STEP-GAUSS STOCHASTIC TESTING METHOD APPLICATION FOR TRANSPORTABLE REFERENCE ADC DEVICE

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Abstract – The Step-Gauss stochastic test method has been developed to enable testing of precise AD converters that are difficult to test by standard methods using deterministic signal. A transportable high stable reference AD device was designed and realised for a comparison of systems for testing a dynamic quality of ADCs or AD modules using mainly those standard (deterministic) test methods. However, the stochastic test methods require different conditions and test arrangement due to large number of samples that has to be acquired during the stochastic test. This article describes how the stochastic test has been designed, arranged and performed considering its specific features.

Keywords: ADC testing, stochastic test signal, reference AD device

INTRODUCTION

To enable testing of high-linearity and/or high-resolution AD converters that are difficult to test by standard methods using deterministic signal [1], stochastic test methods have been developed [5]. Histogram test can use various input signals and principally allows use noise as the input signal. To overcome difficulties related to generation of large-scale uniformly distributed stochastic signal, a method based on superposition of Gaussian noises with equidistantly spaced DC shifts has been proposed [4] and theoretical analysis has been provided there. The practical applicability of this method has been verified by comparison of results obtained by this method and by standard histogram test using deterministic (ramp) testing signal for an internal ADC of digitising oscilloscope.

HISTOGRAM STOCHASTIC TEST

Each particular testing signal is Gaussian noise with probability density function $f_G(\mu,\sigma)$ where μ is the mean value and σ means standard deviation. It is easy to show that

$$\lim_{\Delta\to 0}\left[\left(\sum_{k=-\infty}^{\infty} \mathrm{f}_G(\mu + k.\Delta,\sigma)\right) - \frac{1}{\Delta}\right] = 0, \quad k \text{ integer} \qquad (1)$$

Independently on the value of μ and σ. In other words, the superposition of Gaussian distributed noises with the equidistantly spaced DC values by step Δ is for suitably small values of Δ an excellent approximation of uniformly distributed signal. Measurement is provided for each Gaussian noise separately but histograms are cumulated. Theoretical analysis of such signal has been provided in [4].

The sensitivity of resulting probability density function to the variances in DC positions of Gaussian sub-signals, to variations of their power (r.m.s. value) and the border error was described there. It is important to know that from that analysis follows that testing signal that can be used to test high-resolution ADCs can be built in this way.

Moreover, it is useful to note that in the case that particular Gaussian stochastic signals are generated by DAC, the used DAC should provide better accuracy than only the relevant portion of tested ADC. It means it is not necessary to compare the linearity of the full scales of tested ADC and testing DAC.

ENOB CALCULATION

ENOB (Effective Number of Bits) calculation follows the usual way that is described in [3] or in IEEE-STD-1241. In the concrete, DNL values are estimated from the measured histogram and INL values are then calculated using DNL:

$$DNL_i = \frac{Oi - O}{O} \qquad INLj = -\sum_{i=1}^{m-2} DNL_i \qquad (2,3)$$

where O_i is the value of the i-th code of cumulative histogram and O is its ideal value that can be achieved by the following way (the common way of indexing of code words 0,1,…,m-1 is expected) :

$$\mathrm{O} = \frac{\sum_{i=1}^{m-2} \mathrm{O}_i}{m-2} \qquad (4)$$

Assuming statistical independence of INL values and quantisation error, the standard deviation of ADC output can be calculated as

$$\sigma_c = \sqrt{\frac{1}{12} + \frac{1}{m-2}\sum_{i=1}^{m-2} INL_i^2} \tag{5}$$

Then, ENOB can be calculated as

$$ENOB = \log_2 \frac{m}{\sigma_c \sqrt{12}} \tag{6}$$

It is possible to obtain set of values of integral ENOB for particular (narrow) frequency bands by including tunable band-pass filter to the input signal path and by procedure repetition for different settings of middle filter frequency. Description of this procedure and relevant relations, as well as practical results obtained on digital oscilloscope and PC plug-in ADC board has been provided in [5]. In this case, the variance of (wide-band) noise source has to be high enough, or, in different words, the step of DC calibrator has to be small enough. To overcome this difficulty of the method, its new modification has been developed. It substitutes band-pass filter that reduces signal variance significantly with low-pass tunable filter. In this case, it is necessary to recalculate output values in the following way.

