

USE OF SOFTWARE ENVIRONMENTS AND OPEN SOURCE PLATFORMS FOR TEACHING MIXED-SIGNAL CIRCUITS

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Abstract

The purpose of the authors of this paper is to share their experience in the use of the Multisim and Proteus software environments as well as the open source Arduino platform for teaching and examining mixed circuits in engineering higher education.

Multisim and Proteus are Spice (Simulation. Program with Integrated Circuit Emphasis) based and are intended for simulation and analysis of analog, digital and mixed-signal circuits. Their interface is constantly improved and their capabilities are expanding. This makes them suitable for teaching and mastering mixed-signal circuits through circuit modelling.

An Arduino 2560 integrated environment was chosen to serve as the microcontroller, as it is intended for application development in various fields. In the current article it is used to extend the capabilities of the Texas Instruments Analog System Lab Kit PRO (ASLK PRO) and to enhance the ability of the students to develop their own projects.

Proteus is suitable for simulating, testing and analyzing the processes taking place in digital-to-analog converters (DACs), since it keeps the teaching focused on the concepts of the course and provides the opportunity to study the hardware and software aspects of the material taught. Trainees learn about the engineering workflow: designing and simulating the feasibility of circuits using virtual tools.

A simulation model of a DAC with summation of voltages, made of 8 bit R2R matrix was created in the Proteus Design Suite. It allows the trainees knowledge of the principle of the superposition theorem to be easily reinforced. In order to demonstrate the resolution of the DAC, the input binary combinations are generated by an Arduino Mega 2560.

The output waveforms observed with the EasyScope software oscilloscope are displayed on a computer monitor. EasyScope allows control and adjustment of the generated signals so that their parameters can be read with high accuracy.

A DAC simulation model with current summation was created in the Multisim environment. A Multisim simulation is a good method for the successful training of the students to prototype a real circuit. The model uses switches to send different combinations of the bits of the digital input signal, for which currents and voltages in the circuit branches are measured with measuring probes without the need to wait or to restart the simulation. The article presents the theoretical calculations for the resolution of a 4-bit DAC and an 8-bit DAC and compares the obtained simulation results.

The simulation models can be deployed using real hardware (a laboratory platform) to conduct physical experiments. Proteus and Multisim enhance the students' creative thinking and prepare them for the physical examination of these types of DAC.

The trainees verify the results of the DAC simulation tests using the laboratory models created. The results of the experimental studies are presented.

Training future engineers necessitates using diverse strategies and resources for teaching, training and support. The transformation of the learning process into a modern educational environment requires students to master methods of knowledge, among which the combination of simulation and experimental study of mixed-signal circuits is becoming increasingly important.

Keywords: Proteus, Multisim, mixed-signal circuits, engineering higher education.

1 INTRODUCTION

The study of mixed signal circuits directly affects the students' mastering of the basic principles of building Digital-to-Analog Converters and the formation of competences and skills for combining

simulation and experimental study in their work, as these circuits are an important link between the digital and the analog part of electronic devices and systems.

The Proteus and Multisim software environments are suitable for application in engineering education to teach mixed signal circuits in the Electronic Circuit Engineering courses to the students from the undergraduate courses at the University of Plovdiv Paisii Hilendarski, Faculty of Physics and Technology (BULGARIA). They simulate, test and analyze the processes taking place in DACs, while maintaining the focus of teaching on the concepts of the course, providing the opportunity to study the hardware and software aspects of the subject matter being taught.

The simulations developed in these environments enable the trainees to follow and master the workflow of engineering: creating a design of the mixed signal circuit that is being examined, simulating its performance, testing, conducting real-time measurements of the signals in the circuits using virtual tools and debugging.

The computer-based simulation circuits can be of varying complexity depending on the level of the trainees – participants in either undergraduate or graduate courses.

The Proteus and Multisim software environments provide the opportunity to deploy the simulation schemes of the DACs under study in real hardware — by building laboratory modules to conduct physical experiments.

