Instituto Politécnico Nacional

Ingeniería en Sistemas Computacionales

Laboratorio de Instrumentación

Práctica N° 7 Convertidor Analógico-Digital.

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Fecha de elaboración: 19/11/21.

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Objective

The student will learn how to use the analog-digital converter, as well as how to connect the different components that go with it, in order to find the binary value that corresponds to the analog variable under measurement.

Equipment employed

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

Introduction

What is an ADC?

ADC converters are electronic devices that establish a one-to-one relationship between the value of the signal at its input and the digital word obtained at its output. The relationship is established in most cases, with the help of a reference voltage. Analog to digital conversion has its theoretical foundation in the sampling theorem and in the concepts of quantification and coding.

To perform this task, the ADC converter (Analog-to-Digital Converter) must carry out the following processes.

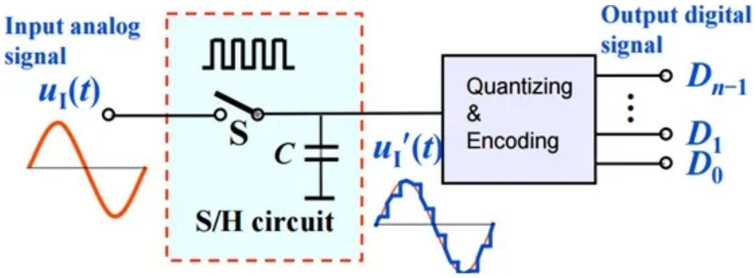
1. Sampling of the analog signal: It consists of taking discrete values of voltage or voltage at regular intervals at different points of the sine wave.

2. Quantization of the signal itself: For this part of the process, the continuous values of the sinusoid are converted into a series of discrete decimal numerical values corresponding to the different levels or voltage variations contained in the original analog signal.

3. Codification of the quantization result, in binary code: Allows you to assign equivalent binary numerical values to the values of voltages or voltages that make up the original analog electrical signal.

How does it work?

To recapitulate, the ADC process is as follows



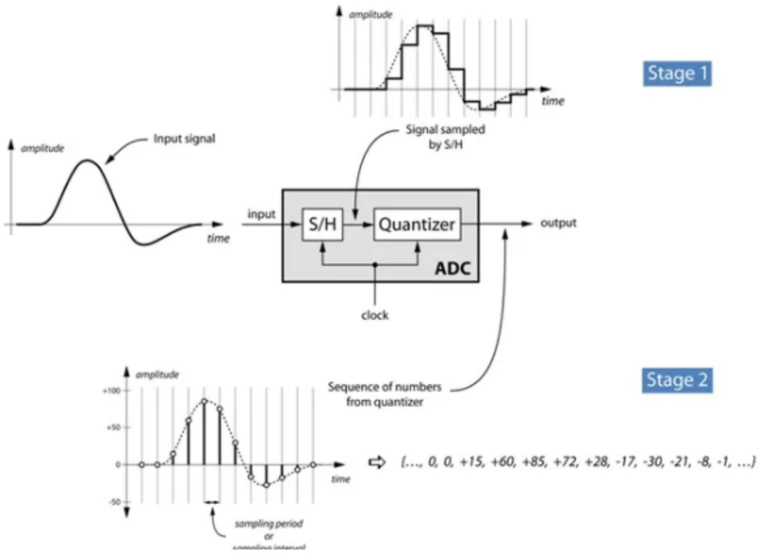
1. Sampling and holding, analog signals change continuously over time, so to measure a signal we have to keep it stable for a certain time in order to digitize and sample it. Minimum sampling rate should be at least twice the highest data frequency of the analog signal

   This is done by a sample and hold circuit, where the switch is normally open and when we want to find a measurement the switch closes momentarily.

2. At the output of (S/H) there is a certain voltage level to which we assign a numerical value. Then we look for the closest value, corresponding to the amplitude of the sample and hold signal. This value is obtained from a limited set of possible values. It depends on the range of the quantizer and the range is given in a power of 2, 2^n where n is the number of bits.

   Once the closest value is known, it is assigned a numerical value and encoded as a binary number. The binary encoded numbers generated by the quantizer are represented by n bits and the resolution of an ADC can also be denoted by n bits.

The figure show the full process of sample, holding and quantizing



The values obtained after the quantization and coding process are approximations to real-world values. The accuracy of the quantizer depends largely on the resolution of the quantizer, the higher the resolution, the more accurate the values will be. If the set of possible values, among which the closest one has to be searched, is larger, more time will certainly be needed. But to speed up this process, more techniques have been developed.

Types

Flash Converters

Parallel flash converters use a set of comparators that compare the input voltage to a set of reference voltages across a resistor network. The voltages start at a value equal to that for one-half the least-significant bit (LSB) and increase in equal voltage equivalent to one LSB for each comparator.

As the input voltage increases, the comparators set their outputs to logic 1 starting with the lowermost comparator. A digital encoder circuit converts the comparator outputs into a n-bit binary-weighted code.

Flash converters are fast, but they have drawbacks because they require so many comparators, flash ADCs consume considerable power, making them impractical for battery-powered equipment.

