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# ADC TESTING PROCEDURES ON SOME STATISTICAL METHODS BASIS

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*Abstract: An evaluation method of ADCs integral non-linearity on the basis of testing random signals application with given statistical parameters is represented.*

*Keywords: ADC, integral non-linearity, uniform distributed random test signals*

## 1 INTRODUCTION

Digital measurement systems are strongly affected by ADC errors. By adding distortion and non-linearity ADCs restrict measuring system dynamic. Frequency bandwidth, measurement accuracy etc.

In ADC error investigation the use of models has became more and more widespread. Modeling and simulation of ADC allows the errors characteristic to be analyzed. ADC with high performance requires to set new testing methods able to correctly estimate metrological characteristics [1-5].

A test of ADC metrology characteristics sometimes connected to significant volume of measurements. In particular, the definition of integral and differential nonlinearity requires an estimation for each code combination.

Special testing procedures should be developed for ADC embedded to measurement system or expert system which operation algorithms are based on statistical method [1]. Such testing procedures should be developed on the statistical methods, which are used for processing and analysis of information signals by such systems. Radiophysical signal processing systems, medical systems, vibration diagnostics systems are belongs to such system class.

The present paper deals with the evaluation method of ADCs integral and differential nonlinearity based on the testing random signals application with the given statistical parameters.

## 2 METHODS AND INSTRUMENTS

The static integral nonlinearity as a function of code bin $k$ is given

$$INL[k] = \frac{e[k]}{2^n Q} 100\% \tag{1}$$

where $Q$ -the ideal code bin width; $n$ - the number of digitized bin ; $e[k]$ - the difference between ideal and real code transition level $T[k]$. ($T[k]$ is the code transition level between code $k-1$ and code $k$). The maximum $INL$ is the maximum value of $INL[k]$.

The calculated histogram should have $2^n$ intervals for reliable estimation of ADC integral nonlinearity (where $n$ is the number of ADC bits).

For example, for 12 bit ADC a recommended number of histogram intervals is equal $n = 4096$. As far as not less than 20 values are required that in each interval of histogram should hit, the sample size of an analyzable information signal should be not less than 80200 values. Certainly, graphic representation and analysis of such histogram is very difficult procedure. However, using such type of histogram it is enough simple to define so-called missing codes.

An estimation of differential nonlinearity is more complicated procedure. It is suggested that tested histogram interval width is equal to the ideal width of code bin. Each interval of a histogram should be divided to a number of equal parts. The accuracy of differential nonlinearity (DNL) definition is depend on the number of partition of each testing histogram interval. If a number of partition of each test histogram interval is only 4 we have to analyze a histogram with 16384 intervals for 12 bit ADC. We can calculate the DNL of tested ADC only with 0.25 code bin width accuracy. In this case it is expedient to use the zoom procedure.

The differential nonlinearity can be determined as follows

$$DNL[k] = \frac{G\,W[k] - Q}{Q} \tag{2}$$

where, $W[k]$ - is width of code bin $k$ ; $Q$ - ideal code bin width $G$ - static gain.

Theoretically the nominal resolution of an ADC is determined by its physical number of bits N. In practice the effective number of bits $N_{ef}$ of an ADC identifies the actual resolution of the converter taking into account the signal to noise and distortion ratio.

$N_{ef}$ can be interpreted as follows: if the actual noise is attributed only to the quantization process, the ADC under test can be considered as equivalent to an ideal $N_{ef}$ -bits ADC insofar as they procedure the same RMS noise level. This parameter has an essential value, it depends on hardware of the measuring system, in which tested ADC is embedded.

It is necessary to apply a special hardware to realize corrective methods of some methodical errors. For example, analog filters of low pass frequencies filters (LPF) and high pass frequencies filters (HPF), system of rejector filters (RF) may be embedded to the hardware.

Even in concrete measuring system at application of such devices parameters $N_{ef}$ for different combinations of the filters application can be various.

The considered method of ADC integrated nonlinearity testing assumes to develop special hardware and software.

