Instituto Politécnico Nacional

Ingeniería en Sistemas Computacionales

Laboratorio de Instrumentación

Práctica N° 6 Conversión de Digital a Analógico: aplicaciones.

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Objective

The student will apply DACs in two specific control functions: speed control of a DC motor and digital control of the amplitude of a sinusoidal signal.

Equipment employed

- Computer
- Software tool for electronic circuit simulation (Multisim or PROTEUS).
- Internet connection.

Introduction

Digital Analog Conversion

This process is made by a Digital Analog Convertor (DAC) that associates to each binary value a previously established voltage level. The most important and hardest part of the process is, how to match a sample with the next one? The easiest way to do that is to keep the voltage of one sample until the next one comes.

What is a DAC?

A DAC is a device that receives digital information in the form of a word of n-bits and transforms it into an analog signal. The transformation is done through a correspondence between 2^n binary combinations and 2^n voltages (or currents) obtained from a reference voltage (Vref).

Specifications

Those are divided into two categories: static and dynamic. Static specifications are the behaviors observed at the DAC output in a stable output state, therefore describe it in the DC domain. Dynamic specifications refer to the behaviors observed during a code-to-code transition.

The main characteristics of a DAC are:

- **Full scale output**, this is the maximum analog value that the output can have, this when the maximum binary value is input to the input.

- **Resolution**, is the voltage difference that occurs at the output of the converter for a subsequent change of its binary value.

  It is calculated as 1/3 V or as the inverse of the number of discrete steps of the output (%), i.e. 1/((2^n)-1) where n is the number of bits.

It can also be understood as the number of bits to be converted.

- **Linearity**, is the deviation from the ideal output.

- **Monotonicity**, is when a DAC does not produce inverse steps when sequentially applying its full range of input bits.

When we talk about linearity and the DAC transfer function, we only have to take into account the static specifications, so we will focus on these characteristics in the following.

Static

- **Offset error**, measures how much the entire DAC transfer function is shifted up or down. Generally the measurement starts from a best-fit line taken from a two-point measurement around 10% and 90% of full scale.
- **Zero-code error**, occurs when all 0's are fed to the DAC in the measurement where ideally the output voltage should be 0V, but due to the free space requirements for the output buffer, a small 0V offset is usually present.
- **Gain error**, describes a change in the slope of the ideal DAC curve, is usually expressed in percentage of FSR and is calculated following the removal of the offset error.
- **Differential non-linearity**, also called differential-linearity, is the maximum deviation of the actual analog output step from the ideal step value of 1 LSB. It represents the difference between each actual voltage output and the ideal curve.
- **Monotonicity**, when having a differential nonlinearity of less than - 1 LSB the transfer function is non-monotonic for a DAC . If a DAC is nonmonotonic, the magnitude of the analog output of the DAC is smaller for an increase in the digital input code or vice versa.
- **Integral non-linearity**, it is a measure of the slight deviation of the actual DAC transfer function from the ideal, thus encompassing DNL errors.

Applications

- **Control**, a digital output can be converted into an analog control signal to adjust the speed of a motor or to control almost any physical variable.
- **Automatic analysis,** consists of generating the analog signals through a DAC, whose analog output response of the test circuit will normally be converted to a digital value by an ADC.
- **Digital amplitude control**, a multiplicative DAC can be used to digitally adjust the amplitude of an analog signal.
- **A/D converters**, several A/D converters use DACs as part of their circuitry.

Development

1. **Speed control of a motor with a weighted resistor DAC.**

   In the circuit simulation software tool, assemble the circuit in Figure 1 using the LM358 Operational Amplifier, which will be energized with +VDC=12 V.

   To adjust the motor speed, manipulate the value of the binary input by driving a voltage of 5V for logic '1' and 0V for logic '0' across each input terminal to the DAC, using a 5V voltage source or ground connection.

   Practically test the speed control operation for at least 5 different speeds by noting in each case the current through the motor and at 3 different step sizes to fill in Table 1. Modify the value of the resolution by changing the value of the 1KΩ potentiometer that serves as Rf for the DAC.

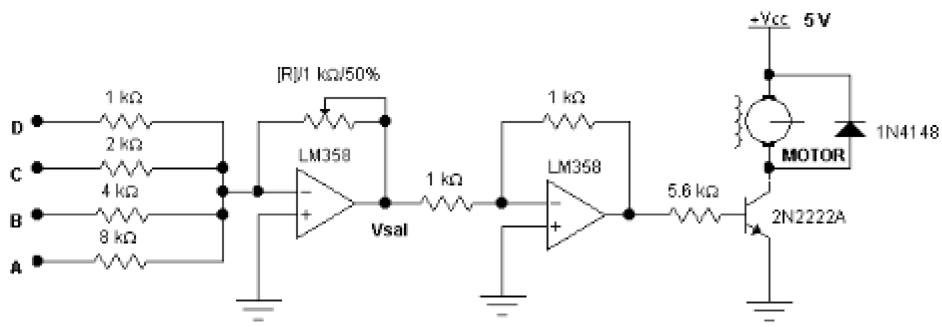


Figure 1.

Resolution (mV)	Binary input	Measured Vsal (V)	Current through the motor (mA)
206	0000	0	0
	0011	-0.62	0.54
	0110	-1.25	20.3
	1100	-2.50	61.2
	1111	-3.12	80
425	0000	0	0
	0011	-1.28	21.5
	0110	-2.56	63.3

	1100	-5.13	133
	1111	-6.41	164
625	0000	0	0
	0011	-1.88	41.7
	0110	-3.77	98.3
	1100	-7.53	1.89
	1111	-9.42	288

Table 1 Speed control with a DAC in three different pitch sizes.

2. **Digital amplitude control for a sinusoidal signal with an R2R ladder network DAC.**

   In the simulator, assemble the circuit in Figure 2, using an AC source and the oscilloscpe, as illustrated, to analyze its operation. Use V=±7V DC to energize the Op-Amp.

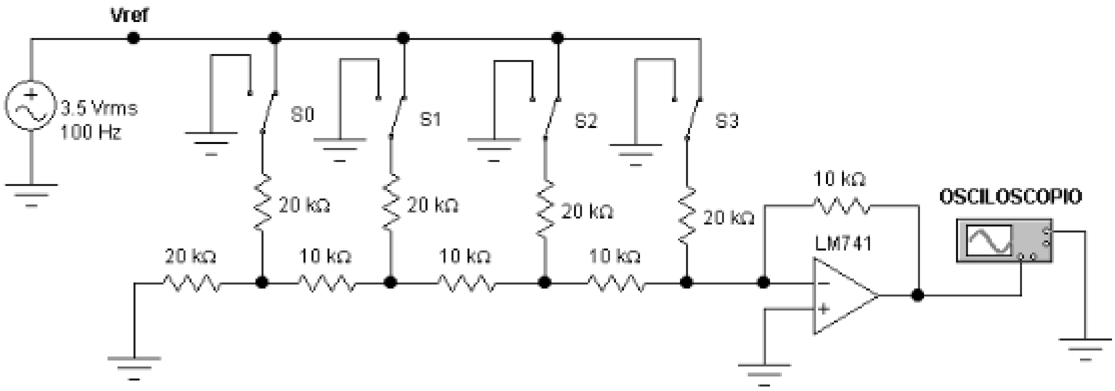


Figure 2.

For digital amplitude control of a signal, the sinewave provided by the AC source (with the characteristics shown in Figure 2) will be the VREF of the DAC. The output voltage should have the same waveform as the VREF input but its amplitude will depend on the digital input applied to the DAC. The digital input will change by changing the position of switches S0, S1, S2 and S3 to VREF for a logic '1' or to ground node for a logic '0'.The amplitude of the output signal should always be equal to or less than the input signal and can be calculated as follows:

$$V_{SAL} = \frac{V_{REF}}{2^n} xB$$

Fill in the following table2 to verify the digital amplitude control with the requested data and keep the sine wave (VREF) with a fixed amplitude of 3.5VRMS.

Input code	Amplitude of the output signal measured (V)	Amplitude of the output signal calculated (V)
0000	0	0
0001	0.21829	0.21875
0010	0.440	0.4375
0011	0.6526	0.65625
0100	0.8734	0.875
0101	1.09	1.093
0110	1.31	1.3125
0111	1.53	1.5312
1000	1.75	1.75
1001	1.97	1.9687
1010	2.18	2.1875
1011	2.41	2.40625
1100	2.62	2.625
1101	2.85	2.8437
1110	3.06	3.0625
1111	3.27	3.2812

Table 2 Digital control of the amplitude of a signal with a DAC.

