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STATIC CHARACTERIZATIONS OF ANALOG TO DIGITAL CONVERTER.

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Abstract – This paper deals with the assessment of the metrological performance of analog-to-digital converters in order to use them in some metrology applications. Hence, digitizers of a commercial DVM have been characterized under DC voltages, with respect of several parameters such as aperture time, dead time and the autozero function.

Keywords : digitizers, aperture time, sampling techniques.

1. INTRODUCTION

In the last past decades, a considerable progress in microelectronic fabrication has allowed the development of analog-to-digital converters (ADCs) of great accuracy and very small integration times. That makes it possible the use of sampling techniques for determining any AC quantity as well in impedance, power, phase as in voltage measurements. Considering voltage measurements in the frequency range 20 Hz – 400 Hz, the common digitizers used by the National Metrology Institute are the well-known Agilent 3458A digital voltmeters (DVM) [1]. They convert a continuous analog signal into a series of discrete samples by three different methods: DC voltage measurements (DCV mode), direct-sampling and sub-sampling. The aim of this study is to get a better understanding of the behaviour of the DVM in the DCV mode. Using it, digitizing can be done simply by specifying DC voltage measurements with a short integration time or aperture time T_a. For that reason, the ADCs of the digitizers have been first characterized under DC voltage by studying the effect of parameters as aperture time, dead time, sampling frequency....

2. EXPERIMENTAL SET-UP

The DC voltage signal U_{ref} of 1 V is supplied by a calibrated Zener source or a calibrator and applied to the DVM used in the DCV mode. Each sample is the result of the integration of the signal during the aperture time T_a. A frequency generator is used to trigger the DVM and control the sampling process. The error e_{DC} relative to the voltage reference value is defined as:

$$e_{DC} = \frac{U_m - U_{ref}}{U_{ref}}$$

where U_m is the mean value of the considered samples.

3. STATIC CHARACTERISATIONS

The main advantages of DCV mode are a lower noise level and a higher resolution (up to 28 bits), which depend on the selected aperture time T_a. The knowledge of the characteristic e_{DC} = f(T_a) is then of primary importance. Our work consists in determining this characteristic with respect to the following parameters : dead time T_m, sampling period T_e (or sampling frequency f_e), and time T_z necessary for using the autozero function (when required).

These time parameters are linked by the two relations:

- $T_e = T_a + T_m$, when autozero function is not active,
- $T_e = T_a + T_m + T_Z$, when autozero function is active.

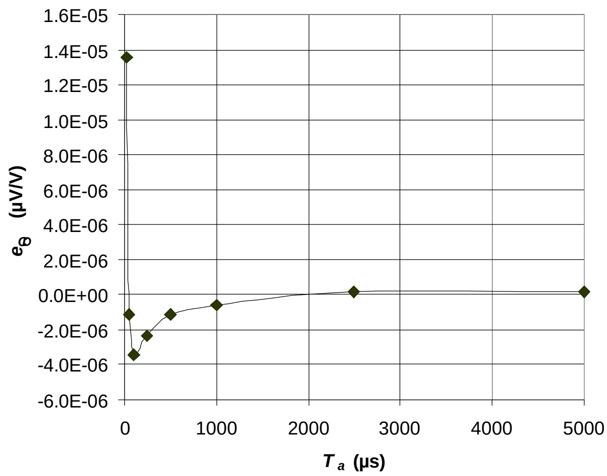

Fig.1. Characteristic e_{DC} =f(T_a).

Fig.1 shows the characteristic e_{DC} = f(T_a) for aperture times ranging from 10 µs to 5000 µs. The applied voltage is 1 V and the sampling frequency is 100 Hz. Before the measurements, the DVM is calibrated in the 1 V range with a long integration time (1 s). It means that, after this calibration, U_m differs from U_{ref} by just a few parts in 10^7 for

T_a = 1s. Decreasing the aperture time, this error remains constant up to 2000 µs as shown in fig.1. Below this value, it becomes more and more negative and reaches – 4 µV/V at 100 µs. For shorter aperture times, the error grows up again from – 4 µV/V up to + 14 µV/V for T_a = 10 µs. Let us note that this transition point at 100 µs corresponds exactly to a change in the number of digits of the DVM specified by the manufacturer (change from $5^{1/2}$ to $6^{1/2}$ digits at 100 µs).

