National Polytechnic Institute
Superior School of Computer Sciences

Analog Electronics.

Practice 6 - Level Detector Circuits.

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November 7, 2017

Contents

1 Objective:

The student will implement the detector configurations:

- **Zero-Crossing Detectors.**
- **Hysteresis Detectors.**

And also learn how to know how to interpret the results obtained for the aforementioned circuits.

2 Introduction:

Zero crossing detectors are used to detect the types of signals, or different meanings of signals. Something very simple would be to consider a signal that 'in its positive part' will indicate a 'logical one' and in its negative part a 'logical zero'. The zero crossing detector is part of the detection circuit 'by level' to determine if a 'one' or a 'zero' has been received. With analog signals the zero crossing detectors operate with waveform much more variants than those of the digital case, they can be used to determine the type of the waveform, the average level of the signal, help integrate or differentiate signals, etc. All that 'mathematical function' to apply to the signal that requires determining the 'zero level' of such a signal. A practical example of this configuration is the zero-crossing inverting and non-inverting detectors showed in Figures 1.0 and 1.2 respectively.

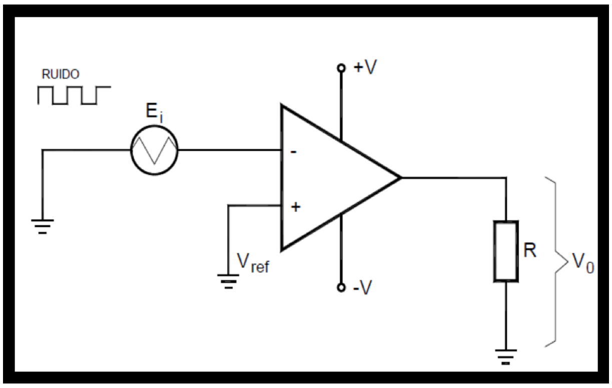

Figure 1.0: Zero-crossing inverting level detector.

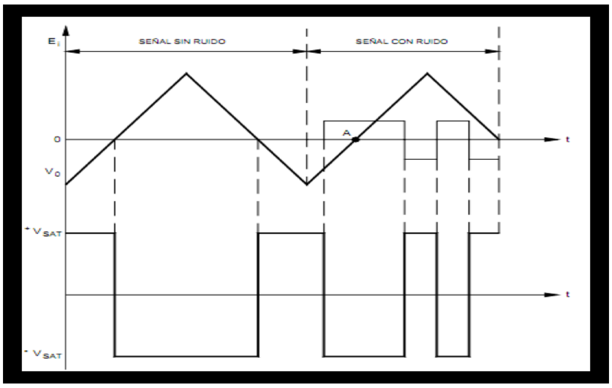

Figure 1.1: Input and output waveform of Figure 1.0.

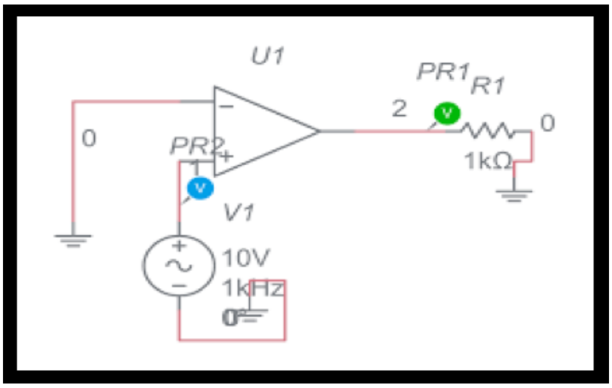

Figure 1.2: Zero-crossing non-inverting level detector.

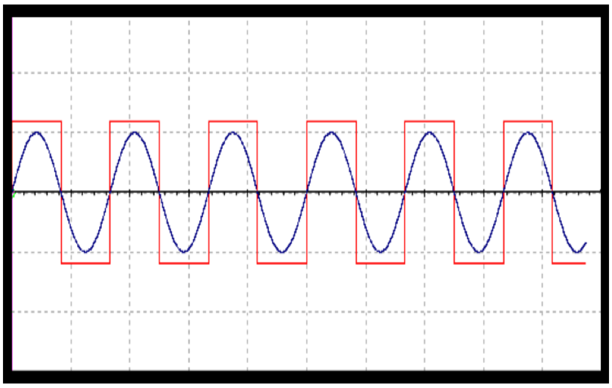

Figure 1.3: Input and output waveform of Figure 1.2.

2.1 Level Detector With Hysteresis:

Also know as Schmidt Trigger, the circuit of the Figure 1.1.0 corresponds to a level detector with Hysteresis. The operational amplifier is powered between +Vcc and -Vcc. Note that the Operational amplifier does not receive negative feedback and instead has positive feedback through R_2. In the level detector with hysteresis, the output of the operational amplifier oscillates between the two possible saturation states, +Vcc and -Vcc, according to the values take by the input signal V_g in relation to the reference voltage V_{ref}, and to the values of the resistance network R_1 and R_2.

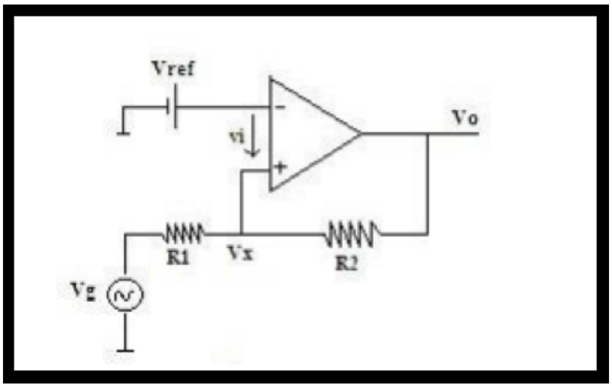

Figure 1.1.0: Level detector with hysteresis configuration.

In an operational amplifier, when $V_i > 0$ is satisfied, the output V_o saturates negatively (V_o = -V_{sat}); on the other hand if $V_i < 0$ then the output V_o saturates positively ($V_o = V_{sat}$). According to the previous circuit, $V_i = V_x$ - V_{ref}. To determine V_{ix} we use the equivalent circuit shown below:

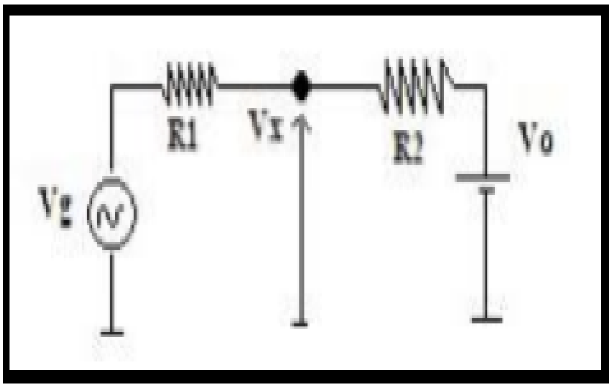

Figure 1.1.1: Circuit equivalent for Figure 1.1.0.

