XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6–11, 2009, Lisbon, Portugal

ADVANCED ADC TESTING BY MULTIEXPONENTIAL STIMULI

Linus Michaeli[1], Ján Šaliga[2], Michal Sakmár[3], Ján Buša[4]

[1,2,3] Dept. of Electronics and Telecommunications, [4]Department of Mathematics,
[1,2,3,4]Technical University of Košice, Letná 9, 04120 Košice, Slovak Republic,
[1]linus.michaeli@tuke.sk, [2]jan.saliga@tuke.sk, [3]michal.sakmar@tuke.sk, [4]jan.busa@tuke.sk

Abstract – The paper presents a new approach to ADC histogram test by exponential stimulus signal. The basic, early published, method based on simple exponential stimulus can hide some low code frequency errors in ADC integral nonlinearity. This effect is caused by estimation method of exponential stimulus. The authors proposed new advanced method in processing of histograms achieved by exponential stimulus signal. The basic idea of the new method is in application of periodical exponential stimulus signal consisting of rising and falling parts within its period. Subsequently the estimation of INL is done by minimising of cost function given by the difference between INLs calculated for rising and falling part of signal. Performed simulations and experimental results show that the suggested method is usable in real measurement and it is not more complex in comparison with basic exponential stimulus test method both in hardware realisation and in data processing algorithm.

Keywords: ADC measurement, estimation of INL, exponential stimulus signal

1. INTRODUCTION

Histogram testing of ADC by the harmonic stimulus signal belongs to the most popular ADC testing methods [1]. Achievable distortion of the generated harmonic signal determines limits of its implementation. Harmonic signal generators suitable for testing 16 and more bits ADCs are rather expensive and less common in laboratories.

Because of this constraint other stimulus signals have been proposed for histogram tests [2], [3], [4], [5]. Periodical repetition of increasing and decreasing exponential function with the same time constant is one of them. Its main advantage is extremely simple generating circuit with just passive *R*, *C* components. Circuit simplicity ensures generation of the signal (Fig. 1) coincident to its analytical model represented by mathematical formulas (1) and (2). Influence of exponential stimulus generating circuit components (*R*, *C*, etc.) was studied and presented by authors in [6]. It was shown that the most important source of stimulus distortion is capacitor (its nonlinear properties).

Samples out of full scale range – FSR (F_2-F_1) (Fig.1.) which are not properly defined by the analytical model because of switching effects of the excitating rectangular signal at the input of the forming *RC* circuit are registered in two marginal code bins. Those two code bins are subsequently excluded from the testing (algorithm) procedure. Therefore the fact whether the exponential stimulus reaches or not reaches its saturation state has no influence on results of testing.

Another advantage of the periodical exponential stimulus signal with both slopes is symmetry of the acquired histogram around centre of the FSR as it is for harmonic test signal. Moreover, exponential stimulus gives the possibility to build it on chip for on-board testing subcircuit.

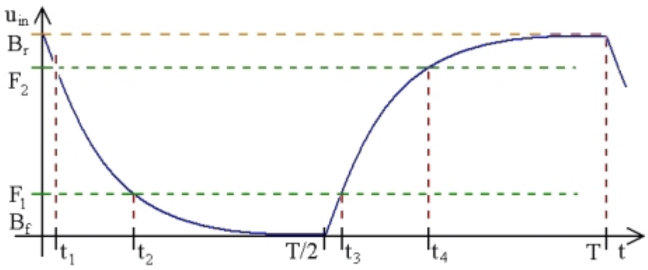

Fig. 1. Exponential stimulus signal

$$y(t)=\begin{cases}(F_2-B_f)\cdot e^{-\frac{t-t_1}{\tau_1}}+B_f, & for \quad (t_1<t<t_2),\\ B_r-(B_r-F_1)\cdot e^{-\frac{t-t_3}{\tau_2}}, & for \quad (t_3<t<t_4)\end{cases} \qquad (1)$$

where τ is the time constant of exponential pulse, F_1 and F_2 determines full-scale input range of ADC under test and B_1, B_2 are limit values of exponential signal for $t\rightarrow\infty$ for each direction of signal (saturation of exponential signal).