To measure AC voltage for signals in the industrial frequency range (from 20 Hz to 400 Hz), the minimum sampling frequency f_e is around 2.2 kHz to be at least twice the highest frequency component of all the signals being measured (Nyquist theorem). Then, the maximum aperture time, which can be selected, is approximately 400 µs. For this reason, the characteristic e_{DC} = f(T_a) has been studied more precisely for aperture times varying from 10 µs to 400 µs. The results are presented in fig.2. It clearly appears that except for the shortest aperture times (T_a < 50 µs), the error is lower than 5 µV/V whatever the selected aperture times. Between 50 µs and 100 µs, it is less than 1 µV/V. Nevertheless, it is better to select longer aperture times (T_a > 230 µs) even if the error is a little higher because, as previously indicated, the number of digits of the DVM changes from $5^{1/2}$ to $6^{1/2}$ digits for T_a > 100 µs.

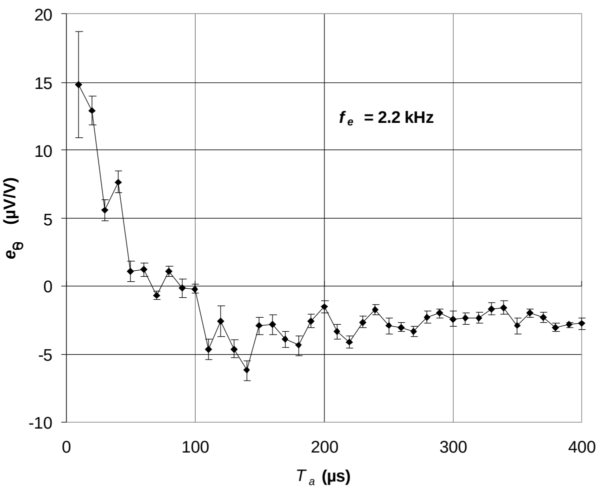

Fig.2. Characteristic e_{DC} = f(T_a) for short aperture times (T_a ≤ 400µs).

3.1. Influence of the sampling frequency

Fig.3. shows the variation of the error e_{DC} relative to the voltage reference value as a function of the aperture time T_a, ranging from 10 µs to 400 µs for different sampling frequencies between 0.5 kHz and 10.9 kHz. No significant influence (around 2 µV/V) of the sampling frequency on the error e_{DC} is observed for 50 µs ≤ T_a ≤ 100 µs, provided its value does not exceed 7.8 kHz. For aperture times higher than 100 µs, the influence remains negligible for sampling frequencies up to 2.2 kHz.

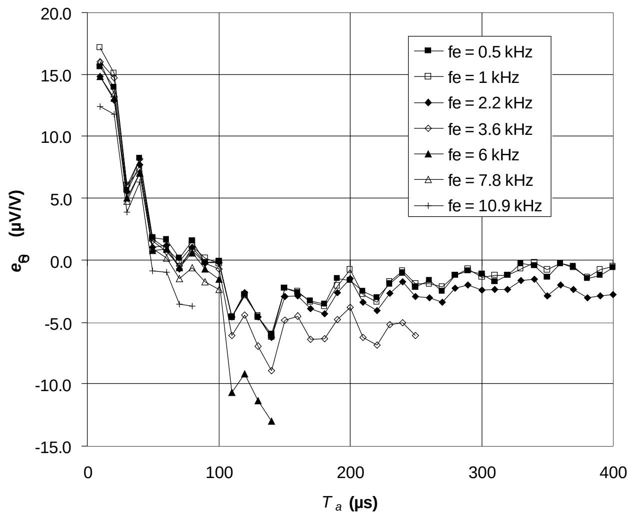

Fig.3. Characteristic e_{DC}=g(T_a) for short aperture times (T_a ≤ 400µs) and for different sampling frequencies f_e.

