On the evaluation of ADC static parameters through dynamic testing

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ABSTRACT

Full characterization of ADC requires both a histogram-based approach and a spectral analysis to determine respectively static and dynamic parameters. This paper investigates whether static performances can be extracted from spectral analysis, in order to develop a low-cost test procedure. Results show that under appropriate test conditions, the dynamic parameters extracted from a classical FFT exhibit significant variations against ADC offset and gain errors.

I. INTRODUCTION

Due to the considerable evolution of Analog-to-Digital Converters (ADC) in terms of resolution and/or speed, testing ADC frequently contributes to half of the price of the device itself. Moreover, the whole set of performance features cannot be obtained by a single test. Two kinds of parameters actually define a converter, one related to its transfer function (static parameters), and another that expresses the deformation induced on the converted signal (dynamic parameters). Both require a specific test method [1]: a histogram-based approach (static test) is usually coupled to a spectral analysis (dynamic test). Finding a link between static and dynamic parameters would enable to deduce the complete set of ADC parameters from a unique test acquisition and processing [2]. Spectral analysis would be preferable to histogram method for two reasons [3]: firstly, it is more representative of the converter running reality, and secondly it requires less samples, which means shorter processing time and reduced storage resources, two major considerations in the perspective of low-cost ADC testing. Hence, the objective of this work is to investigate whether the dynamic test parameters are sensitive to ADC static errors and under which test conditions.

Experiments described in this paper are based on a 6-bit ADC. Additional validations have been performed to generalize the study to higher resolution ADCs.

II. EXPERIMENTAL SETUP

The typical test setup for ADC dynamic testing on a classical ATE is illustrated in figure 1 [4]. The waveform synthesizer generates a sine-wave signal with an input frequency f_{in}, an amplitude A_{in} and an offset V_o. This stimulus is applied on the converter input and resulting samples are acquired in the capture memory at the rate of the sampling frequency f_s. These samples are then transferred to the CPU for further processing.

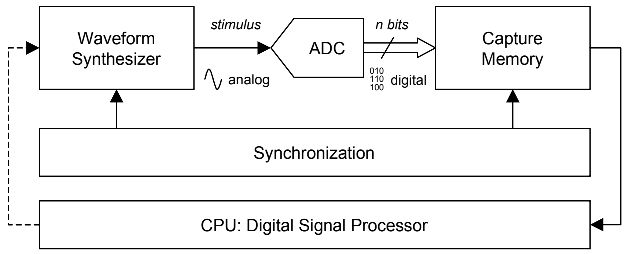

Figure 1. Test setup

Spectral analysis of ADC is based on the exploitation of the Fourier transform of the digital samples acquired at the converter output when a pure sine wave is applied to its input [5]. The resulting spectrum is analyzed to evaluate the following parameters, characteristic of the ADC dynamic performances: the *SINAD* (SIgnal-to-Noise And Distortion ratio), the *THD* (Total Harmonic Distortion), and the *SFDR* (Spurious Free Dynamic Range). As commonly accepted, the *THD* is restricted to the five first harmonics in the study.

This experimental setup has been implemented on the HP VEE software, a measurement programming environment that can be used for both simulation and physical test (used in industrial ATE HP93000). An ADC behavioral model based on the transfer function (ideal or affected by gain and offset errors) has been developed for simulation.

III. ACCURACY ON DYNAMIC PARAMETERS EXTRACTION

The test setup factors susceptible of having an effect on the extracted dynamic parameters of a given ADC are the number of samples N considered to perform the FFT, the number of periods M of the input sine-wave during acquisition, and the input signal amplitude A_{in}.

The number of samples N taken into account for the analysis is an important factor to consider for low-cost testing. Theoretically, FFT only requires at least one sample per code is present in the data record. However, this demands a perfect synchronization difficult to ensure in practice. For illustration, figure 2 gives the measured *SINAD* for several input signals presenting a small phase shift. It clearly appears that the measured value does not depend on the number of samples provided it is high enough. Similar results have been observed for all dynamic parameters. Hence, we will use 1024 samples for each FFT computation afterwards in order to leave out of account the uncertainty on the synchronization.