2. BOTTLENECK OF BASIC EXPONENTIAL HISTOGRAM TEST METHOD

Basic exponential histogram test method based on monotonic exponential stimulus signal was introduced in [7] and studied later in [6], [8], [9] and [10].

Lots of experiments and simulations performed within last years indicate the small but not negligible difference between INL acquired by this method and the standardised methods (static and sinewave histogram) as it can be seen from a simulation example in Fig. 2 - 4. Fig. 2 presents reference INL of simulated 8-bits ADC. A typical shape of this INL that usually causes an important error of estimation was chosen. Fig. 3 shows INL of the same ADC calculated from basic exponential stimulus histogram test method using monotonic stimulus and Fig. 4 the difference between the reference INL and INL acquired from simulated test.

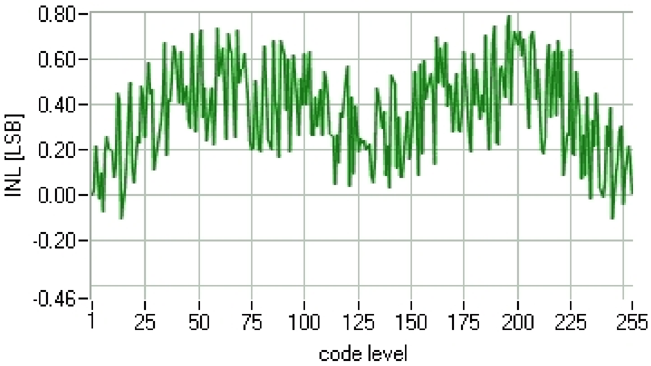

Fig. 2. Reference INL of simulated ADC

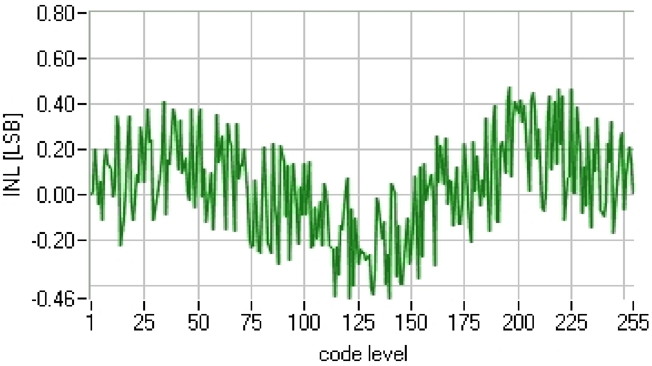

Fig. 3. INL from simulated test by simple monotonic exponential stimulus

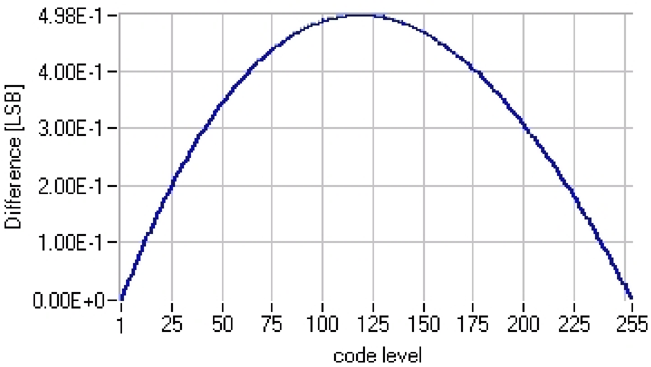

Fig. 4. Difference between the reference INL (Fig. 2) and INL from simulated test (Fig. 3)

The difference (error) in Fig. 4 is not zero and also not only caused by finite number of hits in processed histogram. To describe this error the unified error model consisting of Low Code Frequency INL (INL_{LCF}) and High Code Frequency (INL_{HCF}) [11], [7], [12] can be very efficiently applied. Applying this error model on error expressed by the difference of reference and "measured" INL (Fig. 4) we can assert that the basic monotonic exponential stimulus histogram test method very effectively represents the high code frequency component of ADC under test but partially masks the low code frequency component. This phenomenon is caused by the property of least mean square fit that can mask low code frequency changes in measured INL.