3. Operation of the DAC08 integrated circuit.

Using the circuit simulation software tool, build the circuit shown in Figure 3, using the DAC08, and verify the conversion process in the bipolar mode of the DAC and fill in Table 3 with the requested data. With this circuit, verify the conversion process in the bipolar mode of the DAC and fill in Table 3 with the requested data. The digital input of the DAC08 is from its terminals 5 to 12.

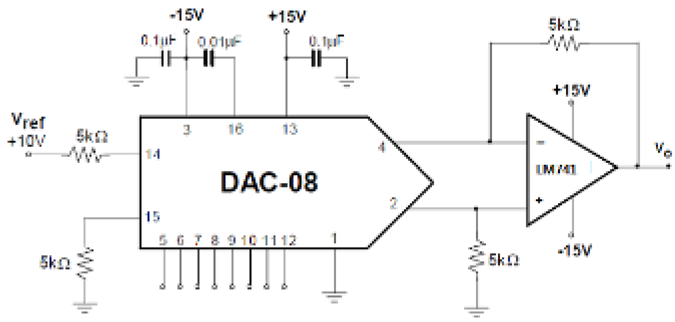


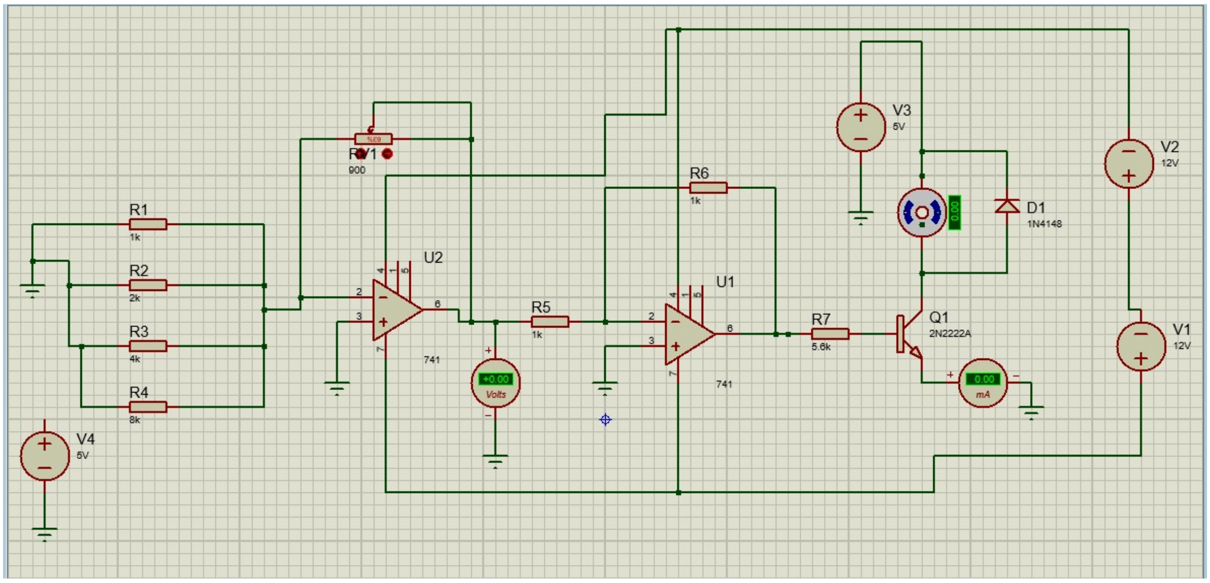
Figure 3.

Input code	Output voltage (V)
00000000	-10
00000001	-9.92
00000010	-9.84
00001000	-9.37
00010010	-8.59
00110111	-5.70
01000101	-4.61
01100110	-2.03
01111111	-0.07
10000000	0
10010101	1.64
10110101	4.14
11001000	5.63

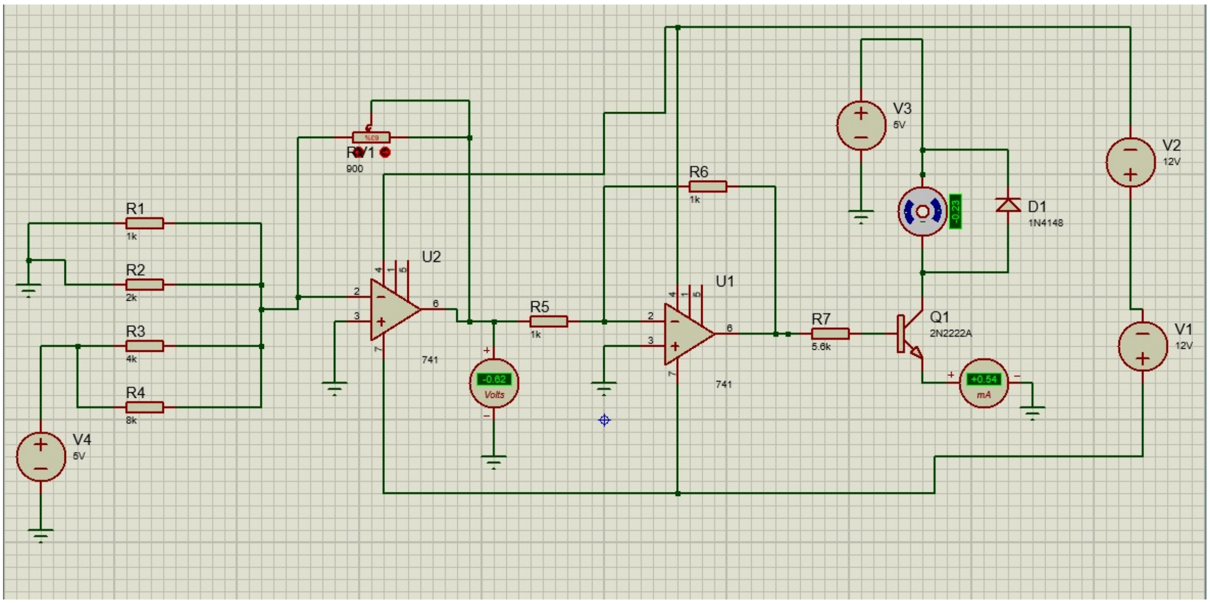
11010110	6.72
11101100	8.44
11100111	8.05
11111100	9.69
1111111	9.92

Table 3 DAC08 operation in bipolar mode.

