Modeling of the D/A and A/D conversion techniques based on virtual instrumentation

W. Tłaczała[*,1], **G. Gorghiu**[2], **A. García de la Santa**[3], **M. Kordaki**[4], **J. T. Rodriguez**[5] and **J. Użycki**[1]

[1] Faculty of Physics, Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland
[2] Science of Systems, Automatics and Informatics Department, Valahia University Targoviste 130082, Targoviste, Romania
[3] Teacher Training and Educational Innovative Center Valladolid II, 47-010 Valladolid, Spain
[4] Department of Computer Engineering and Informatics, University of Patras, 26-500 Patras, Greece
[5] Teachers Training Center of Gijon, 33-212 Gijon, Spain

This paper describes models of the digital electronics experiments with respect to D/A and A/D converting - DAC with R-2R ladder network, dual-slope ADC and ADC with successive approximation. The models of the measurement systems are completed with the models of the measurement instruments. The virtual electronics experiments presented in the paper simulate the real measurement processes. The presented models of the measurement processes are built using the input/output black box method of modeling. All the applications illustrated in this paper are built using LabVIEW environment.

Keywords e-Learning; virtual laboratory; LabVIEW; teacher training; Socrates Project; Comenius 2.1

1. Introduction

Models of the measurement processes can be built using two methods: one based on mathematical modeling and the second based on measurements performed using the real measurement system regarded as a black box with taken into account only input-output relations for particular properties presentation. The models of the measurement processes presented in this paper (used also for the calibration curves recording and data analyzing) are built based on the second method.

2. Modeling of the D/A and A/D conversion techniques

Digital to analog converters (DAC) and analog to digital converters (ADC) are the fundamental link between analog and digital electronics. The DAC converts the input digital signal into an equivalent analog output signal. The ADC digitizes the analog input signal into a digital value.

2.1 Digital to analog converting method with R-2R ladder

There are several ways in which the digital to analog converting can be accomplished. One method is the binary weighted resistor techniques based on the circuit with a network of parallel branches, one branch for each bit. Each branch contains a resistance weighted in proportion to the significance of the bit in the digital word. The disadvantage of the weighted resistor method is that its implementation needs to use the precision resistors, because the accuracy and stability depend on the precision of the resistance values. For a large number of digits, the absolute value of the later resistance can become quite large.

An alternate method is the *R-2R* ladder network (Fig. 1). This network is essentially a current divider. The resistance looking in any direction from any node of the ladder network is $2R$, what results in the binary weighting given by the following equation:

$$U_0 = \left(a_{n-1} 2^{-1} + a_{n-2} 2^{-2} + a_{n-3} 2^{-3} + \ldots + a_0 2^{-n} \right) U_{ref}. \tag{1}$$

* Corresponding author: e-mail: tlaczala@if.pw.edu.pl, Phone: +48 22 2347547

The functional block diagram of the DAC, built with the R-$2R$ ladder network, is visible on the front panel of the application shown in Fig. 1. Unlike the weighted R method, the ladder method only requires resistance of R or $2R$, and the stability of the ladder depends only on the resistance.
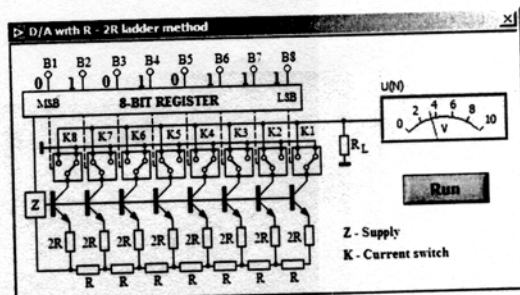

Fig. 1   *The front panel of the application for D/A converting process simulation.*

The application shown in Fig. 1 simulates D/A converting process. It presents how the input digital words (B1÷B8) are converted into the corresponding output voltages.

