

EDUCATION METHODS OF ANALOGUE TO DIGITAL CONVERTERS TESTING AT FE CULS

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Abstract. Education methods for testing of Analogue to Digital (A/D) converters in laboratory exercises at the Czech University of Life Sciences Prague, Faculty of Engineering, Department of Electrical Engineering and Automation are stated in the paper. A/D converters are inseparable parts of significant quantity of sensors and actuators used in agriculture machinery. Short introduction to the background and principles of A/D converters and to their parameters are presented. Next part of the article deals with a description of the test methods in time and frequency domain. The used methods are the histogram test and the best sine wave fit method in time domain and frequency analyses using Discrete Fourier Transformation in frequency domain. The measured parameters are Effective Number of Bits (ENOB), Signal-to-Noise Ratio (SNR), Signal-to-Noise And Distortion (SINAD), Effective Resolution (ER), Total Harmonic Distortion (THD) and Spurious-Free Dynamic Range (SFDR). The following part contains an implementation of the proposed algorithms in LabVIEW graphical programming language. Finally, the created program for education of testing A/D converters and its principles is described and the results of the methods are discussed.

Keywords: education, digitization, Analogue to Digital Converters, testing, signal processing, LabView.

Introduction

In the past widely used analogue data records, which have been stored onto physical principle data storage media, are gradually diminishing. Together with the recent development of technology in agriculture, increasing situations where the measured data have to be further processed, sent or stored, arise to work with digital data. Analogue data records have to be digitized using Analogue to Digital Converters (ADC). ADC are necessary parts of all systems used in agricultural machinery where analogue signals need to be digitally processed and evaluated. Further evaluation of the measured data depends on the quality of analogue to digital conversion. The quality depends on the parameters of ADC. These parameters are, for example, Effective Number of Bits (ENOB), Signal to Noise Ratio (SNR), Spurious-Free Dynamic Range (SFDR) or Total Harmonic Distortion (THD).

Tested Parameters of Analogue to Digital Converters

The basic parameters of ADC can be divided into the static and dynamic parameters. Static parameters deal with Static Transfer Characteristic of the converter. Dynamic parameters of ADC are related to examination of the conversion of a continuous variable to the digital variable in time. The laboratory exercises are focused on the dynamic characteristics of the tested converter.

The first presented ADC parameter is Effective Resolution (ER). For determination of this parameter the Histogram Test can be used. *ER* is defined as a ratio of Full Scale *FS* of the ADC to the RMS value of the noise σ_s .

$$ER = \log_2 \frac{FS}{\sigma_s} \quad [bit]. \quad (1)$$

Probably the most frequently used parameter of ADC is the *ENOB*. *ENOB* parameter is always lower at the real converter than at the ideal converter of the same resolution. *ENOB* is primary determined from the Best Sine Wave Fit method and can be determined by standard deviation of residuals between the reconstructed and fitted signals ε .

$$ENOB = N - \log_2 \left(\frac{\varepsilon}{q} \right) \quad [bit], \quad (2)$$

where $q = \frac{2^N}{\sqrt{12}}$ is ideal quantization error and *N* is the number of bits.

Another important parameter which can be determined from the Best Sine wave Fit method is Signal-to-Noise and Distortion (SINAD). *SINAD* parameter can be calculated as a ratio of the RMS_{Sin} value of the basic harmonic component to the RMS_{Tot} value of the total noise including harmonic distortion, spurious components and various types of noise (3).

$$SINAD = 20 \log_{10} \frac{RMS_{Sin}}{RMS_{Tot}} [dB]. \quad (3)$$

Parameters *SINAD* and *ENOB* are related by well-known formula (4) [1].

$$SINAD = 6.02 \times ENOB + 1.76 [dB]. \quad (4)$$

For determination of the last couple of parameters (*THD* and *SFDR*) the Frequency analyses using Discrete Fourier Transformation (DFT) is used. *THD* represents the nonlinearity of the ADC transfer characteristic. It is defined as a ration of the root sum of squares of all the harmonic distortion amplitudes, including their aliases in the spectral output A_i of the converter to the amplitude of the carrier harmonic A_1 of the sine wave signal (5).

$$THD = 20 \log_{10} \frac{\sqrt{\sum_{i=2}^{N/2} A_i^2}}{A_1} [dB] \quad (5)$$

Dynamic range of the tested ADC can be also considered by the parameter *SFDR*. *SFDR* is defined as a ratio of the RMS value of the amplitude of the carrier frequency A_1 to RMS value of the next highest harmonic or non-harmonic amplitude A_2 (6).

$$SFDR = 20 \log_{10} \frac{A_1}{A_2} [dB] \quad (6)$$

For more details about these parameters, please, see the IEEE standards [2-3].