The article proposes a laboratory module for the experimental study of DAC with summation of voltages. The experimental study aims to provide students with lasting knowledge of the basic parameters of DAC: the number of bits and the reference voltage determining the maximum DAC resolution; the speed of obtaining the results; the transmission characteristics - the dependence between the output and input values, etc.

The laboratory module is useful for the formation of the students' engineering skills and competences when making real measurements, and when presenting the obtained results or analyzing them.

The purpose of combining simulation procedures and experimental research is to help the students to develop with flexible skills to study the principles of digital-to-analog conversion and the operation of this type of converters.

2 DIGITAL TO ANALOG CONVERTER WITH SUMMATION OF VOLTAGES

2.1 Simulation study of R-2R Ladder Digital to Analog Converter with summation of voltages in the Proteus environment

In this section we present a simulation model of R-2R Ladder Digital to Analog Converter (DAC). R-2R Ladder Digital to Analog Converter is a basic principle of building a DAC found in integrated circuits. More details on these topics can be accessed from [1].

Students use the Proteus environment to simulate the DAC's performance and visualize its transmission characteristics based on the dependence:

$$U_{out} = U_{ref} \left(\frac{N}{2^n} \right) \quad (1)$$

where n is the number of bits, N is the decimal value of the binary conversion combination and U_{ref} is the reference voltage.

The simulation model of the R-2R Ladder Digital to Analog Converter in the Proteus environment is presented in Fig. 1. For building the model, the following constituent elements have been used:

$R_1=R_2=R_3=R_4=R_5=R_6=R_7=R_8=5K\Omega$; $R_9=R_{10}=R_{11}=R_{12}=R_{13}=R_{14}=R_{15}=R_{16}=R_{17}=10K\Omega$;
ATMEGA 2560; Oscilloscope.

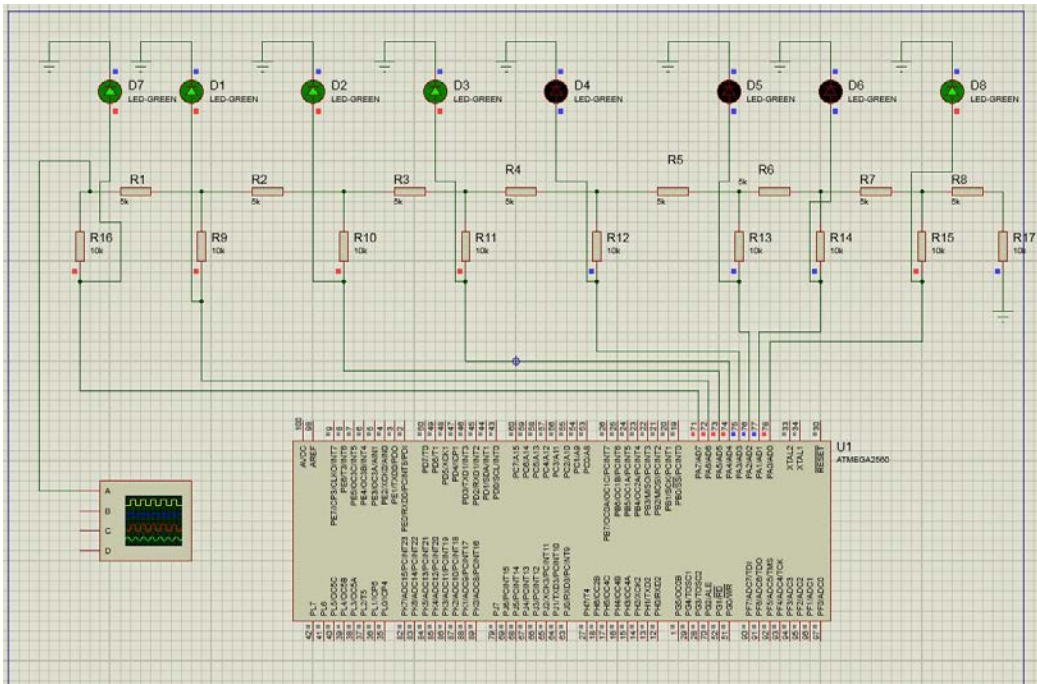


Figure 1. Simulation scheme of an 8-bit DAC with a R-2R matrix created in the Proteus environment.