2.2   Analog to digital converting methods

Dual slope method of the analog to digital converting. Figure 2a shows modeling of the logic and timing relations for the ADC converter based on the dual-slope method. In this method, the input signal is first used to charge a converter capacitor C (see the circuit in Fig. 4b), which is charged at constant time and a rate set by the current proportional to the analog input signal U_{in}. This capacitor is then run down, i.e. discharged at the constant rate. In this method an integrating amplifier is used to integrate input current. During the time (ΔT) the capacitor charge and run down are taking place, pulses from a constant frequency clock are gated into a scaler. The scaler is gated off at the zero-crossing point. The contents N of the scaler is then a number proportional to the analog (height or level) input signal.
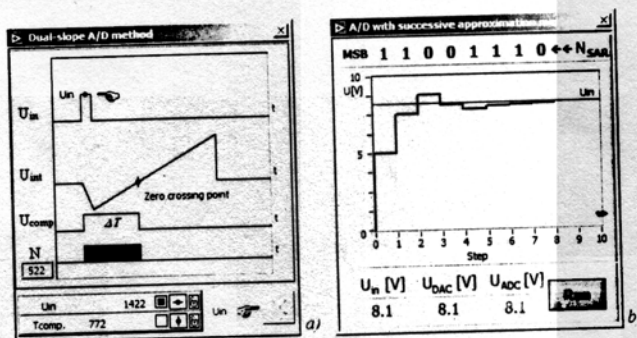

Fig. 2   *The front panels of the applications for A/D converting processes simulation: a) for dual-slope A/D method, b) for A/D with the successive approximation method.*

Successive approximation method of the analog to digital converting. The successive approximation method is the most widely used technique of analog to digital conversion, also when the input signal is the pulse signal. In last situation, first the duration of the incoming pulse is prolonged at its peak value, and then this peak value is compared to a series of reference voltages to determine the height of the pulse. The converting process can be explained using the VI shown in Fig. 2b true for the 8 bit ADC.

If the ADC range is, for instance, 0 to 10 V and the incoming pulse height is 8,1 V, the ADC first compares the peak value to a reference of 5 V. Because the peak value is greater then 5V the MSC bit (most significant bit) of the digital number is set to logic 1. Then the one-half previous reference (2,5 V) is added to make a new reference of 7,5 V and comparison again. Since the signal is greater, the second bit is also set to 1. One-half is again added on to make 8,75 V. This time the peak value is less than reference value, so that the third bit is set to logic 0. Now half is subtracted from the reference and a comparison is made. This continues until the 8 bits (8 steps) is obtained. After ADC calibration the output digital value can be read as $U_{ADC} = a \times N_{SAR}$, where a is the calibration coefficient.

3. The VIS for digital-analog and analog-digital converters testing

The virtual experimental arrangement for the DAC and ADC testing simulates the real one, which can be completed, for instance, with the laboratory power supply, digitally controlled power supply, the digital oscilloscope, the digital multimeter, converters to be tested and PC equipped with the suit software. The experimental set-up (Fig. 3) used to perform virtual measurements is completed with models of the real instruments.

3.1 The VIS for the digital-analog converters testing

The virtual instrumentation system (VIS) user interface, before VIS preparation to measurements, is shown in Fig. 3a. A user can select the converter to be tested, connect and switch on/off all instruments, select correct instrument presets and measurement conditions. The front panel of the VIS contains graphical objects used for mode and parameter settings, measurement control, measurement data presentation and acquired data displaying. The measurement parameters can be set using numeric controls. A user can start measurement with the *Run* pushbutton. The current values of the ADC inputs and DAC outputs are displayed in corresponding numeric indicators on the PS and DMM displays.
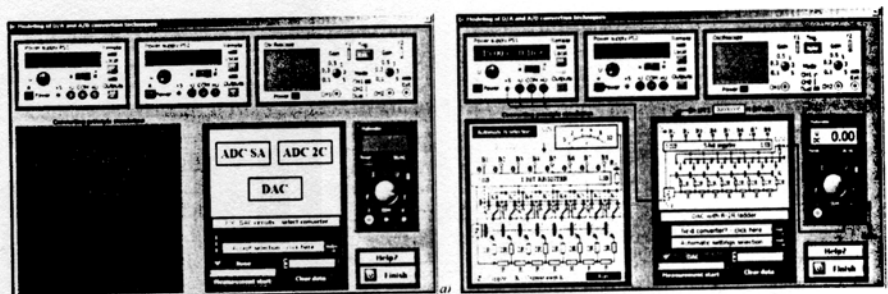

