Analog to Digital Converter Performance Testing Based on MATLAB

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Abstract. In this paper, a new calculation method is proposed to seek the performance of the analog-to-digital converter (ADC). During the designing process of the ADC, the parameters would be simulated repeatedly for improving performance, but some parameters cannot be obtained directly through simulating. Therefore, MATLAB is utilized to analyze the simulation output data of the ADC in order to obtain the characteristics values. The MATLAB based calculation algorithm can be applied to performance testing during ADC design and practical measurement of the ADC chip.

1. Introduction
With the development of CMOS technology, digital circuits have great advantages over analog circuits in storage, transmission and processing. Natural signals are analog signals. A bridge ADC must be needed for converting analog signals to digital signals. Therefore, the performance evaluation of ADC is particularly important during circuit designing.

Many ADC performance testing methods have been proposed. The INL and DNL of ADC can be tested by stepping signal through the input ramp signal [1], and they also can be obtained by the distribution histogram testing of the input signal [2]. The dynamic performance parameters of ADC are obtained by sine wave fitting method [3] and spectrum analysis [4]. Basically, the static parameter test and dynamic parameter test of ADC are separated. Aiming at this problem, this paper proposes a MATLAB program [5] that can test static and dynamic parameters of ADC at the same time.

The paper is organized as follows: Section 2 describes the testing principle of ADC and the implementation in MATLAB. Section 3 introduces the verification of testing code of ADC. Section 4 gives the summarization of proposed ADC parameters testing technique.

2. ADC Testing Principle & MATLAB Test Code Implementation
The ADC characteristic refers to the relationship between the input analog quantity and the output digital code. The performance of ADC is determined by a lot of parameters, which are usually divided into static and dynamic parameters. In order to obtain the static and dynamic parameter of ADC from a set of ADC output data, input signal to ADC under test is set as a sinusoidal signal and the output data are transferred to MATLAB for data analyzing.

2.1. Testing Methods for Static Characteristics
The static characteristic of ADC refers to the error between the actual output curve with the ideal output curve [6]. The most important aspect of ADC static parameters is nonlinear characteristics. So, differential nonlinearity and integral nonlinearity are the testing objects of this program.

This MATLAB implementation uses the code density test method. The input signal is single tone...
sine signal and its probability density function is,

\[ p(x) = \frac{1}{\pi \sqrt{1 - x^2}} \]  

(1)

The probability density map of an ideal 16-bit ADC output data is shown in Fig.1.

**Figure 1.** The probability density of the output (Sample size@2^{20}) of the actual ideal ADC

then, The ADC characteristic curve can be obtained from the probability distribution.

\[ \text{code distribution} = -\cos \frac{\pi F(x)}{\text{sum(code)}} \]  

(2)

There, \( F(x) \) can be obtained from \( p(x) \) integral and \( \text{sum(code)} \) refers to the number of codewords. By this step, the width of the codeword can be calculated.

\[ \Delta_k = \text{code}(k+1) - \text{code}(k) \]  

(3)

The length of 1LSB is equal to the average of all codeword widths.

\[ \text{LSB} = \frac{\text{sum(\Delta_k)}}{k} \]  

(4)

At last, DNL and INL can be calculated.

\[ \text{DNL}(k) = \frac{\Delta_k}{\text{LSB}} - 1 \]  

(5)

\[ \text{INL}(k) = \sum_{i=0}^{k-1} \text{DNL}(i) \]  

(6)

2.2. Testing Methods for Dynamic Parameters

The dynamic performance parameters of ADC mainly reflect the ability of ADC to suppress noise and harmonics [6]. The dynamic characteristic parameters of ADC include quantization noise (QN), signal-to-noise ratio (SNR), signal-to-noise distortion ratio (SNDR), effective number of bits (ENOB), total harmonic distortion (THD) and spurious free dynamic range (SFDR).