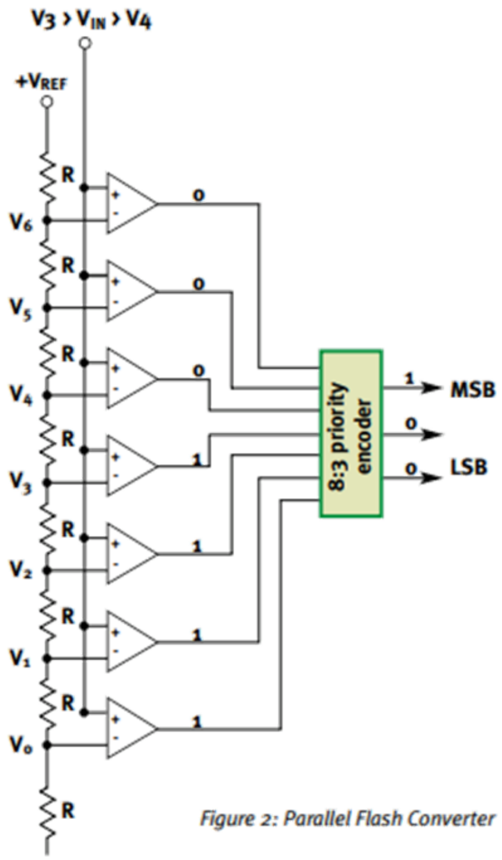
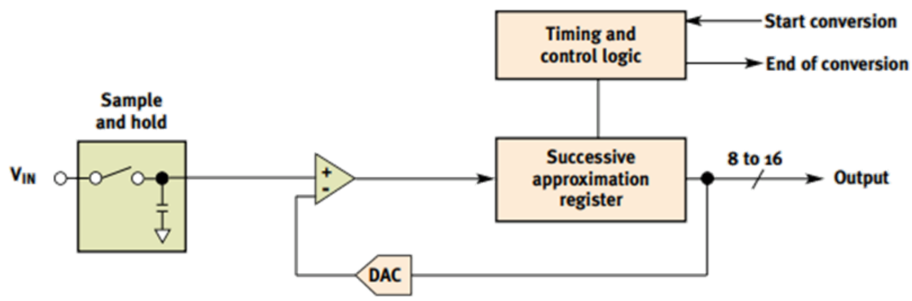


Figure 2: Parallel Flash Converter

SAR Converters

Successive Approximation Registers are the most popular ADCs in measurement products.If you use a PC plug-in data-acquisition board or PCexternal data-acquisition system, you probably use an SAR converter.

At the start of a conversion sets its successive-approximation register output so that all bits except the MSB produce logic 0. That sets the DAC's output to one-half of the device full scale input. The comparator sets its output based on the difference between the DAC output and the sampled voltage.

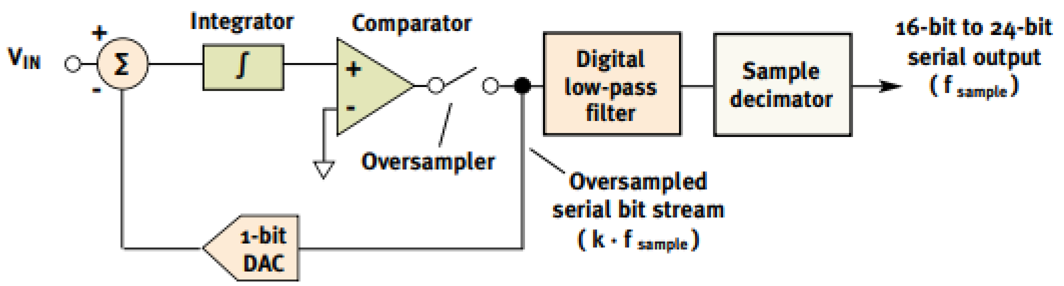


Sigma-Delta Converters

Many measurement applications don't need the conversion rates possible with SAR converters, but these need finer resolution. Sigma-delta ADCs can provide resolution as fine as 24 bits and they can trade resolution for speed, also are more complex than others.

The oversampled analog signal goes through an integrator whose output drives a comparator that, in turn, drives a 1-bit DAC in the feedback loop. Through a series of iterations, the integrator, comparator, DAC, and summing junction produce a serial bit stream that represents the oversampled input voltage.

Once digitized, the oversampled signal goes through a digital filter to remove frequency components at or above the Nyquist frequency, which is one-half of the ADCs output-sampling rate. A digital low-pass filter removes those high-frequency components, and a data decimator removes the oversampled data. The final output is a serial bit stream.



Development

1. **Basic circuit with ADC.**

   In the electronic circuit simulator, assemble the circuit shown in Figure 1.Use +V= 5 VDC to energize the integrated circuit.

   As soon as the circuit is energized, the ADC has to start operating, if not, press and release the push button S1.

   To verify that the ADC is in operation, you have to observe that the LED's light up and that the LED's turn on and off as the potentiometer value is modified.