Testing methods

The testing methods standard IEEE Std 1241-2000 introduces many ways how to test converters. The basic division of the testing methods is, same as in ADC parameters, static and dynamic. This paper deals with the dynamic methods. It is necessary to have a sufficient amount of measurement data from the output of the converter when using the dynamic methods. These data are evaluated in both, the time and frequency domains. A sufficient amount of the measured data is a significant factor for accuracy of the method, especially those using statistical calculations.

Histogram Test

Like other statistical methods for testing of ADC, the histogram test has to work with a large number of samples. The principle of the method is in determining the effective value of the Inherent Noise of the ADC as the root mean square deviation σ_s at the grounding input. From the resulting histogram (Fig. 1) *ER* can be determined (1). More details about the histogram test, please, see [4].

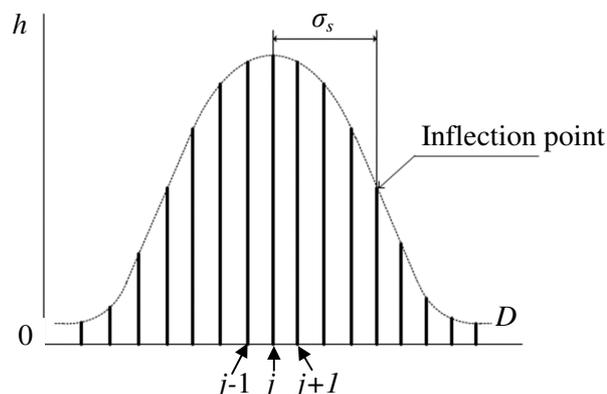


Fig. 1. Histogram Test method

Best Sine Wave Fit

In industry this method is used because of the easy availability of a sine wave generator. There is a requirement on a sine wave generator to fulfill good results. The generator distortion level has to be, at least, 20 dB lower than the level of a tested A/D converter distortion. A/D converter is to interleave the specified points of the curve, in this case, an ideal sine wave, during the reconstruction of the signal. If the original signal before conversion be chopped at the same time stamps as the stamps of the reconstructed signal, the samples, for which is assumed that the sum of squared deviations (errors) of the sample points and the reconstructed signal is minimal, are obtained (see Fig. 2).

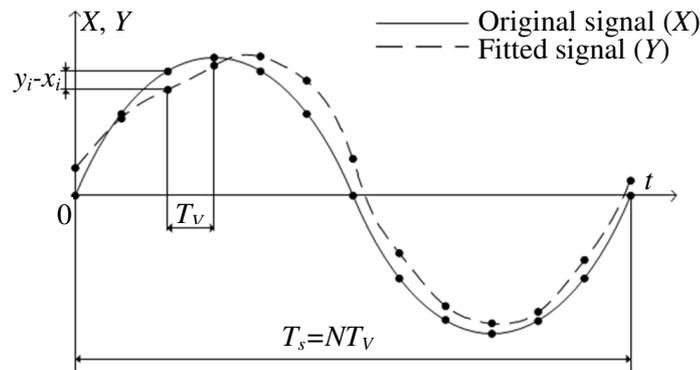


Fig. 2. **Best Sine Wave Fit method:** x_i resp. y_i are samples of reconstructed resp. fitted signal, T_v is sampling time and T_s is period of the signal.

The signal can be reconstructed by the least squares method. For one period of the reconstructed signal sinusoidal signal can be reconstructed by (7). For more details, please, see [5]. *ENOB* and *SINAD* parameters can be calculated thanks to this method by (2) and (4).

$$x(t) = X \sin(\omega t + \varphi) + C = A \cos \Omega t + B \sin \Omega t + C, \quad (7)$$

- where φ – phase shift between the reconstructed and the original signal;
 ω – frequency of the reconstructed signal;
 t – time;
 X – amplitude of the reconstructed signal;
 Ω – frequency of the original signal;
 A – amplitude of the original signal;
 B – phase of the original signal;
 C – DC component of the original signal.