Fig. 3 *The VIS for DAC and ADC testing: a) before converter selection and switching on the virtual instruments, b) after the DAC selection and before measurements.*

The user interface of the VIS, after the DAC with R-2R ladder selection, is presented in the Fig. 3b. It shows this interface before running.

3.2 The VIS for the analog-digital converters testing

Figure 4a shows the user interface of the VIS, selected for the successive approximation method presentation and used to control the virtual experiment devoted to studies of the ADC based on this method. The figure shows the running VIS after preparation of the experimental set-up to measurements.

Figure 4b presents the user interface of the VIS, selected for the dual-slope method presentation and used for the testing of the ADC based on this method. The figure shows this interface during measurements.

The instrument settings can be selected individually for each instrument independently or automatically and complexity for all instruments used for the VIS building. The data collected during the virtual measurements are not simulated data but the data early obtained during the real measurements in electronics lab and incorporated in the program when the application was built (the black box method). Therefore, the data collected in the virtual experiment are like those recorded during the real measurements in the real lab. Also the lasting of each step of the measurements is the same as in reality.
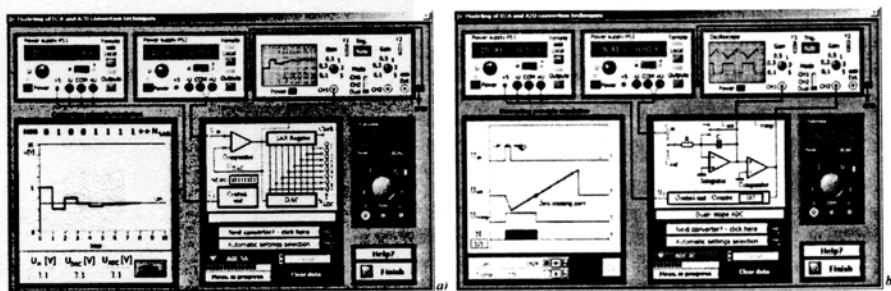

Fig. 4 *The VIS for ADC testing: a) ADC with successive approximation during measurements, b) dual-slope ADC during measurements.*

The user interface of the each of three presented experiments allows experimenter to see how the converter is built what instruments and their settings are needed for the measurements. Also how a digital signal is converted into an equivalent linear signal (for DAC) or an analog signal into a digital signal (for ADC). Last possibility is available with the applications, which simulate conversion processes, placed on the left side of the user interface.

4. Calibration curves presentation and analysis

During measurements running a user may possibility observe how the calibration curve is completed and - after measurement finishing - can see the completed calibration curve looks like and finally, analyze it.
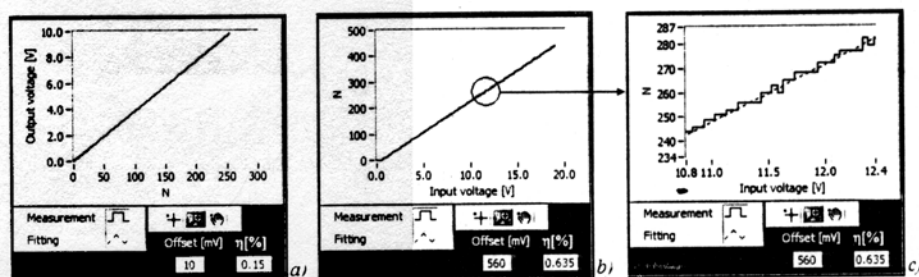

Fig. 5 *The calibration curves: a) graph with the DAC calibration curve, b) graph with the dual-slope ADC calibration curve, c) graph with the part of the zoomed dual-slope ADC calibration curve.*

The set of collected data is available from the table and presented on the X-Y graphs (Fig. 5), which can be selected, instead circuits presentation, with the text ring control, placed on the user interface. Currently after every measurement the calibration curve parameters, offset and integral nonlinearity (η) are calculated and displayed in the numeric indicators. On the graph with the zoomed curve (Fig. 5c) a user can observe different kinds of deviations met during the conversion process.