For each measured value, the standard deviation has also been calculated and reported in Fig.4. As expected, its value decreases when aperture time increases. Above T_a = 150 µs, standard deviations are smaller than 1 µV/V whatever the sampling frequency. It also appears that for a given aperture time, the sampling frequency has no significant influence on the standard deviation except for very low values of T_a (10 µs and 20 µs).

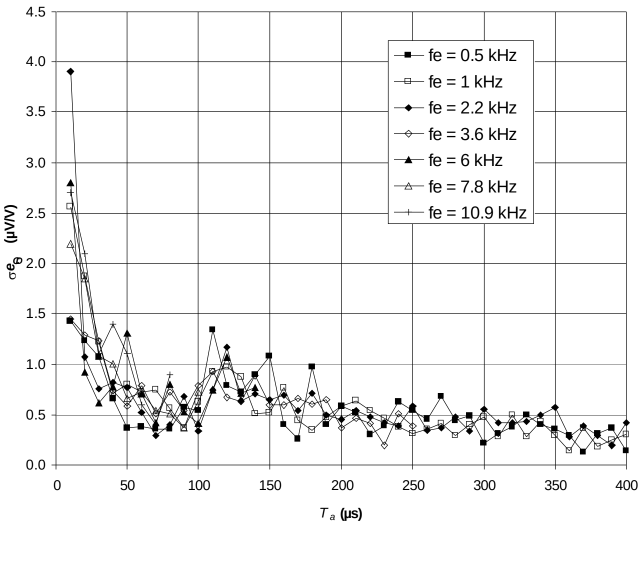

Fig.4. Characteristic σe_{DC}=g(T_a) for short aperture times (T_a ≤ 400µs) and for different sampling frequencies f_e.

3.2. Influence of the autozero function

When the autozero function is active, the DVM makes a zero measurement following every reading and algebraically subtracts the zero measurement from the reading.

Before studying the influence of the autozero on the measurements, some experiments have been carried out to determine the time T_z necessary to the DVM to use this function. This time varies according to the aperture time T_a

and the minimum dead time T_m^{min} [2]. Fig.5 represents the characteristics $(T_a + T_m^{min})/T_z$ as a function of T_a. As the minimum time required per reading T_e^{min} is given by $T_e^{min} = T_a + T_m^{min} + T_Z$, the characteristic shows that for long integration time (T_a > 3000 µs), the use of the autozero function approximately doubles the time T_e^{min}, whereas for shorter values of T_a, it can be multiplied by a factor of more than 10.

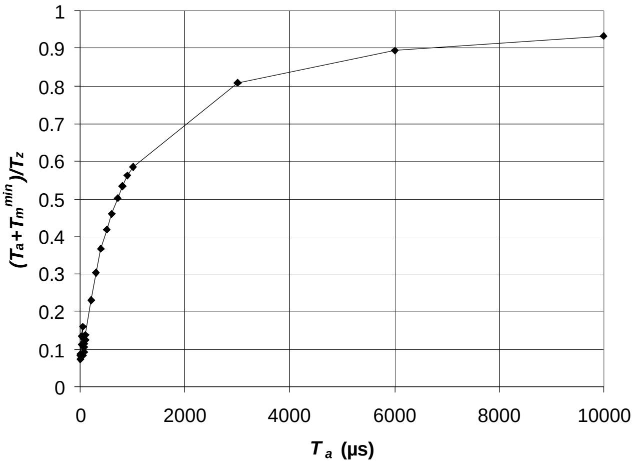

Fig.5. Characteristics $(T_a + T_m^{min})/T_z$ as a function of T_a.

To determine the influence of the autozero function, all the experimental conditions are as previously defined except that the source is now a calibrator instead of the calibrated Zener source. Then, the voltage reference has been defined as the voltage read by the DVM in the DC mode for long integration time (1s):

$$U_{ref} = U_m\,(T_a = 1s)$$

The sampling frequency has been fixed at 400 Hz.