In Fig. 2. the oscillograms from the software oscilloscope obtained from the simulation study of the DAC with the R-2R matrix are presented.

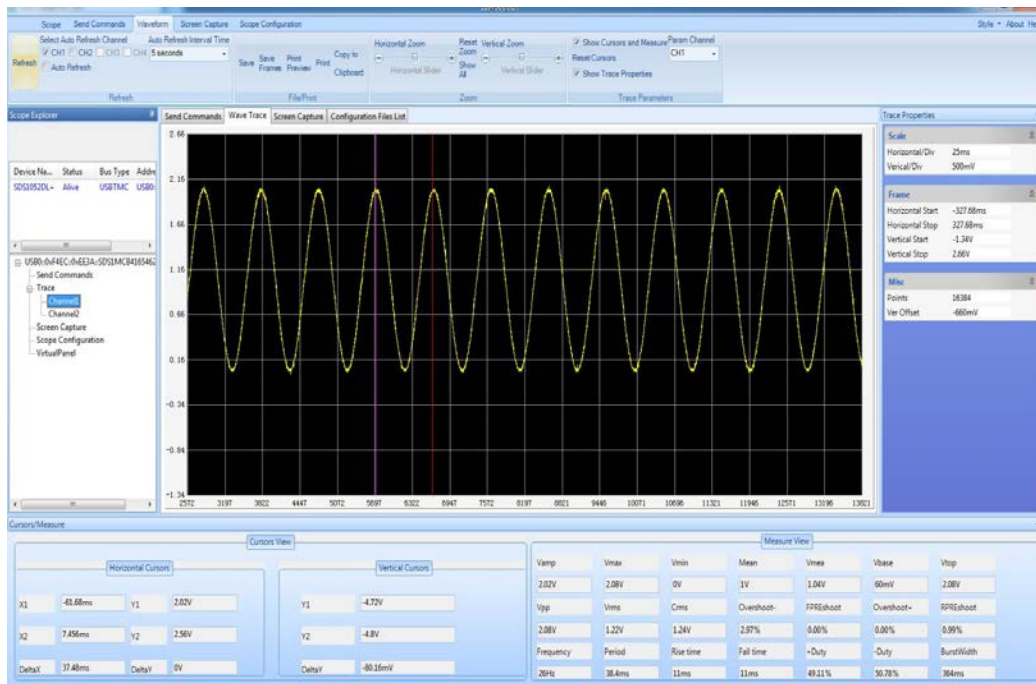


Figure 2. Oscillograms from the conducted simulation study.

2.2 Experimental study of R-2R Ladder Digital to Analog Converter

To validate the results of the simulation study of the R-2R Ladder Digital to Analog Converter, the laboratory module, the block diagram of which is presented in Fig. 3, has been created [2], [3], [4], [5].

On a breadboard the students connect the eight-bit R-2R matrix with resistors $R = 10 \text{ k}\Omega$ and $2R = 20 \text{ k}\Omega$.