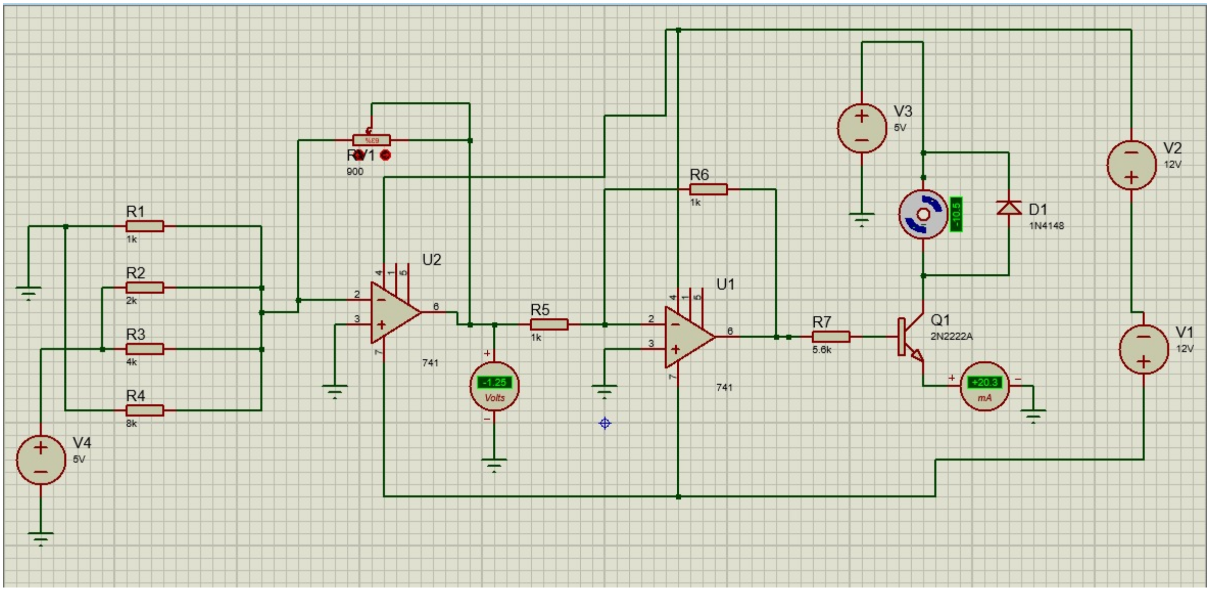
Evidence circuit 1



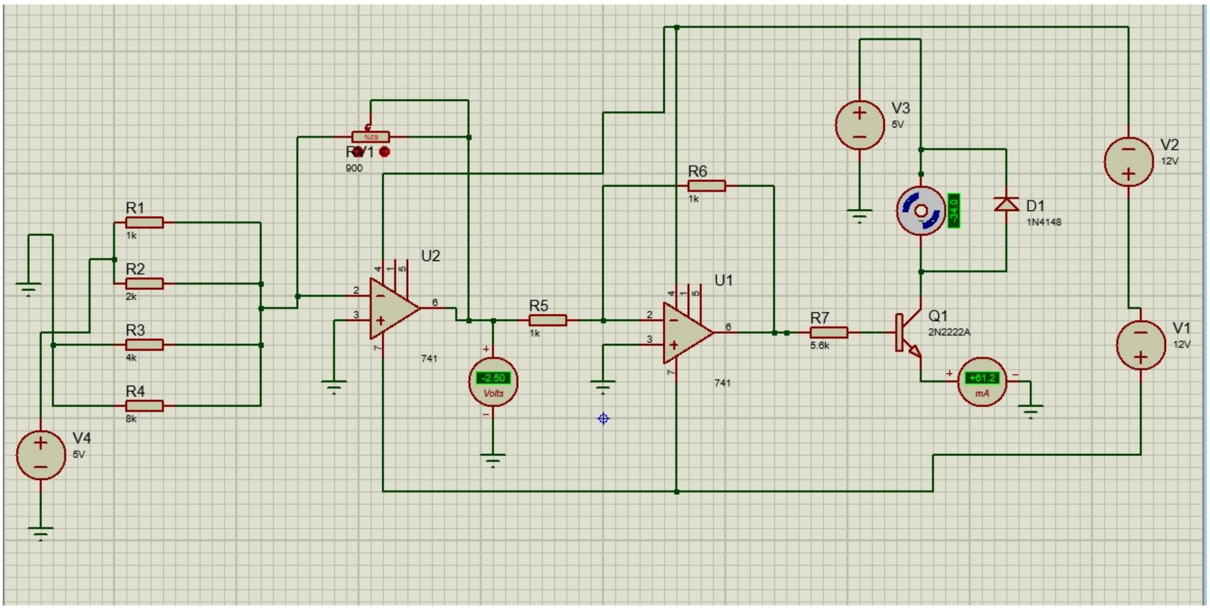
Resolution 206mV, input 0000



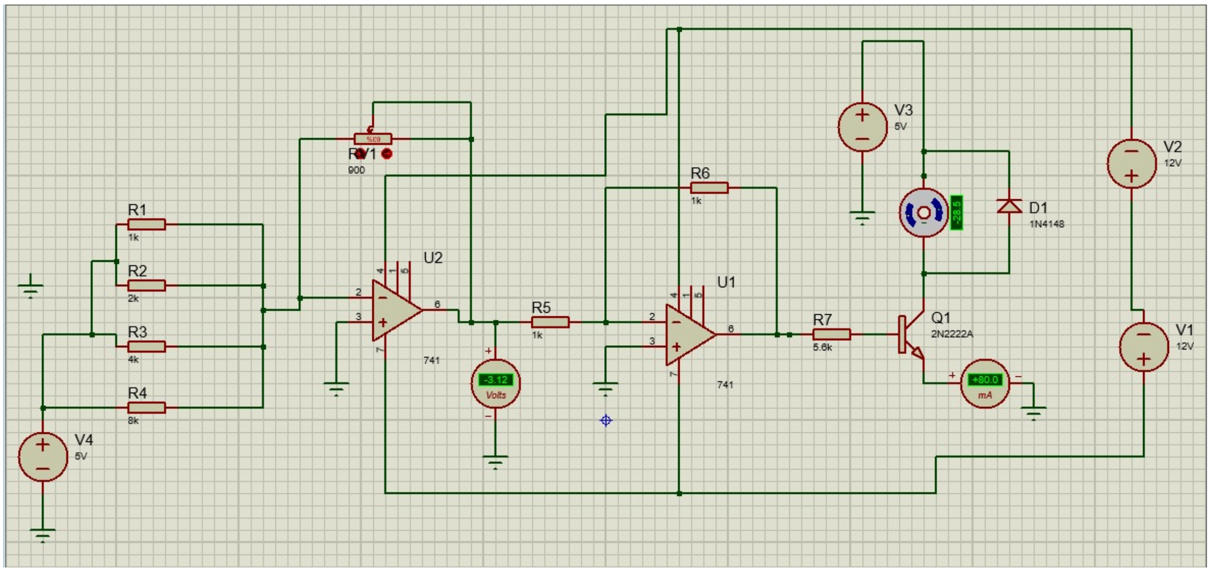
Resolution 206mV, input 0011



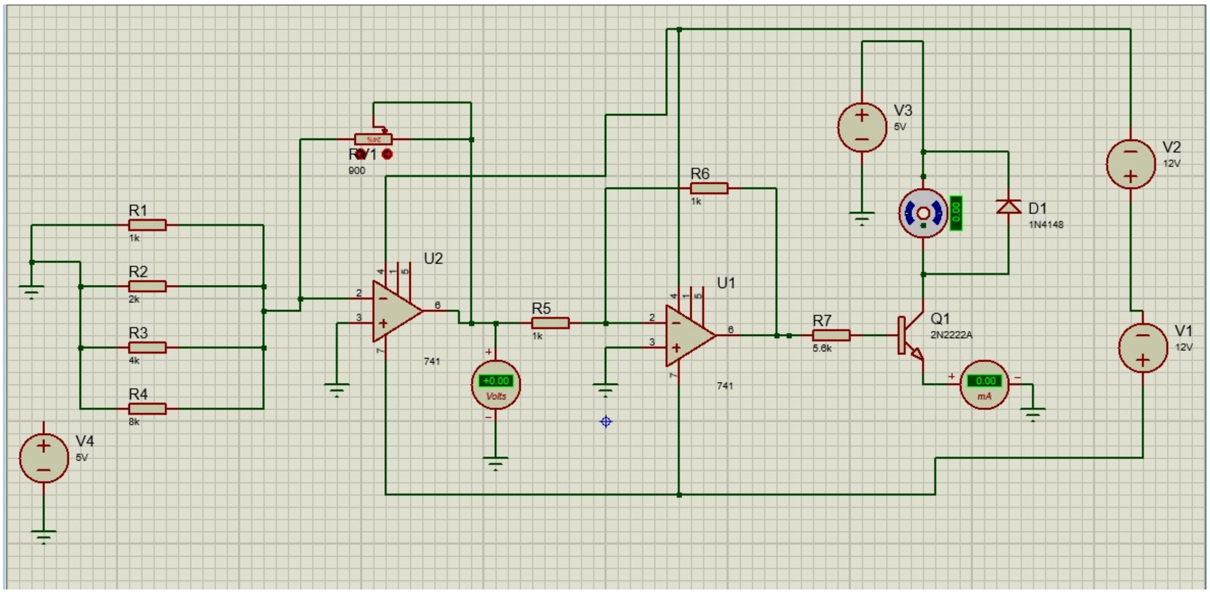