The dynamic performance parameters of ADC are obtained by spectrum analysis. The ADC input signal takes the single tone sine signal, and the amplitude is -2dBFs to -1dBFs with a full range. Assuming the frequency of the input signal is \( F_{\text{in}} \), the period number of the input signal is \( N_1 \), the sampling frequency is \( F_S \), and the number of data points analyzed is \( 2^{N_2} \). In order to ensure that FFT data are not duplicated, \( N_1 \) and \( 2^{N_2} \) should be prime numbers. Therefore

\[ F_{\text{in}} = \frac{N_1}{2^{N_2}} F_S \]  

(7)
First, Fast Fourier transform (FFT) is used to the digital from ADC. Next, Finding the main peaks and harmonics of the signal using the obtained spectrum diagram. Then, the intensity of these signals is calculated. There, Noise power equals the sum of square output.

\[ P_{\text{noise}} = \sum A_{\text{date}}^2 \]  \hspace{1cm} (8)

Signal power equals to main peak power.

\[ P_{\text{signal}} = P_{\text{HD,1}} \]  \hspace{1cm} (9)

Finally, the dynamic parameters of ADC are calculated.

\[ \text{SNR} = 10 \log_{10} \frac{P_{\text{signal}}}{P_{\text{noise}}} = 20 \log_{10} \frac{A_{\text{signal}}}{A_{\text{noi}}} \]  \hspace{1cm} (10)

\[ \text{SNDR} = 10 \log_{10} \frac{P_{\text{signal}}}{P_{\text{noise}} + P_{\text{HD}}} = 20 \log_{10} \frac{A_{\text{signal}}}{A_{\text{noise}} + A_{\text{HD}}} \]  \hspace{1cm} (11)

\[ \text{ENOB} = \frac{\text{SNDR} - 1.76}{6.02} \]  \hspace{1cm} (12)

\[ \text{THD} = 10 \log_{10} \frac{\sum_{i=2}^{n} A_{\text{HD,}\text{i}}^2}{A_{\text{HD,1}}^2} \]  \hspace{1cm} (13)

\[ \text{SFDR} = 10 \log_{10} \frac{P_{\text{HD,1}}}{\max(P_{\text{HD,2},P_{\text{HD,3}}})} \]  \hspace{1cm} (14)

2.3. MATLAB Test Code Implementation

The proposed MATLAB code implementation flow is shown in Fig.2. Users need to enter the sampling frequency of ADC, the number of bits designed by ADC and start point number for FFT. Users also can choose add windows, static analysis or dynamic analysis. Then the above principle be used to compiling the code. At last, the graph be outputted.

![Figure 2. ADC static and dynamic analysis flow charts](image)
3. Program Verification

In order to verify the reliability of the program, a set of ideal 16bit ADC conversion data was generated by MATLAB.

3.1. Verification of Static Characteristic Test Program

From Fig.3, it is not consistent with the characteristic curve of ideal ADC. Theoretically, the INL and DNL of the ADC should be zero, but because of the quantization error, the test results will be biased. To eliminate quantization errors, it takes larger sampling samples.

$$\text{sample size} \geq \frac{Z_{\alpha/2} \pi 2^{N-1}}{\beta^2}$$  \hspace{1cm} (15)

Among them, $Z$ obeys normal distribution. $N$ is the bit of ADC. $\beta$ represents the accuracy range of ADC. That is, the confidence range of test accuracy in $(1-\alpha)$ is within $\pm \beta$ LSB.

After modifying the amount of data, the retest is shown in Fig.4.

![Figure 3. ADC static characteristics INL and DNL (Sample size@2^{20})](image)

![Figure 4. ADC static characteristics INL and DNL (Sample size@2^{28})](image)
3.2. Verification of dynamic characteristic test program
From Fig.5, the limit of ideal ADC has been reached. It can be seen mainly from ENOB to 15.9948 bits. The harmonic component is small, indicating that the system does not contain other nonlinear errors besides quantization error. It accords with the output of ideal ADC, which shows that the program is reasonable.

![Figure 5. ADC dynamic characteristics INL and DNL (Sample size@2^20)](image)

4. Conclusion
This paper mainly introduces a method to test the basic static and dynamic performance parameters of ADC by MATLAB. At the same time, this paper also gives the requirement of testing the input signal of ADC. As well as the number of samples required for ADC static performance test, a formula that can be calculated is given. The reliability of the program is verified by analyzing the output data of the ideal 16-bit ADC.

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