5. The ADC applying to measurements in the physics experiment

Figure 6 shows the example of the ADC applying to measurements in the physics experiment. The high-resolution time measurements can be performed using the combination of the time to amplitude (TAC) and analog to digital (ADC) converters. Figure 6a presents experimental arrangement for time of flight measurements used in the nuclear physics experiments. The principle of the time to amplitude converting is presented in Fig. 6b. Modeling of the logic and timing relations for a START-STOP time to amplitude conversion is shown in Fig. 6c. The START pulse, produced by the START detector, gates on the converter capacitor C, which begins to charge at a rate, set by the constant current (I_z) source, until the arrival of the STOP pulse, produced by the STOP detector. The total charge collected thus forms an output signal whose height (A) is proportional to the time difference (ΔT) between the START and STOP signals. This pulse is usually fed to an ADC for pulse-height digitizing.
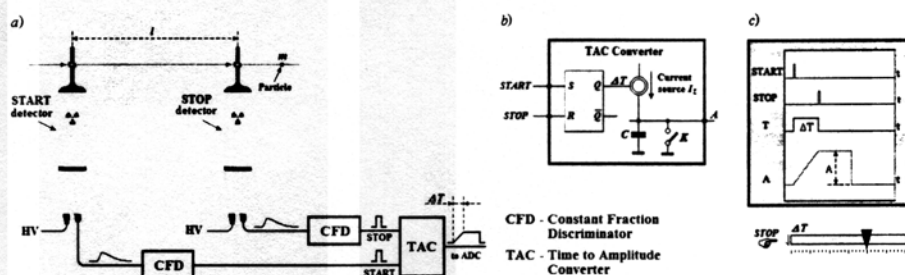

Fig. 6 *The ADC applying to the high resolution time measurements: a) experimental arrangement, b) time to amplitude converting principle, c) simulations of the logic and timing relations.*

Conclusions

Described virtual experiments became a part of the digital electronics laboratory, easy of approach from CD as LabVIEW applications – executable programs developed in LabVIEW environment. They can be used for a home training as a part of the home virtual digital electronics lab for disabled students and also for the similar lab in the secondary schools. The home training allows a user to be familiar with the experimental arrangements, used in the digital electronics lab and D/A and A/D conversion techniques, before entering into the real electronics laboratory. Finally, teachers and lecturers can use them for demonstrations during the theoretical lessons.

The presented experiments will become part of the *Virtual Instrumentation e-Space*, a web based virtual learning environment with virtual tools and instruments for training Science disciplines, the main output of a recent approved European Socrates - Comenius three years project: 128989-CP-1-2006-1-RO-COMENIUS-C21, funded by European Commission, School Education: Socrates. The project activities will be developed during October 2006 – September 2009.

References

[1] D. W. Heermann, "Computer Simulation Methods in Theoretical Physics", Springer-Verlag Berlin Heidelberg, 1990.
[2] L. P. Mari, "Models of the Measurement Process", *Handbook of Measuring System Design*, edited by Peter Sydenham and Richard Thorn, © 2005 John Wiley & Sons, Ltd, pp. 681-684.
[3] G. W. Johnson, "Graphical programming: practical applications in instrumentation and control", 2nd ed., McGraw-Hill, 1997.
[4] W. Tłaczała, "Modeling with LabVIEW™", *Handbook of Measuring System Design*, edited by Peter Sydenham and Richard Thorn, © 2005 John Wiley & Sons, Ltd, pp. 685-694.