Experimental setup for the characterization of the output section of arbitrary waveform generator

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Abstract- An experimental setup is pointed for the characterization of the output section of Arbitrary Waveform Generator (AWG). It is based on test method pointed out for high resolution Digital to Analog Converter. The output signal of the AWG under test is reconstructed by the zero crossing time sequence detected into the resulting signal obtained by subtracting the sinusoidal signal fed by reference AWG. The characterization of the output section of the AWG is carried out by analyzing this signal in time and frequency domain. Proper procedure is pointed out to evaluate the transfer characteristic of the output section to overcome the difficulties arising from the functionality modality of the AWG.

I. Introduction

The output section of Arbitrary Waveform Generator (AWG) is constituted by the Digital-to-Analogue Converter (DAC) cascaded by analog filter. The experimental characterization involves similar difficulties occurring in the characterizations of the high resolution DAC. In fact, the acquisition system of the output signal should be characterised by higher both resolution and linearity than that of the device under test [1]-[6].

To overcome these difficulties, in [7] is proposed a test method that translates the problem of high resolution acquisition into that of high frequency acquisition. It is based on the experimental detection of the Zero Crossing Time Sequence (ZCTS) into the resulting signal obtained as difference between the output signal of the DAC under test and the reference signal. The detected ZCTS is used to infer the values of the reference signal, and to reconstruct the non-uniformly sampled output signal of the DAC under test. Therefore, the sampling frequency and not the resolution of the analog to digital conversion influences the method accuracy.

Based on this method, in the paper is proposed an experimental setup for the reconstruction of the output signal of the AWG under test. This signal is non-uniformly sampled and can be analysed in time and frequency domain [8], [9].

Indeed, for the time domain analysis the best-fit sinewave algorithm is not influenced by the non-uniformly sampling.

Differently, for frequency domain analysis, the non uniformly sampling generates a spectrum that differs from the spectrum of the same signal uniformly acquired. To overcome this problem the reconstruction algorithm of the uniformly sampled spectrum from the non-uniformly sampled is used according to the correction procedure [7]. The reconstructed uniformly sampled spectrum is used to evaluate the SINAD and ENOB parameters, according to the procedure proposed in the draft IEEE P1658 [8].

Particular efforts are devoted to evaluate the transfer characteristic of the output section of AWG under test. Indeed, on the basis of the operating mode of the AWG, the output signal is generated once the input code vector is available. The correspondence between each input code and the corresponding output value disappears. As a result, the acquisition time and the generation time can not be synchronized. In order to overcome this difficulty, in the paper is proposed a proper procedure to correlate the input code with the output signal.

The paper is organised as follows. Initially, the theoretical basis of the test method is abstracted. The experimental setup for the reconstruction of the output signal of the AWG is shown. Successively, the procedure to evaluate the transfer characteristic of the output section of the AWG is presented. Finally, the results of tests to validate the experimental setup and the characterization procedure of the output section of the AWG are discussed.

II. Theoretical basis of the test method

Fig.1 shows the block scheme of the measurement system for the characterization of the AWG. The AWG is set up to generate the sinusoidal signal with known amplitude V_{AWG} and frequency f_{AWG}. At the output voltage $v_k(t)$

of the AWG is subtracted the signal $v_{st}(t)$ fed by the reference generator. The resulting signal $v_r(t) = v_k(t) - v_{st}(t)$ is over-sampled by low resolution ADC#1 and stored in the PC.

Because the ADC#1 resolution is lower than that of the AWG under test, the quantization noise can be higher than the noise superimposed to the output voltage of the AWG.

In the proposed test method the AWG output voltage is acquired not by the output codes of the ADC#1, but by using the ZCTS detected on the resulting signal. By the ZCTS the values of the reference signal are infered and, consequently, the corresponding values of the output voltage of the AWG are determined.

Assuming:

$$v_k(t) = V_{AWG}\sin(2\pi f_{AWG} t + \varphi) \tag{1}$$

$$v_{st}(t) = V\sin(2\pi f + \phi) \tag{2}$$

where f is the frequency and V the amplitude of the periodic sinusoidal signal. The sinusoidal voltage can be generated by the reference generator with higher resolution than the DAC under test.

Denoted by $t_1,\ldots t_n$ the sequence of the n zero crossing time, the (2) permits to determine the value of the sinusoidal voltage values and, consequently, the corresponding values of $v_k(t_m)$.

The obtained ZCTS is non-uniformly distributed in the time domain, therefore, the reconstructed signal $v_k(t_m)$ is characterised by non-uniform sampling.

ADC#2 is used to digitize the reference signal in order to evaluate V, f and ϕ by sine fitting algorithm.

