# ADC and DAC converters

Laboratory Instruction

Prepared by:

Łukasz Buczek

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1. Aim of exercise

The aim of exercise is to learn the basics of the analog-to-digital (ADC) and digital-to-analog (DAC) conversion, to learn the basic parameters of the real ADC and DAC and to familiarize with the aliasing effect.

2. Model description

The block diagram of the laboratory model used during the exercise is shown in the figure below.
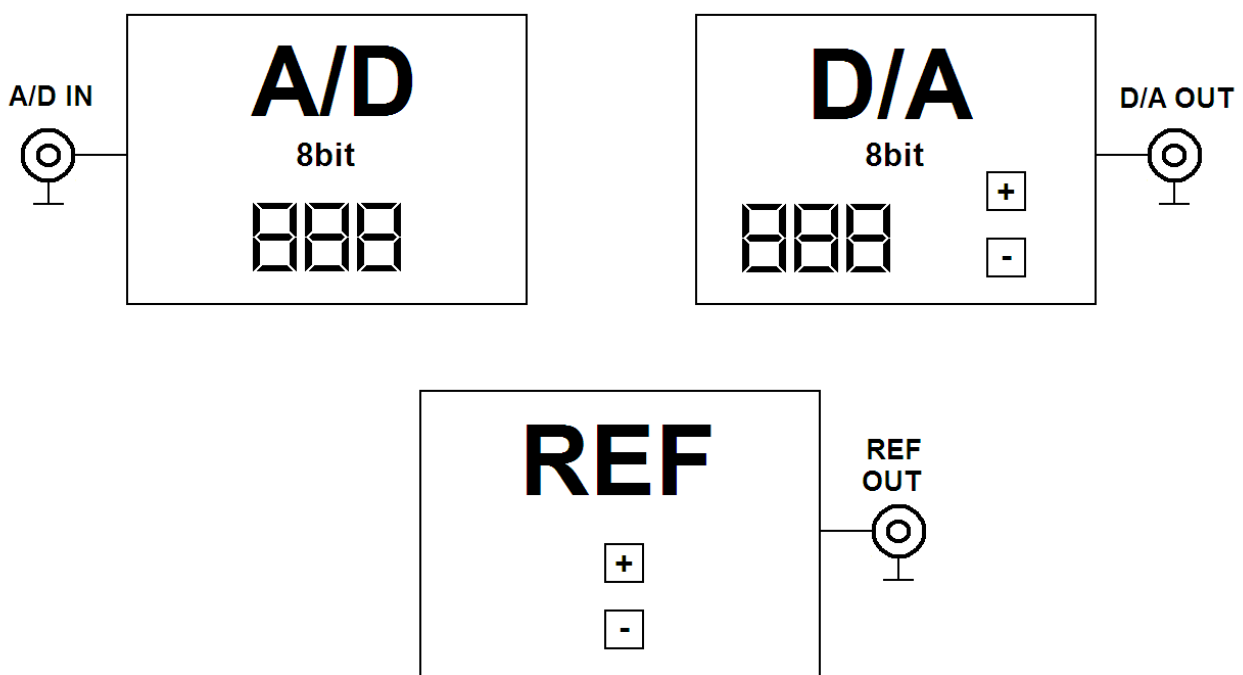
The model consists of three functional blocks: the 8-bit ADC the 8-bit DAC and the precise adjustable voltage source (marked as REF). The model may work in three different modes described below.

Mode 1

In this mode the 8-bit ADC is active. This mode is entered by pressing the button labeled „A/D" and is confirmed by a green LED. In this mode the 8 bit ADC works continuously and the result of the conversion is presented on the displays in the numerical form. The analog signal is supplied to the input named „A/D IN". The precise adjustable voltage reference is also active. The voltage from the reference is available at the output named „REF OUT". Its value may be changed by

pressing the buttons labeled "+" and "-". Holding the button pressed for a longer time causes faster change of the voltage at the „REF OUT" output.

Mode 2

In this mode the 8-bit DAC is active. This mode is entered by pressing the button labeled „D/A" and is confirmed by a green LED. In this mode an analog signal from the D-to-A converter is available at the output marked as „D/A OUT". The value of the output signal may be changed by pressing the buttons labeled "+" and "-". The value that is actually processed by the D-to-A converter is presented on the display in the numerical form.

