APPLICATION OF PERIODICAL EXPONENTIAL STIMULUS SIGNAL FOR ADC DNL TESTING

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Abstract – Testing of ADC's differential nonlinearity (DNL) by the histogram method requires signal generator with extremely low distortion and high stability. Author developed new histogram-based testing method with exponential stimulus signal. In this paper, the modification of this method is presented. The single exponential test signal is replaced by periodical exponential signal. The histogram from the recorded samples and that for the best fitted shape allows determining the differential nonlinearity of ADC. This modification gives some advantages presented and discussed in the paper. The proposed method was experimentally verified and achieved results compared with those by the single exponential method and by the standardized histogram method with harmonic stimulus signal.

Keywords: ADC testing, histogram method, DNL and INL, periodical exponential stimulus signal.

1. INTRODUCTION

The deviation of actual ADC transfer characteristic from ideal one is described by differential and integral nonlinearity (DNL, INL). These parameters can be tested by standardized methods [1], [2], [3], which are generally categorized into two groups - static and dynamic methods. The static method requires high accuracy DC calibrator and voltmeter. It is also consuming a long time. The dynamic histogram method is faster and for that reason it is applied more often. Dynamic histogram assesses the distribution of the acquired samples for known stimulus signal (most often sinewave), carrying information about the actual $DNL(k)$ of ADC. However, the high accuracy of stimulus signal generator, required for this method relative to a DC calibrator, is the main disadvantage of dynamic testing in statistical domain. High cost of testing generator and severity of test system does not allow to use it for self-testing by end-user or in automatic diagnostic process.

The histogram method has another drawback. Interfering input voltage of various origin and thermal noise tends to equalize the code bin width $W(k)$ in the ADC under test and hides $DNL(k)$ errors in the histogram shape. For these reasons, the testing stand besides high accuracy of the stimulus signal shape requires high reduction of the electromagnetic interference generated on the ground wires. The optimal calibrating generator should be powered independently from other instruments and connected star-like at the ground terminal of the ADC input. These facts always call for new test methods, e.g. [4], [5], [6], [7]

2. EXPONENTIAL PULSE TESTING METHOD

The new testing method based on exponential stimulus signal and histogram processing was described in paper [5]. The novelty of the developed test method is in replacing standard test signals by exponential waveform, which can be generated by discharging a capacitor across resistance. The generator of the exponential stimulus signal with galvanic separation from the control unit is shown in Fig.1.

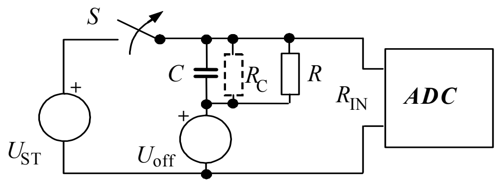

Fig. 1. Circuit generating single exponential stimulus signal.

The voltage memorized (U_{ST}) on capacitor C is discharged across the resistance R connected in parallel to the ADC input resistance R_{IN} and resistance R_C that represents the ohmic losses in real capacitor. The offset voltage U_{off} represents the final steady level created by stimulus voltage. The acquired digital samples from the output of ADC under test allow calculation of the best fitted exponential shape. The code occurrence for the real code bin width together with the ideal one estimated for the best fitted exponential shape allows determining the $DNL(k)$ for any code level k.

The advantages and disadvantages of such signal and testing method are:

+ Easy circuit implementation – usable for the preliminary test by end-user or for a self test.
+ Signal isolation from the common ground.
+ Simple generation of exponential shape – close to the ideal one. The closeness depends mainly on quality of capacitor. Because of possible dielectric

absorption, the test signal usually contains at least two exponential components.

- The necessity of large values of the capacitor and the resistance to create very slow exponential decay of stimulus pulse which is necessary to obtain a large set of acquired samples. The real capacitors with a large value of capacity have usually low electrical quality and significant effect of dielectric absortion.

The mentioned disadvantages could be eliminated by repetition of relatively short-time exponential pulses.