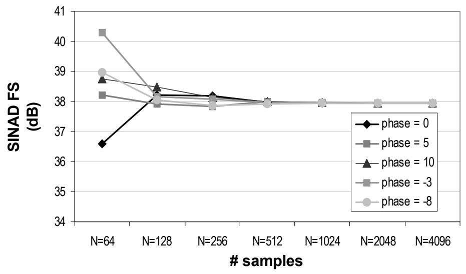

Figure 2. SINAD vs. number of samples

It is widely accepted that the number of periods *M* of the input signal, adjusted to collect the required sample set with respect to the coherence sampling condition, has no impact on the measured parameter values. Experiments undeniably confirm this assumption.

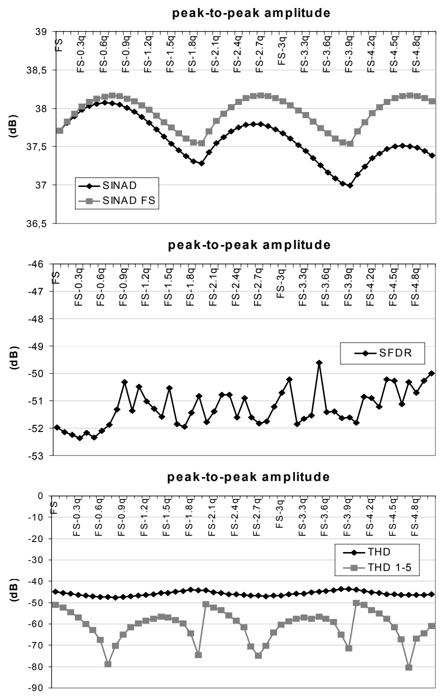

Figure 3. Dynamic parameters vs. signal amplitude ($2A_{in}$ < FS)

Regarding the input signal amplitude, the situation is far different. The values of all dynamic parameters are sensitive to this amplitude. However in a testing environment, we cannot precisely guarantee the value of the generated input signal amplitude. In order to evaluate the potential error on the extracted parameters, we determine the maximal variation of the dynamic parameters for a large range of input signal amplitudes, both inferior and superior to the ADC full scale.

In a conventional dynamic test, the input signal peak-to-peak amplitude is chosen slightly lower than FS. Figure 3 presents the evolution of the ADC parameters for decreasing amplitudes from full scale. In this situation, the *SINAD* and *SFDR* are sensitive to amplitude variations but in a tolerable range. A total variation of 0.6 dB is observed for the *SINAD*, which corresponds to a relative accuracy of 1.6%. In the same way, a total variation of 2.8 dB is observed for the *SFDR*, which corresponds to a relative accuracy of 4.6%. In contrast, the *THD* presents an extreme sensitivity to any amplitude variation, with a total variation higher than 30 dB. A deviation in the input signal peak-to-peak amplitude of less than 0.1 quantization step (0.1 LSB) can result in a variation of 20dB or more in the measured harmonic distortion, corresponding to a relative accuracy of 50%.Amplitude deviations of this size are quite common in a production environment, where amplitude deviations around 1% may occur, yielding a deviation of more than one half quantization step in a 6-bit converter [6]. The present-day solution to this sensitivity problem is noise dithering [7]. But this technique has several drawbacks, in particular the relatively high number of samples required to achieve a significant reduction in the sensibility of the *THD* and the influence of the noise dither on the *SINAD* parameter.

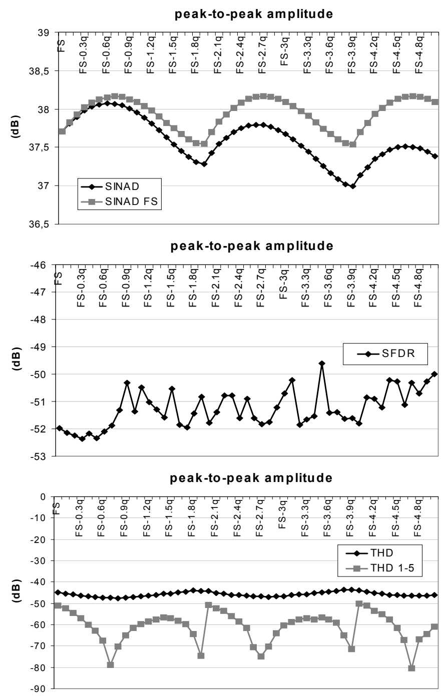

Figure 4. Dynamic parameters vs. signal amplitude ($2A_{in}$ > FS)