Let's consider in detail both theoretical basis of proposed method and hardware necessary for development of such ADC testing system.

Theoretical basis of the considered ADC testing method is followed. If random uniform distributed analog test signal is applied to the ADC input, the ADC output signal is random discrete time uniform distributed signal with the same statistical parameters. We assume a correctly operated ADC is used in the ideal case.

But in practice random signal generator, auxiliary hardware, ADC and software have instrumental and methodical errors. Many of the errors have an stochastic behavior. Therefore application of statistical approach for the test method development is profitable. Suitable statistical criterion should be selected for the ADC test procedure development.

Let's considered some statistical criteria that can be applied for the test procedure development.

1. A test of ADC output signal uniform distribution can be carried out by application of Kolmogorov criterion [ 6 ]. The criterion was successful applied to test of a stationarity of vibrating signals. The criterion is based on a statistics

$$D_n = \max_{-\infty<x<\infty} \left| F_n(x) - F_0(x) \right| \tag{3}$$

where, $F_n$ is empirical distribution function. The function is estimated on the ADC output random signal basis. It is necessary to remark that construction of the empirical distribution function is based on ranking of data. But volume of samples for developed testing procedure is more than 10000. It is complex problem to construct ranking set for the samples.

2. Other criterion that may be used for a test of ADC output signal uniform distribution is $c^2$ The main point of the criterion is followed. Let $m$ is the number of histogram intervals; $n_i$ is the relative frequency of hit to the $i$ -th interval

$$n_i = \frac{k}{n};$$

where $k$ is the number of hits to the $i$ -th interval; $n$ is the size of sample .

Statistic of the criterion is following,

$$l = m\,n \sum_{i=1}^{m} \left( n_i - \frac{1}{m} \right)^2 .$$

$l$ - has distribution $c^2$ with $r = m - 1$ degree of freedoms. If $l \le C$ - the hypothesis about uniform distribution of analyzed sample is trues. The threshold $C$ may be defined by application of the tables [9].

3. A test of ADC output signal uniform distribution can be carried out by application of estimation of kurtosis $g$ . Results of the paper [10-11] were used for the confidential interval definition. A confidential interval for kurtosis $g$ of uniform distribution with probability $P = 0.95$ is following

$$1.8 - \frac{2.248}{\sqrt{n}} \leq g \leq 1.8 + \frac{2.248}{\sqrt{n}}$$

where, $n$ is the sample size.

The experimental model of ADC nonlinearity testing system is developed in the Institute of Electrodynamics of the Ukrainian National Academy of Sciences. The system was constructed on the basis of vibration diagnosis system model [ 8,12,13]. A block diagram of the system model is shown in Fig. 1.

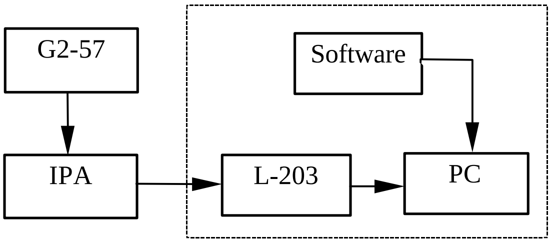

**Figure 1.** Block diagram of ADC testing system model.

Let’s considered elements of the system model in detailed.

*Low-frequency noise generator G2-57*. The generator allows to generate pseudo-random analog signals with binary, Gaussian or uniform distributions.

*Instrument of preliminary processing and filtration of analog signals (IPA)* instruments has been developed in the Institute of electrodynamics. It includes systems of analog Low pass filters (LPF) , High pass filters (HPF) and Rejector filters (RF).

*Data Acquisition Device L-203.* The L-203 is high-performance, multifunction analog, digital, and timing I/O board for the IBM PC. It contains a 12-bit ADC with up to 16 analog inputs.

*Special software.* Developed special software includes estimation of empirical histograms with some robust procedures and estimation of necessary statistical parameters. Peculiarities of developed software will be discussed below.