2.1 PERIODICAL EXPONENCIAL STIMULUS SIGNAL

The DNL and INL determination process is similar to this one proposed for the single exponential pulse test method [5]. The process consists of following steps:

1. The record of samples - $x(i)$ (Fig. 2), which have periodical exponential form over full-scale range of the ADC under test must be pre-processed so that the new pre-processed record – $x`(i)$ (Fig. 3) have to contain the integer number of cycle. More over, only the parts of the record containing the run of the stimulus signal within the ADC input range may remain in the new pre-processed record $x`(i)$ (Fig. 3).
2. The pre-processed record $x`(i)$ is being used for calculation of real histogram $H(k)$ (Fig. 4).
3. The histogram $H(k)$ is utilised to recalculation of substituting exponential pulse $x``(i)$ (Fig. 5). The distribution function is determined by formula

$$P(k) = \frac{n(k) - 0}{M} = \frac{\tau . \ln \dfrac{T(k)}{A}}{M.T} \qquad (1)$$

Where $n(k)$ is sample number for transient level $T(k)$, M is total number of samples, τ and A are parameters of exponential function.
Therefore the inverse relation (1), the transient code level $T(k)$ vs. distribution function $P(k)$ is reflected by the substituting exponential pulse $x``(i)$.
4. Considering $INL(2^N\text{-}1)=INL(0)=0$ and symmetrically distributed DNL around zero level, the substituting exponential shape $x``(i)$ allows to estimate parameters of input exponential stimulus signal $x(i)$ by the least squares method.
5. For estimated input signal $x(i)$ the ideal (reference) histogram $H_{id}(k)$ can be calculated (Fig. 4).
6. Using formula (2) and (3) the $DNL(k)$ and $INL(k)$ values are calculated from the real histogram $H(k)$.

$$DNL(k) = \frac{H(k)}{H_{id}(k)} - 1 \qquad \text{[LSB]} \qquad (2)$$

$$INL(k) = \sum_{j=1}^{k} DNL(j) \qquad \text{[LSB]} \qquad (3)$$

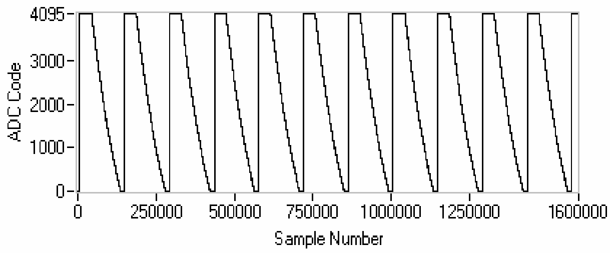

Fig. 2. ADC data record for periodical exponential. stimulus signal.

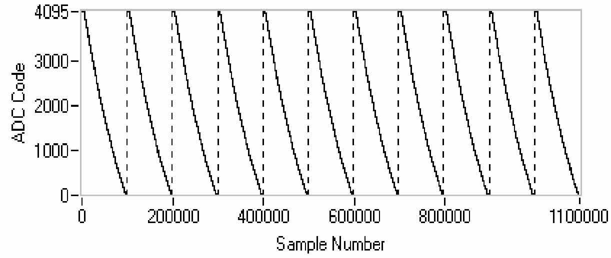

Fig. 3. The pre-processed data record of periodical exponential test signal.

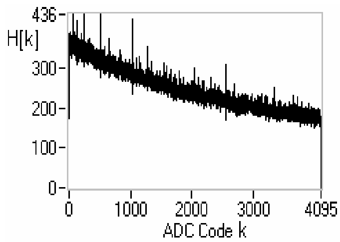

Fig. 4. The histogram built from pre-processed data record.

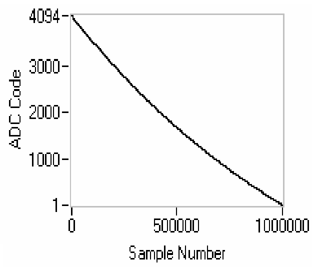

Fig. 5. Single exponential pulse obtained from histogram.

3. EXPERIMENTAL RESULTS

Described idea was verified by experiments. The test stand consisted of PC plug-in board PC-LAB-1200 by National Instruments and stimulus signal generator as it is shown in Fig.6.

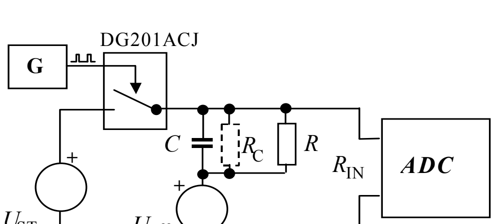

Fig. 6. Circuit generating periodical exponential stimulus signal.

The generator of the periodical exponentials contained the precise electronic switch DG201ACJ [8] controlled by pulse generator G.

