Characterization of the amplitude frequency response of Analog-to-Digital Converters

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Abstract—This paper describes a method for the characterization of the amplitude frequency response of Analog-to-Digital converters at frequencies up to 20 kHz using a true quantum reference calibrated semiconductor based DAC arbitrary waveform generator, developed within the EMPIR project Q-WAVE, jointly founded by the European Union and the participating countries. The procedure that can be used for the characterization of any ADC is applied to the DCV function of a Keysight 3458A digital multimeter. The measurement conditions and the main uncertainty sources are identified and evaluated for complete uncertainty estimation by means of the Monte Carlo Method.

Index Terms—Analog-to-Digital converter, Digital-to-Analog converter, thermal converter, AC quantum standard, Monte Carlo method, measurement uncertainty.

I. INTRODUCTION

Analog to digital conversion of sampled measurement is a key element of digital metrology. The improvement on accuracy, resolution and sampling rate of commercial Analog to Digital Converters (ADCs) and Digital to Analog Converters (DACs) facilitates an increasing number of analogical measurement systems being replaced by digital systems, not always necessarily with improved uncertainties but featuring easy integration and full automation. This is the case of digital impedance bridges [1] or digital power measurements [2], and providing the necessary metrological infrastructure, the ADCs can, in the near future, replace thermal converters. Q-WAVE project will facilitate their use by providing direct traceability to SI for sampled electrical measurements.

To support the traceability chain a DAC based source has been developed within the Q-Wave project [3]. This paper describes a procedure for the metrological characterization of ADCs frequency response and its practical application to the DCV function of a Keysight 3458 Digital multimeter [4]. This procedure could be used as a reference document for possible improvement of standards related to DACs or ADCs characterization.

II. OVERVIEW OF THE METHOD

The method is based on the comparison of the known input reference (fundamental and harmonics) with the values obtained by sampling the input signal using the ADC under test. The reference is a calibrated, dual precision sine wave generator (DualDAC 2) designed for metrological applications

at low frequencies (0.1 Hz to 20 kHz). Waveforms are defined by two individual 16-bit DACs with sampling rate of 2 Msps and maximum number of samples per period of 16 384 for each channel. Sine amplitudes are adjustable with separate 20-bit DACs [3]. The source is calibrated with a true quantum based AC voltage standard [5].

For each frequency f, the calibrated AC source voltage is applied to the ADC at defined conditions. From the samples taken and using a Four Parameters Sine wave fitting algorithm (4PSWF) [6], the output signal is estimated. The estimated signal is them corrected for the error introduced due the integration of the signal during the aperture time T_a. The corrected estimated signal is used to obtain the error for each particular frequency.

The measurements are performed for a set of frequencies within the ADC working range, and the error and uncertainty for each frequency is obtained. From these set of values a transfer function is fitted to provide the error and uncertainty to any interpolated frequency. The measurements were done using the 1 V DCV range of the multimeter.

III. ERROR SOURCES EVALUATION

Several sources of frequency-dependent errors have been already evaluated and published for the DCV sampling function of a Keysight 3458 Digital multimeter for AC voltage measurement [7]. In this paper the errors are considered from the point of view of the influence they have on the intrinsic characteristics evaluation of the DAC frequency response and their specific measurement conditions. Some error evaluations follow.

A. Aperture time

The uncertainty in the measured effective multimeter aperture time (T_a) [8], time jitter [9] and time resolution contribute to the frequency response uncertainty due to the time aperture correction, and also to the digital multimeter gain aperture dependence. The time aperture correction is necessary due to the finite integration time and consequently averaging the measured value during the multimeter aperture time, corresponding to time T_a. Equation 1 gives the theoretical correction. The T_a uncertainty influence becomes significant when the product (fT_a) approaches unity.

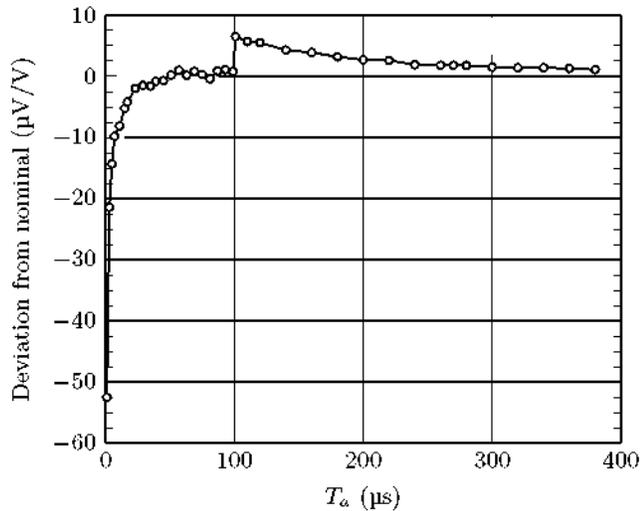| f (Hz)	T_a (μs)				
	1	3	5	7	9
53	−103	−34	−22	−16	−13
1000	−144	−76	−62	−55	−51
5000	−855	−777	−751	−738	−728
10 000	−2900	−2810	−2770	−2740	−2720
20 000	−10 660	−10 590	−10 460	−10 390	−10 330