Applying the superposition theorem results:

$$V_x = \left(V_g \cdot \frac{R_2}{R_1 + R_2} \right) + \left(V_o \cdot \frac{R_1}{R_1 + R_2} \right)$$

To analyze the level detector we assume an initial state in negative saturation (V_o = -Vcc) and that V_g is a variable signal that is increasing from negative values, so that $V_x < V_{ref}$ is fulfilled. Figure 1.1.2 shows the relationship between V_o and V_g:

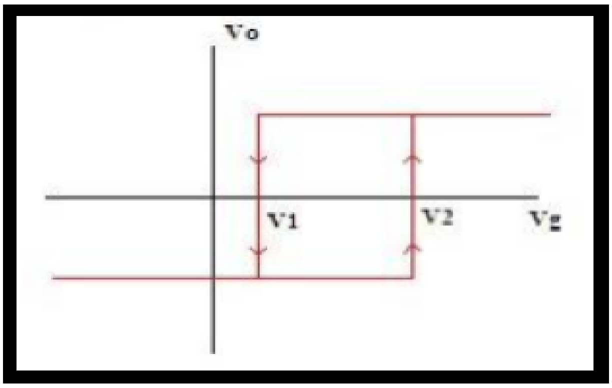

Figure 1.1.2: Transfer function for the hysteresis circuit.

2.2 Practical Application:

The most common use of a zero crossing detector is to govern the application of alternating current to a load, for example to reduce the intensity of a bulb (dimmer): the alternating current is a sine wave that is circulating in one direction and in another at a rate of 60 cycles per second, then each half period passes through zero, that is, its intensity is zero. In AC circuits to decrease the power of the load, the zero crossing is detected, a pause is taken and a TRIAC is triggered; During the pause, the load remains off, when the TRIAC is triggered, the load is turned on and stays on until the vol-point goes through zero, automatically turning off the TRIAC. The period of the alternating cycle at 60 cycles / second is 16.67 milliseconds, every 8.3 milliseconds crosses zero; if a circuit detects zero crossing and pauses 4.15 milliseconds then the load is halved.

3 Development:

We are going to analyze the circuits presented in section 2 implementing an op-amp **TL071** with a 12 V source.

Observation: *For all the circuits we need a positive and negative voltage source in terminals 7 and 4 of the op-amp respectively. In the sources, we choose the option **SERIES** and connect both E_1 and E_2 in series by connecting the negative terminal of E_1 to the positive terminal of E_2, this "new" terminal will be connected to the common ground, thus, the positive terminal of E_1 and the negative terminal of E_2 will be the positive and negative voltages respectively.*

3.1 Non-Inverting Zero-Crossing Level Detector:

Setting the *waveform generator* in a sinusoidal signal with a frequency of 1 KHz and 16 V_{pp} we connect the positive terminal of the *generator* to the V_i terminal of the circuit in Figure 3.1.0 and the negative terminal to the common ground. Then, once the respectively sources in the terminals 7 and 4 were connected, we turned on the *generator* and the voltage sources, thus, connecting the channel 1 of the oscilloscope in V_i and the channel 2 in the V_o we registered the waveform in Figure 3.1.1. Finally, we change the oscilloscope mode to X-Y and captured the transfer function in Figure 3.1.2.

Observation: *In the practice format, the peak-to-peak voltage for this circuit was of 5 V_{pp}, but the first circuit we measure was the one with **Hysteresis**, then, we forget to modify the waveform voltage, so we use a 16 V_{pp} voltage.*

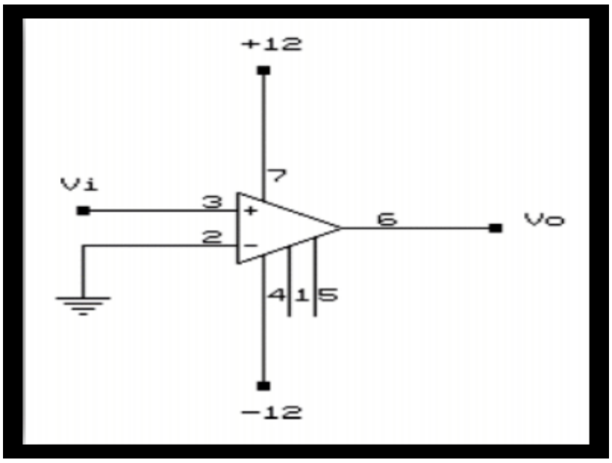

Figure 3.1.0: Non-inverting zero-crossing circuit.

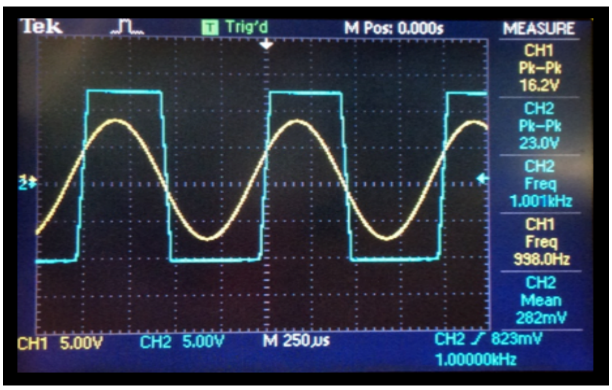

Figure 3.1.1: Input and output waveform.

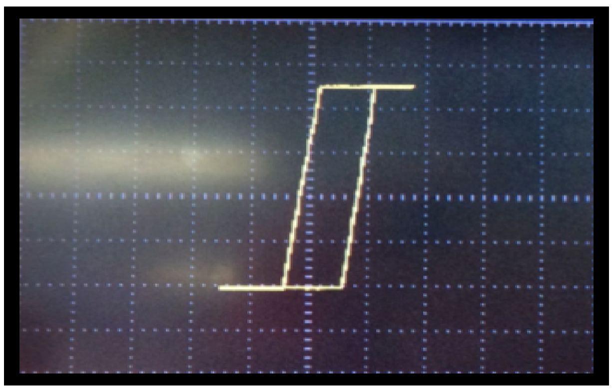

Figure 3.1.2: Transfer function for Figure 3.1.1.