Mode 3

In this mode both ADC and DAC converters are active. This mode is activated by pressing two buttons labeled „A/D" and „D/A" simultaneously. It is confirmed by two green LEDs. In this mode the DAC is driven by the signal from the ADC. The sampling frequency may by changed by pressing the buttons labeled "+" or "−".

3. **Preparation to the exercise**

1. Design and draw the connections between the blocks of the model and the digital multimeter (Agilent U3401) allowing measuring the parameters of the ADC and DAC.

2. Design and draw the connections between the model and the generator (Rigol DG1022) and oscilloscope (Tektronix TBS1154) for observing the results of the analog to digital conversion and further reconstruction back into the analog domain (Mode 3). In this mode the ADC and DAC are internally connected in the model board.

3. Calculate the value of 1 LSB for the 8-bit ADC. Assume that the reference voltage is equal to 5 V.

4. Calculate the value of 1 LSB for the 8-bit DAC converter. Assume that the reference voltage is equal to 4.096 V.

5. Learn (with understanding) the definitions of basic errors introduced by ADC and DAC: offset error, gain error, integral nonlinearity (INL) and differential nonlinearity (DNL). Propose a method to determine these errors having measured a fragment of the transfer characteristic of the converter.

6. Write down the equations for the coefficients of the least mean square linear approximation (also known as linear regression method) allowing determining the offset and gain errors. Write down the equations for relevant uncertainties.

7. Get acquainted with the aliasing phenomenon. Familiarize with terms: sampling frequency and Nyquist frequency. Name the conditions, when aliasing can be observed during sampling oscilloscope measurements.

8.	Read from the manual of the multimeter and copy to your notebooks the data concerning the uncertainty of DC voltage measurement. Understand the meaning of these parameters.

## 4.	<u>Measurement plan</u>

1.	<u>ADC – Mode 1</u>

   a.	Build the measurement setup for testing the ADC accordingly to the block diagram you prepared.

   b.	Measure the height of 1 LSB step and compare measured value with those calculated theoretically.

   c.	Measure the data necessary to draw the INL characteristic in the range given by the teaching assistant

   d.	Measure the data necessary to draw the DNL characteristic in the range given by the teaching assistant

   e.	Measure the data necessary to calculate ADC offset error (minimum 7 data points).

   f.	Measure the data necessary to calculate ADC gain error (minimum 7 data points).

2.	<u>DAC – Mode 2</u>

   a.	Build the measurement setup for testing the DAC accordingly to the block diagram you prepared.

   b.	Measure the height of 1 LSB step and compare the measured value with those calculated theoretically.

   c.	Measure the data necessary to draw the INL in the range given by the teaching assistant

   d.	Measure the data necessary to draw the DNL characteristic in the range given by the teaching assistant

   e.	Measure the data necessary to calculate DAC offset error (minimum 7 data points).

   f.	Measure the data necessary to calculate DAC gain error (minimum 7 data points).

3.	<u>ADC and DAC system – Mode 3</u>

   a.	Build the measurement setup for testing a simple conversion system composed of the ADC driving the DAC. Supply a sinusoidal signal with the frequency of 10 Hz from the output of the generator to the input labeled „A/D IN". Instantaneous value of this signal should be in the range of 1 V to 4 V. Connect the output labeled

„D/A OUT" to the oscilloscope using the coaxial cable terminated with two BNC connectors.

b. Observe the output signal changing the shape of the input signal (triangle, square wave, sinusoid) and its frequency. Change the frequency of the input signal with 1 Hz resolution. Note characteristic features of observed signals in your notebooks.

c. Determine the sampling frequency in the system using the time markers.

d. Observe the aliasing effect. Increasing the frequency of the input signal (chose sinusoidal signal and increase its frequency even above the sampling frequency of tested system) observe cyclical increase and decrease of the signal frequency observed at the output of the system. Change the frequency of the input signal with 1 Hz resolution.

5. Data processing

- Determine the offset and gain errors by fitting the straight line to your measured data using the least mean square method. Determine the uncertainty of both offset and gain errors.

- Draw the INL and DNL characteristics for tested ADC and DAC in the measured range.