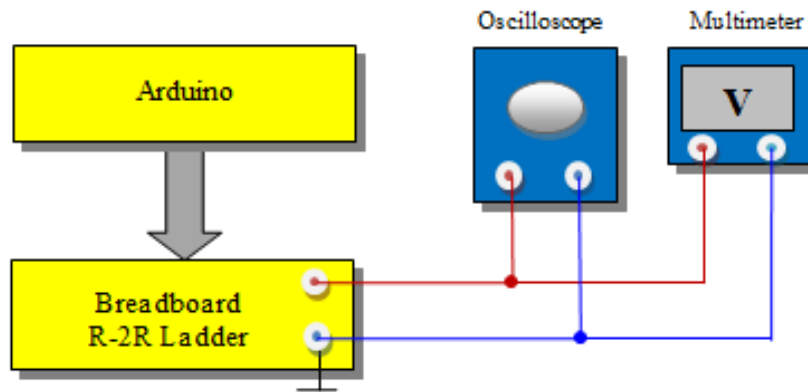


Figure 3. Block diagram of the laboratory module used to examine R-2R Ladder Digital to Analog Converter, managed with an Arduino.

Four-bit and 8-bit digital-to-analog conversion programs have been written for the experiment.

```
// test1
void setup() {
  /*
  pinMode(22, OUTPUT);
  pinMode(23, OUTPUT);
  pinMode(24, OUTPUT);
  pinMode(25, OUTPUT);
  */
  DDRA =255;
}
void loop() {
  for (char i=0; i<16; i++) {
    PORTA = i*16;
    delay(100);
  }
  PORTA = 0;
  delay(100);
}

//test2
void setup() {
  /*
  pinMode(22, OUTPUT);
  pinMode(23, OUTPUT);
  pinMode(24, OUTPUT);
  pinMode(25, OUTPUT);
  */
  DDRC =0xFF;
}
void loop() {
  for (char i=0; i<256; i++) {
    PORTC = i*256;
    delay(100);
  }
  PORTC = 0;
  delay(100);
}
```

The experimental study is carried out in two stages: processing of 4-bit binary numbers and of 8-bit binary numbers, at a reference voltage $U_{ref} = 5 \text{ V}$.

The laboratory module used to conduct the experimental study is shown in Fig. 4

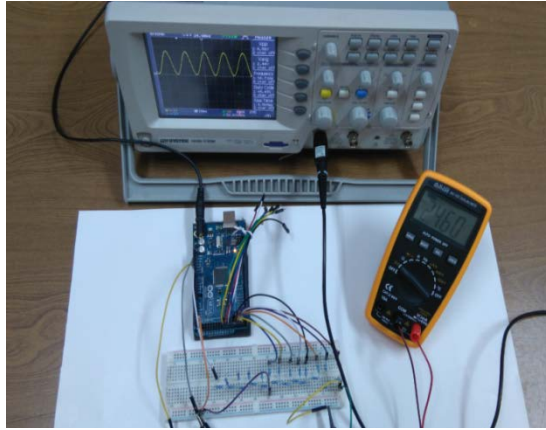


Figure 4. Laboratory module used to conduct the experimental study of R-2R Ladder Digital to Analog Converter, managed with an Arduino.

The transmission characteristic of the 4-bit binary numbers processed by an oscilloscope is shown in Fig. 5. The transmission characteristic when processing 8-bit binary numbers is presented in Fig. 6.

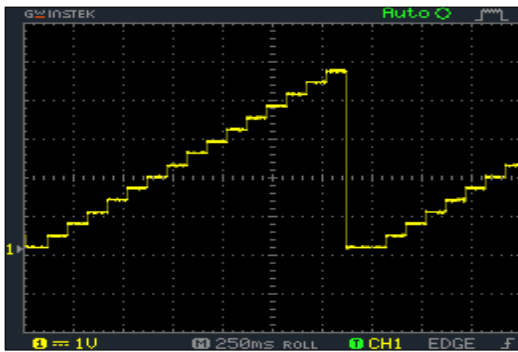


Figure 5. Oscillogram of the output voltage for the processing of 4-bit binary numbers.

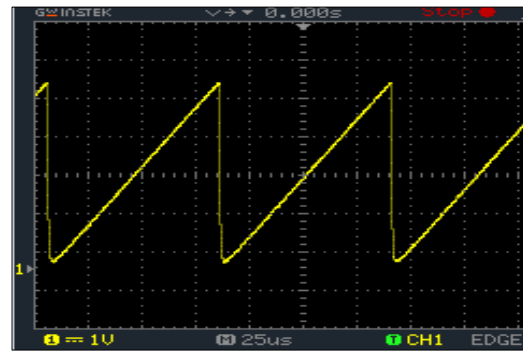


Figure 6. Oscillogram of the output voltage of the DAC in the processing of 8-bit binary numbers.

