Some errors of analogue signal sources for ADC exponential stimulus histogram test

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Abstract-This paper present some typical errors of exponential stimulus generated by analogue signal sources and their influence on errors of ADC testing by the histogram method. The analysed exponential signals are very close to linear signals such as triangular and sawtooth signals that can be very simply generated by active integrating circuit or passive integrating circuit with long time constant and/or the final voltage far beyond the ADC input range. The experimental measurements of some analogue generators on the market as well as passive and active generating circuit specially designed for the testing were performed. The sources of signal shape errors were investigated and capacitor was determined as the most critical component of generating circuit. The limitations of signal shape error were evaluated and related to the INL test error.

I. Introduction

ADC histogram test methods are widely used and some of them are standardised in IEEE and other standards. One of the main problems of these methods is the requirements of testing signal quality. In [1] the histogram test methods based on exponential stimulus was introduced. The main advantageous of exponential stimulus is that the exponential shape of signal is native shape of any transient effect in electronic circuit. It leads to the idea that exponential signal can be very simply generated and to the expectation that it could be simple to achieve a high quality of such signals. In [2] the influence of noise on exponential stimulus histogram test was analysed. The results showed that the longer is the time constant and the bigger is the final voltage of the signal for $t \to \infty$ the smaller is the influence of noise on the accuracy of testing. The exponential signals meeting these requirements are very close to linear ones such as triangular or sawtooth within the input range of ADC under test. The sources of such exponential signals are very common - it is generally known that the analogue generation of the most of triangular or sawtooth signals (pseudo-linear signals) is based on integrating circuit in role of generating circuit that produces de facto an exponential signal with long time constant and/or with an extreme virtual value of the signal in infinity. On the other hand the strict linear signal would be the ideal signal for INL and DNL testing because of the lowest number of samples required for testing with given uncertainty in comparison with all other shapes of ADC stimulus This fact leads the author to the idea to employ such analogue generators of pseudo-linear signals for ADC testing by histogram method where, instead of strict linear signal that is nearly impossible generate in praxis, the exponential stimulus model is used for real signal modelling and for post determination INL and DNL.

II Shape errors of pseudo-linear signal generators

Some common analogue function generators generating pseudo-linear signal were tested to evaluate to evaluate the restrictions of their application on ADC testing by exponential stimulus histogram method [2]. The output signals of generators were recorded by National Instruments PCI-6289 multifunction card with 18-bit resolution and INL < 10ppm of full scale range [3]. To avoid this residual ADC INL error, the digitised samples were rounded to 16 bits. Then, both exponential and linear fits were calculated using generally known least-square fit method (LMS) to evaluate the applicability of exponential fit and linear fit, respectively. LMS fit method for exponential stimulus (1) leads to the system of nonlinear equations that can not be solved analytically therefore the iteration method was applied. The differences between the real signals and its LMS fits (shape errors - Err) were calculated in LSB. Because of analogue source of the signals, their do not contain any discontinuities and a relatively small number of samples is needed to estimate their shape error. Therefore the sampling frequency (f_s) was chosen so that the total amount of recorded samples within the shot of the signal (T_s)

over the ADC input range was about a few thousand samples. The various combinations of T_s, f_s, ADC input range (*FS*), peak-to-peak value of signal (V_{pp}) and DC offset (*DC*) were tested. Because of noise in the signal for better evidence of the shape error behaviour the calculated error has been approximated by a polynomial in the figures. The figures below show some typical results acquired from analogue function generators on the market. The x-axis (k) represents the sequential number of the sample in analysed record.

