

ADC Testing Based on Frequency Estimation

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CONTENT

The additive noise causes in general the variation of the frequency of signal. In the special case of the analogue to digital conversion the quantisation noise is an inherent part of the conversion process and causes variation of the frequency of the digitised signal. The frequency of the signal on the output of A/D converter can be estimated from the set of samples using LMMSE criterion of estimation. For the sinusoidal input signal the difference between actual frequency f and frequency estimate of the output signal \hat{f} is given by the relation

$$2\pi\hat{f} = 2\pi f + \frac{\sum_1^N W_i \sum_1^N t_i W_i \delta_i - \sum_1^N t_i W_i \sum_1^N W_i \delta_i}{\sum_1^N W_i \sum_1^N t_i^2 W_i - \left(\sum_1^N t_i W_i\right)^2} \quad (\text{A})$$

where

t_i time instants of sampling,

$$\frac{1}{\cos^2(2\pi f t_i + \theta)} = \frac{1}{W_i}, \quad \delta_i = \frac{e(t_i)}{\cos(2\pi f t_i + \theta)}$$

$e(t_i)$ samples of additive noise.

The variation of the frequency estimate

$$\text{var}(2\pi\hat{f}) = \sigma^2 \frac{\sum_1^N W_i}{\sum_1^N W_i \sum_1^N t_i^2 W_i - \left(\sum_1^N t_i W_i\right)^2} \quad (\text{B})$$

is proportional to the variance σ_N^2 of the noise process $e(t_i)$. In the followed case the term σ_N^2 represent the quantisation noise of ADC.

In the practical implementation of this procedure for finding ENOB of ADC under the test, the sinusoidal signal with exactly known frequency f and small THD is applied to the ADC input. Then the batch of samples is taken at time intervals randomly distributed from the origin of time scale (e.g. zero crossing of the signal). For each batch the frequency difference and variance is calculated. The resultant average standard variance is evaluated and formula (B) is implemented for finding ENOB.

The novelty of the method until now rarely used for ADC testing consists in the modification of the formula for the frequency estimates and eliminating the errors caused by formerly used relations approximating the equation (B).

The proposed method represents an alternative to the existing variety of ADC test methods. The experimental results performed on several types of ADC shows that measured ENOB is less than nominal and in majority cases even slightly less than one obtained by other methods (usually by 0.5 bit). The reason may lie in the fact, that the proposed method is more sensitive to the sampling time jitter.

PRACTICAL MEASURING OF AD CONVERTER

Method of frequency estimation, similar to row of others, uses input harmonic signal. Even here is necessary to cover whole range of AD converter so that all available bits could be measured and on the other hand the input signal must not be cut off and so distorted. This method of measurement differs from traditional reconstruction tests by request on exact knowledge of sampling and signal frequency, its amplitude and offset but also of the start-time of equidistant sampling. Therefore complete AD converter could be tested and e.x. uncertainties of begin of sampling and offset are counted in results.

All measurements of AD converters were based on configuration on fig. 1. As generator of reference harmonic signal a low-distortion generator Stanford Research DS360 was used. Its *OUTPUT* was connected directly to the AD converter and its reference synchronous output *SYNC* was connected to a universal counter Stanford Research SR620. This counter serves for exact measurement of period of harmonic signal and also for measurement of time-delays between the first AD conversion (signalized with output *BUSY*) and zero crossing of sinewave.

The real phase delay T_{real} could be counted as difference of period of harmonic signal and measured time T_{meas} (see fig. 2). This time should be corrected for exact calculation because of the different delay of signals *SYNC* and *BUSY*. Therefore for determination of relation between T_{meas} and desired phase ϕ several data files with default frequency was measured and using sinewave curve fit method ideal phases were counted. For these phases linear regression was applied and the desired relation expressed.

Owing to the minimal mean quadratic deviation 4.10^{-5} rad could be claimed that this relation is exact enough.

The number of half-periods n was chosen 10 and number of samples per half-period m 4,2. Then with sampling rate 4 882,711 Hz is the frequency of input harmonic signal 1 162,550 Hz and samples 21.

Because the final formulas of method of frequency estimation are derived using arcsin function which is defined only in interval $-\frac{\pi}{2} \div \frac{\pi}{2}$, re-count of all data to this interval is needed. Samples with distance of multiples of 2π could be simply moved here with their corresponding phase, samples with distance of multiples of 2π and in addition π could be moved to this interval with their value multiplied by -1 (see fig. 3).