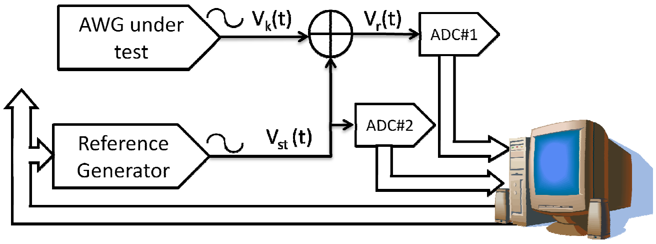

Figure 1. Testing equipment for the dynamic characterization of DAC.

III. Experimental setup

In Fig.2 is shown the block scheme of the experimental setup pointed out for the reconstruction of the output signal of AWG.

The Device Under Test (DUT) is the AWG Sony-Tektronix 2021. The output section is equipped by 12bit DAC and Bessel cut-off filter. The reference signal is fed by the Tektronix AWG 420. The output section is equipped by 16bit DAC and Bessel cut-off filter. According to [7], the differential amplifier Tektronix ADA400 with

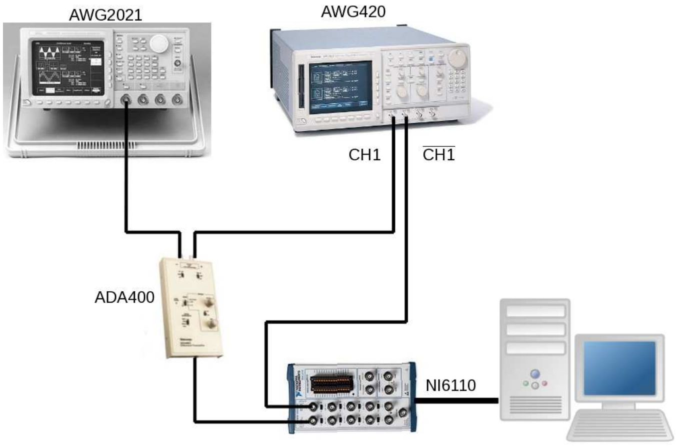

Figure 2. Experimental set up to reconstruct the AWG output signal.

external power supply is used to perform the difference between the reference signal and the output signal of the DUT. The resulting signal is acquired by the Data AcQuisition board (DAQ) National Instruments NI6110. Because the reconstruction of the output signal of AWG requires information about the frequency and the phase of the reference signal, the signal provided by the complimentary output channel of the AWG420 is acquired by the DAQ, as shown in Fig.2. The amplitude and the phase of the reference signal are accurately estimated by the four parameters sine-fitting algorithm [9], [10].

IV. Transfer characteristic evaluation

The transfer characteristic evaluation needs the correlation among input codes of the AWG output section and the reconstructed output samples of the AWG. By taking into consideration the memory limits of the acquisition system, the number of the reconstructed samples decreases with the increasing of the sampling frequency. This effect can involves that the reconstructed signal is composed by a number of samples lower than the number of waited level at the output of the AWG under test, or that there isn't one sample for each possible code of the AWG.

To overcome this problem an iterative procedure is pointed out. The acquisition and reconstruction method of the AWG output signal is repeated. For reconstructed signal at each time instant of the ZCST is evaluated the theoretical input code at the output section of the AWG. In this manner it is possible to associate each reconstructed sample to the corresponding code. Each couple, constituted by the sample and the code, is stored and, successively, processed to evaluate the transfer characteristic of the AWG.

The procedure iteration permits to evaluate several time the samples relative to the same code. In this case, the mean value of the reconstructed samples recognized for the same code are used with the effect to reduce the noise.

The main steps of the AWG transfer characteristic evaluation procedure are:

1. AWG output signal is reconstructed by using the method of paragraph II;
2. sine fitting algorithm is used to infer the phase, amplitude and frequency parameter of the sinusoidal reconstructed signal. These parameters are used to evaluate the theoretical input code C_j corresponding to each reconstructed sample v_k;
3. couples $[C_j, v_{km}]$ are sorted, were v_{km} is mean value of the signal corresponding to code C_i;
4. previous steps are repeated until all the possible value of C_j are evaluated.

V. Preliminary experimental tests

The preliminary experimental tests are devoted to asses the correct operating mode of the experimental setup pointed out. The AWG2021 is forced to generate the sinusoidal signal at the frequency equal to 300Hz and amplitude equal to 0,9V. The AWG420 generates sinusoidal signal at the frequency equal to 5kHz and amplitude