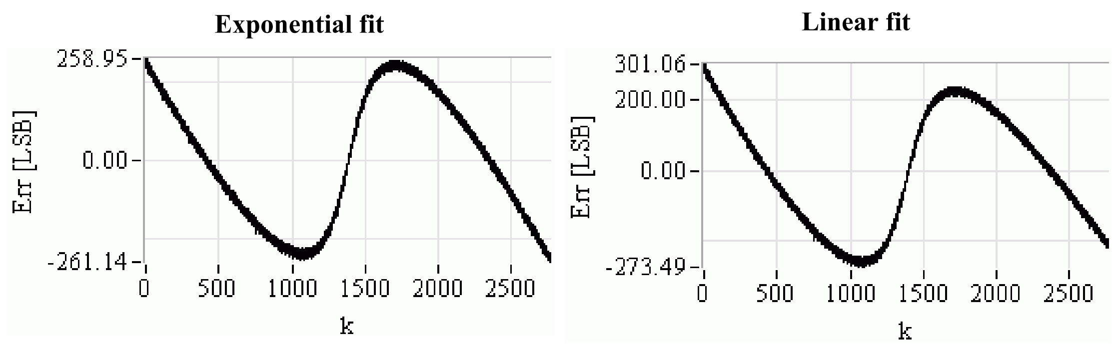

Fig. 1. Generator EZDIGITAL ([4]) FG7002C, f_s=625kHz, V_{pp} = ±12V, *FS* = ±10V, *DC* = 0V.

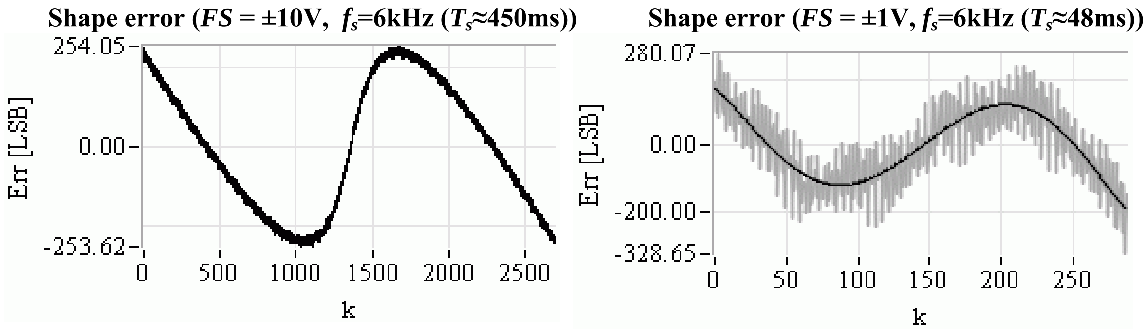

Fig. 2. Generator FG7002C [4], V_{pp} = ±12V, *DC* = 0V, exponential fit.

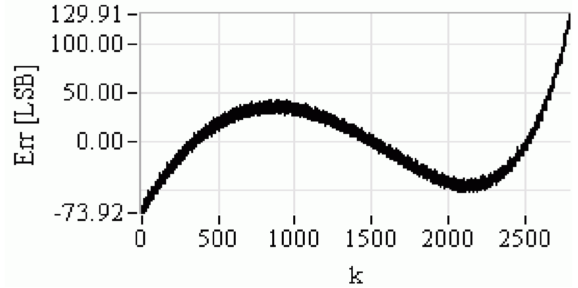

Fig. 3. Generator Metex 9150 [5], f_s=625kHz (T_s≈4.5ms), V_{pp} = ±12V, *FS* = ±10V, *DC* = 0V, exponential fit

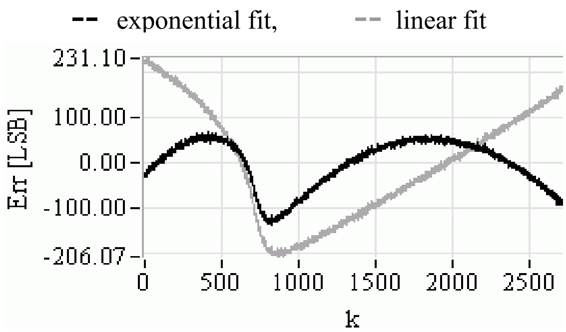

Fig. 4. Generator NG1-81, f_s=625kHz (T_s≈4.3ms), V_{pp} = ±12V, *FS* = ±10V, *DC* = 0V.

The acquired results confirmed the assumption that the pseudo-linear signals from the analogue function generator are closer to the exponential than linear one. Any change in duration of signal (generator frequency) and/or signal peak-to-peak value in relation to ADC input range has no important influence on shape error of the generated signal. Unfortunately the signal shape errors totally discredit such generators (at least those under test) from accommodation in ADC testing even using the exponential approximation.