Observation: *In Figure 3.1.1 we can see two waveform, the yellow one it's the input of the circuit, analogously, the blue it's for the output.*

3.2 Inverting Zero-Crossing Level Detector:

Setting the *waveform generator* in a sinusoidal signal with a frequency of 1 KHz and 16 V_{pp} we connect the positive terminal of the *generator* to the V_i terminal of the circuit in Figure 3.2.0 and the negative terminal to the common ground. Then, once the respectively sources in the terminals 7 and 4 were connected, we turned on the *generator* and the voltage sources, thus, connecting the channel 1 of the oscilloscope in V_i and the channel 2 in the V_o we registered the waveform in Figure 3.2.1. Finally, we change the oscilloscope mode to X-Y and captured the transfer function in Figure 3.2.2.

Observation: *In the practice format, the peak-to-peak voltage for this circuit was of 5* V_{pp}*, but the first circuit we measure was the one with* ***Hysteresis****, then, we forget to modify the waveform voltage, so we use a 16* V_{pp} *voltage.*

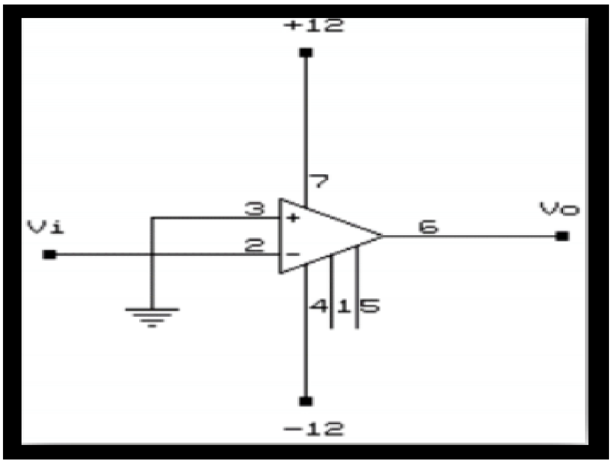

Figure 3.2.0: Inverting zero-crossing circuit.

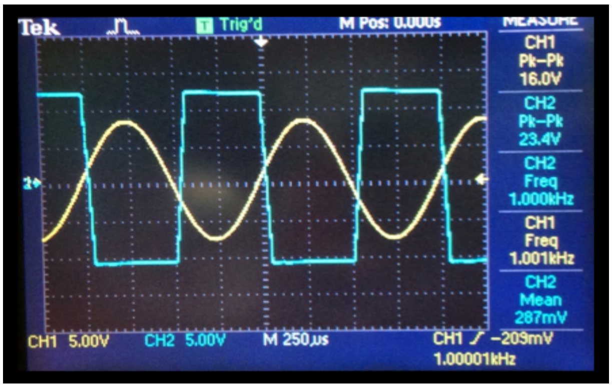

Figure 3.2.1: Input and output waveform.

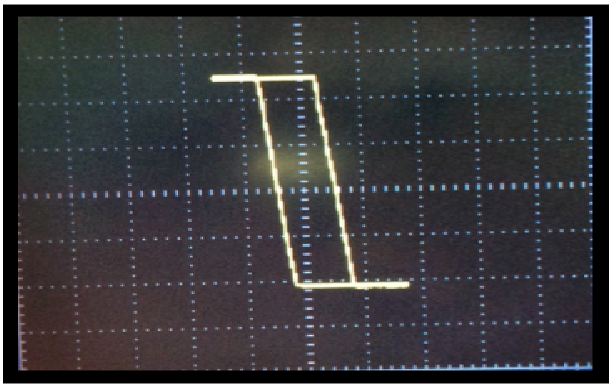

Figure 3.2.2 Transfer function for Figure 3.2.1.

Observation: *In Figure 3.2.1 we can see two waveform, the yellow one it's the input of the circuit, analogously, the blue it's for the output.*

3.3 Inverting Zero-Crossing Level Detector With Hysteresis:

Setting the *waveform generator* in a sinusoidal signal with a frequency of 1 KHz and 16 V_{pp} we connect the positive terminal of the *generator* to the V_i terminal of the circuit in Figure 3.3.0 and the negative terminal to the common ground. Then, once the respectively sources in the terminals 7 and 4 were connected, we turned on the *generator* and the voltage sources, thus, connecting the channel 1 of the oscilloscope in V_i and the channel 2 in the V_o we registered the waveform in Figure 3.3.1. Finally, we change the oscilloscope mode to X-Y and captured the transfer function in Figure 3.3.2.

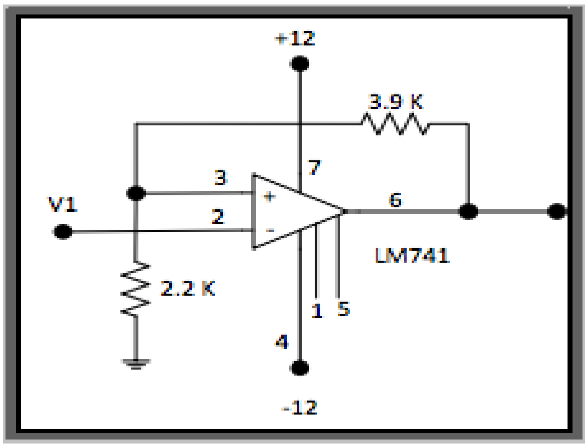

Figure 3.3.0: Inverting zero-crossing level detector with hysteresis.

Figure 3.3.1: Input and output waveform.

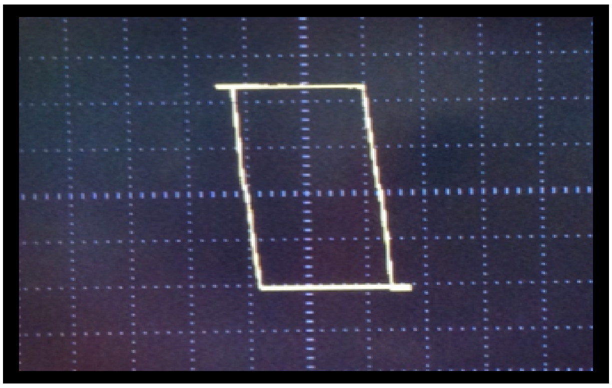

Figure 3.3.2: Transfer function for Figure 3.3.1

Observation: *In Figure 3.3.1 we can see two waveform, the yellow one it's the input of the circuit, analogously, the blue it's for the output.*

3.4 Voltage Level Detector Applications:

Once the circuit in Figure 3.4.0 were assembled, we start to increase and decrease the potentiometer resistance to visualize what does this circuit do. And, depending of the voltage level in V_i the LED's start to turn on, this because the voltage divider of 1 K Ω resistors and the implementation of the Level Detectors. When each LED went on, we measure the voltage in V_i and registered the results in Table 1.