Resolution 206mV, input 0110



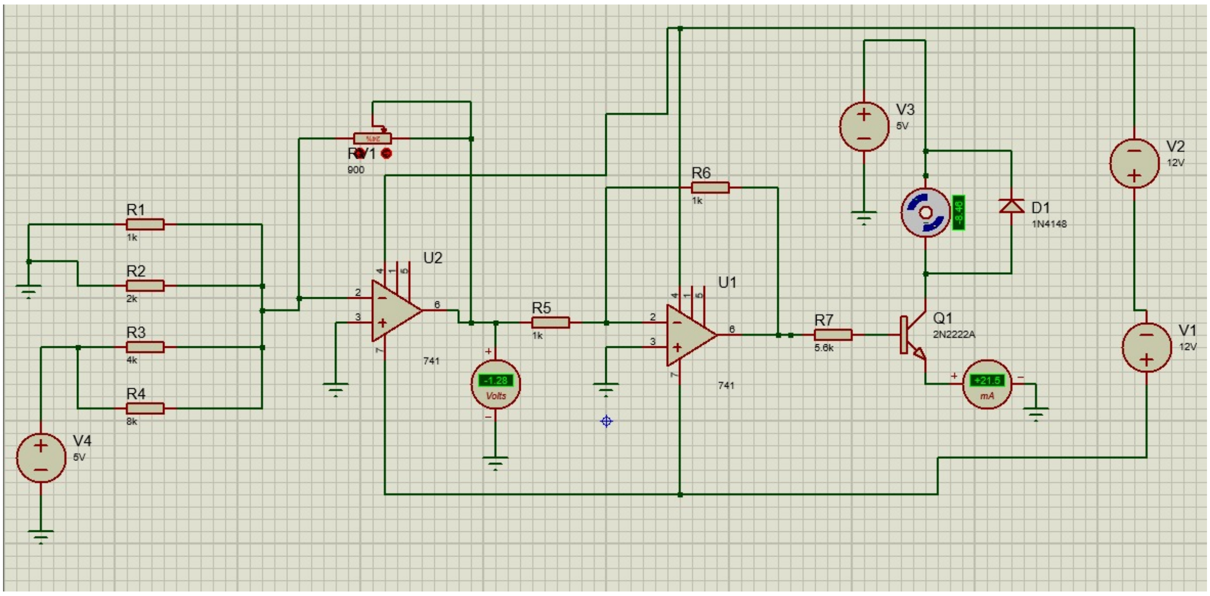
Resolution 206mV, input 1100



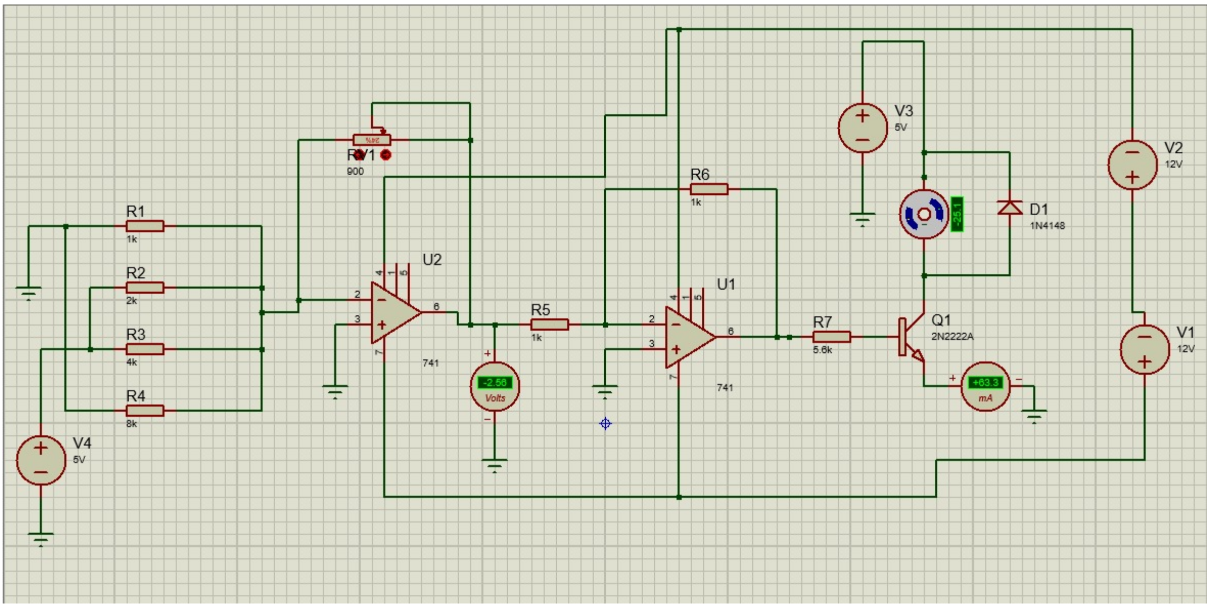
Resolution 206mV, input 1111



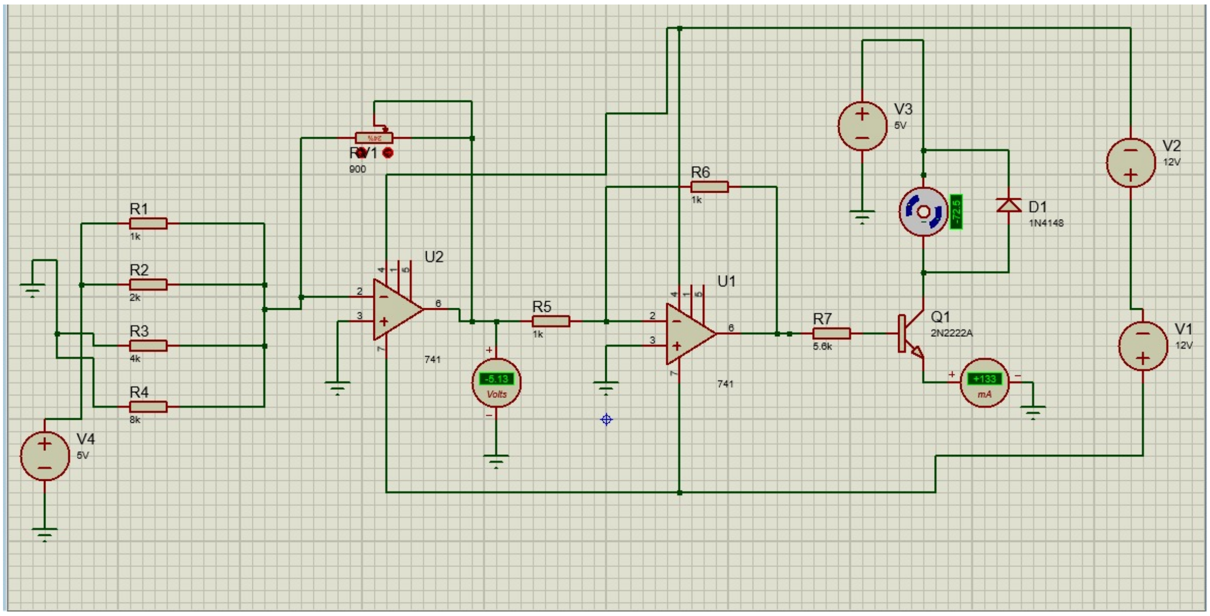
Resolution 425mV, input 0000