Let us expect

$$\sum_{i=0}^{j} \Delta f_i = f_j \tag{7}$$

$$ENOB_{LP}(f_j) = \frac{1}{f_j} \cdot \sum_{i=0}^{j} \Delta f_i \cdot ENOB(f_i) \tag{8}$$

where $ENOB(f_i)$ represents measurement results for pass-band filter of mean frequency f_i and bandwidth Δf_i application. Then follows

$$ENOB_{LP}(f_j) = \frac{1}{f_j} \cdot \left[\sum_{i=0}^{j-1} \Delta f_i \cdot ENOB(f_i) + \Delta f_j \cdot ENOB(f_j) \right] \tag{9}$$

$$ENOB(f_j) = \frac{1}{\Delta f_j} \cdot \left[f_j \cdot ENOB_{LP}(f_j) - \sum_{i=0}^{j-1} \Delta f_i \cdot ENOB(f_i) \right] \tag{10}$$

$$ENOB(f_j) = \frac{f_j}{\Delta f_j} \cdot ENOB_{LP}(f_j) - \frac{f_{j-1}}{\Delta f_j} \cdot ENOB_{LP}(f_{j-1}) \tag{11}$$

For wide bandwidths (f_{i-1}, f_i), it is more accurate to write as index of the result :

$$ENOB(\sqrt{f_i \cdot f_{i-1}}) = \frac{1}{\Delta f_j} \cdot \left[f_j \cdot ENOB_{LP}(f_j) - f_{j-1} \cdot ENOB_{LP}(f_{j-1}) \right] \tag{12}$$

where $ENOB(f_{i-1}, f_i)$ is the means effective number of bits estimation in the frequency band (f_{i-1}, f_i), $ENOB_{LP}(F_i)$ is the integral effective number of bits obtained by application of low-pass filter with cut-off frequency f_i. Uniformly distributed power spectral density of input stochastic test signal is expected.

PORTABLE REFERENCE ADC DEVICE

To assess the real precision of ADC testing systems and to compare advantages and disadvantages of applied methods, a transportable high stability reference AD device was designed and realised in the Dept. of Measurement of FEE - CTU in Prague in 2000-2003 [2]. Its usability was confirmed during the first comparative measurements among the Laboratoire de micro-électronique IXL - University Bordeaux, the laboratory of Institute of Microelectronics and Mechatronics Systems Ilmenau, and the ADC T&M Laboratory of the Dept. of Measurement of FEE CTU in Prague. In current development stage, it can host the following AD ICs:

- 14-bits cascade ADC AD9240; 10 MSa/s;
- 16-bits sigma delta ADC AD7723; 1,2 MSa/s;
- 16-bits successive approximation ADC AD976A; 200 kSa/s.

MEASURED RESULTS

In our case, the last IC (AD976A) has been tested. The following measuring equipment was used: Stanford Research signal generator DS360 as the noise generator and Fluke 5100B as a DC voltage source. Low-cost op-amp TL081 served as a summing amplifier.

According [4], 10^8 samples are necessary for Step Gauss test of 16-bits ADC to achieve 5% confidence level of DNL evaluation and the same statistical error of DNL evaluation. Due to nature of Step Gauss test, this amount of samples has been split into 44 blocks with different DC offsets of test Gauss signal. The measured DNL and INL are depicted in Fig. 2.

The result differences between different tests fit easily into uncertainty interval (see Tab. 1). However, they confirmed well known rule that sine-fit test provides lower ENOB due to the fact that also input and internal noise are considered, while for long-record-based FFT test and for all histogram-based methods those types of noise are filtered out.

Tab. 1 Test results for SAR ADC of 16 bit ADCAD976

	Deterministic (harmonic) signal			Stochastic s.
Test Freq.	ENOB DFT	ENOB SIN-FIT	ENOB HIST-SIN	ENOB STEP-GAUSS
10 kHz	14,62	14,37	14,62	14,38
20 kHz	14,31	14,24	14,35	14,23
50 kHz	14,14	14,18	14,23	14,11

CONCLUSION

The applicability of Step-Gauss stochastic test method has been confirmed on 16 bit, 200 kSa/s successively approximating ADC housed in portable reference device. It enables to perform comparative measurements even for stochastic tests, however, it is necessary to carefully design the test conditions to balance the requirements for high number of samples necessary for stochastic tests and limited data transfer capability of the device. Detailed results and their comparison with deterministic test results will be shown in the full text.