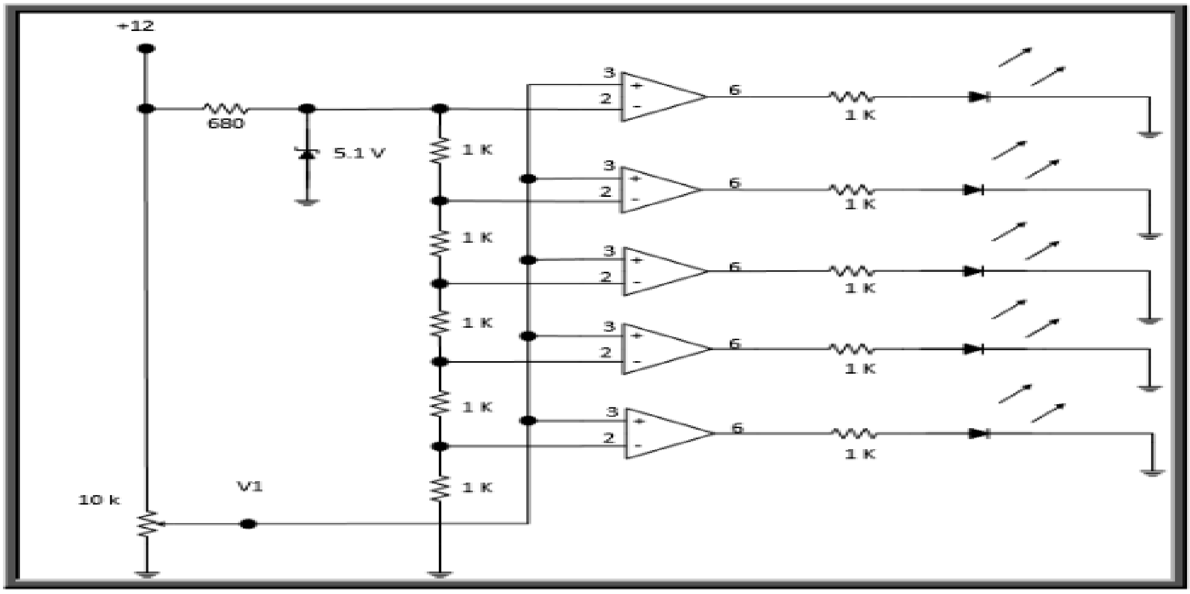

Figure 3.4.0: Voltage level detector application I.

LED	V_i
1	1.4 V
2	2.5 V
3	3.4 V
4	4.38 V
5	5.45 V

Table 1: Figure 3.4.0 voltage levels.

Once the circuit in Figure 3.4.1 were assembled, we start to increase and decrease the potentiometer resistance to visualize what does this circuit do. Finally we set the potentioner when the bulb started to "flash", in other words; When the bulb weren't to brighter but neither to dimmer. We were able to visualize that if the photocell were receiving light, then the bulb turned off; when the photocell weren't receiving light the bulb turned on. Then, we registered the result in table 2.

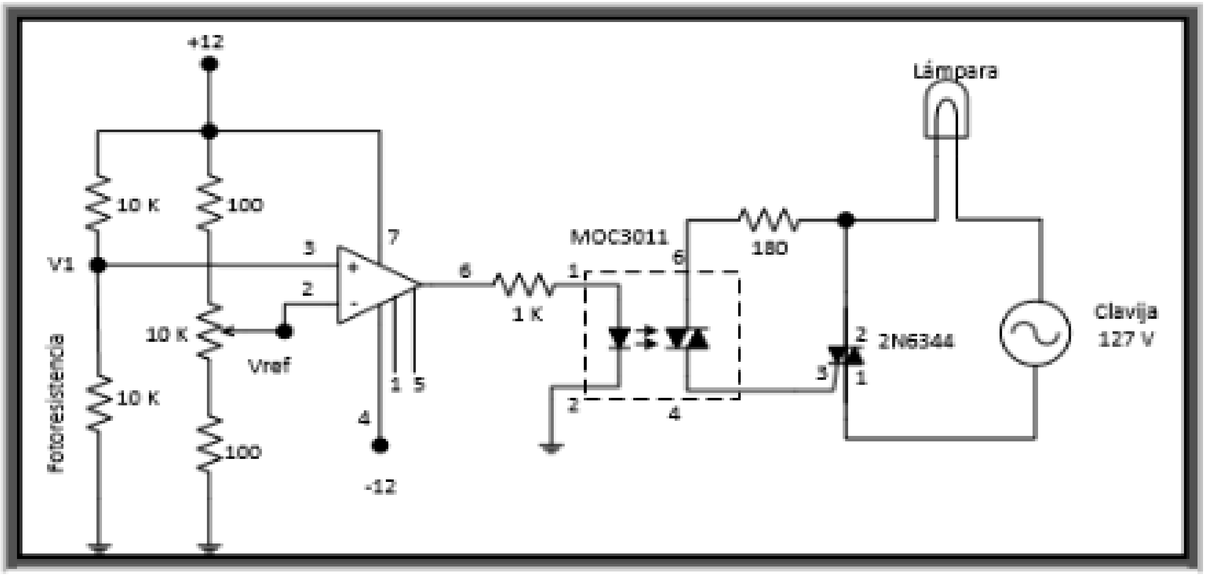

Figure 3.4.1: Voltage level detector application II.

	V_i
V_{ref}	7.17 V
Photocell with light	6.76 V
Photocell without light	4.85 V

Table 2: Figure 3.4.1 voltage levels.

3.5 Voltage Level Detector With Hysteresis Applications:

Once the circuit in Figure 3.5.0 were assembled, we started to increase and decrease the potentiometers resistance to visualize what does this circuit do. Finally we adjust the presets when the bulb went on and off appropriately, this means, when there were no "noise" (oscillations) in the bulb. This circuit were very similar that the one in figure 3.4.1, so, we measure the voltage in the photocell when there were no light and analogously, when there were light. This voltage values were registered in table 3.