III. Sources of shape errors in pseudo-linear signal generating circuits.

To determine the sources of shape errors of pseudo-linear signals the simple passive and integrating circuits with various types of capacitors, resistors, reference sources and amplifiers have been experimentally evaluated. First of all the passive integrating circuit was tested according to Fig. 5. NI

PCI 6289 was used to generate reference voltage (V_{ref}) to charge the capacitor as well as the generated signal digitiser. The recorded samples were rounded to 16bits resolution by the same way as it had been done for testing of generator hereinbefore.

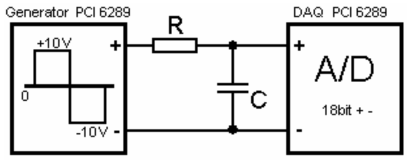

Fig. 5. Test stand for passive integrating circuit

Eighteen diverse capacitors were tested. Four from them were polypropylene and the rest - fourteen polyester metallised film capacitors. Some typical results are shown in the following figures.

Shape error (FS = ±5V) Shape error (FS = ±1V)

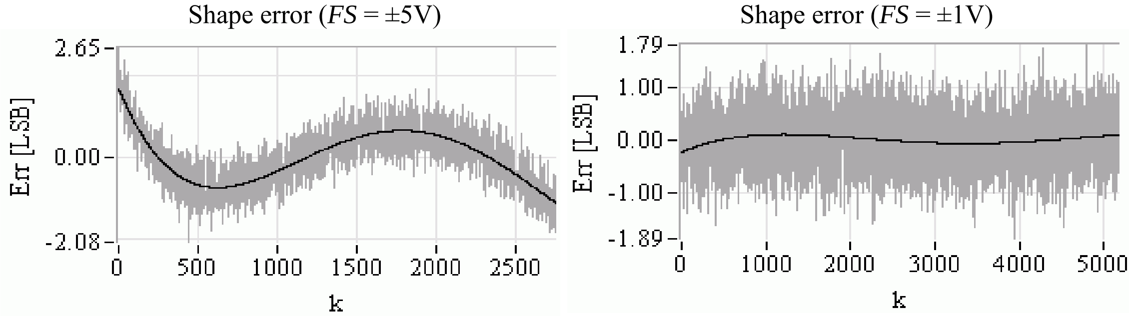

Fig. 6. Capacitor 470n/100V (ARCOTRONICS, MKT series: polyester [6]), R=82k, V_{ref}=±10V.

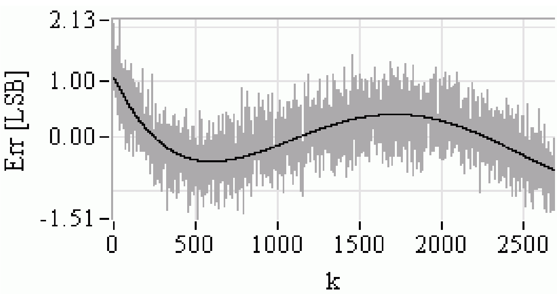

Fig. 7. Capacitor 470n/400V (ARCOTRONICS, MKT series: polyester [6]), R=82k, V_{ref}=±10V, FS=±5V.

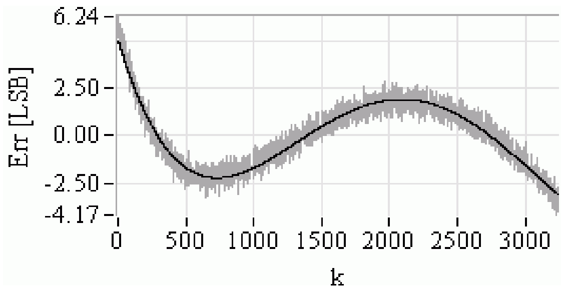

Fig. 8. Capacitor 470n/63V (WIMA, SMD 2824 series: polyester [10]), R=820k, V_{ref}=±10V, FS = ±5V.