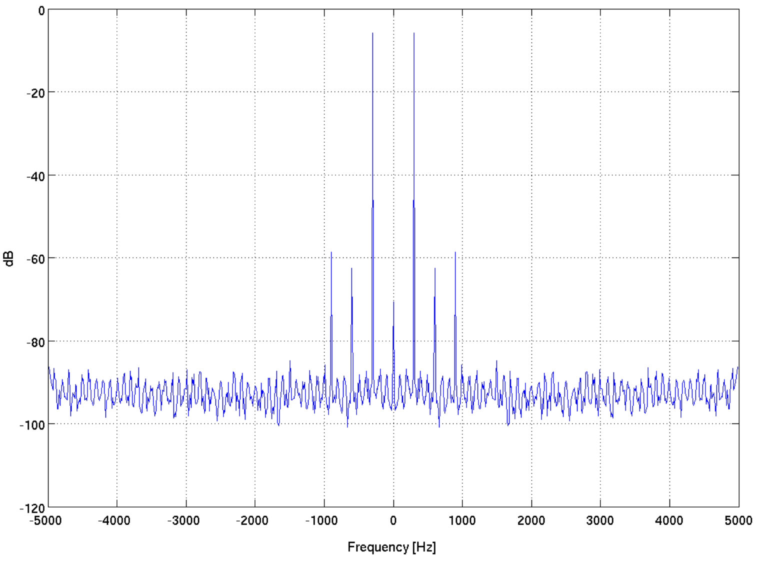

Figure 3. Frequency spectrum of the reconstructed signal.

equal to 1V.

The NI 6110 acquires the resulting signal at the sampling frequency equal to 2MS/s into the range [-5, +5]V. The number of acquired samples for each test is set equal to 1000.

Fig.3 shows the mean amplitude spectrum obtained by 10 tests. This spectrum highlights the presence of second and third harmonics, lower than the fundamental component at -57dB. In order to verify the absence of artefacts due to both the experimental setup and the numerical procedure used, the spectrum is evaluated on 10 uniformly sampled acquisition, each one of 1000 samples, of the output signal of the AWG2021. In this test the DAQ is configured in same operating condition of the previous tests as concerning with the amplitude range included in interval [-5, +5]V. Differently, the sampling frequency is equal to 10kHz. Results of this test highlights the presence of second and third harmonic with amplitude values equal to the values obtained by the previous tests.

Other tests are devoted to determine the minimum value of the bit number of the DAQ guarantying the same performances. With this purpose the DAQ number of bit is numerically decreased. It can be noted that: (i) the performance not changes up to 6 bit, and (ii) the noise floor in the spectrum increases under 6 bit, only.

VI. Conclusions

A very simple experimental set-up is proposed and experimented for the characterization of the output section of Arbitrary Waveform Generator (AWG). It includes auxiliary reference AWG, differential amplifier and low resolution data acquisition system. The output signal of the AWG under test is reconstructed by the zero crossing time sequence detected into the resulting signal obtained by subtracting at the AWG output signal the one fed by reference AWG. The characterization of the output section of the AWG is carried out by analyzing the constructed signal in time and frequency domain. Proper procedure is pointed to evaluate the transfer characteristic of the output section.

Preliminary experimental tests confirm the validity of the experimental setup and the processing procedure of the reconstructed signal for the AWG characterization.

References

[1] Analog Device, Inc., “Analog-Digital Conversion Handbook”, D.H Sheingold, Ed. Englewood Cliffs, NJ. Prentice-Hall, 1986.

[2] A. Hairapetian, G.C. Temes, Z.X. Zhang, “Multibit sigma-delta modulator with reduced sensitivity to DAC nonlinearity”, Electronics Letters, 23 May 1991, vol. 27, No. 11, pp. 990–991.

[3] J. Steensgaard, “High-resolution mismatch-shaping digital-to-analog converters”, Proc. of Inter. Symp. on Circuits and Systems, ISCAS 2001, 6-9 May 2001, vol. 1, pp. 516–519.

[4] K. Uchimura, T. Hayashi, T. Kimura, A. Iwata, “Oversampling A-to-D and D-to-A converters with multistage noise shaping modulators”, IEEE Trans. on Acoustics, Speech, and Signal Proc., 12 Dec. 1988, vol. 36, pp. 1899–1905.

[5] R.S. Norsworthy, R. Schreier, G.C. Temes, “Delta-Sigma Data Converters: Theory, Design, and Simulation”, IEEE Press, 1997.

[6] C. A. Serra, P. Daponte, L. Michaeli, “ADC and DAC modelling and testing - state of the art”, Metrology and Measurement Systems. Vol. 12, no. 3 (2005), p. 231-248.

[7] A. Baccigalupi, D.L. Carnì, D. Grimaldi, A. Liccardo, “Experimental Implementation of Test Method for Dynamic Characterization of DAC Based on Over Sampling and Low Resolution ADC”, IEEE Instrum. and Meas. Tech. Conf. (I2MTC), May 3-6 2010, Austin TX, Pag.142– 146.

[8] IEEE P1658 “Draft Standard for Terminology and Test Methods of Digital-to-Analog Converter Devices”.

[9] D.L. Carnì, D. Grimaldi, “Characterization of High Resolution DAC by DFT and Sine Fitting”, Instrumentation and Measurement Technology Conference, 2009, Singapore, 5-7 Madly 2009,ag.1244 – 1249.

[10] D.L. Carnì, D. Grimaldi, “Static and Dynamic test of High Resolution DAC based on Over Samplig and low Resolution ADC”, Measurement, 2009.