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C–code Software Implementation of Standardized ADC Test Methods

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Abstract *– Parameters characterizing analog–to–digital converters are evaluated by means of several techniques defined in the frequency–, time– or amplitude–domain. Published scientific literature does not explicitly indicate which is the optimal algorithm to be employed for estimating each figure of merit. In particular, IEEE standards 1241 and 1057 suggest the use of the frequency–domain test for evaluating spectral parameters, but do not outline which is the criterion to follow for choosing the window that reduces the spectral leakage while maximizing the accuracy of the estimates. Such information is critical when the algorithm has to be applied to data acquired from high–order* $\Delta\Sigma$ *converters with high oversampling ratio, for which the windowing process is needed also if the coherent–sampling condition is applied. In this paper, a software environment for evaluating performance of any kind of digital converter by means of several techniques is presented. The software is highly portable since it has been written in C– language and calculates automatically the window which maximizes the accuracy of the estimates. Implemented algorithms have been applied to experimental data in order to validate the effectiveness of the software environment and of the proposed windows.*

I. INTRODUCTION

Analog–to–digital converters (ADCs) are widely used in electronic systems for digitizing information in analog form such as sound, light, temperature, and pressure. In particular, most static and dynamic measurements, are made by evaluating the voltage outputs of appropriate transducers using numerical techniques. It follows that the accuracy of such digital systems is mainly due to the performance of the employed ADC. Thus, it is important to have appropriate tools for estimating the performance of such devices.

IEEE standards 1241 and 1057 [1] [2], together with the european draft standard Dynad [3], describe the most effective ADC testing procedures to apply for evaluating figures of merit of such devices. Methodology usually employed are based on the analysis of data generated at the ADC output when a spectrally pure single– or dual–tone is applied to the input of the device under test (DUT). However, it is not possible to determine all figures of merit by means of a unique algorithm. Moreover, many ADC parameters can be estimated by applying different procedures. As a consequence, manufacturers may evaluate a specific parameter by means of different algorithms or by using the same algorithm but with different settings, thus reducing measurement repeatability and complicating performance comparison of similar devices.

Whenever frequency–domain based algorithms are applied, published standards do not explicitly indicate the criterion to follow for choosing the optimal window to be used for reducing spectral leaking phenomenon while maximizing the accuracy of the estimates of the parameters. Such kind of information is critical in many cases, i.e. for evaluating the performance of converter which presents $\Delta\Sigma$ topology with high oversampling ratios (OSRs). In fact, the in–band noise power of such devices is usually evaluated in the frequency–domain by integrating the estimated power spectral density of the output data in the band of interest. Although the coherency condition is typically applied for executing the test, the windowing process is always required for reducing the leakage induced by the filtered wide–band noise [4].

In order to compare results given by the application of different procedures and by the use of various windows when frequency–domain algorithms are applied [5]–[6], a software environment, which estimates the performance of ADCs by means of various test methodologies, has been developed and can be downloaded at www.miteq.diei.unipg.it. Procedures implemented in such environment attain to both the time–, amplitude– and frequency–domain test, and allow evaluation of the main dynamic ADCs parameters, such as the signal–to–random–noise ratio (SRNR), signal–to–non—harmonic distortion (SNHR), signal–to–noise and harmonic distortion (SINAD), equivalent bit (b_e), total harmonic distortion (THD), spurious–free–dynamic–range (SFDR), integral (INL) and differential (DNL) non–linearities.

Scientific literature reports on many software implementation of the standardized ADCs test methods [7]–[9]. However, all of them require an additional software environment, such as Matlab or Labview, thus reducing partially the possible applications areas. Algorithms proposed in this paper, have been written in C–code and compiled by means of *gcc*, a freely distributed compiler which allows to produce easily executable files for most computer platforms. As a consequence, the proposed environment is portable on most of the employed operating systems (all Windows versions, Linux, Unix) without requiring peculiar software environment for evaluating its ef-

