function of the DMMs internal temperatures for each aperture time.

In table 1 temperature coefficients for the multimeter DMM_1 have been presented for different aperture times, together with the standard deviations. Calculations were done twice for the same temperature, first when increasing temperature from 20 ºC to 26 º (DMM_1-up) and then when decreasing temperature from 26 ºC to 20 º(DMM_1-down) in order to verify that there is no significant difference so that the AC source stability could be evaluated.

Table 1. Temperature coefficients for DMM_1 (µV/V/ºC)

T_a (µs)	DMM_1-up	DMM_1-down	Mean	Std
10	-2.39	-2.81	-2.60	0.21
20	-3.22	-3.49	-3.35	0.14
40	-3.50	-3.84	-3.67	0.17
90	-3.76	-4.07	-3.91	0.16
140	0.33	0.06	0.20	0.13
200	0.42	0.27	0.34	0.08
300	0.36	0.31	0.33	0.02

The temperature coefficients obtained in a previous work [17] for both multimeters when a DC signal was digitalized were compared with those obtained in this work when an AC input signal of 0.8 V and 1 kHz were used. The results of this comparison are presented in table 2 and 3, for DMM_1 and DMM_2, respectively. The temperature coefficients when applying a DC signal are similar to those obtained when applying an AC signal. Furthermore, two different temperature coefficients were obtained, one for aperture times higher than 100 µs and another for values lower than 100 µs.

Table 2. Temperature coefficients for DMM_1 with DC and AC reference (µV/VºC)

T_a (µs)	DC	AC
10	-2.95	-2.60
20	-3.56	-3.35
40	-3.74	-3.67
90	-3.90	-3.91
140	0.33	0.20
200	0.32	0.34
300	0.26	0.33

Table 3. Temperature coefficients for DMM_2 with DC and AC reference (µV/VºC)

T_a (µs)	DC	AC
10	-6.16	-5.72
20	-6.35	-6.23
40	-6.69	-6.56
90	-6.87	-6.70
140	0.11	0.19
200	0.18	0.17
300	0.18	0.12

V. CONCLUSIONS

The procedure and experimental set-up performed at CEM to evaluate the temperature influence on the frequency response of two DMMs in the DCV sampling mode when used to digitalize an AC input signal of 0.8 V and 1 kHz provided by an AC source has been presented.

Results show that a similar behaviour to that found employing a DC voltage reference [17] has been achieved and similar temperature coefficients were obtained. As expected, two different temperature coefficients were found, depending on the aperture times considered being higher or lower than 100 µs.

VI. ACKNOWLEDGMENT

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