To assess the new developed test method results, the reference DNL and INL characteristics of the plug-in board PC-LAB-1200 were obtained by the standard dynamic histogram test by [1]. They are shown in Fig. 7 and Fig. 8.

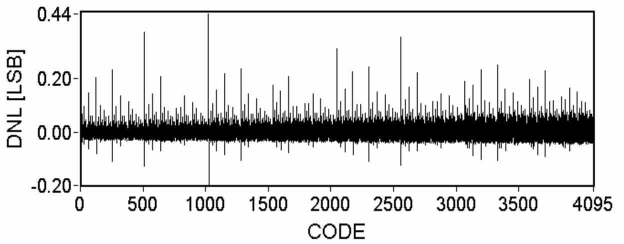

Fig. 7. DNL of LAB-PC-1200 acquired by the standardized dynamic testing method. f_{in}=13.777Hz, M=4MS.

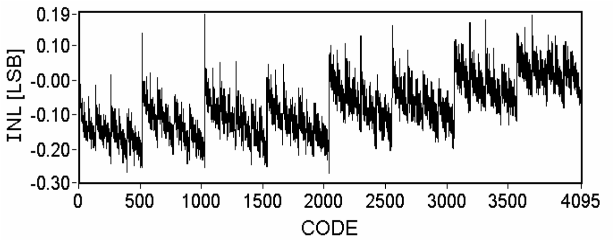

Fig. 8. INL of LAB-PC-1200 acquired by the standardized dynamic testing method. f_{in}=13.777Hz, M=4MS.

Fig. 9 and Fig. 10 show the same characteristics obtained by the new proposed testing method. The both INLs by the standard method and by the proposed one indicates a relatively good consonance.

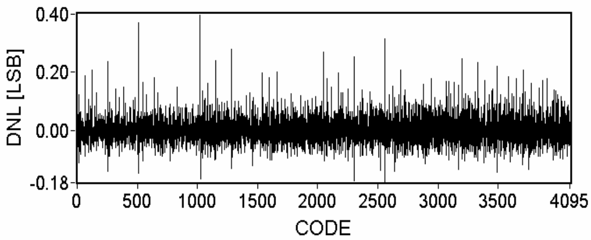

Fig. 9. DNL - periodical exponential test signal. C=10uF, R=120kΩ, M=1.2MS, U_{off}=-12V, U_{ST}=+11V, f_G=0.8Hz.

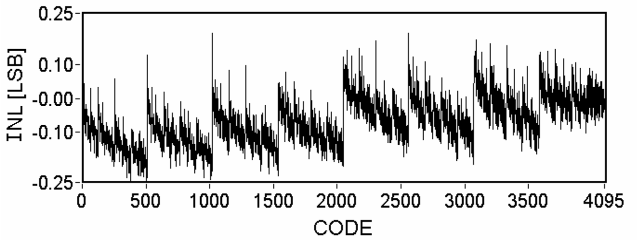

Fig. 10. INL - periodical exponential test signal, C=10uF, R=120kΩ, M=1.2MS, U_{off}=-12V, U_{ST}=+11V, f_G=0.8Hz.

The variations of capacity value C in the stimulus signal generator circuit (Fig. 6) and the adequate changes of impulse generator frequency f_G, didn't caused any significant difference in the form of measured DNL and INL (Fig. 11 and Fig. 12).

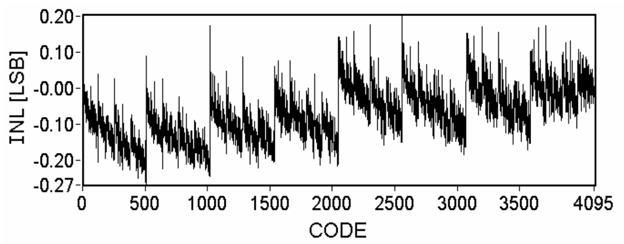

Fig. 11. INL - periodical exponential test signal. C=1uF, R=120kΩ, M=1.2MS,, U_{off}=-12V, U_{ST}=+11V, f_G=8Hz

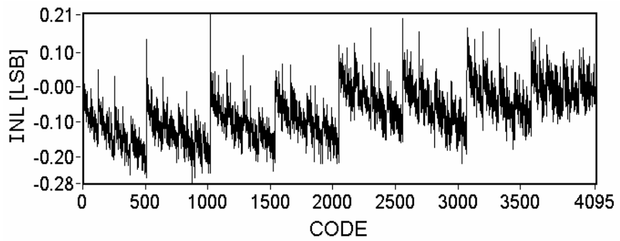

Fig. 12. INL - periodical exponential test signal. C=0.1uF, R=120kΩ, M=1.2MS, U_{off}=-12V, U_{ST}=+11V, f_G=80Hz.