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TABLE I

PARAMETERS ESTIMATED BY APPLYING THE FREQUENCY–DOMAIN BASED ALGORITHM

$\widehat{SRNR}$ [dB]	$\sigma_{\widehat{SRNR}}$ [dB]
$\widehat{be}_{SRNR}$	$\sigma_{\widehat{be}_{SRNR}}$
$\widehat{SNHR}$ [dB]	$\sigma_{\widehat{SNHR}}$ [dB]
$\widehat{be}_{SNHR}$	$\sigma_{\widehat{be}_{SNHR}}$
$\widehat{SINAD}$ [dB]	$\sigma_{\widehat{SINAD}}$ [dB]
$\widehat{be}_{SINAD}$	$\sigma_{\widehat{be}_{SINAD}}$
$\widehat{SFDR}$ [dB]	$\sigma_{\widehat{SFDR}}$ [dB]
$\widehat{SFDR}$ [dB]	$\sigma_{\widehat{SFDR}}$ [dB]
$\widehat{THD}$ [dB]	$\sigma_{\widehat{THD}}$ [dB]

fectiveness. Moreover, acquired data to be processed and settings of the algorithm parameters are stored in separate text files which represent the software inputs. Thus, it is possible to test any kind of acquisition system.

Next sections describe briefly the procedures implemented and the architecture of the software environment. Moreover, experimental results obtained by applying algorithms to data acquired from the board AT–MIO–16XE50 and the fourth–order $\Delta\Sigma$ modulator AD1555 with OSR equal to 1024, are presented.

II. DESCRIPTION OF THE IMPLEMENTED ALGORITHMS

Algorithms developed in this ADC testing environment are the histogram, the frequency–based and the sine–fit tests, as described in [1]–[3]. Each algorithm processes a given number of acquired records of data (N_{REC}), each of length N, obtained by applying a sinewave of appropriate amplitude (A), frequency (f_{in}) and offset (of), to the device under test.

The *histogram test* is based on the concept that an ADC stimulated by a repetitive signal with a given probability density function (pdf) generates output codes with known distribution. By comparing the experimental and the ideal distribution, it is possible to estimate DUT parameters such as the INL, DNL, gain (G) and offset (of) [10]. Each record of data of length N represents an integer number, J, of input signal period, with J and N prime, according to indications given in [1] and [2]. Such parameters, together with the sampling frequency f_s, define the value of the input signal frequency, which influences directly the performance of the algorithm, since dynamic errors increase with the signal frequency value, thus decreasing the accuracy in the estimate of the transition levels. The choice of the values of these parameters is usually critical. In fact, a large number of acquired samples N for each signal period guarantees an accurate estimate of the pdf by means of the histogram, but, conversely, it increases the accuracy with which the frequency signal have to be set, thus requiring the employment of a high resolution signal generator.

TABLE II

PARAMETERS ESTIMATED BY APPLYING THE HISTOGRAM ALGORITHM

of [dB]	G
DNL_{max}	INL_{max} [dB]

TABLE III

PARAMETERS ESTIMATED BY APPLYING THE SINE–FIT ALGORITHM

$\widehat{SINAD}$ [dB]	$\sigma_{\widehat{SINAD}}$ [dB]
$\widehat{be}_{SINAD}$	$\sigma_{\widehat{be}_{SINAD}}$

The *frequency–domain* test, evaluates spectral parameters, such as the SRNR, SINAD, SFDR, SNHR and THD, from the discrete power spectral density of the output codes estimated by employing the fast Fourier Transform (FFT) algorithm applied to the windowed data record. The implemented algorithm can calculate automatically the window coefficients which optimize the estimates of the figures of merit on the basis of the resolution of the ADC under test and of the employed input test signal by following the criterion given in [4].

The *sine–fit* test is based on the interpolation of the output samples by means of a sinusoidal function which minimizes the root mean square error of the output samples. The algorithm searches the optimal value of the amplitude, phase, frequency and offset of the interpolation function, and calculates the residual error, $r[\cdot]$, and the relative mean squared value, σ_r^2. If the ratio between the sampling and the input frequencies is known, the three parameter algorithm is applied. If the input frequency is unknown, the four parameter algorithm is applied iteratively, until the variations between two consecutive estimates of the four parameters are smaller than an arbitrarily small threshold, ε.