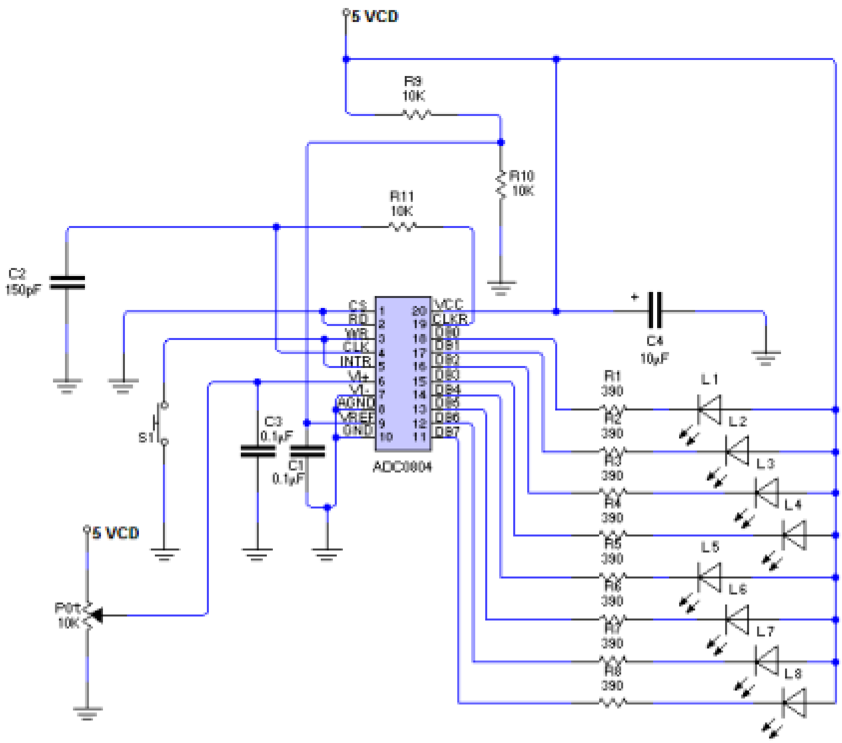


Figure 1.

Calculate the resolution voltage at which the ADC is working, based on the reference voltage that is being sent to it, write down this value and the other values requested in table 1.

Resolution=V_REF/(2^n-1) = 5V/(2^8-1) = 19.6 mV

Resolution= 19.6 mV									
V_A measured (V)	**Binary Combination**								**V_A calculated (V)**
	B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**	
0.0	0	0	0	0	0	0	0	0	0.00
0.5	0	0	0	1	1	0	0	1	0.49
1.0	0	0	1	1	0	0	1	1	0.99
1.5	0	1	0	0	1	1	0	0	1.48

2.0	**0**	1	1	0	0	1	1	0	1.99
2.5	**0**	1	1	1	1	1	1	1	2.48
3.0	**1**	0	0	1	1	0	0	1	2.99
3.5	**1**	0	0	1	1	0	0	1	3.48
4.0	**1**	1	0	0	1	1	0	0	3.99
4.5	**1**	1	1	0	0	1	0	1	4.48
5.0	**1**	1	1	1	1	1	1	1	4.99

Table 1 ADC operation.

To fill table 1, you have to measure the voltage that arrives at the terminal 6 of the ADC, having to modify the value of the potentiometer, so that this one gets different voltage values that are requested in the first column of table 1.

2. ADC connection to a sensor signal conditioning circuit.

Disconnect the potentiometer shown in the diagram in figure 1. Next, assemble the circuit illustrated in the image of the diagram in figure 2, and connect the output terminal of this conditioner circuit to terminal 6 of the ADC.

You have to calculate the values of R and Rf so that the conditioner circuit has a voltage range that is between the value of 0 V and 5 V. Consider for this calculation that the range in which the LM35 will work is from 0 to 100°C, with its output changing by 10mV/°C and that you have 250mV at 25°C approximately.

Record the value of the calculated gain in the space provided in the table below. Once you have everything ready, proceed to carry out the measurements required to fill in table 2.

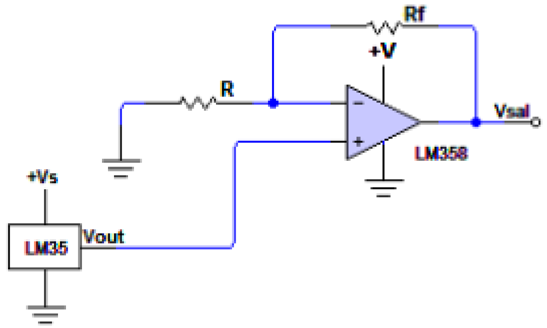


Figure 2.

$$Av = 1 + \frac{RF}{RI}$$
$$With\ RF = 10K\ \ we\ have$$
$$Av = 1 + \frac{10k}{RI}$$
$$5 = 1 + \frac{10k}{RI}$$
$$RI = \frac{10k}{4}$$
$$RI = 2.5\ k$$

$$Av = \frac{V_{OUT}}{V_{IN}}$$
$$For\ 5v\ output\ we\ have\ 1v\ input$$
$$Av = \frac{5v}{1v}$$
$$Av = 5$$
$$Av = 1 + \frac{10k}{2.5k}$$
$$Av = 1 + 4$$
$$Av = 5$$

Av= 5									
Sensor V_{OUT} (mV)	**Op-Am V_{OUT} (V)**	**Binary Combination**							
		B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
250	**1.26**	0	1	0	0	0	0	0	0
300	**1.51**	0	1	0	0	1	1	0	1
350	**1.77**	0	1	0	1	1	0	1	0
400	**2.02**	0	1	1	0	0	1	1	1
450	**2.27**	**0**	1	1	1	0	1	0	0
500	**2.52**	**1**	0	0	0	0	0	0	0
550	**2.77**	**1**	0	0	0	1	1	0	1
600	**3.02**	**1**	0	0	1	1	0	1	0
650	**3.27**	**1**	0	1	0	0	1	1	1
700	**3.52**	**1**	0	1	1	0	0	1	1

Table 2 Digitized values of the conditioning circuit.