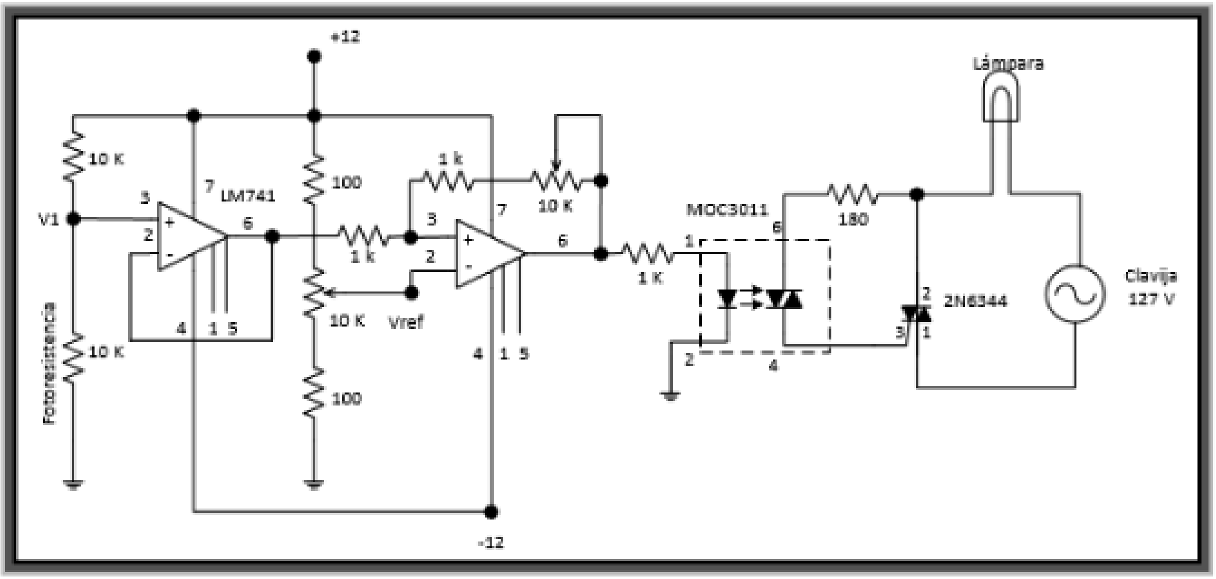

Figure 3.5.0: Voltage level detector with hysteresis application

	V_i
V_{ref}	7.5 V
Voltage in nR (Voltage source turned off)	10.48 V
Photocell with light	6.9 V
Photocell without light	11.15 V

Table 3: Figure 3.5.0 voltage levels.

4 Simulations:

For each circuit that we have analyze in the section 3, we simulate each one of them, and we proceeded to make a comparative table with all the simulated results and the development ones.

4.1 Non-Inverting Zero-Crossing Level Detector:

For the circuit in Figure 3.1.0 we simulate it and captured the results in Figures 4.1.0, 4.1.1 and 4.1.2:

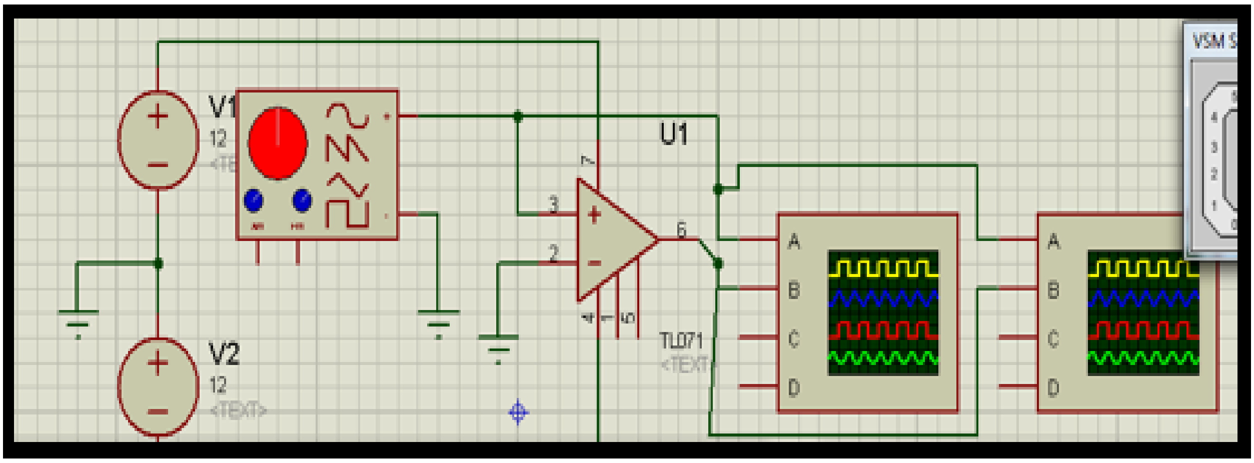

Figure 4.1.0: Non-inverting zero-crossing circuit.

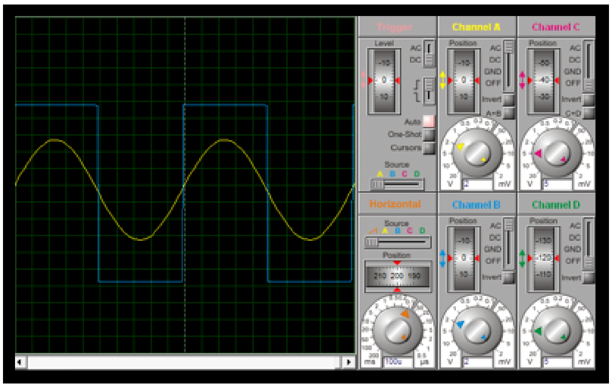

Figure 4.1.1: Input and output waveform.

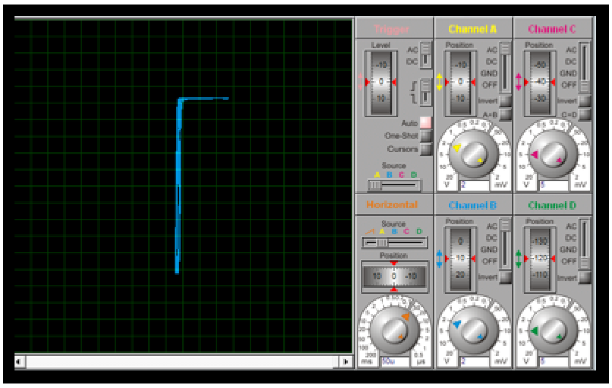

Figure 4.1.2: Transfer function for Figure 4.1.0.