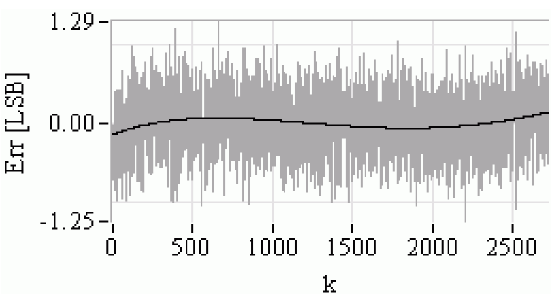

Fig. 9. Capacitor 470n/630V (SOLEN, MKP-FC series: polypropylene [7]), R=82k, V_{ref}=±10V, FS=±5V.

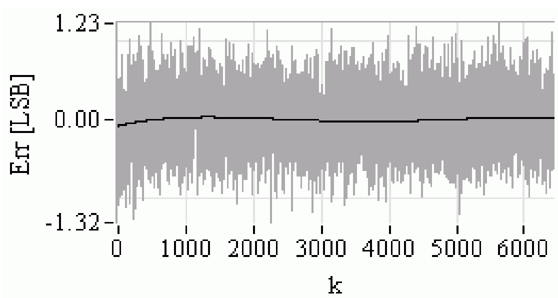

Fig. 10. Capacitor 470n/275V (ARCOTRONICS, R.46, MKP-x2 SH series: polypropylene [11]), R=82k, V_{ref}=±10V, FS=±5V.

We also exchanged resistors in the integrating circuits but their types and values have had no influence on exponential signal shape error. The performed test indicates that the main and the most significant source of signal shape error and the critical component is the capacitor. The tests indicate that the different types of capacitors (dielectric and other materials, internal construction, etc.) produce

different shape errors. The most important factor seems to be the dielectric. The polypropylene film capacitors have yielded better results than the polyester ones as it can be seen from the Fig. 6-10.
The performed tests also confirmed that some of the common capacitors on the market can be applied in exponential stimulus generating circuit for testing ADC up to 15-16 bits resolution.

IV. Shape errors in active integrating circuits.

The active integrating circuits are more common in praxis. To evaluate the influence of the active component – amplifiers on generated exponential signal shape error, seven different types of integrated amplifiers under test were used in active integrating network connected according to Fig. 11 . The short overview of the amplifiers under test and their basic parameters are shown in Tab. 1.

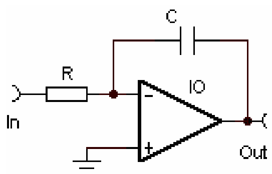

Fig. 11. Connecting diagram of active integrating network.

Model	**OPA604AP**	**MC1458**	**CA3130EZ**	**LF412CP**	**µA741CN**	**OP284F**	**OPA2134PA**
Technology	BiFET	Bipolar	BiMOS	JFET	Bipolar	BiFET	BiFET
R_{in}	10TΩ	300kΩ	1.5TΩ	1TΩ	2MΩ	-	10TΩ
SR	25V/µs	0.8V/µs	30V/µs	13V/µs	0.5V/µs	4V/µs	20V/µs
GBW	20MHz	1MHz	15MHz	3MHz	1MHz	4.25MHz	8MHz

Tab. 1. Some parameters of used integrated circuits.

Some of the acquired results are shown in following figures. First of all we compared the linear and exponential approximation of integrator output signal to proof that the signal is closed to exponential shape than linear one. Fig. 12 confirmed this assumption. Fig. 13 and Fig. 14 show the results acquired for the top amplifier and the low cost one. The results are very similar and the only little differences can be seen in noise background.

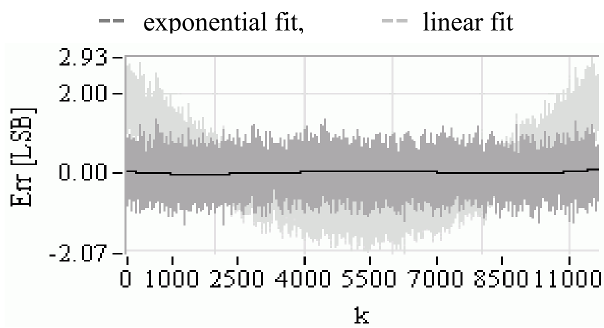

Fig. 12. Signal shape error on the output of active integrator: capacitor ARCOTRONICS 470n/275V, R=820k, amplifier: Analog Devices OP284F ([8], power ±12V, V_{pp} on output ±6V), FS = ±5V