III. SOFTWARE STRUCTURE

The software reads a given set of text files which contain the information related to the device to test, the input signal, the testing algorithm and the algorithm parameters. This information is processed as shown in the flow–chart of Fig. 1. In particular, it is possible to select between a generic digital instrument, for which the user must provide a text file of acquired data, and a set of given DUT which are present in the laboratory of MITEQ at DIEI of University of Perugia–Italy (i.e. the AT–MIO–16XE50 acquisition board, the Infiniium oscilloscope, the hp54603 oscilloscope, AD–1555 $\Delta\Sigma$ converter).

After that, it is selected the kind of test to execute, and then the parameters characterizing the acquisition process are set, i.e. the number of acquired record (N_{REC}), the length of each

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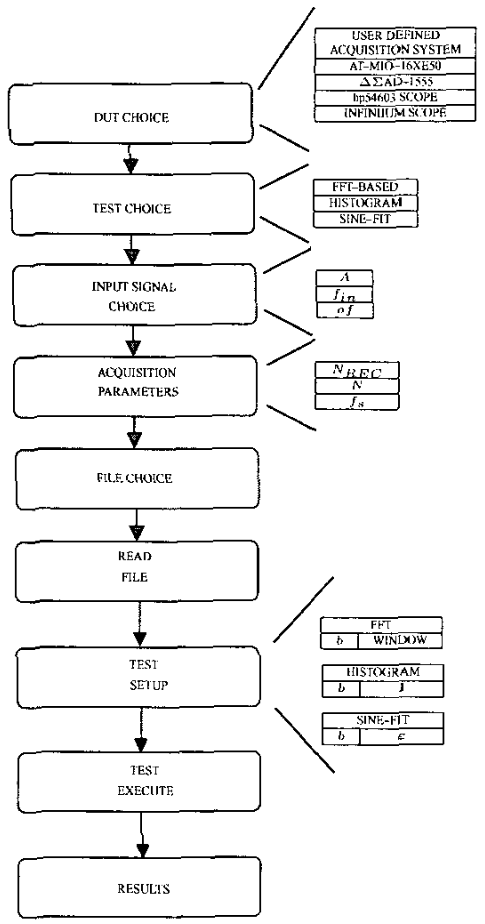

Fig. 1. Flow chart of the implemented testing software.

record (N), the sampling frequency (f_s), the type of input test signal and its frequency (f_{in}), amplitude (A), and offset (of). The value of these parameters are employed for selecting the proper data file from the user data-base. If none of the files present in the database satisfies the selected acquisition parameters, the program exits without executing the test.

Once the acquired data file has been selected from the database, parameters characterizing the selected test algorithm are set. In particular, the FFT-test requires the definition of the DUT resolution, b, and of the window to be employed, which can be selected by the user or calculated by the algorithm itself. The histogram and the sine-fit test require the knowledge of the J and ε parameters, respectively. Finally, the test is executed on each record available and results are printed in a text file, which reports, for each estimated parameter $\widehat{x}$, the average on the N_{REC} values, $\overline{\widehat{x}}$, and the corresponding experimental uncertainty expressed as standard deviation, $\sigma^2_{\widehat{x}}$, as indicated in Tabs.I–III for each implemented algorithm. In particular, $\widehat{be}_{SRNR}$, $\widehat{be}_{SINAD}$, $\widehat{be}_{SNHR}$, represent the $\widehat{SRNR}$, $\widehat{SINAD}$ and $\widehat{SNHR}$ value, expressed as equivalent bit as indicated in [5].

TABLE IV

$\overline{\widehat{SINAD}}$ OF THE 16-BIT AT–MIO–16XE50 BOARD ESTIMATED BY MEANS OF THE FFT AND THE SINE–FIT TESTS FOR MANY FREQUENCIES OF THE INPUT TONE. THE INPUT AMPLITUDES ARE EQUAL TO 9.85 V FOR THE FFT– TEST AND 10.00 V FOR THE SINE–FIT TEST.