4.2 Inverting Zero-Crossing Level Detector:

For the circuit in Figure 3.2.0 we simulate it and captured the results in Figures 4.2.0, 4.2.1 and 4.2.2:

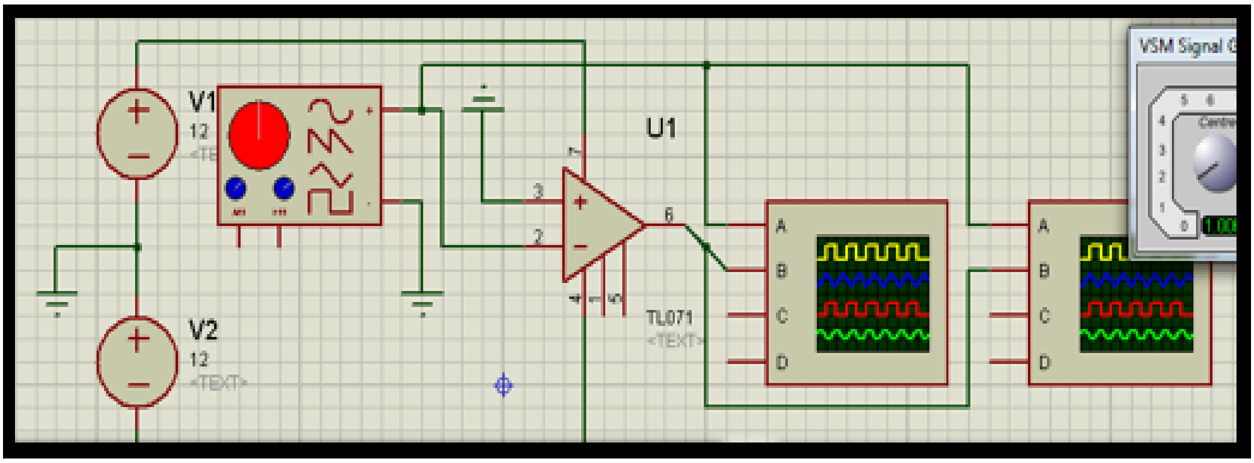

Figure 4.2.0: Inverting zero-crossing circuit.

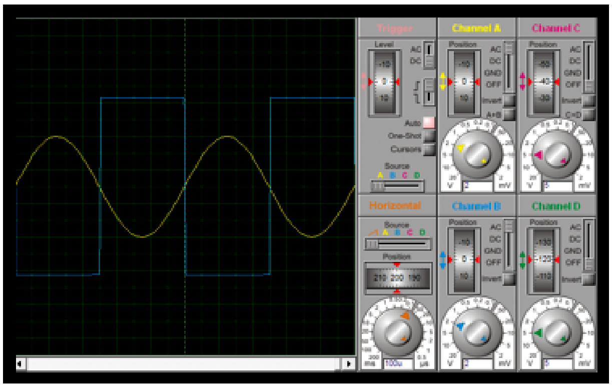

Figure 4.2.1: Input and output waveform.

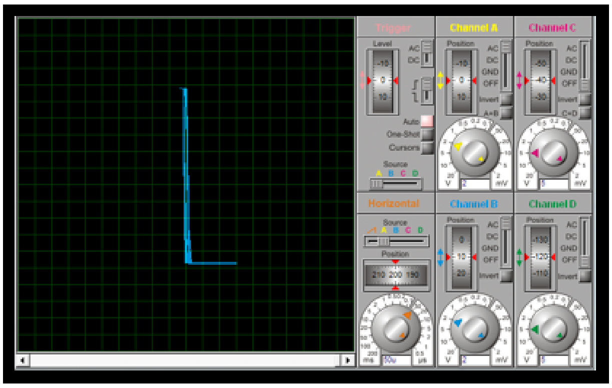

Figure 4.2.2: Transfer function for Figure 4.2.0.

4.3 Inverting Zero-Crossing Level Detector With Hysteresis:

For the circuit in Figure 3.3.0 we simulate it and captured the results in Figures 4.3.0, 4.3.1 and 4.3.2:

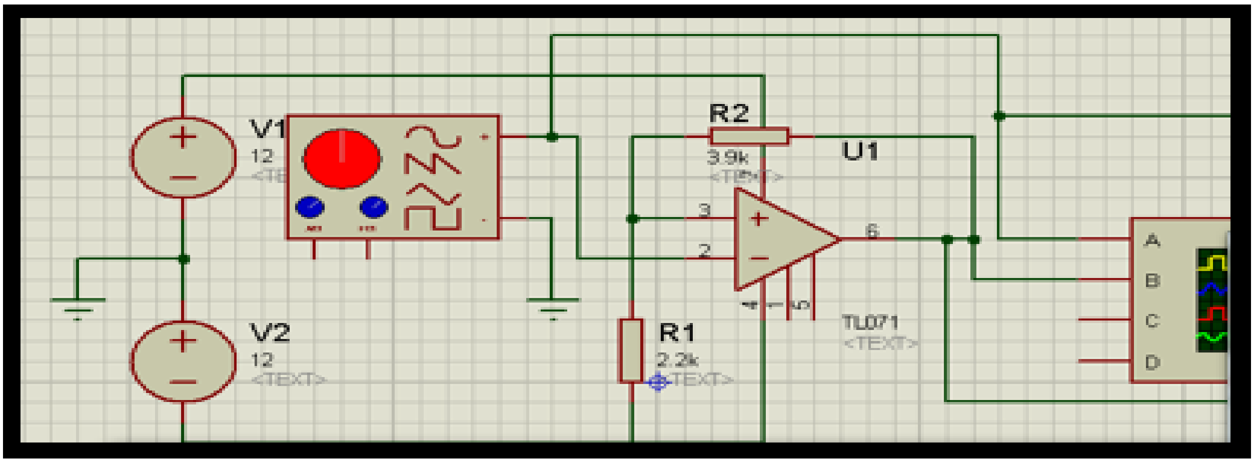

Figure 4.3.0: Inverting zero-crossing circuit.

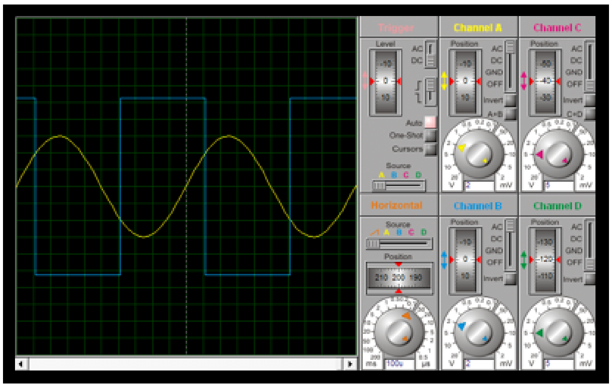

Figure 4.3.1: Input and output waveform.

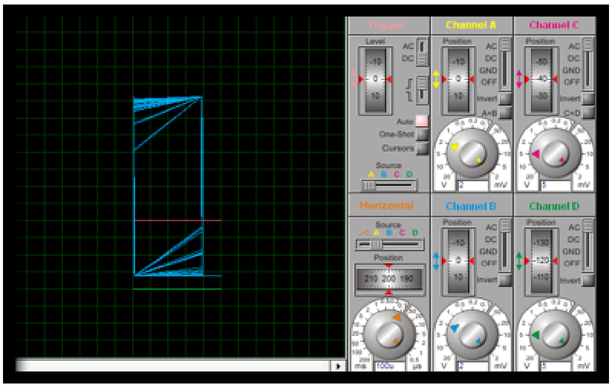

Figure 4.3.2: Transfer function for Figure 4.3.0.