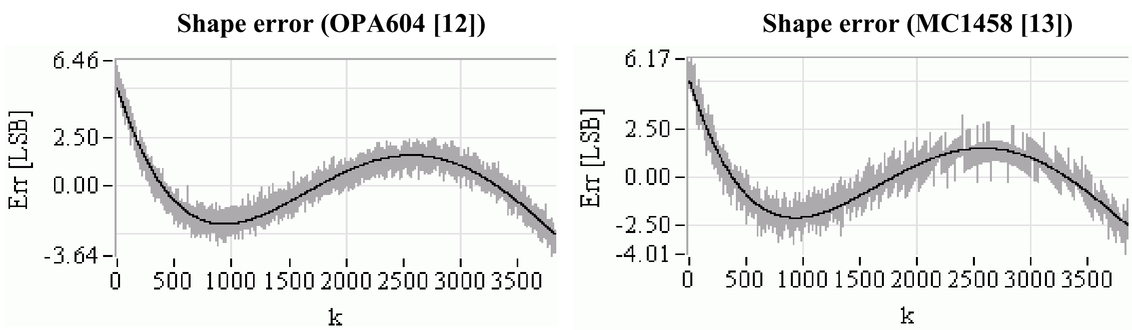

Fig. 13. Signal shape error on the output of active integrator: capacitor WIMA 470n/63V (SMD 2824), R=820k, (power ±12V, V_{pp} on output ±6V, FS = ±5V)

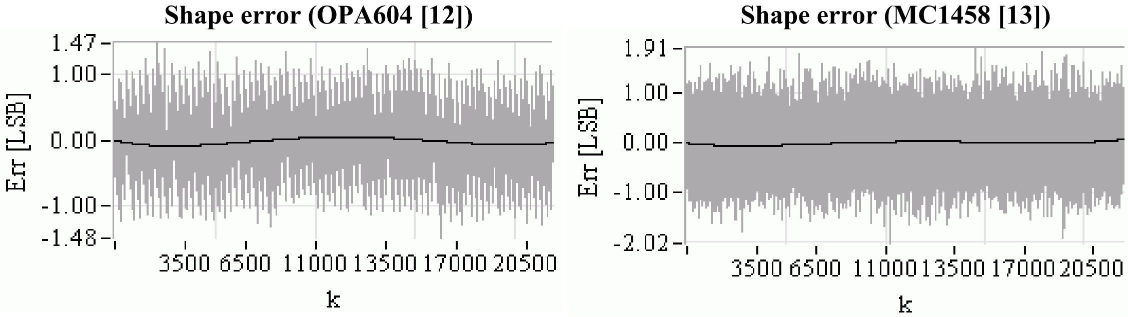

Fig. 14. Signal shape error on the output of active integrator: capacitor ARCOTRONICS 470n/275V (MKP-x2 SH), R=820k, (power ±12V, V_{pp} on output ±6V, FS = ±5V)

All the performed tests indicate that nearly any common operational amplifier can be used in generating circuit and their type has a negligible influence on deterioration of signal shape. Of course this is valid only for exponential signals with a long time constant longer than about tens of milliseconds.

V. Applications of the components in INL testing.

To verify the convenience of the chosen components from the previous test for INL testing by the exponential stimulus histogram testing ([1]) a few experimental tests were performed. The results of the performed tests are shown in Fig. 15 and Fig. 16.