The results of the experimental studies have led to the following conclusions:

- the output voltage of the 4-bit DAC varies in the range from 0.0 V to 4.60 V in 0.30 V steps, and in the 8-digit DAC the variation is from 0.0 V to 4.90 V in 0.02 V steps. The increase in the bit depth of the DAC leads to an increase in the precision of conversion which approaches the value of the reference voltage;
- the influence of the high order bits on the value of the output voltage is greater than the influence of the low order bits due to their greater weight.

3 DIGITAL TO ANALOG CONVERTER WITH SUMMATION OF CURRENTS

3.1 Simulation model of R-2R Ladder Digital to Analog Converter with summation of currents in the Multisim environment

To study the principles of constructing a DAC with summation of currents using the R-2R matrix in the Multisim environment the simulation scheme in Fig. 7 was created, applying the principles of circuit modeling [6].

In conducting the simulation, the students use measuring probes that measure the currents in all branches of the circuit [7], [8].

The model allows the currents flowing in the branches of the circuit to be measured without the need for a wait or for an additional start of the simulation whenever there is any change in the binary number supplied to the inputs.

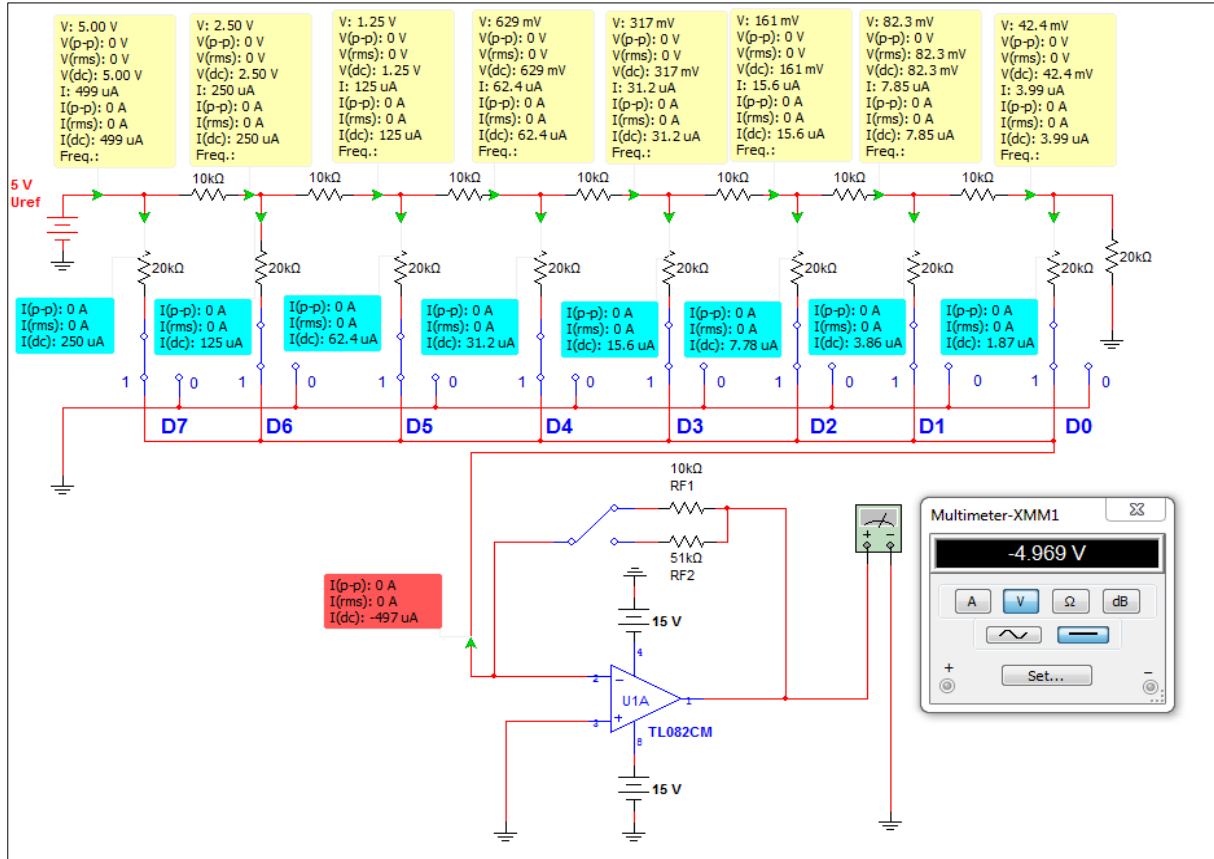


Figure 7. Simulation scheme of DAC with summation of currents in Multisim

3.2 Results of the conducted simulation studies

The main dependence for determining the output current in digital-to-analog conversion with summation of currents is:

$$I_{out} = I_{ref} \left(\frac{N}{2^n} \right), \quad (2)$$

which is analogous to the dependence (1) for expressing the output voltage at the DAC with summation of voltages.

The DAC behavior from FIG. 7 is simulated at reference voltage $U_{ref} = 5V$ and resistor values $R_F = R_{F1} = R = 10k\Omega$ и $R_F = R_{F2} = 51k\Omega$.

The values of currents and voltages in the branches of the circuit are measured using measuring probe simulations and the value of the output voltage is measured using a simulation multimeter.

