DOI 10.5162/SMSI2020/P4.5

Linear Regression Method for Measuring Characteristics of the ADC on Harmonic Test Signals

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Summary:
Discusses the possibility of application linear regression methods and Josephson voltage standard for measurement characteristic harmonic signals or systems based on DAC/ADC in order to improve the accuracy of determination such parameters as amplitudes and phases of the fundamental tone and harmonics, effective number of bits, signal-to-noise ratio, harmonic distortion, and others.

Keywords: ADC, DAC, Josephson voltage standard, linear regression method, harmonic test signal.

Introduction

DAC ADCs are the main element of many measuring systems. The accuracy of the conversion and the accuracy of the measurements depend on their characteristics. In many methods, to determine the characteristics of the ADC, input voltage signals of a constant or step type are used. However, often such signals are not included in the class of ADC working signals, for example, due to the presence of an input filter that cuts off the DC component of the signal. Most ADCs work with harmonic sinusoidal signals of alternating voltage, in which the useful information is in the values of amplitudes, phases of fundamental tone and harmonic components. Until now, THRUE RMS thermoelectric converters have been used at the top level of AC voltage metrology, but their use is limited by sinusoidal signals with low harmonic components. In the case of analog instruments, filters are used to measure signal harmonics contents. In the case of digital processing, FFT, DFT algorithms are often used, which have their own limitations on application and limit the measurement error. The construction of reference generators of test signals and the development of techniques for determining the characteristics of the ADC is an urgent task.

Description of the Method

Great metrology success was due to progress in the creation of AC voltage standards based on the Josephson effect [1, 2]. At the output of such a device, it is possible to obtain both a DC voltage output signal with an exact value and almost zero non-linearity, and AC waveform signals with an exact value of the RMS value of a sinusoidal signal or an exact value of harmonic components. The value of the error in determining the characteristics of meters or ADCs depends on the applied algorithms for processing digital signal realizations. Authors developed algorithms for determining the characteristics of harmonic signals and the characteristics of the DAC/ADCs using the regression analysis method. Software was developed to generate digital implementations of test signals and to determine the characteristics of AC voltage signals or ADC. The process of obtaining the values of the ADC characteristics can be implemented in the following sequence: 1. Submission to the ADC input of an exemplary analog test signal included in the class of permissible signals with specified parameter values. 2. Recording a sequence of digital readings obtained in real-time operating mode in a digital storage device. 3. Recovery of signal parameter values by compute of the recorded sequence using software. 4. Comparison of the obtained parameter values with the given ones and calculation of the values of the ADC characteristics as signal conversion errors. The software consists of two blocks - a computer Generator of digital signals and a processing unit for digital implementations. The Generator creates sequences of digital samples of model implementations for digital-to-analog converters on Josephson binary array, and for other types of DACs. It is also used to generate digital test signals when characterizing signal processing software. The samples of the generated signal consist of the values of the samples of the fundamental tone of the signal, the values of the samples of the harmonic components of the signal with frequencies that are multiples of the frequency of the fundamental tone, samples of additive white noise and the DC offset of the signal. For processing digital implementations, regression analysis method is used. The internal scale parameter of the implementation is the number of samples per period of the fundamental tone. With its known value, the task of reconstructing the parameters of a sinusoidal signal is formulated as a linear regression by the principle of least squares in the class of sums of trigonometric functions. Then, the algorithm calculates the amplitudes and phases of the fundamental tone and harmonics, the coefficient of nonlinear distortion, the effective number of bits of the ADC, the signal-to-noise ratio etc. The study of software characteristics was carried out by their direct determination by model implementations of signals with known values of the specified parameters. To obtain the uncertainty errors in determining the frequency and amplitude parameters, a statistical modeling process was used, consisting of cycles of modeling and processing realizations, statistical processing.

Results

The results obtained are presented below in the form of graphs.

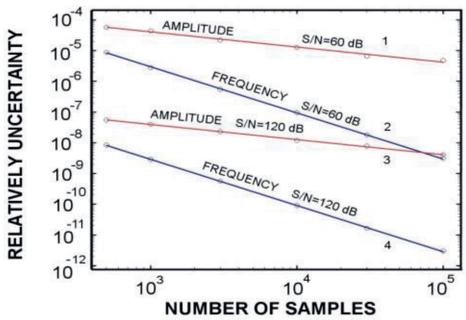

Fig. 1. The dependence of the relative errors in determining the frequency and amplitude on the length of the processed implementation N. Lines 1 and 2 are obtained with a signal-to-noise ratio of 60 dB; lines 3 and 4 at 120 dB.

Modeling and processing were carried out taking into account five harmonics with a harmonic coefficient equal to 0.01%. The noise model is normal white noise. The number of simulation-processing cycles (the number of sample parameter values for statistics) was 500 – 1000. The study of the graphs shows that the error in the amplitude of the fundamental tone is inversely proportional to the signal-to-noise ratio and the number of counts in the signal implementation. Implementation of the signal samples was loaded into the binary Josephson voltage converter.

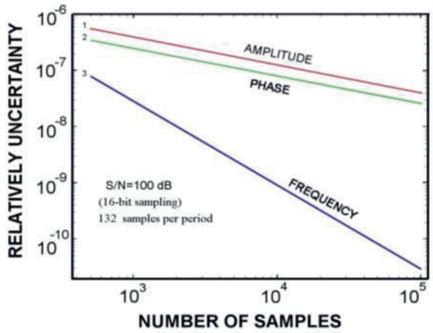

Fig. 2. A graph of the relative errors in determining the frequency, amplitude, and phase versus the implementation length for signal-to-noise ratios of 100 dB (16-bit sampling). Numbers of samples per period was 132.

The output signal from the Josephson setup was fed to 24-bit ADC. Signals with a number of samples from 30 to 4000 for the period of the fundamental tone of the generated signal were used. In the case of measuring purely sinusoidal signals, the minimum achieved error level of the amplitude or RMS value of the AC voltage was about 3.5 – 100 ppm.

Conclusion

The results of statistical modeling using this algorithm showed possible accuracy characteristics for measuring the parameters of the amplitude, phase, frequency of the fundamental tone of the signal and harmonics, which depend on the signal-to-noise ratio and the length of the processed implementation. The errors of the method when processing real signals will depend on the accuracy of the DAC/ADCs used, the accuracy and stability of the signal frequency and sampling frequency. Measurements with a Josephson setup, good results were obtained that were not achievable for other processing methods, such as FFT, DFT. The authors use these algorithms in the development of methods and instruments for measuring the characteristics of the ADCs and the characteristics of the Josephson setup to obtain uncertainty of amplitudes1 ppm and less.

References

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