Set the 10 different voltage values requested and deliver the sensor, by changing the measured temperature.

3. **Modification of the ADC reference voltage.**

The resistors R9 and R10 in the diagram shown in figure 1, constitute a voltage divider, which establishes the value of the reference voltage in the ADC. Then you have to modify (recalculate) the value of these resistors, so that the dynamic range (the reference voltage in turn sets the dynamic range), is between 0V and 3V.

Reconnect the circuit of figure 2 to the ADC, but considering that now the operating range is from 0 V to 3 V, so you have to recalculate the value of resistors R and Rf. Finally, fill with the required values in table 3.

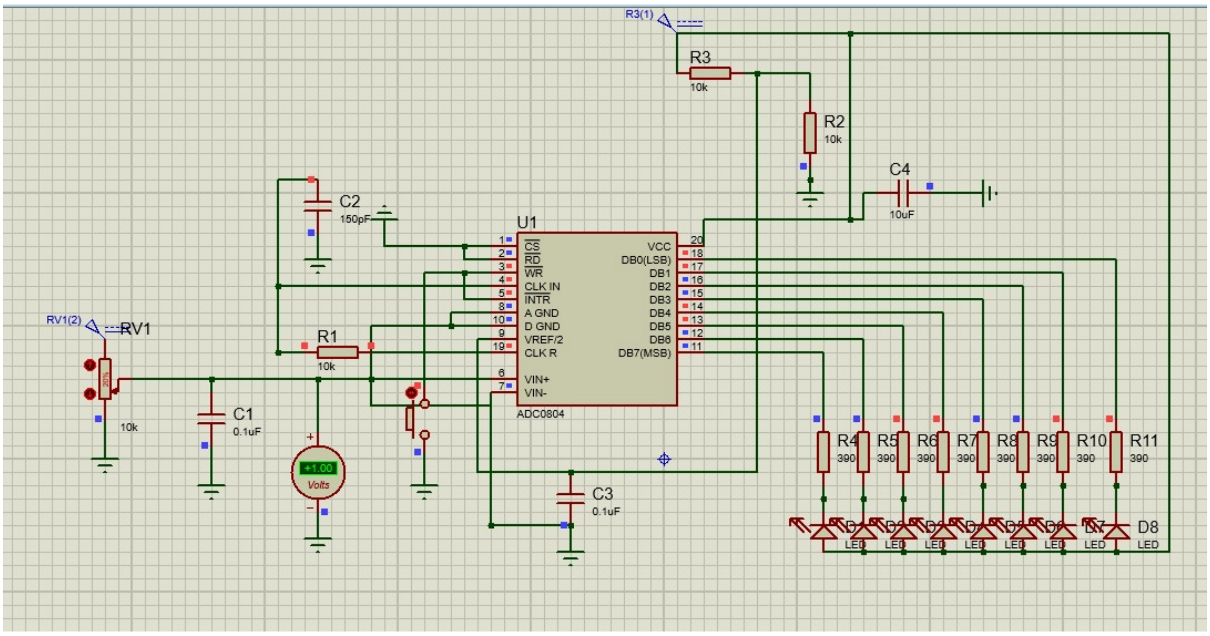
$$Av = 1 + \frac{RF}{RI}$$
$$With\ RF = 10K\ \ we\ have$$
$$Av = 1 + \frac{10k}{RI}$$
$$3 = 1 + \frac{10k}{RI}$$
$$RI = \frac{10k}{2}$$
$$RI = 5\,k$$

$$Av = \frac{V_{OUT}}{V_{IN}}$$
$$For\ 5v\ output\ we\ have\ 1v\ input$$
$$Av = \frac{3v}{1v}$$
$$Av = 3$$
$$Av = 1 + \frac{10k}{5k}$$
$$Av = 1 + 2$$
$$Av = 3$$