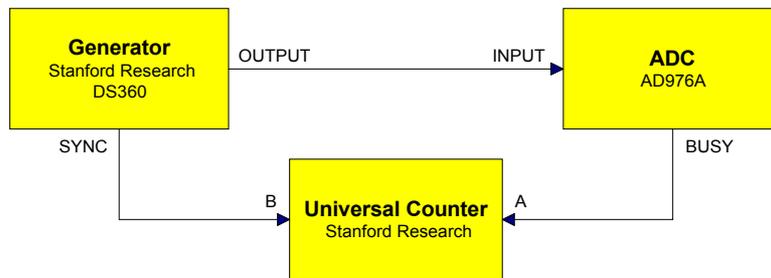


Fig. 1 Block diagram of measurement

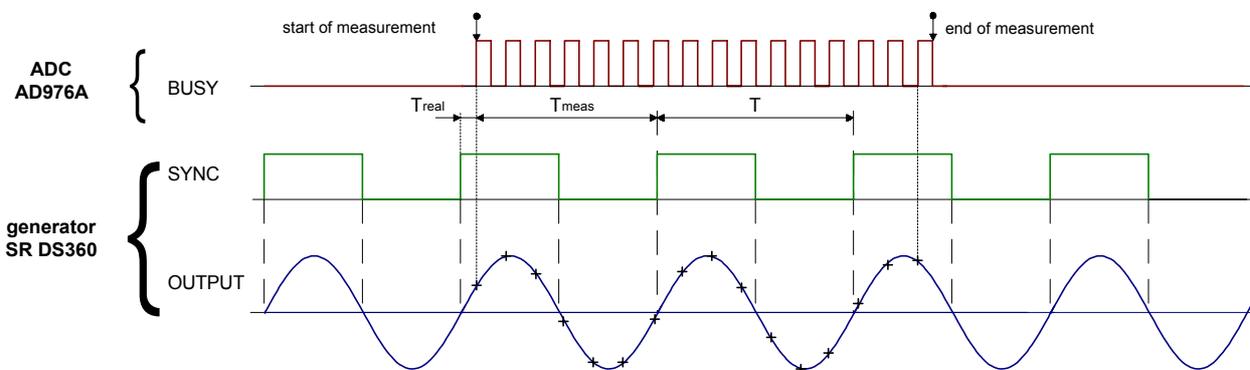


Fig. 2 Time diagram of measurement

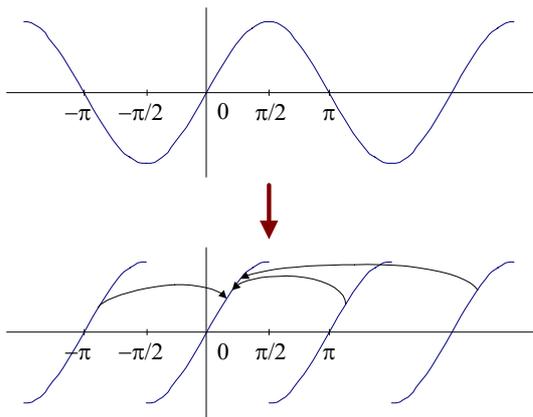


Fig. 3 Folding of sinusoidal wave to the definition interval of arcsin function

Measured and processed were altogether 16 data files. Intention was an equal distribution of phases. From each file estimation of frequency deviation was counted and from all 16 estimations final estimation of frequency deviation and corresponding effective number of bits were determined using selective variance (because of the character of these data). This algorithm was also repeated for another number of half-periods with the same data files (see fig. 4).

Dependence of ENOB on number of samples is naturally a parasitic effect, which should be still explored, especially because from the physical point of view it should never happen. For low number of half-periods the curve is approaching to the same effective number of bits as measured with others traditional methods (~14,01).

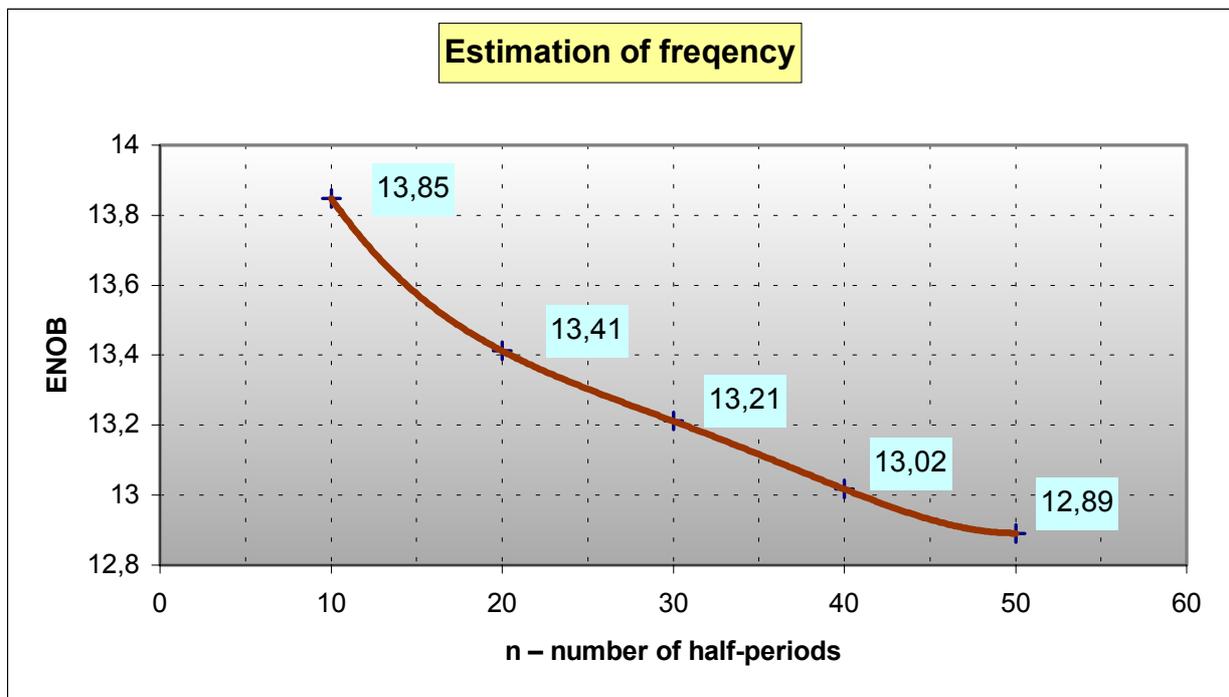


Fig. 4 Dependence of effective number of bits on number of half-periods

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