Fig. 1. Aperture time gain dependence for 0.8 V and 53 Hz.

$$K(f, T_a) = \frac{\pi f T_a}{\sin(\pi f T_a)} \quad (1)$$

The multimeter aperture time dependence has been tested at different input signal frequencies, showing a similar behavior, as can be seen in Table I, showing the values obtained at frequencies up to 20 kHz at several aperture times. Figure 1 shows the results for a 0,8 V 53 Hz input voltage. From the figure the gain variations as a function of T_a are more significant for short aperture times.

B. Reference calibration and stability

The short term stability has been tested and found at the sub-μV/V level. An inter-comparison between several project partners has been programmed and will provide information about reference long term stability. The calibration of the source using an AC Quantum Voltage Standard, included within the project activities, will provide corrections and uncertainties for the fundamental and harmonic content.

C. Number of samples per period

Slightly different amplitude values have been obtained measuring the same signal at different samples per period rate. Their influence in the frequency response characterization needs further investigation.

D. Temperature dependence

The multimeter gain temperature dependence has been evaluated in order to correct the measured values and to calculate its contribution to the total uncertainty estimation. The Keysight 3458A has a sensor to measure the internal temperature. During the measurement the internal sensor temperature reading were taken.

IV. UNCERTAINTY ESTIMATION

Due to the number of influence parameters and due to the possible estimation bias of the 4PSF algorithm the uncertainty evaluation will be performed using a Monte Carlo method. A software toolbox is under development within the Q-wave project. This toolbox will support the characterization of several ADC parameters, including uncertainty estimation for different algorithms. The results obtained using 4PSF will be repeated and compared for the different algorithms available. The best algorithm will be selected for the final characterization of the calibrated multimeter.

V. CONCLUSION

A metrological grade characterization of ADCs including uncertainty estimation is fundamental for high accuracy metrological applications. The complete measurements need yet to be performed and analyzed to provide a complete proposal for the inclusion of uncertainty estimation into the relevant standard.

REFERENCES

[1] L. Callegaro, V. DElia, M. Kampik, M. Ortolano, and F. Pourdanesh, Experiences with a two-terminal-pair digital impedance bridge, *IEEE Trans. Instrum. Meas.*, vol. 64, no. 6, pp. 1460-1465, June 2015.

[2] U. Pogliano, "Use of integrative analog-to-digital converters for high-precision measurement of electrical power", *IEEE Trans. Instrum. Meas.*, vol. 50, no. 5, pp. 1315-1318, Oct. 2001.

[3] J. Nissilä, K. Ojasalo, M. Kampik, J. Kaasalainen, V. Maisi, M. Casserly, F. Overney, A. Christensen, L. Callegaro, V. DElia, N. T. M. Tran, F. Pourdanesh, M. Ortolano, D. B. Kim, J. Penttilä, and L. Roschier, , "A precise two-channel digitally synthesized AC voltage source for impedance metrology", *CPEM 2014 Conf. Digest*, pp. 24-29, Aug. 2014.

[4] Agilent Technologies 3458A Multimeter Users Guide, 4th ed., *Agilent Technologies*, Santa Clara, CA, USA, Dec. 2000.

[5] Jinni Lee, Ralf Behr, Luis Palafox, Alexander Katkov, Marco Schubert, Michael Starkloff and Andreas Charles Bock, "An ac quantum voltmeter based on a 10 V programmable Josephson array", *Metrologia*, vol. 50, pp. 612-622, 2013.

[6] IEEE Std 1241-2010, *Terminology and Test methods for Analog -to-Digital Converters*,IEEE, January 2011.

[7] R. Lapuh, B. Voljč, and M. Lindič, Accurate measurement of AC voltage in audio band using Agilent 3458 sampling capability, *CPEM 2014 Conf. Digest*, pp. 740-741, Aug. 2014.

[8] Kristian B. Ellingsberg, Tore Sorsdal, "Method for computing the effective aperture time in the HP3458",*CPEM 2008 Conf. Digest*, pp. 442-443, June 2008.

[9] R. Lapuh, Bostjan Voljc and Matjaz Lindic, "Evaluation of Agilent 3458 A time jitter performance",*IEEE Trans. Instrum. Meas.*, vol. 64, no. 6, pp. 1331-1335, June. 2015.