To avoid this masking effect and to improve the accuracy of exponential stimulus histogram test method the new approximation algorithm was proposed for estimation of integral nonlinearities testing using real histogram of the periodical exponential stimulus of both slopes.

3. INL ESTIMATION FROM MONOTONIC EXPONENTIAL STIMULUS

Integral nonlinearity of ADC using monotonic exponential stimulus can be estimated from measured cumulative histogram $H_{C\mathrm{real}}$ according to the next expression:

$$INL(k) = \frac{H_{C_{real}}(k) - H_{C_{id}}(k,B)}{H_{id}(k,B)}, \text{ for k=2,3, ... } 2^N\text{-2}. \quad (2)$$

where $INL(1) = INL(2^N - 1) = 0$, H_{id} and $H_{C\mathrm{id}}$ are the ideal histogram and ideal cumulative histogram, respectively, calculated from stimulus parameters as follows (Q is the nominal quantization step):

$$H_{id}(i,B) = \frac{1}{(F_1 + i \cdot Q - B) \cdot \ln\left(\dfrac{F_2 - B}{F_1 - B}\right)}. \quad (3)$$

The ideal cumulative histogram is:

$$H_{C_{id}}(k,B) = \frac{\ln\left(\dfrac{F_1 + k \cdot Q - B}{F_1 - B}\right)}{\ln\left(\dfrac{F_2 - B}{F_1 - B}\right)}. \quad (4)$$

To calculate simple ideal histogram for monotonic stimulus (rising or falling) and subsequently to determine INL of ADC under test only the parameter B of stimulus signal have to be estimated from measured histogram [8]. In praxis the parameter B can be estimated only numerically as follows:

$$\min(CF) = \sum_{k=1}^{2^N - 2} \left(H_{C_{\mathrm{real}}}(k) - H_{C_{\mathrm{id}}}(k,B)\right)^2. \quad (5)$$

The fitting of cumulative histograms is made because the cumulative histogram is more resistant to the superimposed noise and harmonic interferences. It can be done by LMS algorithm by using Newton iteration process (5).

All the expressions hereinabove are independent of stimulus direction and they are valid for rising as well as falling exponential signal.

4. ESTIMATION FOR PERIODICAL STIMULUS WITH BOTH SLOPES.

To build the ideal histogram for monotonic exponential stimulus, only the parameter *B* must be estimated processing the recorded data. As it was mentioned hereinbefore the best estimation can be done from measured cumulative histogram by LMS fit according to (5).

Generally, for nonmonotonic stimulus according to Fig. 1 two independent constants B_r and B_f have to be estimated from two independent cumulative histograms. Applying individual independent estimation according to (5) for each constant will lead to two different INL: INL_r and INL_f. Both of them can hide some part of INL_{LCF} as it was shown in section 2 of this paper.

That is why the different data processing method was chosen to process records in nonmonotonic exponential stimulus. Instead of individual independent estimation of B_r and B_f these constants are estimated in one processing thread minimizing the cost function of two parameters (B_r and B_f) defined as follows:

$$\min(CF) = \sum_{k=1}^{2^N-2} \left(INL(k, B_f) - INL(k, B_r) \right)^2 . \quad (6)$$

In other words the constants B_f and B_r are estimated at the condition that both INL INL_r and INL_f have to be close each other as much as possible. This approach comes from the idea that INL is the inherent parameter of ADC and ADC INL should be the same for any slope of test stimulus. More over the hysteresis of nowadays ADC that can cause dependence of INL on the stimulus slope is negligible in comparison with INL.