The reproducibility of proposed method was verified by statistical analyzes from a set of ten measurements. Fig 13 shows the standard deviations of INL measurement.

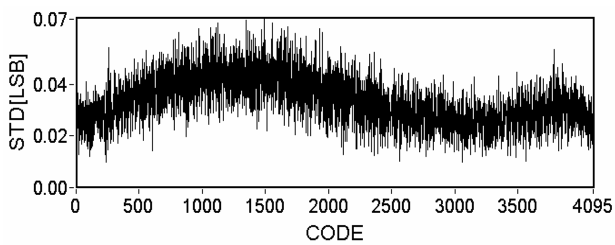

Fig. 13. Standard Deviation of INL for 10 measurements by periodical exponential signal. C=10uF, R=120kΩ, 1.2M samples, U_{off}=-12V, U_{ST}=+11V, f_G=0.8Hz.

Moreover, the testing by the single exponential stimulus signal (according to [5]) was executed for comparison of methods. The obtained DNL and INL are shown in Fig 14 and Fig. 15. The differences in the shapes are not visible. The standard deviations of INL measurement by the single exponential stimulus is shown in Fig. 16.

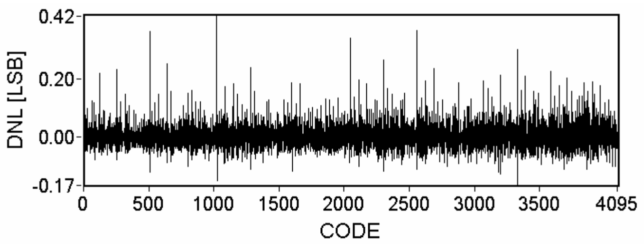

Fig. 14. DNL - single exponential pulse. C=10uF, R=2MΩ, M=1.3MS, U_{off}=-12V, U_{ST}=+11V.

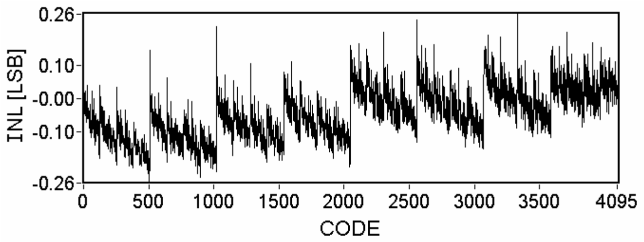

Fig. 15. INL - single exponential pulse. C=10uF, R=2MΩ, M=1.3MS, U_{off}=-12V, U_{ST}=+11V.

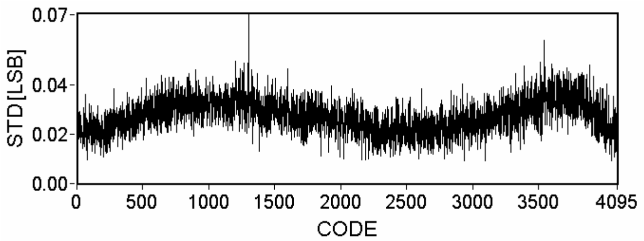

Fig. 16. Standard deviation of INL for 10 measurements by single exponential pulse. C=10uF, R=2MΩ, 1.3M samples, U_{off}=-12V, U_{ST}=+11V.

4. CONCLUSIONS

The main novelty presented and experimentally tested in the paper is the idea of using the periodical exponential shape as a stimulus signal. The advantages of the proposed method are:

- The periodicity of the exponentials allows using capacitors with lower value of its capacity. These capacitors are characterized by smaller parasitic effects (dielectric absorption).
- The method make possible testing ADC with lower input impedances.
- The long periodical waveform can be completed from several repeated short data records. Therefore the hardware requirements are lower – the input digital buffer can be smaller. On the other side, by the repeating of the measurements can reduce the test uncertainty.

The performed experiments confirmed a good consonance between results – INL and DNL – obtained from standard and new developed methods

The further improvement of the proposed method could be done by applying approximation based on two exponential components.

ACKNOWLEDGEMENTS

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