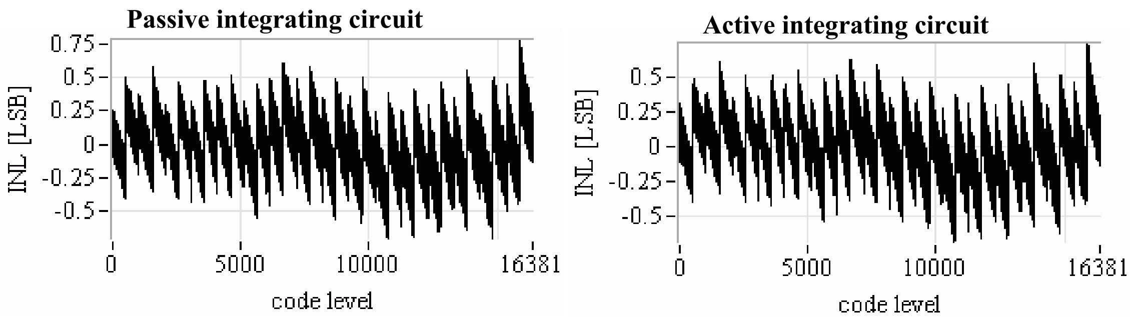

Fig. 15. INL of USB6009 [9] (14 bit, f_s=48kHz, V_{pp} on output ±6V, FS = ±5V) measured by exponential stimulus histogram method.

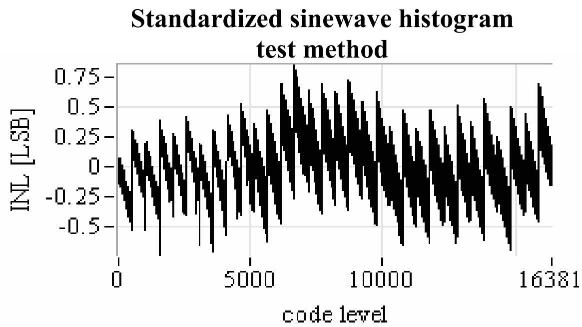

Fig. 16. INL of USB6009 [9] (14 bit, f_s=48kHz, V_{pp} on output ±6V, FS = ±5V) measured by standardised sinewave histogram method.

The figures declares that the exponential stimulus generating network built from common cheap components mainly the capacitor available on the market can generate the exponential stimulus with satisfied accuracy for INL testing at least 14-bits ADCs

VI. Estimation of influence of exponential stimulus shape errors on INL test results

Let suppose that deteriorate stimulus can be described in time domain by the model:

$$x(t) = (FS + B)\exp\left(-\frac{t}{\tau}\right) - B + Err(t), \tag{1}$$

where τ is the time constant of the exponential pulse, the interval (-*FS*, *FS*) is the full-scale input range of bipolar ADC under test, -*B* is the final value of the exponential signal for $t \to \infty$, and *Err*(*t*) is an error time function covering any difference of real signal from the ideal exponential one. Because of linear operations in transformation of signal in time to the histogram of codes from the record for linear ADC and following calculation of INL (normalisation, DC shift), the peak-to-peak value of normalised value of the error function is equal to the peak-to-peak value of errors in final INL:

$$\frac{|\max(Err(t))| + |\min(Err(t))|}{2FS/(2^N - 1)} = |\max(\Delta_{err}(INL[k]))| + |\min(\Delta_{err}(INL[k]))| \tag{2}$$

$\Delta_{err}(INL[k]) = INL_{err}[k] - INL[k]$ is the error of *INL* for code *k*. *INL*[*k*] is the real error-free *INL* of ADC under test and $INL_{err}[k]$ is the spoiled *INL* calculated from cumulative histogram built from deteriorated exponential stimulus. This fact leads to the very simple practical evaluation of quality and applicability of any exponential stimulus source: digitize the test signal from the evaluated source acquired by an ADC with better resolution (accuracy) than the resolution of supposed ADC under test results, then calculate the exponential fit of the record and the residuum of the fit expresses the error function. Its maximum in comparison with required accuracy of testing either accredits or discredits the source for the testing according its shape imperfection.

VII. Conclusions

The paper introduces a simple analysis of deterioration of exponential stimulus for ADC histogram test method based on experimental measurements. The experiments show that the common analogue function generators are not applicable for ADC testing even using the exponential fit. The most critical component of stimulus generating circuit in practical realization is the capacitor. The other components such as source of reference voltage, resistor and amplifiers in active integrator influence on the shape of generated exponential signal but this influence is negligible in comparison with capacitor if common modern components are used. On the other hand, some common capacitors with polypropylene dielectric on the market enable simple realisation an accurate passive and/or active generating circuit. Besides a simple model of signal deterioration was suggested. The model allows simple estimating the limitation of a generator for required ADC testing by exponential histogram method.

Acknowledgement

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References

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