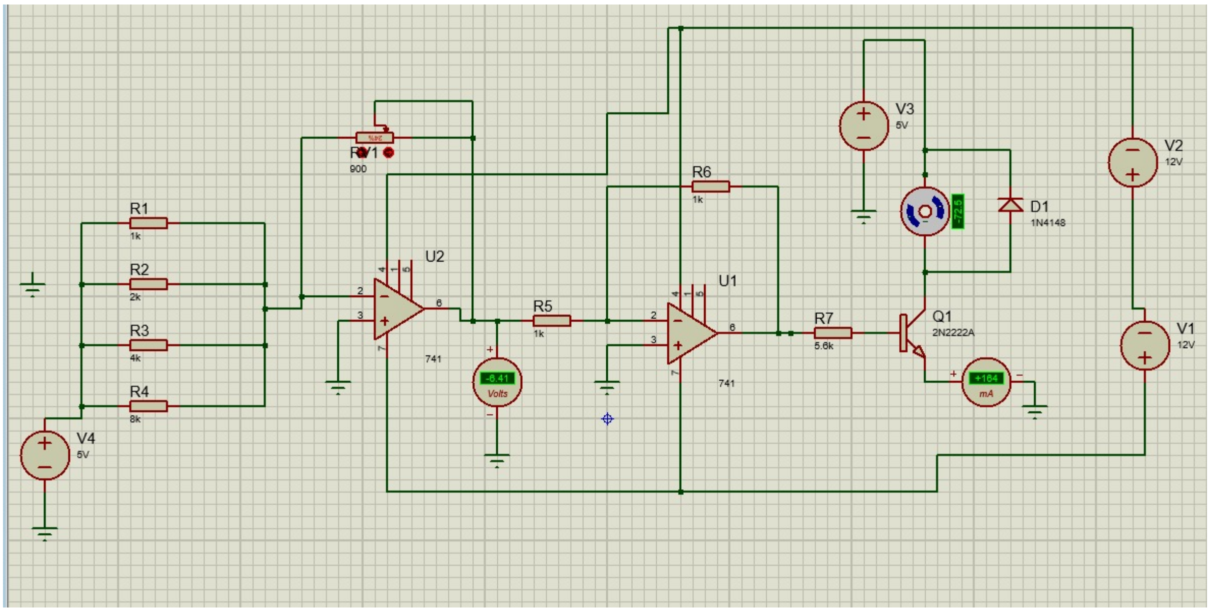
Resolution 425mV, input 0011



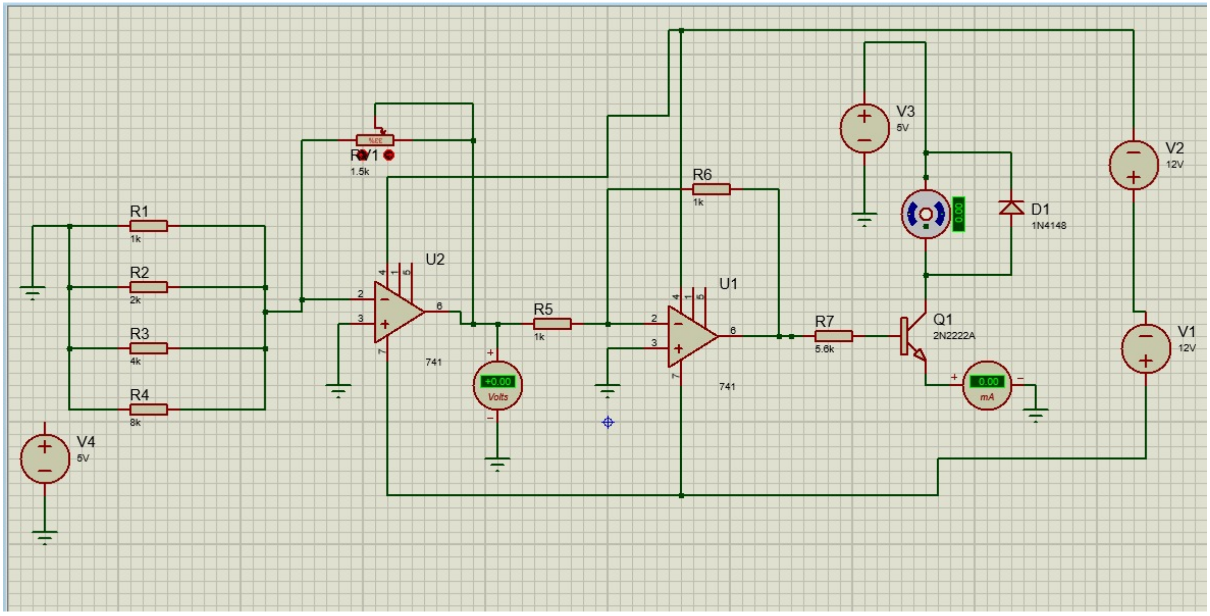
Resolution 425mV, input 0110



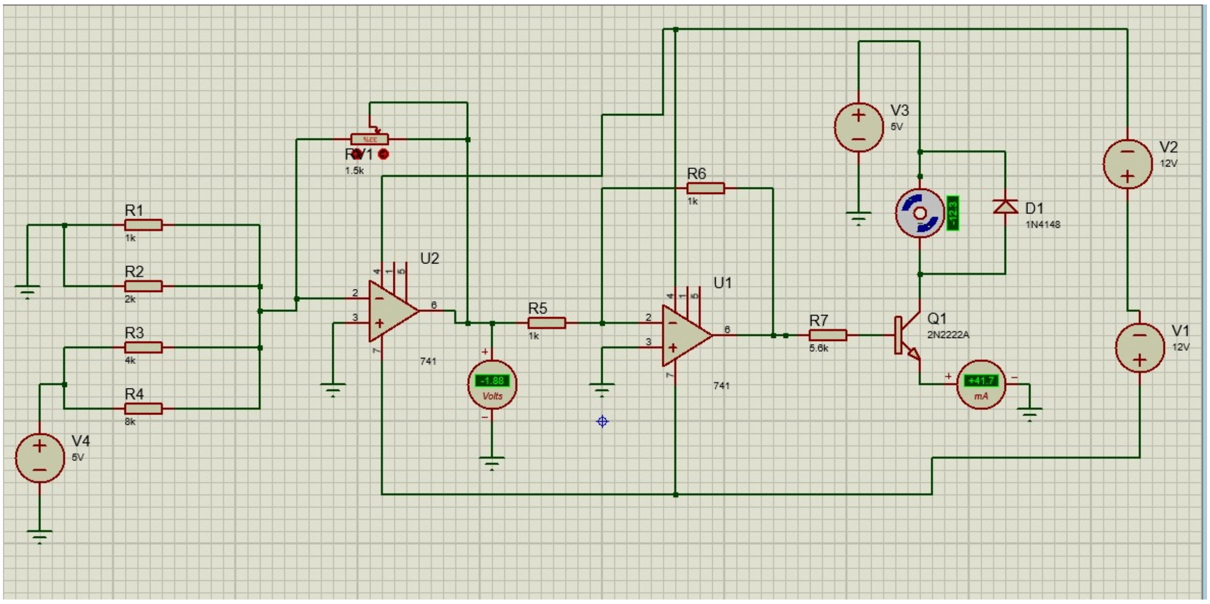
Resolution 425mV, input 1100



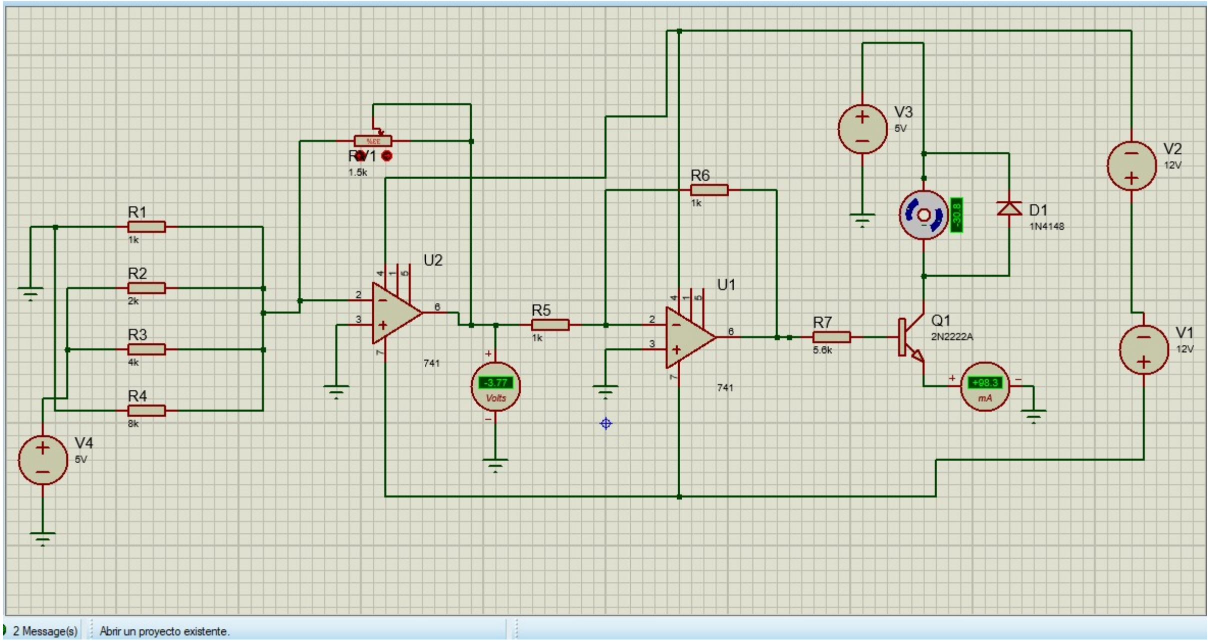