4.4 Voltage Level Detector Applications:

For the circuit in Figure 3.4.0 we simulate it and captured in Figures 4.4.0, 4.4.1, 4.4.2, 4.4.3 and 4.4.4, the results of the measures where registered in table 6:

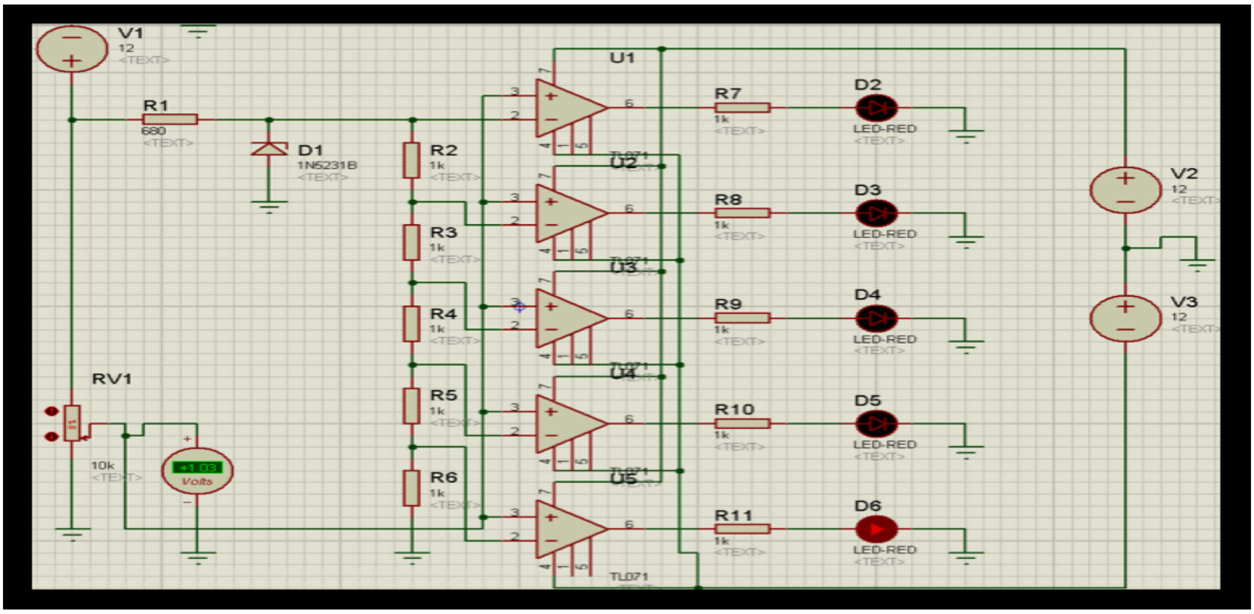

Figure 4.4.0: Voltage level detector application LED 1.

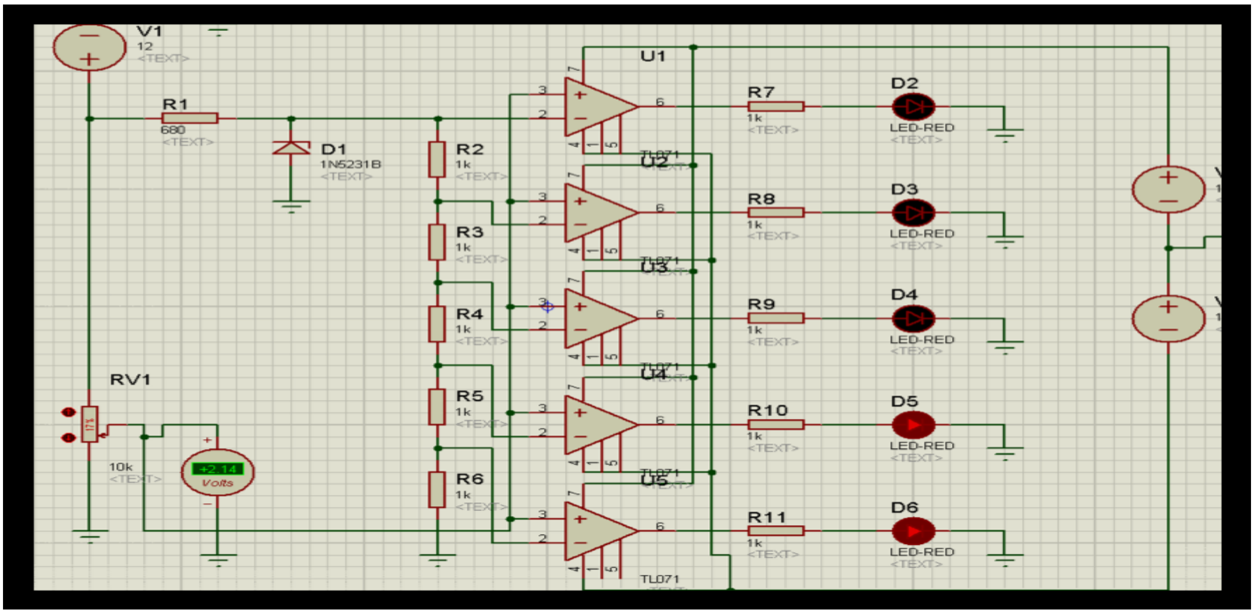

Figure 4.4.1: Voltage level detector application LED 2.