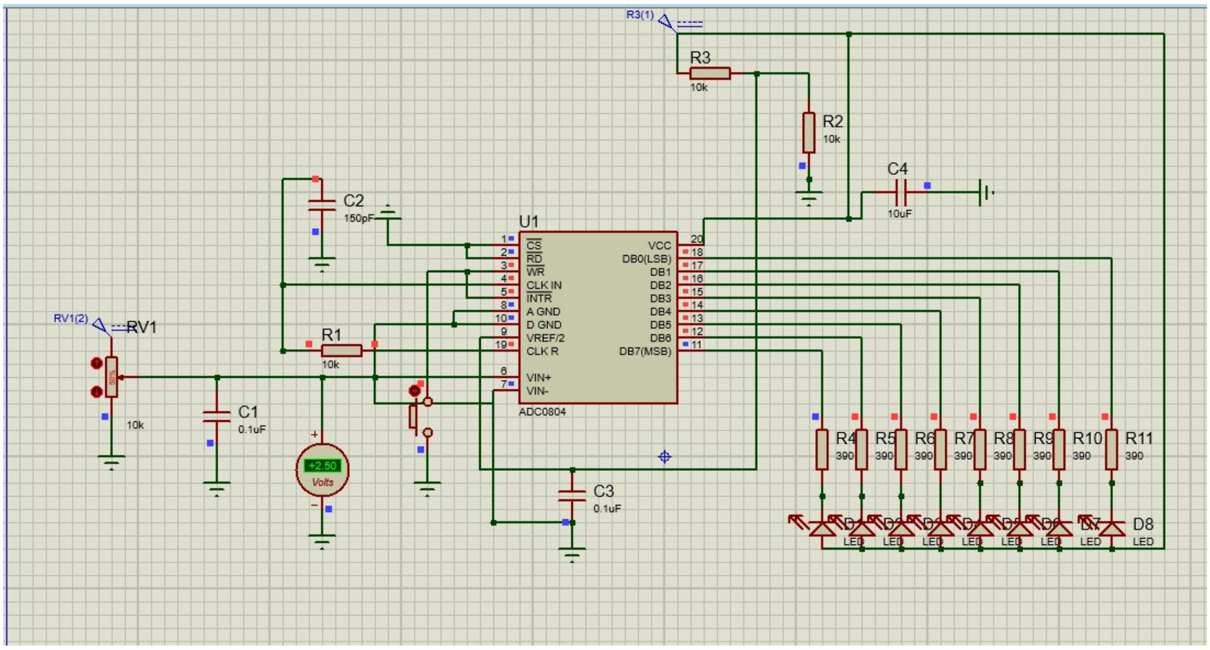
Av=									
Sensor V_{OUT} (mV)	**Op-Am V_{OUT} (V)**	**Binary Combination**							
		B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
250	**0.76V**	0	1	0	0	0	0	0	0
300	**0.91**	0	1	0	0	1	1	0	0
350	**1.06**	0	1	0	1	1	0	0	1
400	**1.21**	0	1	1	0	0	1	0	1
450	**1.63**	**0**	1	1	1	0	0	1	0
500	**1.51**	**0**	1	1	1	1	1	1	1
550	**1.66**	**1**	0	0	0	1	0	1	1
600	**1.81**	**1**	0	0	1	1	0	0	0
650	**1.96**	**1**	0	1	0	0	1	0	0
700	**2.11**	**1**	0	1	1	0	0	0	1

Table 3.