Resolution 425mV, input 1111



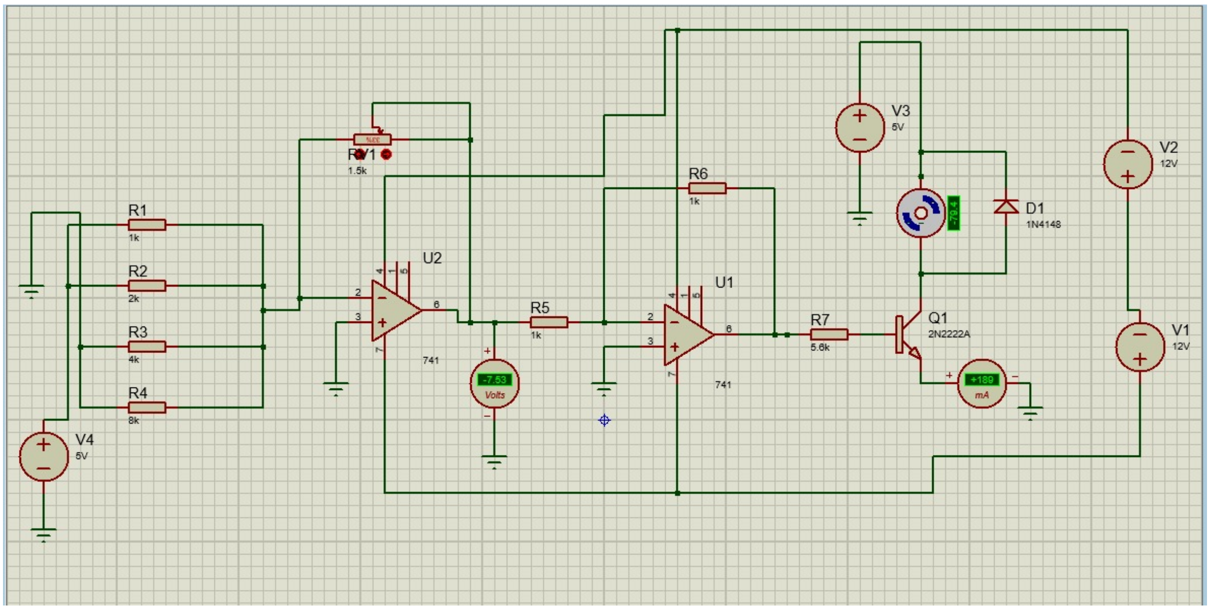
Resolution 625mV, input 0000



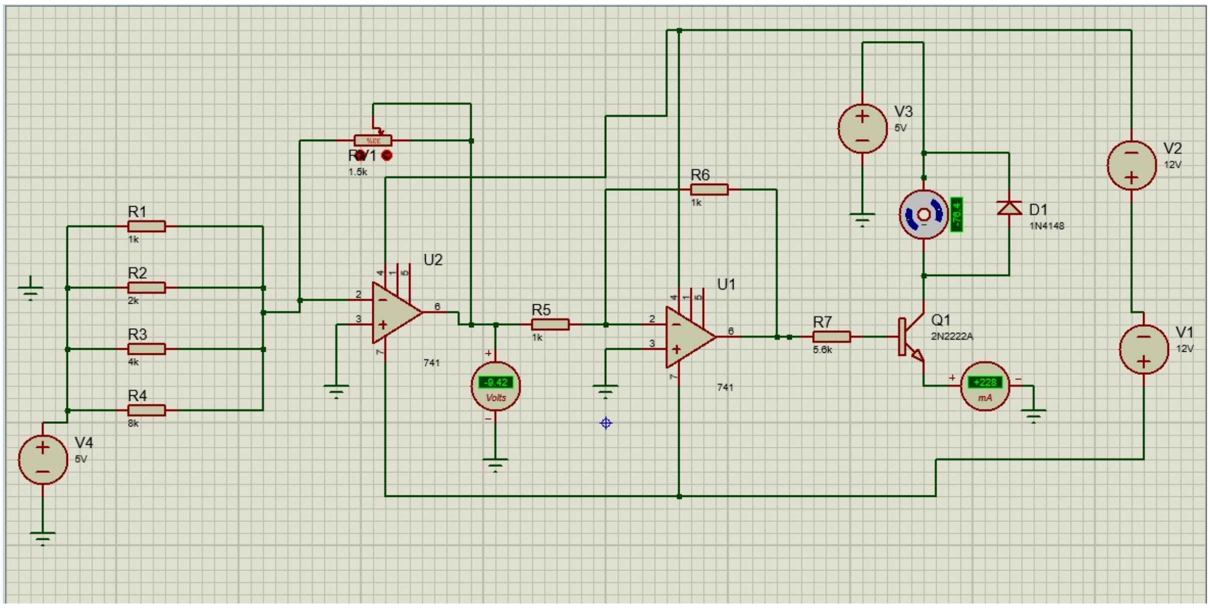
Resolution 625mV, input 0011



Resolution 625mV, input 0110

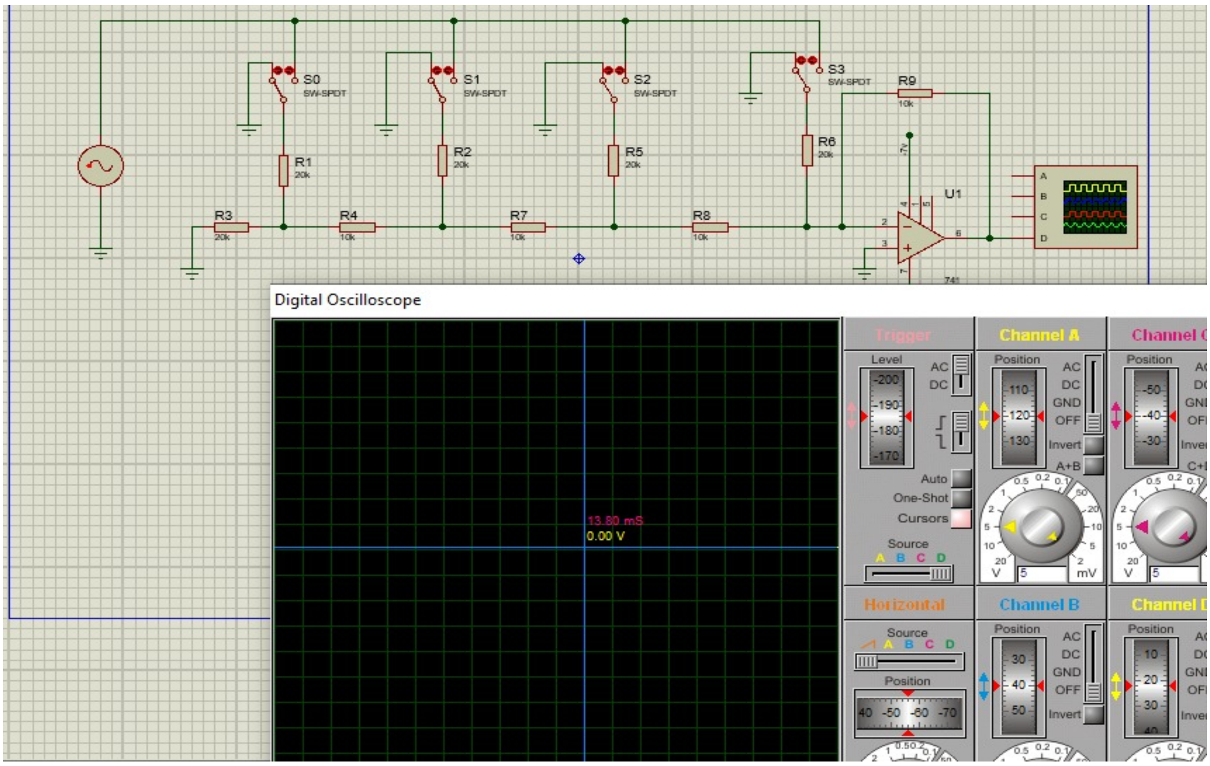