Frequency Analysis DFT

The frequency analysis base is *DFT* because the finite number of samples is used. As a result of this method frequency spectrum of the digitized signal is done. From the amplitudes of the frequency spectrum *THD* (5) and *SFDR* (6) parameters can be determined. For more details about *DFT*, please see [6].

Implementation

For implementation a graphical programming platform LabVIEW is used. LabVIEW integrates graphical, text-based and other programming approaches within a single environment. It offers large integration with a great number of hardware devices and provides many built-in libraries for advanced analysis and data visualization. Thanks to that LabVIEW is suitable as an education tool.

A wide range of different ADC parameters (i.e., various numbers of bits, sampling speed or input range) for needs of the teaching is needed. Thanks to that it is desirable to create a model of ADC, which will enable to change easily the given permanent parameters of the ADC. The aim of modeling of the ADC is to show the differences between the parameters of ideal and real ADC. ADC model block converts continuous variable to digital. As input parameters of ADC model block there are the number

of bits and in case of histogram test the minimum and maximum value of the input voltage. Output from ADC model block is digitized signal represented by an array of values.

The Histogram Test is first implemented method (Fig. 3). Inherent noise of a real ADC, when its input is grounded, has a Gaussian distribution. Therefore, as input (A), standard deviation of the Gaussian noise in multiples of Least Significant Bit (LSB) must be defined (B). The input parameters have to be set regarding of the behaviour of the real ADC, especially the standard deviation which simulates the inherent noise of the converter.

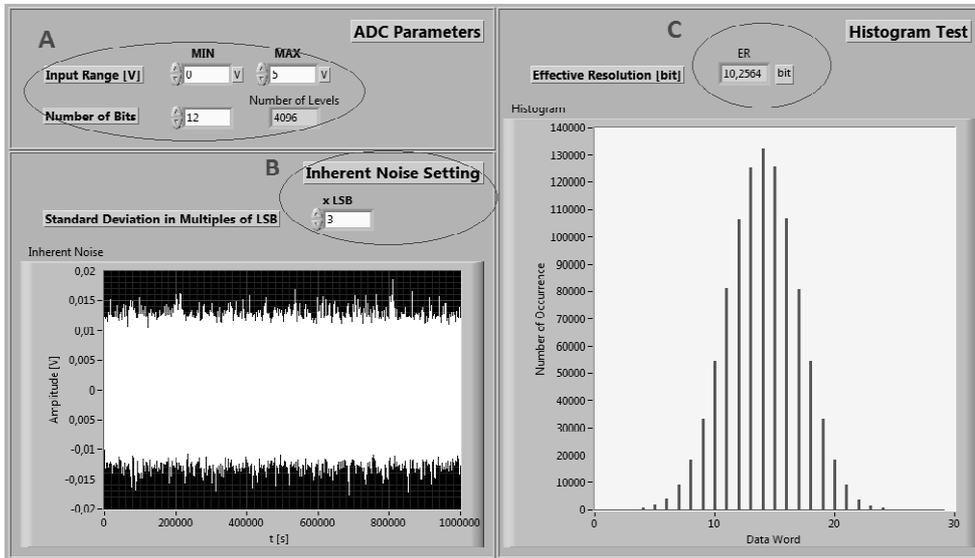


Fig. 3. GUI of Histogram Test

The Histogram Test belongs to the group of statistical tests for which it is necessary to collect a sufficient number of samples. Therefore, the number of samples is set to the default value of one million samples. These modeled values are processed by the Histogram block which is integrated as a function in LabVIEW. As a result of the test *ER* computed by (1) is presented (C).

Another implemented method is Best Sine Wave Fit (Fig. 4). 3-parameter sine wave fit algorithm is used for this implementation [5].