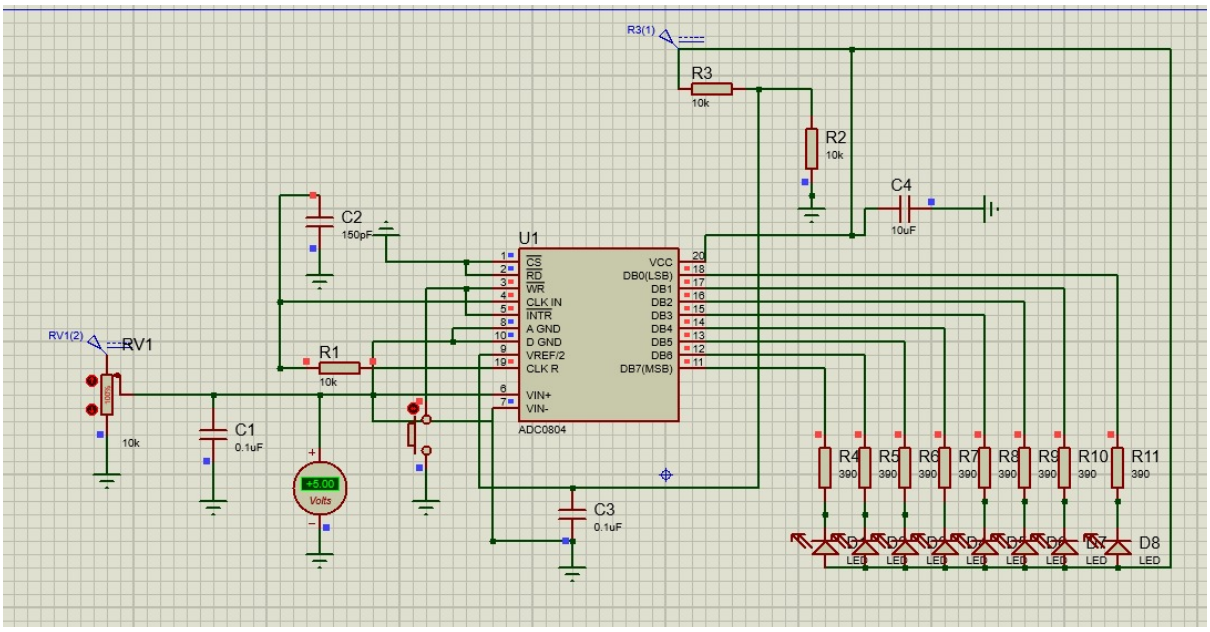
Evidence circuit 1



Va=1v

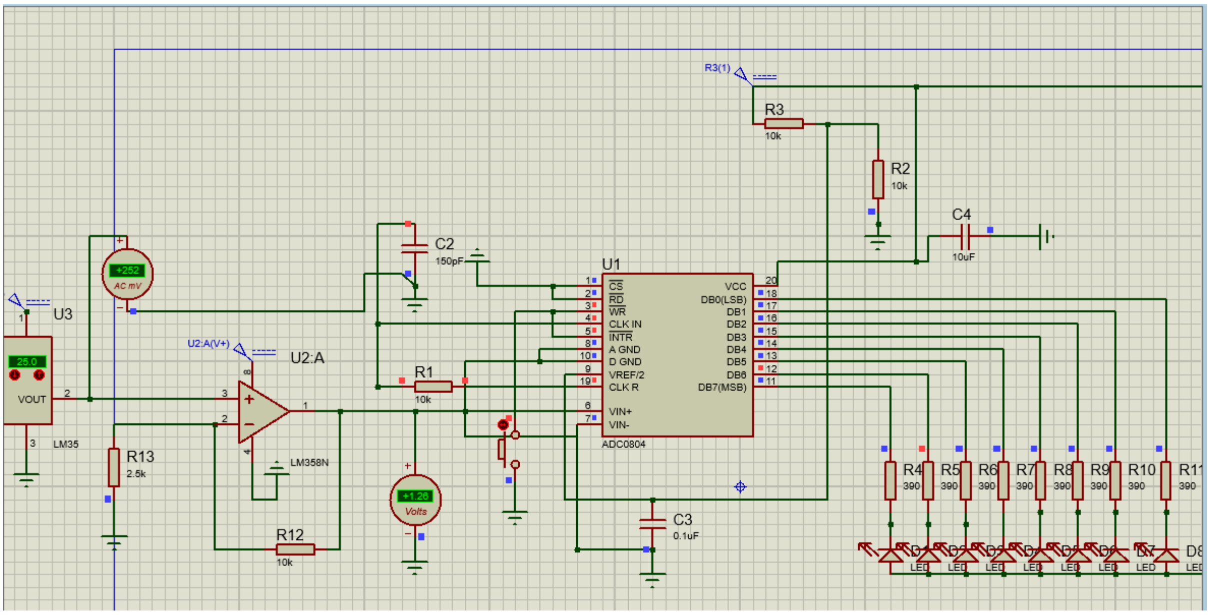


Va=2.5v

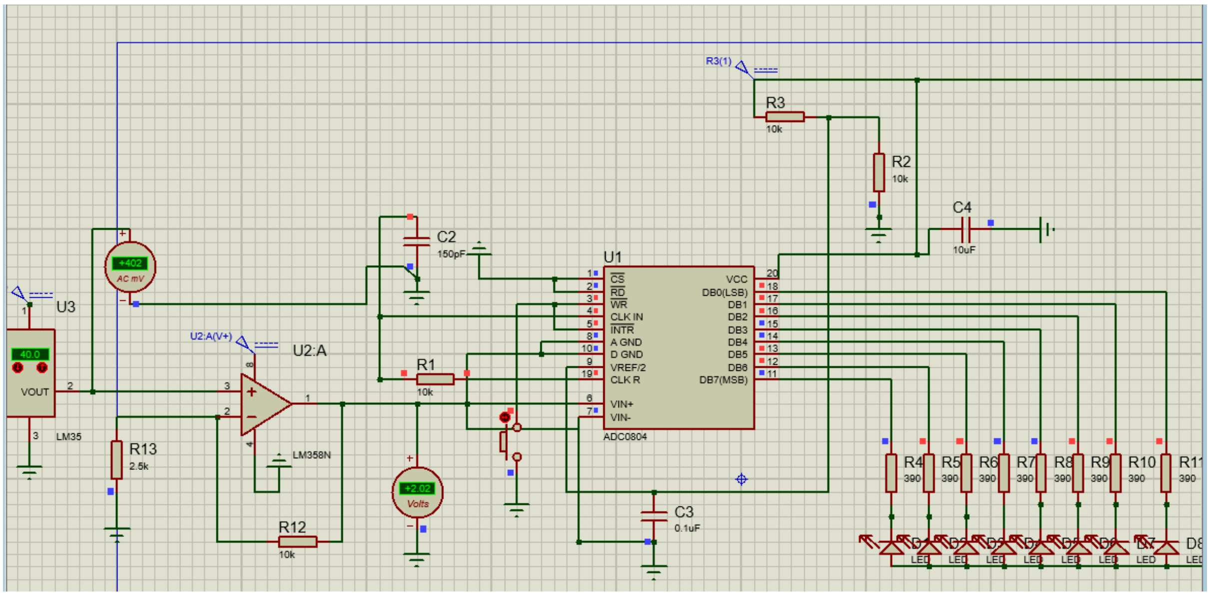


Va= 5v

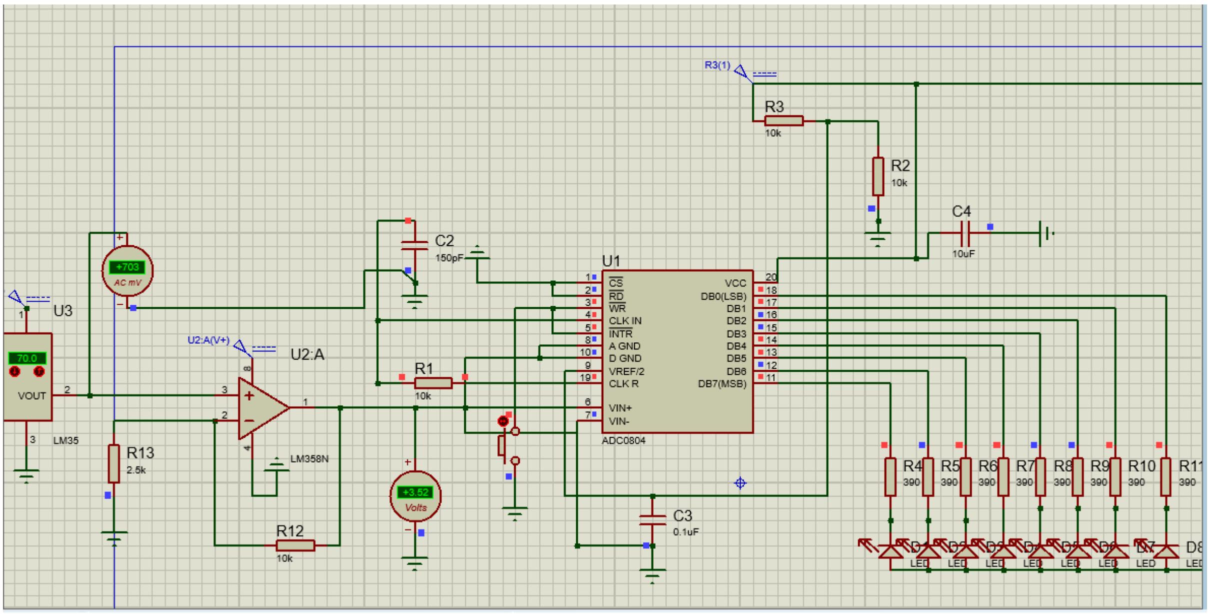
Evidence circuit 2



VSensor= 250 mv

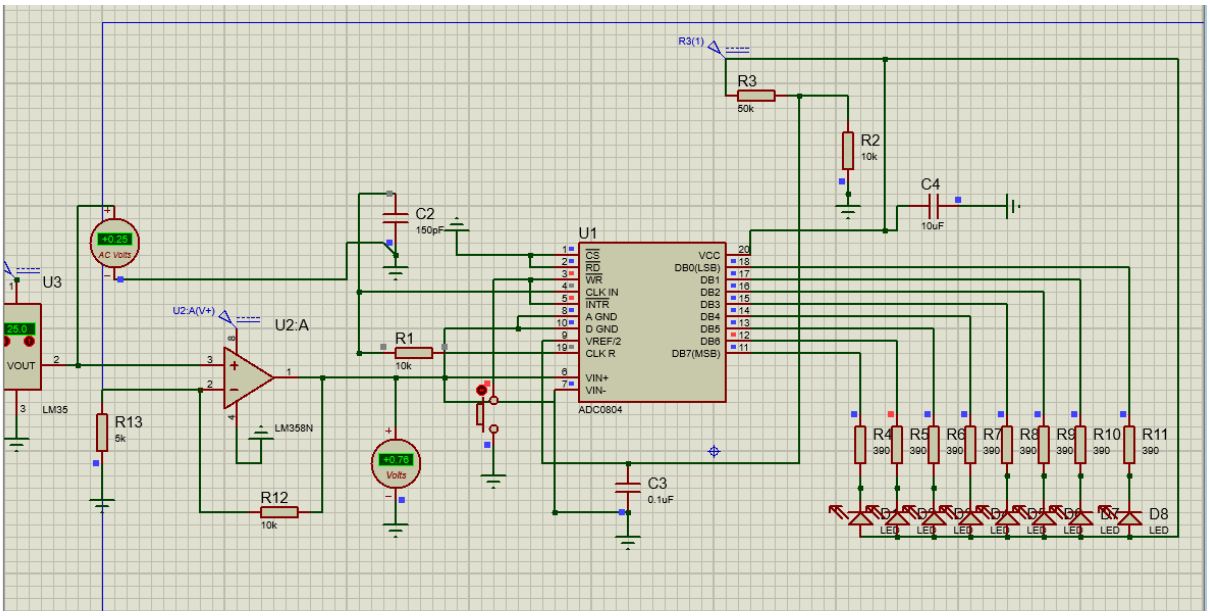


VSensor= 400 mv

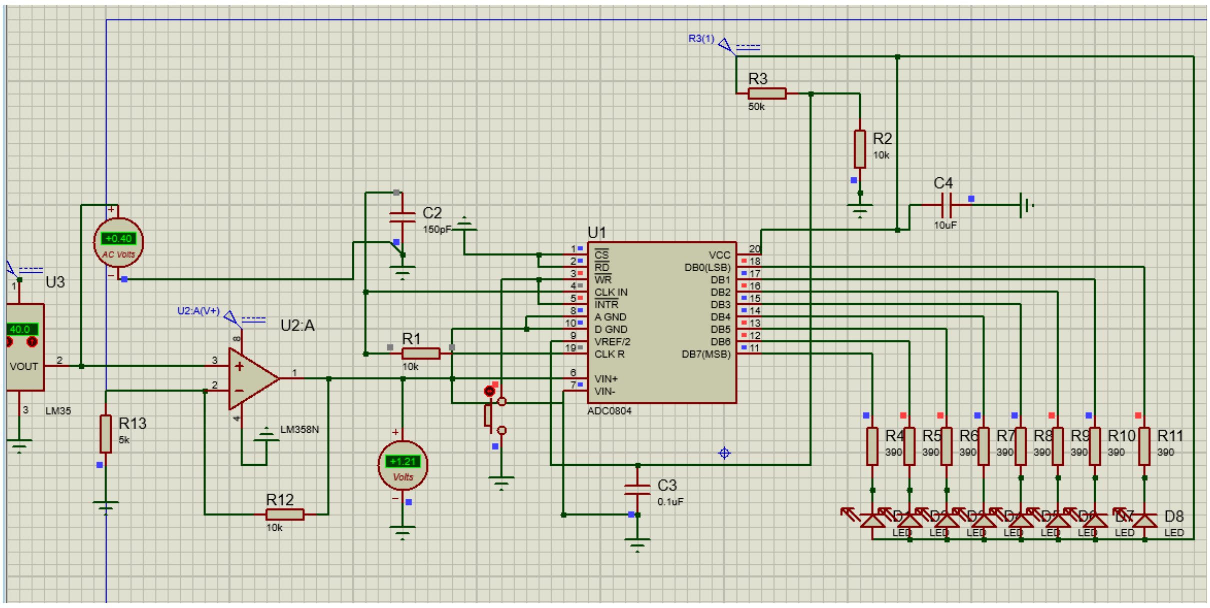


VSensor 700mV

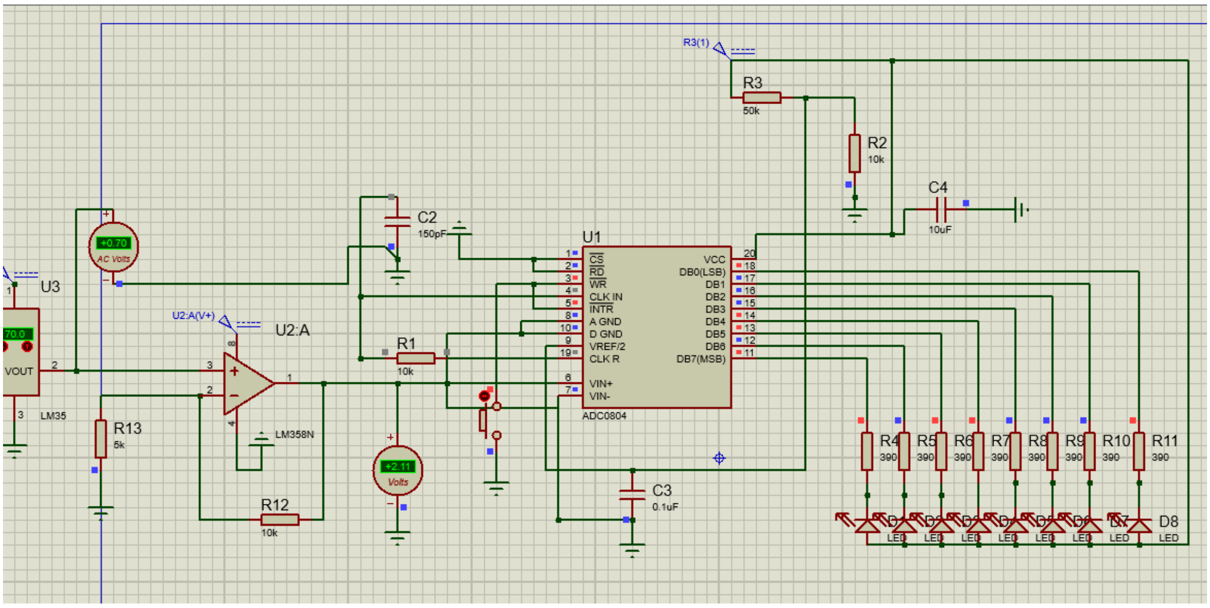
Evidence circuit 3



VSensor= 250mV



VSensor 400mv



VSensor= 700mv

Questionnaire

1. **Explain the conversion technique used by the ADC0804 IC.**

It uses the SAR architecture and works with 0-5 Volts, has 1 Analog input and 8 output pins. ADC0804 comes with an internal clock but to increase or change the clock cycle we could use the external clock.

2. **Which are the most suitable circuits to place the reference voltage in the ADC?**

Voltage divisors.

3. **Mention other analog-to-digital conversion techniques than the one used by the ADC0804.**

There are different architectures that an ADC can use, these techniques are: Flash Architecture, Pipeline Architecture, SAR Architecture, Sigma-Delta Architecture.

4. **What is the difference between the ADC0801 and the ADC0804?**

They use different techniques to convert a signal from analog to digital.

Conclusions

The development of this practice allowed us to observe the operation of an adc and to understand how the digital to analog conversion process is performed as well as the factors that are present. We also recognized the importance of this electronic component that represents the signals that surround us in numerical terms and that are also very present in the technological field as they are implemented in digital multimeters, oscilloscopes, thermocouples, microcontrollers, among others.

References

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