## 3 EXPERIMENTAL RESULTS

Generated by G2-57 pseudo-random signals with uniform distribution acted to the input of IPA. Systems of LPF, HPF, RF were switch off. A dynamic range of G2-57 output signals covers of ADC L-203 dynamic range. Random signals that generated by G2-57 with duration $T = 250$ mSec, $T = 125$ mSec, $T = 62.5$ mSec with sampling frequencies $f_q$ = 250 kHz, $f_q$ = 50 kHz have been analyzed. The sample sizes for $f_q$ = 250 kHz and duration $T = 250$ mSec, $T = 125$ mSec, $T = 62.5$ mSec were respectively $n$ = 62500, $n$ = 31250, $n$ = 15625. The sample sizes for $f_q$ = 50 kHz and duration $T = 250$ mSec were respectively $n$ = 12500.

The empirical histogram obtained from the preliminary analysis of a pseudo-random signal with uniform distribution generated by a generator G2-57 is represented in a fig. 2.

Therefore, generated pseudo-random signals have the outliers. An dynamic range of the outliers higher than the ADC dynamic range. The distortion is connected with peculiarities of analog pseudo-random signal generation. Special software procedures should be included for corrections of the distortions.

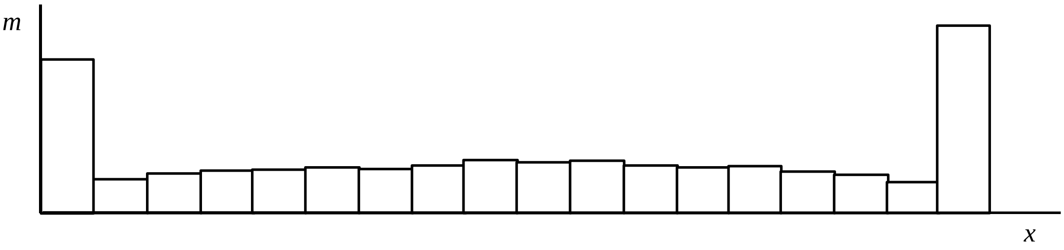

**Figure 2.** Histogram of pseudo-random signal preliminary analysis. $f_q$ = 250 kHz, $T = 250$ mSec

The correction procedure has been developed. It includes to the software for analysis of empirical histograms. A histogram of pseudo-random signal generated by G2-57 with robust correction procedures application is shown in Fig.3

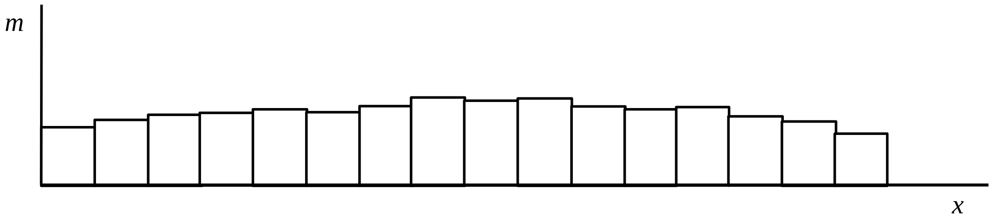

**Figure 3.** Histogram of pseudo-random signal preliminary analysis. $f_q$ = 250 kHz, $T = 250$ mSec

Histogram analysis may be successfully applied for effective number of bits $N_{ef}$ determination. For instants, Histogram of ADC output signal with L-203 short circuit input is represented in Fig.4.

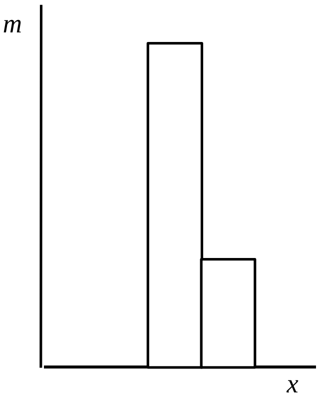

**Figure 4 .** Histogram of ADC output signal with L-203 short circuit input

The histogram proves the normal operating of L-203 board with 12-bit ADC. Histogram of ADC output signal with IPA short circuit input is represented in Fig. 5. A signal from IPA output acts to the L-203 input in the case. The histogram shows that it is necessary to carry out of IPA tuning for decrease of the instrument noise.