When the resistor value is $R_F = R = 10k\Omega$ and the digital combination 1111111 is fed to the inputs, the reference current is $I_{ref} = 499\mu A$. After substitution in (2), the output current is:

$$I_{out} = 499\mu A \left(\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + \frac{1}{64} + \frac{1}{128} + \frac{1}{256} \right) = 499\mu A \left(\frac{255}{256} \right) = 497\mu A.$$

This is the value of the I_{sum} at the DAC output to which the inverting input of the operational amplifier functioning as a current-to-voltage converter is connected.

The voltage at the output of the DAC with summation of currents with a current-to-voltage converter, measured with the software multimeter is $U_{out} = -4.969V$, and the calculated value is: $U_{out} = -(497 \mu A * 10k\Omega) = -4,9701V$.

The output voltage according to is expressed using the dependence:

$$U_{out} = \frac{-R_F}{2^n R} U_R N, \quad (3)$$

where $\frac{-R_F U_R}{R 2^n} = U_{LSB}$.

Substitution in formula (3) for the case under examination yields:

$$U_{out} = \frac{-10k\Omega}{10k\Omega * 256} 5V * 255 = 4.98V \quad (4).$$

The simulation test when the resistor value is $R_F=R_{F2}=51k\Omega$ is carried out in an analogous manner, and the measured value of the output voltage is $U_{out} = -25,36V$, and its calculated value is $U_{out} = -25,4V$.

4 CONCLUSIONS

The article explores the capabilities of the Proteus and Multisim software environments for the design, simulation and analysis to teach specific topics in mixed circuits theory in the Electronic Circuit Engineering course taught to students in the undergraduate courses at the University of Plovdiv Paisii Hilendarski, Faculty of Physics and Technology (BULGARIA). The simulation schemes of the 4-bit and 8-bit R-2R DAC matrices with voltage and current conversion are used as a way of going through the critical stages of the educational process, starting with theory and calculation, and then moving on to circuit simulation and prototyping.

The experimental study of DAC with voltage conversion was performed with a laboratory module developed for this purpose and implemented with the R-2R Ladder, operated with Arduino Mega 2560. The results obtained from the experimental studies are presented and analyzed.

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