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REFERENCES

[1] IEEE Std 1241-2000, *IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters*, The Institute of Electrical and Electronics Engineers, Inc., New York, 2000.

[2] Fischer, J., Haasz, V., Slepicka, D., Vedral, J.: *Transportable Reference AD Device – New Innovated Version*, submitted to XVII IMEKO World Congress, Dubrovnik, Croatia, June 2003

[3] Carbone, P., Petri, D.: *Noise Sensitivity of the ADC Histogram Test*, IEEE Instrumentation and Measurement Technology Conference, St. Paul, Minnesota, May 1998

[4] Holub, J., Vedral, J.: *Signal Source for Statistical Testing of ADC,* XVI. Congress IMEKO, 5th Worshop on ADC Modelling and Testing, Wien 2000.

[5] Vedral, J., Holub,J.: Holub, J., Vedral, J., Kubín. M.: *Improvement of Step-Gauss ADC Stochastic Test Methods*. ADDA&EWADC 2002, Prague, p.115-118.

[6] R. Martins, A. Cruz Serra, *ADC Characterization by Using the Histogram Test Stimulated by Gaussian Noise, theory and Experimental Results*, Measurement, Elsevier Science B. V., vol. 27, n. 4, pp. 291-300, June 2000

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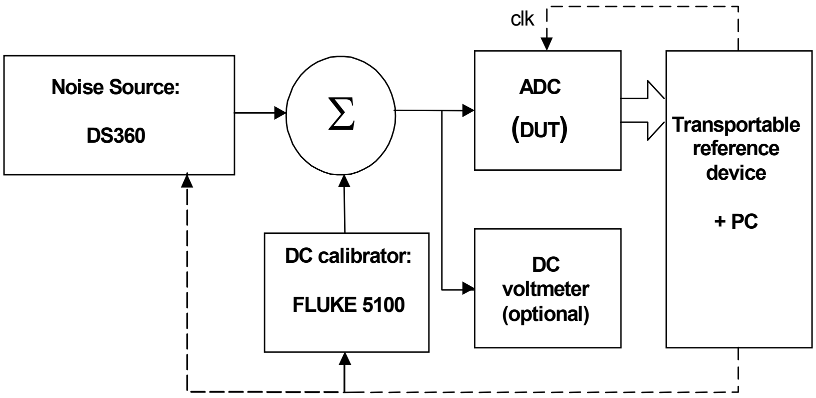

Fig. 1 Step-Gauss Stochastic Test Arrangement

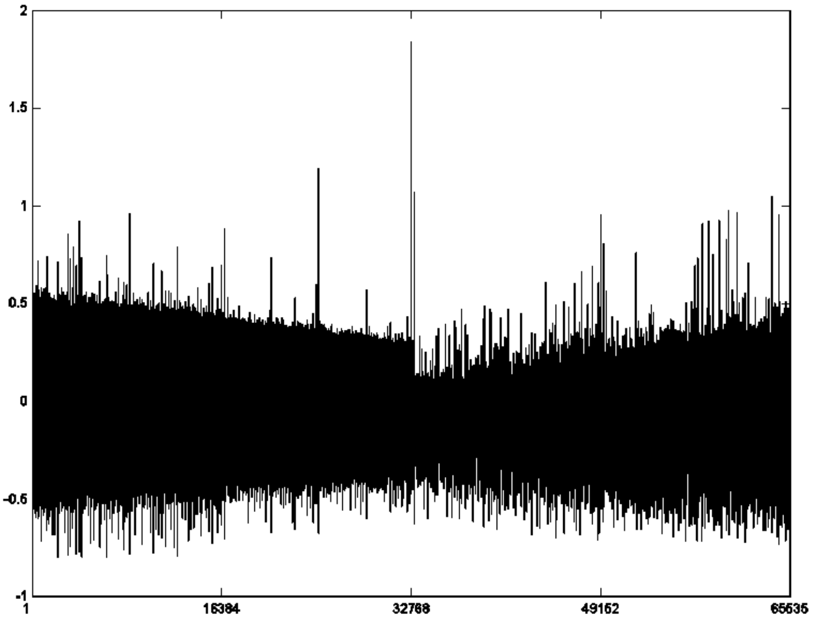

Fig. 2 DNL (top) and INL (bottom) of the tested AD976A [LSB]. Step-Gauss stochastic test method used.