Resolution 625mV, input 1100

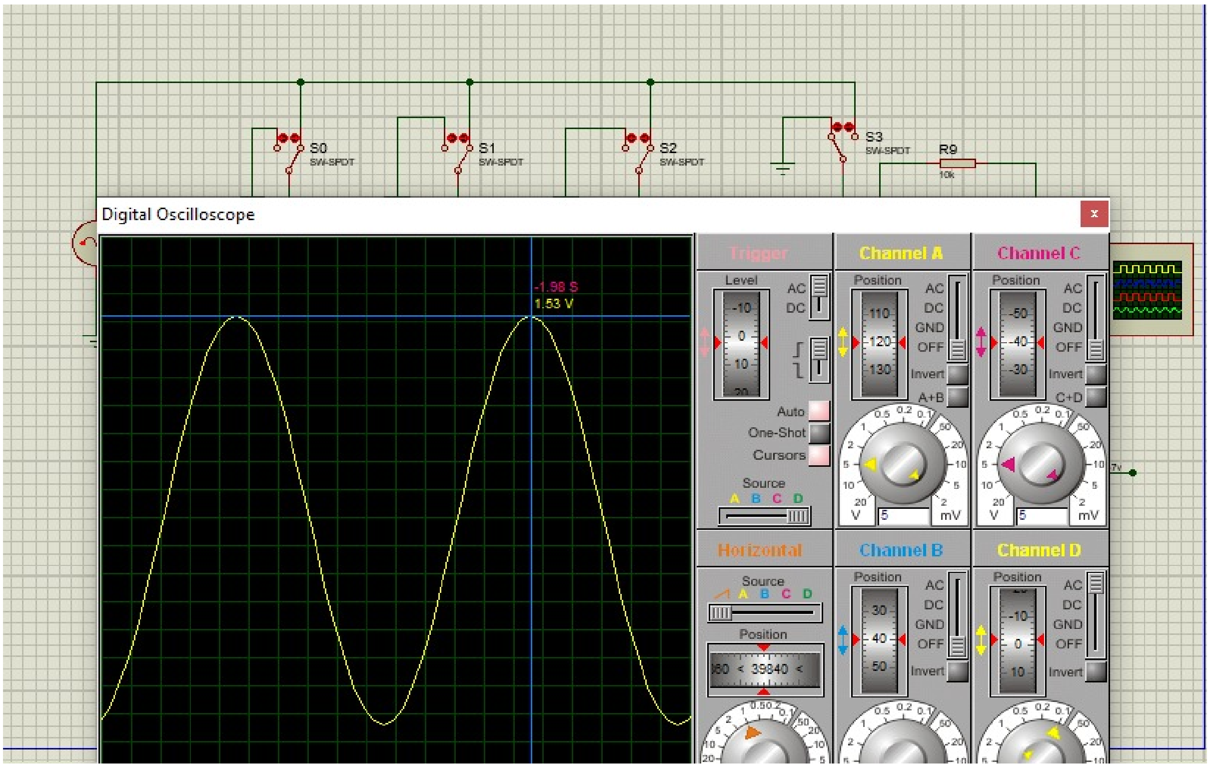


Resolution 625mV, input 1111

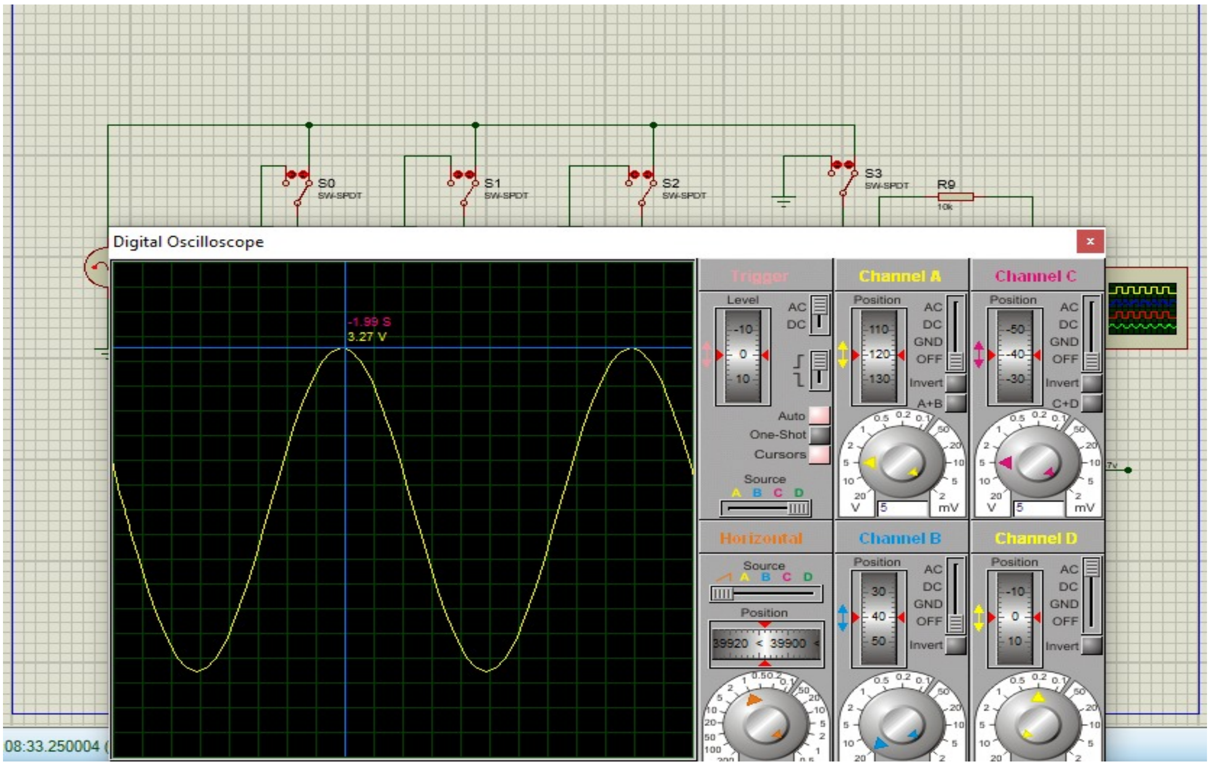
Evidence circuit 2



Input 0000 (0)

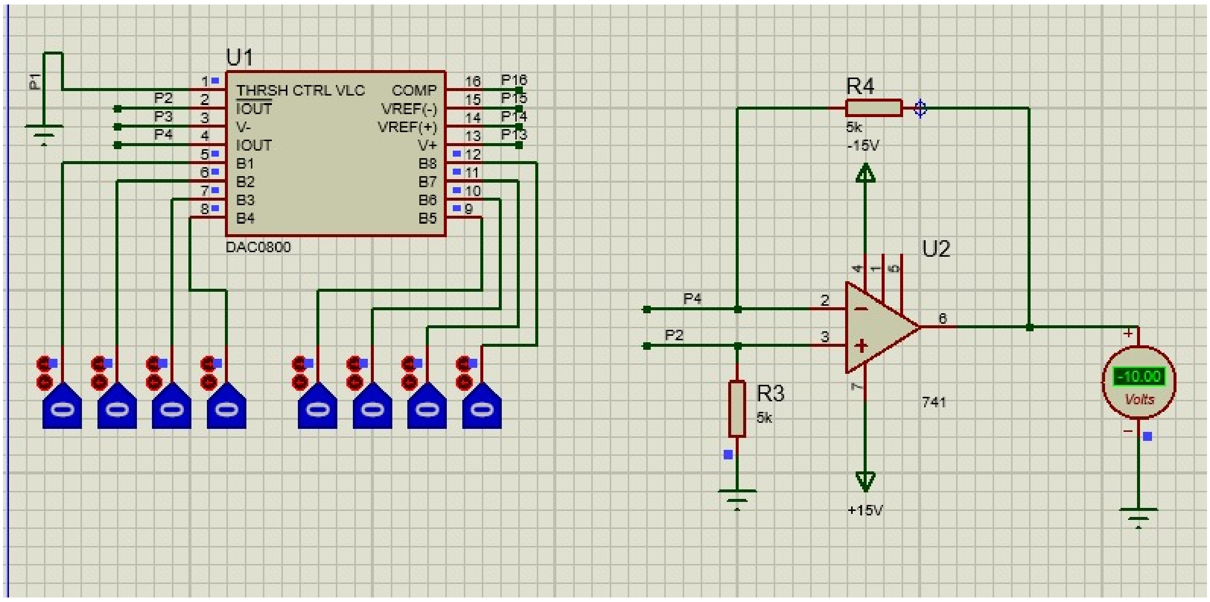


Input 0111 (7)