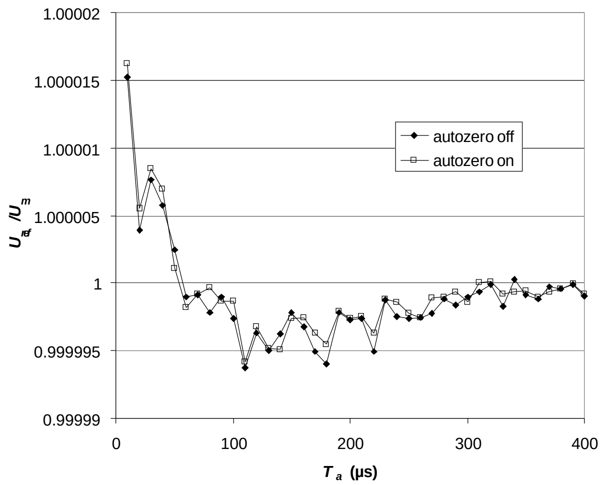

Fig.6. Variation of the ratio U_{ref}/U_m as a function of the aperture time T_a when autozero is active or not active.

The variation of the ratio U_{ref}/U_m is presented in fig.6 as a function of the aperture time T_a when autozero function is active and not active. It shows that the autozero function does not affect the amplitude of the measured value. Besides, the measurement results are more stable when this function is active as shown in fig.7.

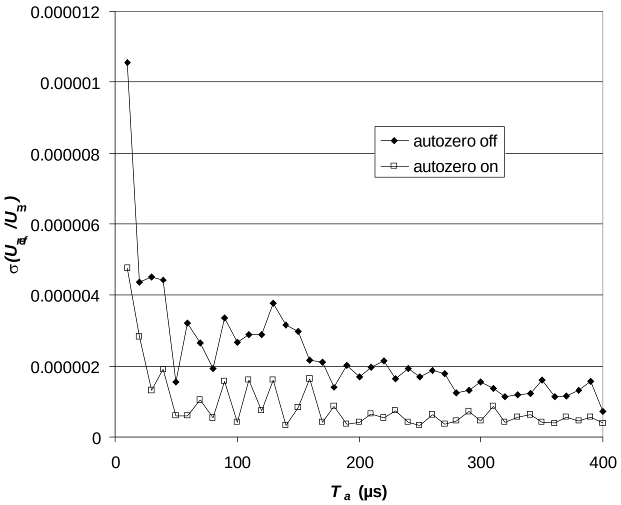

Fig.7. Variation of the standard deviation of U_{ref}/U_m as a function of the aperture time T_a when autozero is active or not active.

3.3. Influence of the voltage range

Measurements have been carried out for direct and reversed voltages. Measured values of the ratio U_{ref}/U_m at various voltage ranges are presented in fig.8 and the associated standard deviations in fig.9. The shape of all curves in fig.8 is similar. When the ratio approaches the unit value, it means that the error introduced by the digital voltmeter in the DCV mode is very close to zero. The minimum errors of the ratio are obtained in the 1 V, 10 V and 100 V ranges for long integration times (T_a > 230 µs). Curves presented in fig.9 show that these values are associated with the lowest standard deviations.

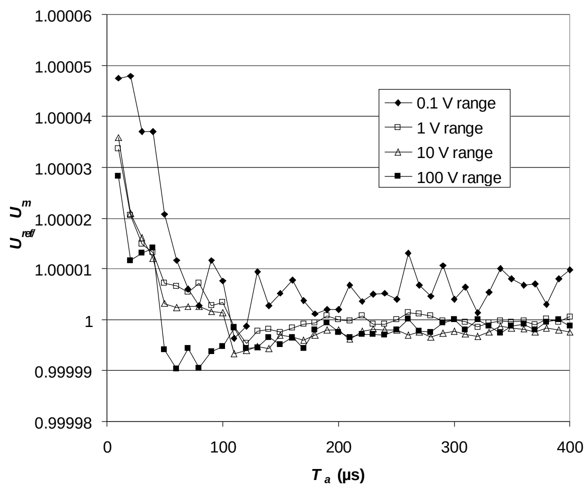

Fig.8. Characteristic U_{ref}/U_m=g(T_a) for short aperture times ($T_a \leq$ 400µs) and different voltage ranges, at f_e = 2.2 kHz.