In contrast to conventional dynamic test, one can apply a signal with a peak-to-peak amplitude slightly higher that the ADC full scale. Figure 4 presents the evolution of the ADC parameters for increasing amplitudes from full scale. The total variation observed in this case appears quite important but much more predictable. For instance considering an input signal with a peak-to-peak amplitude 2 LSB higher than *FS*, a deviation of ±0.1 LSB in the amplitude results in a variation of about 0.4 dB in the *SINAD*, 0.7 dB in the *SFDR* and 0.8 dB in the *TDH*, corresponding to relative accuracy of 1.3%, 2% and 2.2% respectively. The relative accuracy for a given amplitude deviation around a nominal point is therefore greatly improved by the use of an input signal with an amplitude higher than full scale, even if measured values do not directly represent the ADC performances.

IV. EXTRACTION OF STATIC ERRORS FROM DYNAMIC PARAMETERS

In order to evaluate the influence of static errors on the dynamic test parameters, experiments have been performed introducing offset and gain errors in the converter model. Note that the previous section has stated out that the *SINAD*, *SFDR* and *THD* parameters are independent of the number of samples (provided that it is high enough) as well as of the number of input periods. In this study, we use *N=1024* and *M=31*.

At the opposite, the *SINAD*, *SFDR* and *THD* parameters are influenced by any amplitude deviation of the input signal. This sensitivity has therefore to be considered when studying the impact of static errors on dynamic parameters. In particular, one should differentiate between the case of a signal peak-to-peak amplitude lower and higher than *FS*, since relative accuracy achieved in both cases may differ by more than one order of magnitude.

IV.1. Influence of an offset error

First, we consider the offset error influence. Figure 5 gives the relative error between the measured and ideal values of the *SINAD*, *SFDR* and *THD* parameters in presence of an offset error. Three different input signal peak-to-peak amplitudes have been considered, corresponding to *FS-2LSB*, *FS* and *FS+2LSB*. The first comment on these results is that an offset error significantly affects dynamic parameters in many cases, therefore opening the way of a possible detection of static errors through the measurement of dynamic parameters. Indeed, the expected value of the test parameters for an ideal converter is known from the previous study so that any difference between the measured and expected values indicates the converter is affected by an error.

Analyzing more in details the evolution of the dynamic parameters versus the offset error, it should be noted that two different behaviors are observed depending whether the input signal peak-to-peak amplitude is lower or higher than *FS*. We observe monotonous variation of the dynamic parameters with the offset error when the amplitude is higher than *FS*, which is not the case for an amplitude lower than *FS*. Such a monotonous variation is of great interest for the determination of the offset error without ambiguity. For instance, the relative errors of the *SINAD* and *THD* parameters increase almost linearly with the offset value for an amplitude higher than *FS*, which permits a very straightforward evaluation of the offset error. Hence, applying an input signal larger than the full scale range of the converter seems more performing for the detection of static errors in a first view.