	FFT–TEST	SINE–FIT TEST
f (Hz)	$\widehat{SINAD}$	$\widehat{SINAD}$
125	83.77	84.68
250	78.05	78.27
500	78.03	78.24
1000	78.10	77.77

TABLE V

$\overline{\widehat{be}}_{SINAD}$ OF THE SINGLE–BIT ΔΣ CONVERTER AD1555 ESTIMATED BY MEANS OF THE FFT AND THE SINE–FIT TESTS FOR VARIOUS AMPLITUDES OF THE INPUT TONE AND AN OSR EQUAL TO 1024. THE INPUT FREQUENCY IS EQUAL TO 24 Hz.

	FFT–TEST	SINE–FIT TEST
A (V)	$\overline{\widehat{be}}_{SINAD}$	$\overline{\widehat{be}}_{SINAD}$
0.10	14.15	14.60
0.20	15.04	15.57
0.70	16.76	17.29
1.20	17.37	17.91
1.70	16.84	17.27
2.00	16.98	17.53
2.25	17.23	17.56
2.30	17.33	17.63
2.35	17.15	17.71

IV. EXPERIMENTAL RESULTS

Testing algorithms implemented in the software environment have been applied to data acquired from the 16-bit AT–MIO–16XE50 board and the single-bit ΔΣ modulator AD1555. The first one has been used with FS=10 V and f_s=10 kSample/s, the modulator has been employed by setting FS=2.0 V, f_s=256 kSample/s and OSR=1024. Both devices have been stimulated by means of sinusoidal inputs with different amplitudes and frequencies, obtained with the signal generator SRS DS360.

Some figures of merit estimated by means of the various algorithms are presented in Tabs. IV–V. The frequency-domain test has been applied by windowing data with the class of sequences which maximizes the accuracy of the estimated parameters, as indicated in [5]–[6]. Moreover, estimates have been obtained by using N_{REC}=50 and N=4096.

In particular, Tab. IV reports the estimate of the $SINAD$ of the AT–MIO–16XE50 board evaluated by applying the FFT

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and the sine–fit tests for many input frequencies, as indicated by the corresponding column. The amplitude of the applied input is the value that maximizes the estimate when a 1 kHz input tone is employed, i.e. 9.85 V for the FFT–test and 10.00 V for the sine–fit test. Such results show that both algorithms give similar values of the estimates, thus validating the effectiveness of the employed window in the FFT algorithm.

Tab. V reports the estimate of the $SINAD$, expressed as equivalent bit, of the single–bit $\Delta\Sigma$ converter AD1555 obtained by applying the FFT– and the sine–fit tests when a 24 Hz tone with variable amplitude and an OSR equal to 1024 are employed. Experimental results shows that the FFT–test gives values of the estimate similar to the sine–fit test if the optimal window is employed for processing data.

V. CONCLUSIONS

Several testing procedures are usually needed for estimating dynamic performance of analog–to–digital converters and each parameter can be estimated by using more than one technique. Since published scientific literature do not indicate which is the optimal algorithm to apply for evaluating each single parameter, it follows a reduced measurement repeatability of ADCs performance.

In this paper a software environment, which includes ADCs parameters estimation techniques defined in the amplitude—, time– and frequency– domains, has been presented. In particular, the implemented frequency–domain test evaluates figures of merit by windowing data by means of sequences which maximizes the accuracy of the estimates. The optimal sequence is calculated automatically from the knowledge of the ADC resolution and of the number of acquired samples. As a consequence, the user is relieved from choosing the optimal sequence, which is usually a difficult task.

Experimental results validate the efficiency of the proposed environment and, in particular, of the windows implemented with the FFT–test. Estimates obtained by processing data acquired from the 16–bit AT–MIO–16XE50 board shows that the FFT–test gives result similar to those obtained with the sine–fit test. The application of the same algorithms to the fourth–order $\Delta\Sigma$ converter AD1555 confirms the effectiveness of the employed windows also when a high OSR (i.e. 1024) is employed.

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