5. EXPERIMENTAL RESULTS

Proposed algorithm (described in section 4) was verified using simulated model described in section 3. Instead of monotonic stimulus the stimulus according Fig. 1 was applied and the acquired histograms were processed according to formula (6). The final INL is shown in Fig. 5.

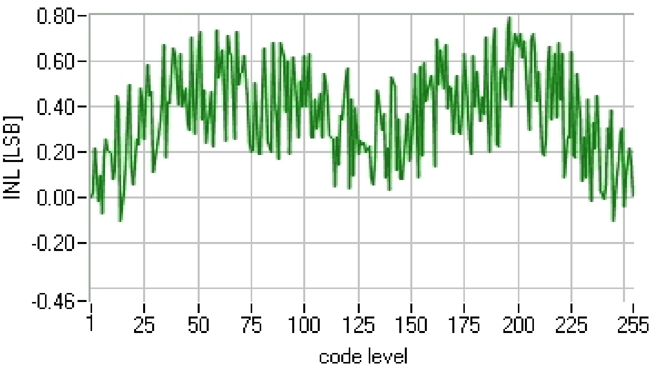

Fig. 5. INL from simulated test by non monotonic exponential stimulus (Fig. 1).

Fig. 6 shows the differences between reference INL (Fig. 2) and *INL* estimated by the proposed new method (Fig. 5). The difference representing the error of the new method is much smaller (more than two orders) than error of basic method (Fig. 4). The residual differences are caused mainly by finite number of samples in simulation and residuum of iteration fitting process.

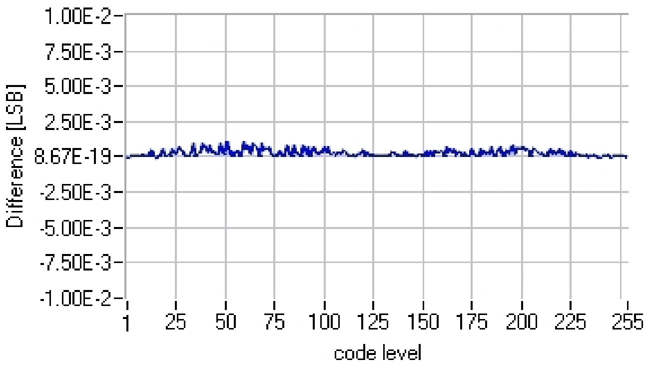

Fig. 6. Difference between the reference INL (Fig. 2) and INL from simulated test by non monotonic stimulus (Fig. 5)

Besides simulations the performance of the proposed method was verified also by real experimental tests. Multifunction data acquisition module USB6009 by National Instruments with 14-bit ADC resolution was used [13]. The module was tested by standardized dynamic histogram testing method using harmonic signal at first. Stimulus signal was generated by ultra-low distortion synthesized function generator Stanford DS360 (20-bit) [14]. The result of this standard test is shown in Fig. 7.

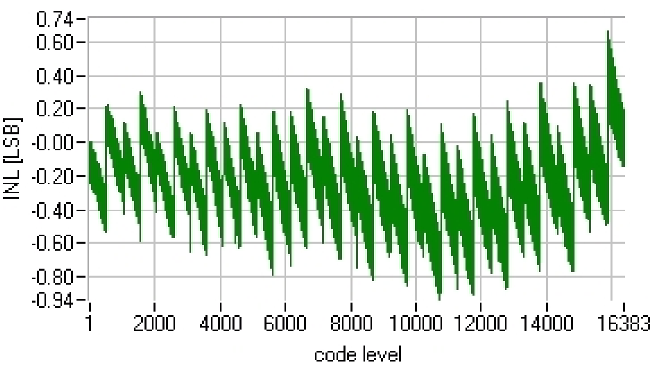

Fig. 7. INL of USB6009 [13] obtained from standardized harmonic stimulus histogram test

Fig. 8 shows INL obtained from the basic monotonic exponential stimulus histogram test (section 3). To compare INL from sinewave test and the monotonic exponential test the difference of INLs was calculated (Fig. 9). The difference that can be supposed to be an estimation of error of basic monotonic exponential stimulus test method is very similar to the results from simulations.