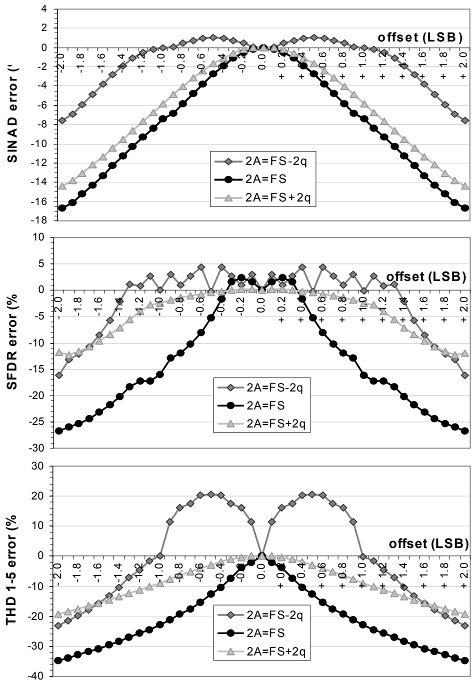

Figure 5. Dynamic parameters vs. offset error

Besides, analyzing the variations of the dynamic parameters with respect to their sensitivity to the signal amplitude reveals that offset error detection is possible only in case of a signal amplitude higher than *FS*. Indeed the relative accuracy of the dynamic parameters measurement is improved in this case, allowing measurements accurate enough to discriminate an offset error from an amplitude deviation. On the contrary, variations induced by an offset error when applying a signal amplitude lower than *FS* remain in the range of variations observed in case of a small deviation of the signal amplitude, preventing discrimination. For illustration, let us assume a signal amplitude guaranteed within ±0.1 LSB around the nominal value. In case of an amplitude 2 LSB lower than *FS*, expected values for the *SINAD*, *SFDR* and *THD* can be determined with an accuracy of 1.6%, 4.6% and 50% respectively, as established in the previous section. Reporting theses values on the corresponding characteristics of figure 5 shows that the *SINAD* and *SFDR* measurements permit to detect offset errors only if higher than 1.4 LSB and 1.5 LSB, while the poor accuracy obtainable on the *THD* measurement prevents from the detection of offset errors as high as 2 LSB. In case an amplitude 2 LSB higher than *FS*, expected values for the *SINAD*, *SFDR* and *THD* are known with an accuracy of 1.3%, 2% and 2.2% respectively, which leads to the detection of offset errors as low as 0.5 LSB, 1 LSB and 0.2 LSB respectively.

IV.2. Influence of a gain error

Considering now a gain error, the evolution of the *SINAD*, *SFDR* and *THD* parameters is reported in figure 6 for the three values of the input amplitude.

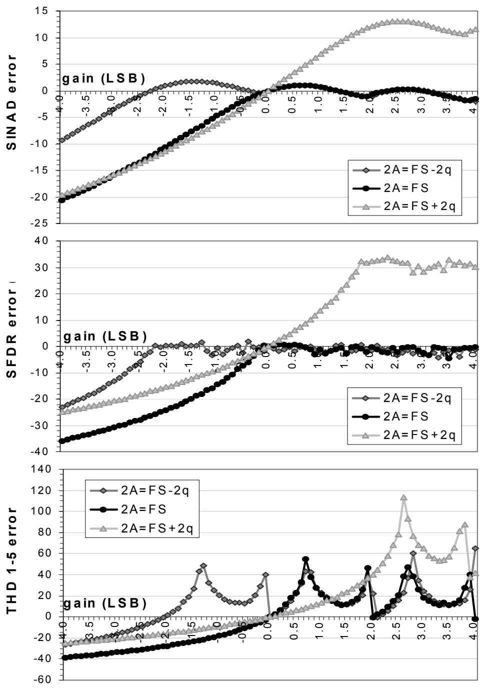

Figure 6. Dynamic parameters vs. gain error

While the evolution of dynamic parameters were perfectly symmetrical in case of positive and negative offset error, the situation is different with a gain error. Indeed, a negative gain error means that the effective ADC full scale is smaller than supposed, which induces a greater clamping of the converted signal. On the contrary, a positive gain error implies that the full scale is larger than expected, then a signal assumed to cover all the codes will not. In the last case, we find again a sensitivity similar to the one upon the signal amplitude.

Despite this difference, similar conclusions as for the detection of an offset error can be derived. In particular, we find out that the use of an input signal amplitude higher than the ADC full scale permits the evaluation of gain errors in a large range. As an example, gain errors of ±0.2 LSB can be deduced from the *SINAD* measurement, ±0.2 LSB from the *SFDR* measurement and ±0.2 LSB from the *THD* measurement. In case of a signal amplitude lower than *FS*, detection of gain error is restricted to -2.7 LSB from the *SINAD* measurement and -2.5 LSB from the *SFDR* measurement, while the high sensitivity of the *THD* to the signal amplitude again prevents the detection of gain errors as high as ±4LSB.

V. Conclusions

The aim of this work was to determine wether ADC static errors could be extracted from a spectral analysis to reduce the cost and time of ADC testing. Hence the evolution of dynamic parameters versus offset and gain errors has been investigated.

We acknowledged in the first part of the study that ADC dynamic performances are strongly influenced by input signal amplitude deviations, that are highly likely to happen in a testing environment. Under conventional test conditions, the relative uncertainty on the dynamic parameters measure appears to reach untolerable range. This sensitivity is greatly reduced considering a peak-to-peak input signal amplitude rather superior to the converter full scale than inferior. Moreover, as ADC dynamic parameters show monotonous and significant variations versus static errors when the stimulus amplitude is higher than the full scale, further static parameters extraction is facilitated. Considering the measure accuracy improvement under these conditions, offset and gain errors as small as 0.2 LSB can be detected.

Hence an original low-cost test setup to characterize both static and dynamic performances of an ADC from a spectral analysis can be developed.

VI. References

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