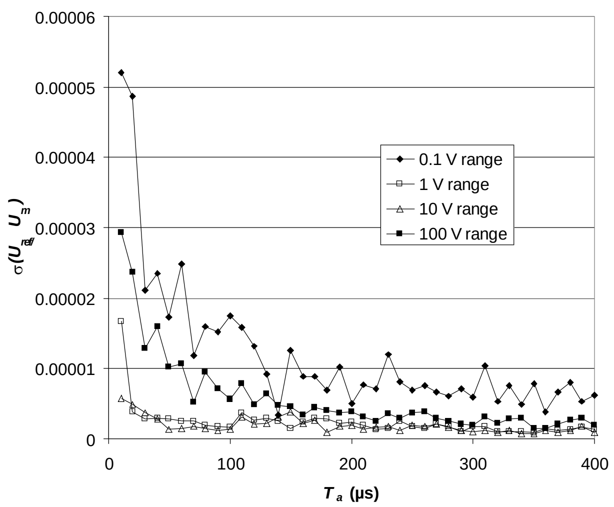

Fig.9. Characteristic $\sigma U_{ref}/U_m$=g(T_a) for short aperture times ($T_a \leq$ 400µs) and different voltage ranges, at f_e = 2.2 kHz.

3.4. Characteristic $U_{ref}/U_m = f(T_a)$ for several DVMs.

The characteristic U_{ref}/U_m = f(T_a) has been determined with three different DVMs at the 1 V range. Fig.10. shows the same error variation for all DVMs. The differences in amplitude are less than 2 µV/V for long aperture times (T_a > 100 µs). Let us note that for T_a < 100 µs, one of the multimeters deviates significantly from the others even if the shape of the characteristic remains the same.

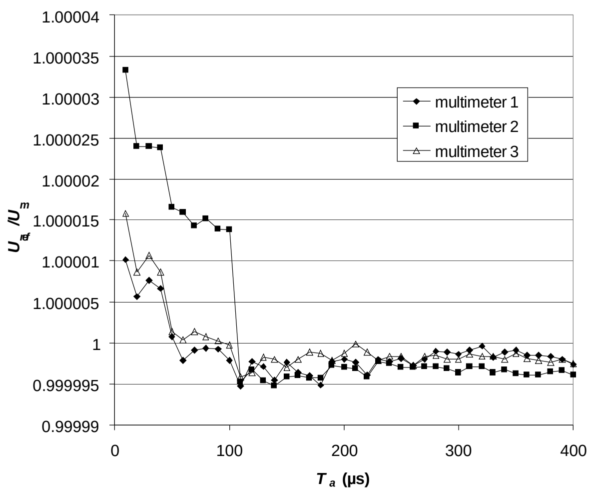

Fig.10. Characteristic U_{ref}/U_m = f(T_a) for short aperture times ($T_a \leq$ 400µs) and three different sampling voltmeters at f_e = 2.2 kHz.

4. CONCLUSION

The analog to digital converters of the Agilent 3458A DVM have been characterized under DC voltage by studying the characteristics e_{DC} = f(T_a) or U_{ref}/U_m = f(T_a) with respect to the dead time T_m, the sampling frequency f_e, and the time T_z necessary for using the autozero function (in the case where this function is active). The most important result is that, for aperture times longer than 230 µs, the errors of all the DVMs tested are below 3 µV/V at 1 V, 10 V and 100 V ranges. These errors are associated with the lowest standard deviations. It has also been shown that the autozero function does not affect the value of the errors but reduces significantly its standard deviation.

Characterization under AC voltage are in progress at LNE for AC measurements applications. Dynamic characterization consists in calibrating the sampling voltmeter against reference thermal converters for different measurement parameters and to examine the influence of these parameters on the result of the calibration.

REFERENCES

[1] Agilent Technologies 3458A Multimeter – Calibration Manual.

[2] P.Espel, A.Bounouh, A.Poletaeff, , “Metrological characterizations of wideband digitizers”, *CPEM*, pp. 390-391, Boulder, USA, 2008.