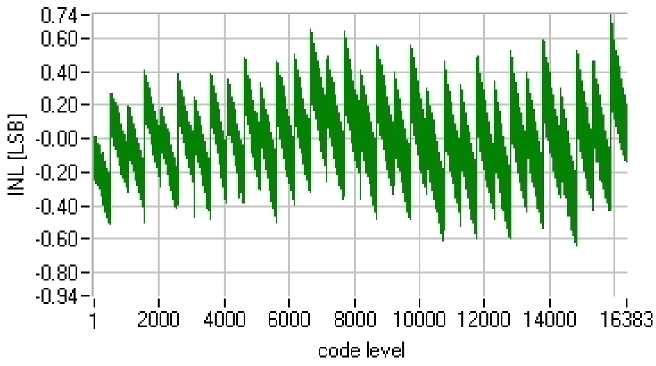

Fig. 8. INL of USB6009 obtained from simple monotonic exponential stimulus histogram test

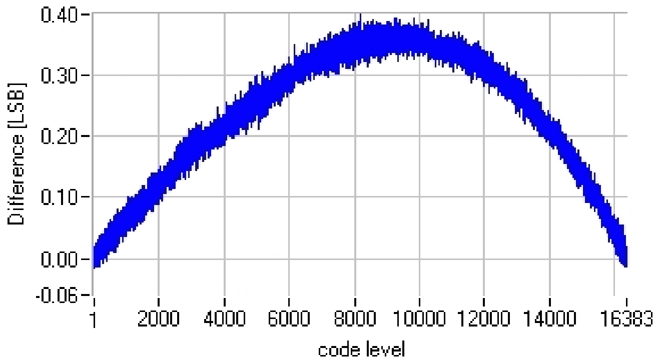

Fig. 9. Difference between INLs from Fig. 7 and Fig. 8

Fig. 10 shows INL obtained from the new nonmonotonic exponential stimulus histogram test (section 4). Fig. 11 presents the difference between INL from sinewave test and the new one. The difference (Fig. 11) is markedly smaller than difference in Fig. 9. The residual error is probably caused only some imperfections in stimulus signal both sinewave and exponential stimulus.

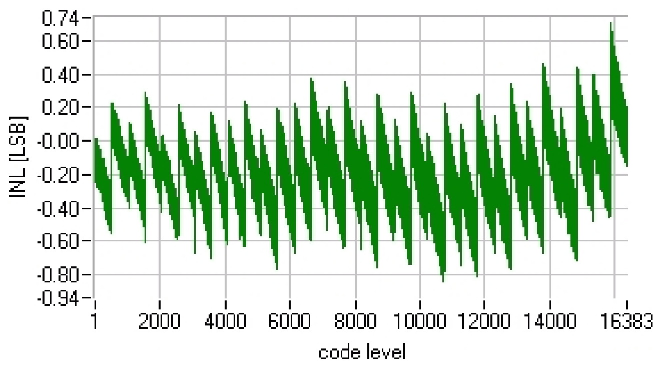

Fig. 10. INL of USB6009 obtained by advanced exponential stimulus histogram test (nonmonotonic stimulus)

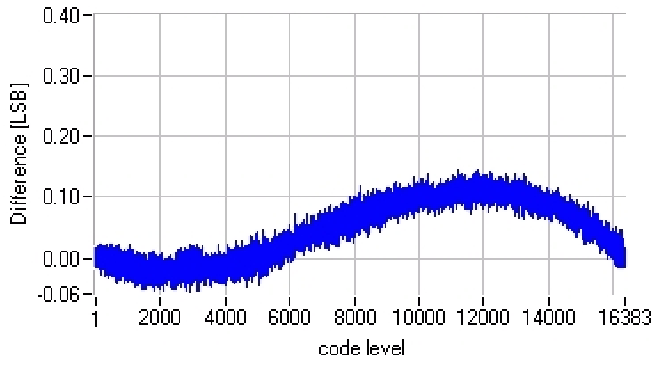

Fig. 11. Difference of INLs from Fig. 7. and Fig. 10.