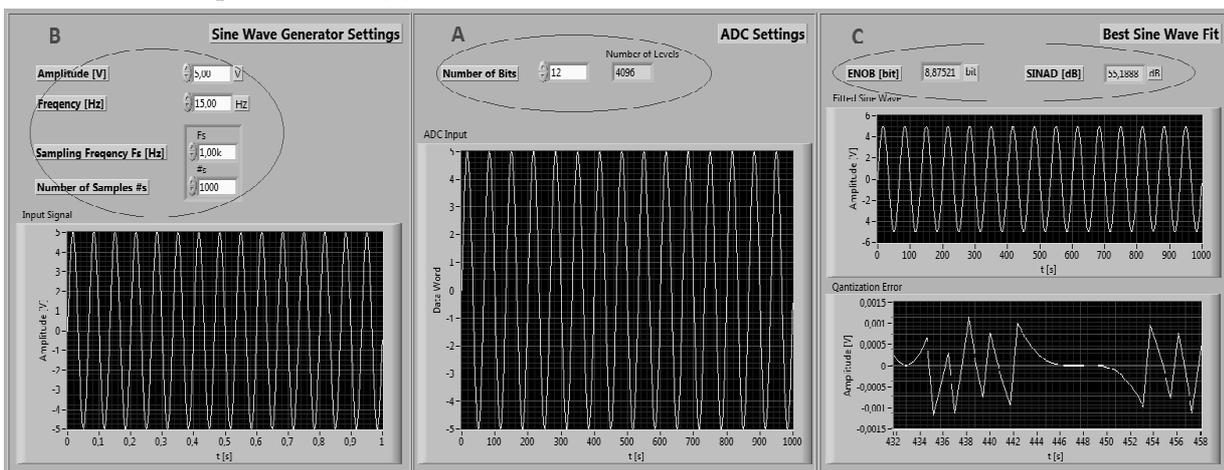


Fig. 4. GUI of Best Sine Wave Fit Test

Together with ADC settings (A) the Sine Wave Generator parameters have to be set (B). The sine wave generator is integrated as a function in LabVIEW. The input parameters of the generator are the amplitude and frequency of the signal. Further sampling frequency as well as the number of the samples must be set. The principle of this method is to create a matrix of the observer [5]. The algorithms based on equation (7). The aim is to obtain a matrix *D* (25) and then calculate the elements of *A*, *B* and *C*. The difference between the values of ADC output and the fitted sine curve is equal to

standard deviation ε . $ENOB$ and $SINAD(C)$ parameters can be then computed by (2) and (4). Quantization error is also shown as a result of the test.

The last method is Frequency analysis based on DFT (Fig. 5). As a result of the method two ADC parameters THD and $SFDR$ are enumerated (A). The entire method can be decomposed into the three sub-tasks. Firstly, the sine wave generator amplitude and frequency as well as sampling frequency and the number of samples have to be set (B). Output of the sine wave is brought to ADC (number of bits have to be set(C)). After the conversion the DFT is computed. For THD enumerating (5) the number of harmonics have to be set. $SFDR$ is then computed by (6). The frequency spectrum of the digitized signal is also shown.