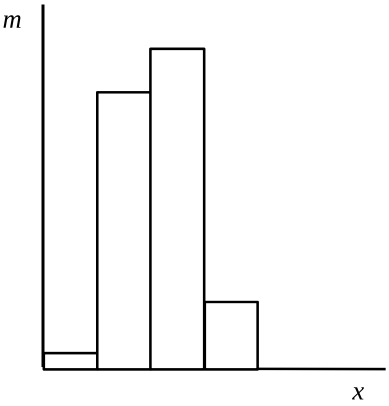

**Figure 5.** Histogram of ADC output signal with IPA short circuit input

Influences of Low pass filters (LPF) , High pass filters (HPF) and Rejector filters (RF) embedded to IPA also have been fulfilled. LPF with upper frequencies 10 kHz, 4 kHz, HPF with inner frequencies 1 kHz, 2 kHz, 500Hz and Rejector filters with rejection frequencies 50 Hz and 100 Hz are used for the investigation. A histogram of pseudo-random signal with uniform distribution generated by G2-57 is represented in Fig 6. The generated pseudo-random signal acted to the IPA input. Filter systems of IPA were switch off.

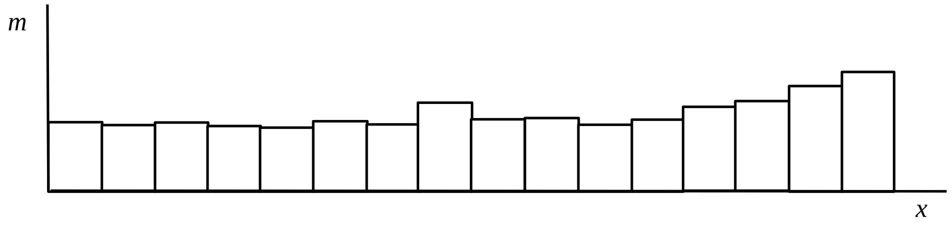

**Figure 5.** Histogram of ADC output signal . IPA Filter systems of IPA were switch off.
$f_q$ = 250 kHz, $T = 250$ mSec

A histogram of pseudo-random signal with uniform distribution generated by G2-57 when filter systems of IPA were switch on is represented in Fig 7. LPF with upper frequencies 10 kHz, HPF with inner frequencies 500Hz and rejector filters with rejection frequencies 50 Hz and 100 Hz are used for the investigation.

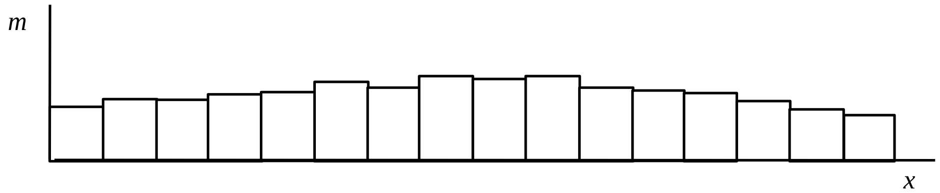

**Figure 5.** Histogram of ADC output signal . IPA Filter systems of IPA were switch on.
$f_q$ = 250 kHz, $T = 250$ mSec

A test on the kurtosis estimation basis was selected for the ADC testing procedure. It is a simple and reliable criterion. The developed software has possibility to divide the dynamic range of tested ADC and to carry out necessary estimation. A histogram could be constructed statistical parameters could be estimated for selected parts of ADC dynamic range.

## 4 CONCLUSION

The represented results prove the necessity to develop special software and hardware for ADC nonlinearity tests. The ADC test system should be included parts of an expert system or measurement systems where the ADC could be embedded.

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