6. CONCLUSIONS

A new improved exponential stimulus test method has been introduced in this paper. The method is based on nonmonotonic exponential stimulus. Histograms for each slope of stimulus are processed in one thread with the goal to determine the most probable estimation of INL of ADC under test. The method was treated by simulations and experimental testing. The results compared with results from standardised sinewave histogram test confirm the improvement of this new suggested method in comparison with the basic simple exponential histogram test method.

ACKNOWLEDGMENTS

The work is a part of project supported by the Science Grant Agency of Slovak republic (No. 1/0103/08).

This work was supported by Agency of the Ministry of Education of the Slovak Republic for the Structural Funds of the EU under the project Centre of Information and Communication Technologies for Knowledge Systems (project number: 26220120020).

REFERENCES

[1] IEE Std. 1241 *IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters*, 2000.

[2] Algeria, F. – Arpaia, P. – Serra, A. C. – Daponte, P.: *ADC histogram test by triangular smallwaves*, Proc. of the 18th IEEE Instrumentation and Measurement Technology Conference IMTC/2001, May 2001, Budapest, Hungary, 1690–1696.

[3] Belcher, R. A.: *Multi-tone testing of quantizers using time and frequency analysis*, 4th Workshop on ADC Modelling and Testing IWADC'99, Bordeaux, France, 173–177, 1999.

[4] Min, M. – Land, R.: *Modified triangular wave for dynamic quality tests of A/D converters*, Advanced A/D and D/A Conversion Techniques and Their Applications, 154–156, 1999.

[5] Holub, J. – Komárek, M. – Macháček, J. – Vedral, J.: *Step-Gauss stochastic testing Method application for*

transportable reference ADC device, Proc. of 8th IWADC 2003, Perugia, Italy.

[6] Michaeli, L. – Šaliga, J. – Sakmár, M.: *Some errors of analogue signal sources for ADC exponential stimulus histogram test*, 12th TC-4 International Workshop, Iasi, Romania, September 18–22, 2007.

[7] Holcer, R. – Michaeli, L. – Šaliga, J.: *DNL ADC Testing by the Exponential Shaped Voltage*, IEEE Trans. on Instrumentation and Measurement, Vol. 52, No. 3, June 2003, 946–949.

[8] Michaeli, L. – Šaliga, J. – Sakmár M. – Buša, J.: *New approximation models for processing exponential stimulus histogram test of ADC*, 16th IMEKO TC-4: Florence, Italy, September 22–24, 2008.

[9] Vedral, J.: *Exponential Fit Test – Theoretical analysis and practically implementation*, 16th IMEKO TC-4 Florence, Italy, September 22–24, 2008.

[10] Šaliga, J. – Michaeli, L. – Holcer, R.: *Noise sensitivity of the exponential histogram ADC*, In: Measurement. – ISSN 0263-2241. – Vol. 39, No. 3 (2006), 238–244.

[11] Arpaia, P. – Daponte, P. – Michaeli, L.: *The influence of the architecture on ADC error modelling*, 4th International Workshop on ADC Modelling and Testing, Bordeaux, France, September 9–10, 1999, 132–141.

[12] Michaeli, L. – Michalko, P. – Šaliga, J.: *A new ADC fast testing method based on the unified error model*, Measurement. Vol. 41, No. 2 (2008), ISSN 0263-2241.

[13] www.ni.com/pdf/products/us/20043762301101dlr.pdf

[14] www.thinksrs.com/downloads/PDFs/Catalog/DS360c.pdf