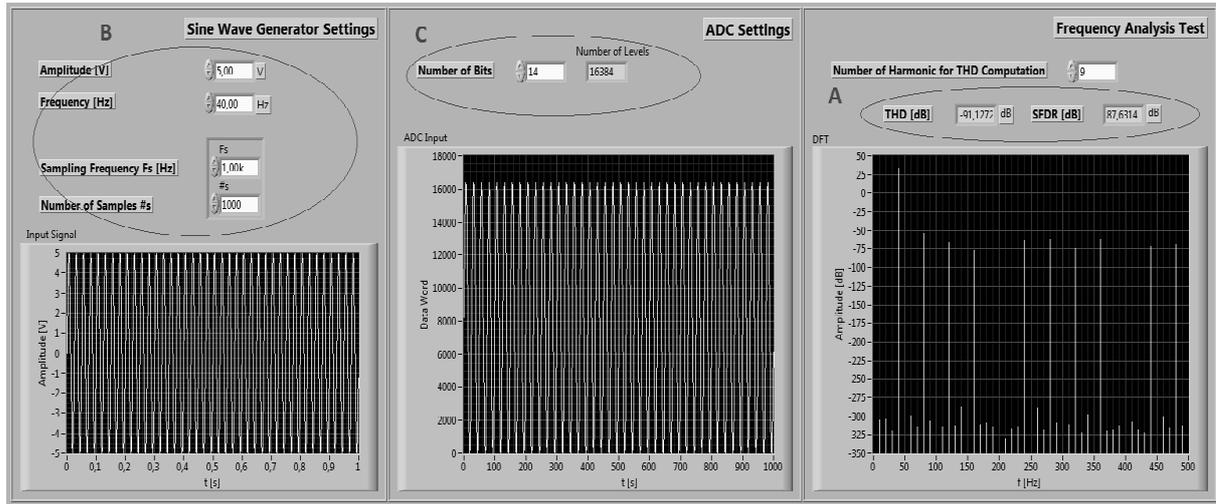


Fig. 5. GUI of Frequency Analysis DFT

Results and Discussion

Comparison of the results of individual methods for 12-bit and 14-bit modeled ADC with different input parameters is presented. The simulated results are in Tables 1-3. Table 1 shows the result of the Histogram Test method. Table 1 shows that with increasing input range of the ADC Effective Resolution increases, too. This character can also be observed in the real converter. Analog signal is brought to the converter input should cover the whole input range of the ADC to get the best results.

Table 1

Histogram Test method results

ADC Setup			Inherent noise, xLSB	Result
Input range, V		Number of bits		ER, bit
Min	Max			
0	2.5	12	3	9.3
0	2.5	14	3	11.3
0	5	12	3	10.2
0	5	14	3	12.2

Tab. 2 shows the results of the Best Sine Wave Fit Test. All simulations were made with $F_s = 1$ kHz and the number of samples 10000. The parameter $ENOB$ in Tab. 3 is always lower than the Nominal Number of Bits. It is corresponding with the real ADC. With increasing the amplitude of the input signal the quantization error is increasing and this result decreases the $ENOB$ parameter. The parameter $SINAD$ is proportional to $ENOB$, see (9). Tab. 3 presents the results of the Frequency Analysis DFT method. All simulations were made with the amplitude of 1 V and the number of samples 1000. From the results it is clear that THD is increasing with the number of bits of the ADC. It is also presented that with decreasing the difference between the frequency of the input signal and sampling the frequency THD is decreasing, too.

Table 2

Best Sine Wave Fit Test results

Sine wave setup		ADC setup	Results	
f, Hz	Amplitude, V	Number of bits	<i>ENOB</i> , dB	<i>SINAD</i> , dB
40	1	12	11.1	68.8
40	4	12	9.1	56.8
40	1	14	12.9	79.5
40	4	14	10.9	67.5

Table 3

Frequency Analysis DFT results

Sine wave setup		ADC setup	Number of	Results	
f, Hz	Amplitude, V	Number of bits	harmonic	<i>THD</i> , dB	<i>SFDR</i> , dB
50	1000	12	9	-84.4	87.5
2000	5000	12	9	-80.5	81.5
50	1000	14	9	-87.6	90.3
2000	5000	14	9	-83.8	85.4

Conclusion

The proposed methods for A/D converters testing in LabVIEW allow the simulation of the real ADC behavior. Typical parameters, as the results of all the proposed methods, are calculated. The created program is designed for an education need of the Czech University of Life Sciences Prague, Faculty of Engineering, Department of Electrical Engineering and Automation. The simulated results are compared with the results obtained on real A/D converters [7]. The created program will be introduced to the subjects Sensors for Measurement and Control (THT95E) and Embedded Microcomputer Systems (THT31E). These subjects are part of Information and Control Technology in Agri-food Complex study programs (IRTN). During the implementation of algorithms emphasis on the clear arrangement of the methods, on transparency and readability of the block diagrams has been put. The graphical user interface has been designed to give a comprehensive view of the program. The user is then able to intuitively set the required inputs and the results could be easily read for each method. The methods differ from each other in terms of the calculation demands and complexity in implementation. The Histogram Test is the easiest of the methods to implement, but there is a need for a large number of samples. This can lead to great demands on the measurement time and on the amount of memory. The DFT Frequency Analysis and Best Sine Wave Fit methods are difficult to implement, but the measurement time and memory requirements are much lower.

References

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