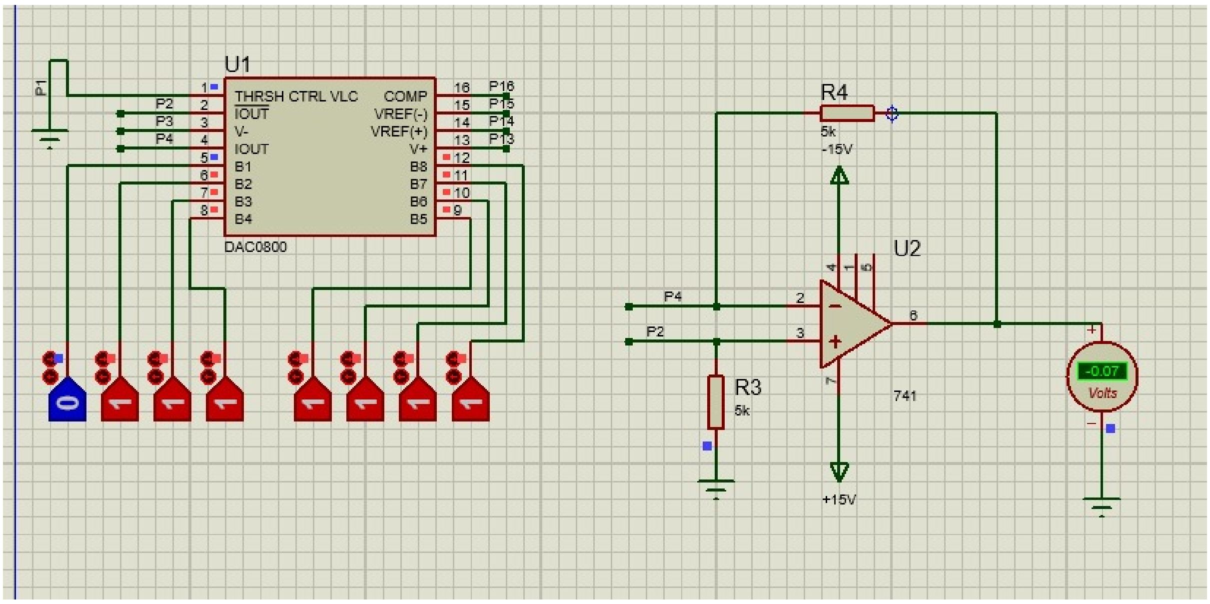


Input 1111 (15)

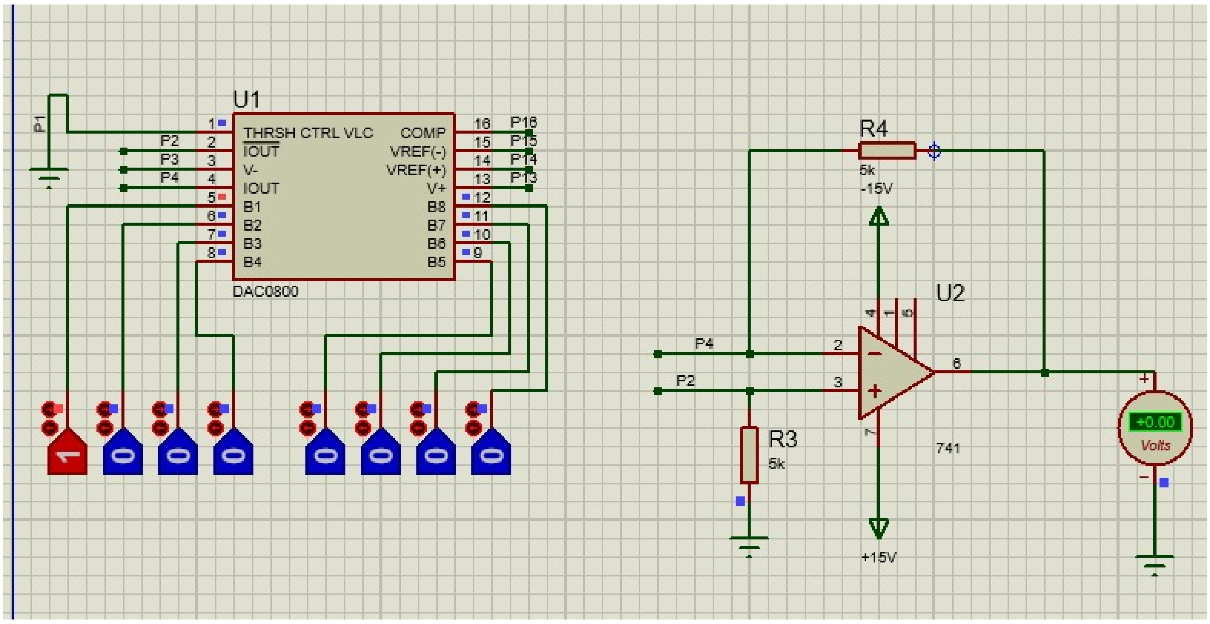
Evidence circuit 3



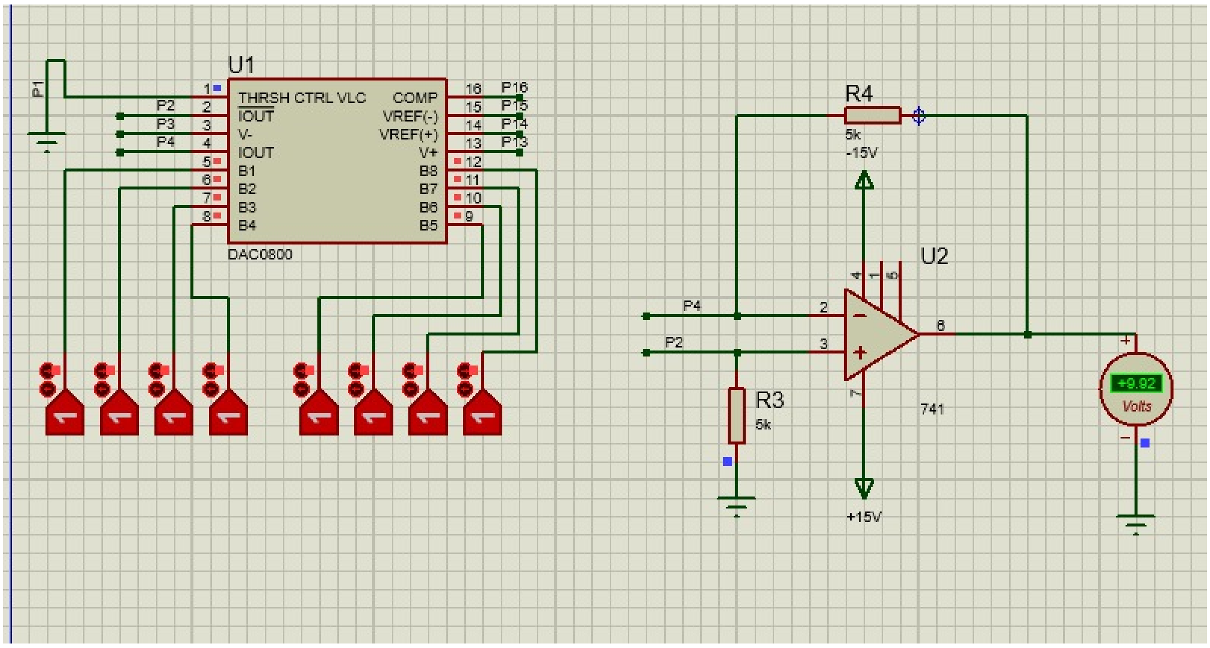
Input 00000000 (0)



Input 01111111 (127)



Input 10000000 (128)



Input 10000000 (255)

Questionnaire

1. **Which are the main applications of a DAC?**
   These sensors generate an output signal out of the magnitude it measures, and do not need an electrical source power.
2. **What are the characteristics of the DAC08?**
   It uses internal transistors to perform the digital to analog conversion, and can work in polar mode where half of the values are negative and half of them are positive.
3. **What is the resolution of a DAC?**
   It is the number of different states that can have a DAC. It is determined by the number of digital inputs that a DAC can accept and the step margin between those states.
4. **How can a DAC be used to control a physic variable?**
   As we saw with the motor this can be used to control the motor's speed by changing the digital input.

Conclusions

In this practice we were able to observe how the characteristics of the DACs influence their operation and the various ways to implement them in a circuit, as well as through the results of the simulation we understood their behavior in terms of voltage and current.

References

https://e2e.ti.com/blogs_/b/analogwire/posts/dac-essentials-static-specifications-amp-linearity
https://www.planetanalog.com/dac-basics-part-3-static-specifications/