IMPROVEMENT OF STEP-GAUSS ADC STOCHASTIC TEST METHOD

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ABSTRACT

Improvement of Analog-to-Digital Converters testing method that is suitable for testing of high-resolution AD converters (e.g. Σ-Δ or dither-based) or on the contrary ultra high-speed AD converters is presented. The method is based on the histogram test driven by stochastic signal with defined probability density function. By repeating of the test for different settings of band-pass filter that is inserted to the input testing signal path it is possible to obtain an estimation of frequency dependency of effective number of bits. The results have to be recalculated to equivalent band-pass filtering. Practical demonstration confirmed wider applicability than for direct band-pass filter application.

Keywords: ENOB, ADC, stochastic signal

INTRODUCTION

Low sampling frequency, high-resolution AD converters (e.g. Σ-Δ or dither-based) or on the contrary ultra high-speed AD converters (e.g. with opto-electronic core) testing by means of deterministic testing signal is problematic due to the lack of (pure) testing signals. In such cases, stochastic input signals seem to be better applicable for testing [1], [2].

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 (Fig.1) has been proposed [3] 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 digitizing oscilloscope [4]. One has carefully design the test setup to obtain enough code words covered by each particular test signal.

HISTOGRAM STOCHASTIC TEST

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

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

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 [3]. 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.

The following formula should be used to calculate the necessary amount of samples to achieve a required accuracy:

$$k = m \cdot \frac{a^2}{\varepsilon^2} \quad (2)$$

where k is number of required samples, m is number of code words of the tested ADC, a = 1,96 for 5% confidence level of DNL evaluation and ε is the statistical error of DNL evaluation (5% in our case).

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:

$$DNL_i = \frac{Oi - O}{O} \qquad INLj = -\sum_{i=1}^{m-2} DNL_i \qquad (3,4)$$

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) :

$$O = \frac{\sum_{i=1}^{m-2} O_i}{m-2} \qquad (5)$$

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

$$\sigma_c = \sqrt{\frac{1}{12} + \frac{1}{m-2}\sum_{i=1}^{m-2} INL_i^2} \qquad (6)$$

Then, ENOB can be calculated as

$$ENOB = \log_2 \frac{m}{\sigma_c \sqrt{12}} \qquad (7)$$

The practical applicability of this method has been verified by comparison of results (Tab.1) obtained by this method and by standard histogram test using deterministic (ramp) testing signal for an internal ADC of digitizing oscilloscope [4].

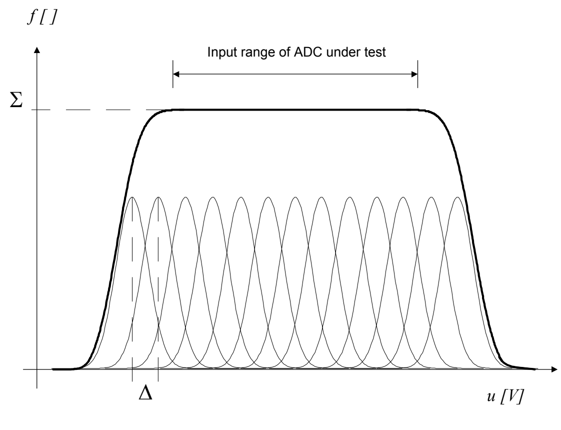

Fig.1 Stochastic test signal generation

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 (see Fig.2) 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:

$$\sum_{i=0}^{j} \Delta f_i = f_j \qquad (8)$$

$$ENOB_{LP}(f_j) = \frac{1}{f_j} \cdot \sum_{i=0}^{j} \Delta f_i \cdot ENOB(f_i) \qquad (9)$$

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

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

$$ENOB(f_j) = \frac{1}{\Delta f_j} \cdot \left[f_j \cdot ENOB_{LP}(f_j) - \sum_{i=0}^{j-1} \Delta f_i \cdot ENOB(f_i) \right] \qquad (11)$$

$$ENOB(f_j) = \frac{f_j}{\Delta f_j} \cdot ENOB_{LP}(f_j) - \frac{f_{j-1}}{\Delta f_j} \cdot ENOB_{LP}(f_{j-1}) \qquad (12)$$

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

$$ENOB(\sqrt{f_i \cdot f_{i-1}}) = \frac{1}{\Delta f_j} \cdot \left[f_j \cdot ENOB_{DP}(f_j) - f_{j-1} \cdot ENOB_{LP}(f_{j-1}) \right] \qquad (13)$$

where *ENOB()* 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.

	Deterministic (harmonic) signal			Stochastic s.
Frequency	$ENOB_{DFT}$	$ENOB_{SIN-FIT}$	$ENOB_{HIST-SIN}$	$ENOB_{STEP-GAUSS}$
500 kHz	6,90	7,02	7,05	7,20
1 MHz	6,92	7,01	7,10	7,00
2 MHz	6,90	7,05	7,08	7,06

Tab. 1 Test results for internal flash ADC of digital oscilloscope HP 54645A (200MSa/s)

Low-pass Filter		Equivalent Nafrrow-band ENOB: Recalculation according (13)	
f_{LP} [kHz]	$ENOB_{LP}$	f_{BP} [kHz]	$ENOB_{BP}$
2	12,08	2	12,08
5	12,03	3,2	12,00
10	11,96	7,1	11,89
50	11,67	22,4	11,60
100	11,56	70,7	11,45
200	11,37	141	11,18
300	10,94	245	10,08

Tab. 2 Test results for ADC Plug-in card AD14DSP (250kSa/s)

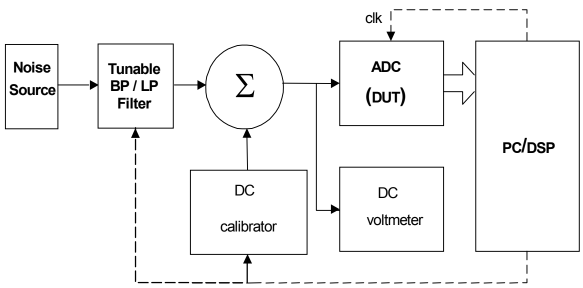

Fig. 2 Arrangement of testing system for ADC stochastic testing

MEASURED RESULTS

Two tested objects have been selected to confirm practical applicability. The results of testing of digital oscilloscope HP54645A are shown in the Tab.1 Since the testing system operates up to several MHz and the sampling rate of the internal flash 8 bit ADC is 200 MSa/s, no differences have been found. Small variations of ENOB values shown in Tab. 1 fall within uncertainty level that is given by finite number of samples, as indicated in formula (2). This topic is deeply analyzed in [4].

However, the results of oscilloscope testing are useful since results of deterministic testing by histogram method driven by harmonic signal are available (see Tab. 1). The differences in evaluated ENOB are less than 2% in all cases.

ADC plug-in board has been tested as the second object. The results are given in the Tab. 2. For this object, deterministic results are not available for corresponding frequencies (we have results of FFT and sine-fit tests available but those can not be compared with histogram method results due to the known fact that histogram methods give generally higher ENOB since internal noise of ADC can not affect the results).

As the summing amplifier the AD825-based circuit has been used. The bandwidth (-3dB) of summing circuit is greater than 10 MHz.

CONCLUSIONS

A new modification of Step-Gauss ADC test method has been developed. In comparison with original version, it allows applications (with given testing equipment) in wider range of test cases since it significantly reduces requirements of noise generator (lower RMS value of the output Gaussian noise is required for the same achieved accuracy of resulting ENOB). Experimental results that confirm the method applicability are available.

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