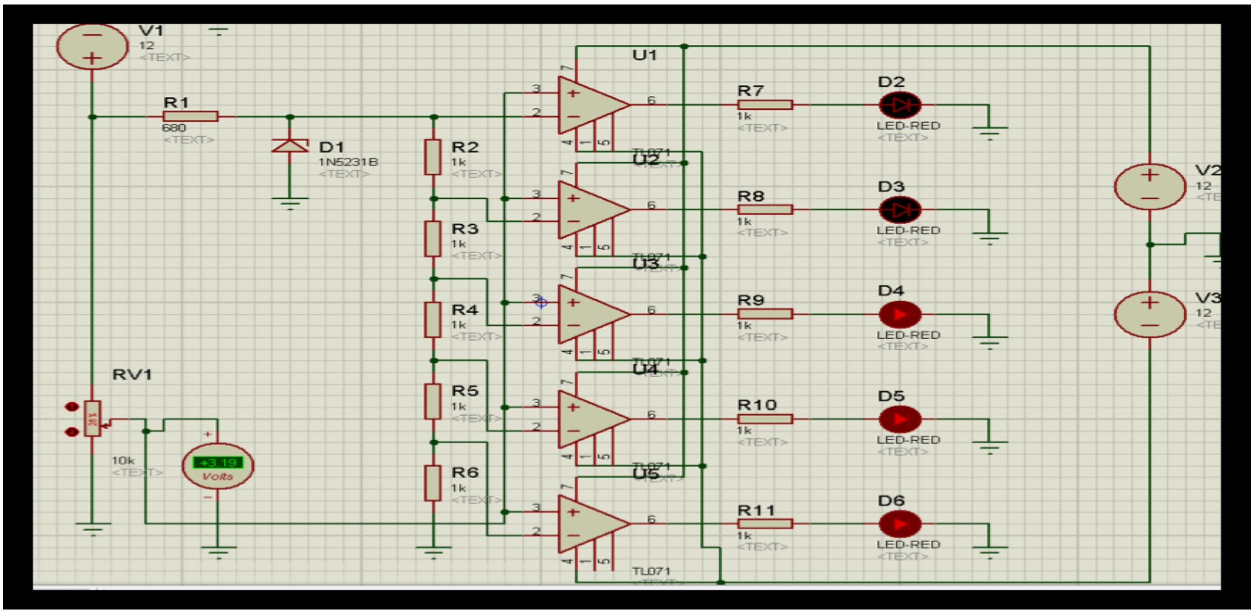

Figure 4.4.2: Voltage level detector application LED 3.

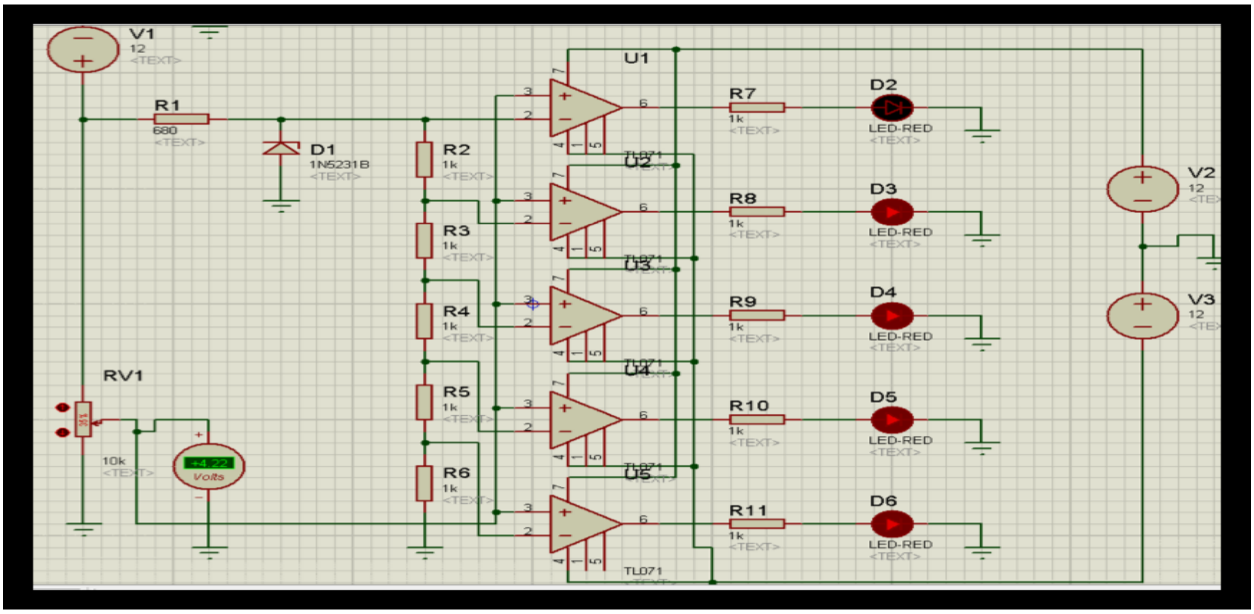

Figure 4.4.3: Voltage level detector application LED 4.

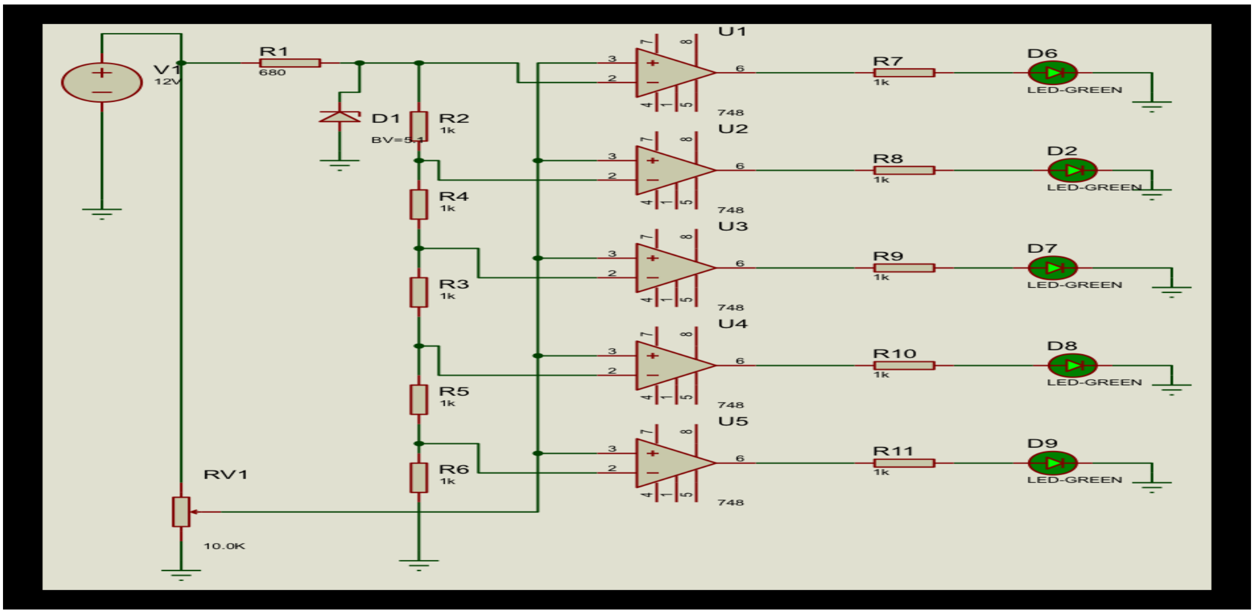

Figure 4.4.4: Voltage level detector application LED 5.

LED	V_i
1	1.3 V
2	2.14 V
3	3.19 V
4	4.22 V
5	5.16 V

Table 4: Figure 4.4.0, 4.4.1, 4.4.2. 4.4.3 and 4.4.4 voltage levels.

For the circuit in Figure 3.4.1 we simulate it and captured in Figure 4.4.5 and 4.4.6 the results of the measures where registered in table 5:

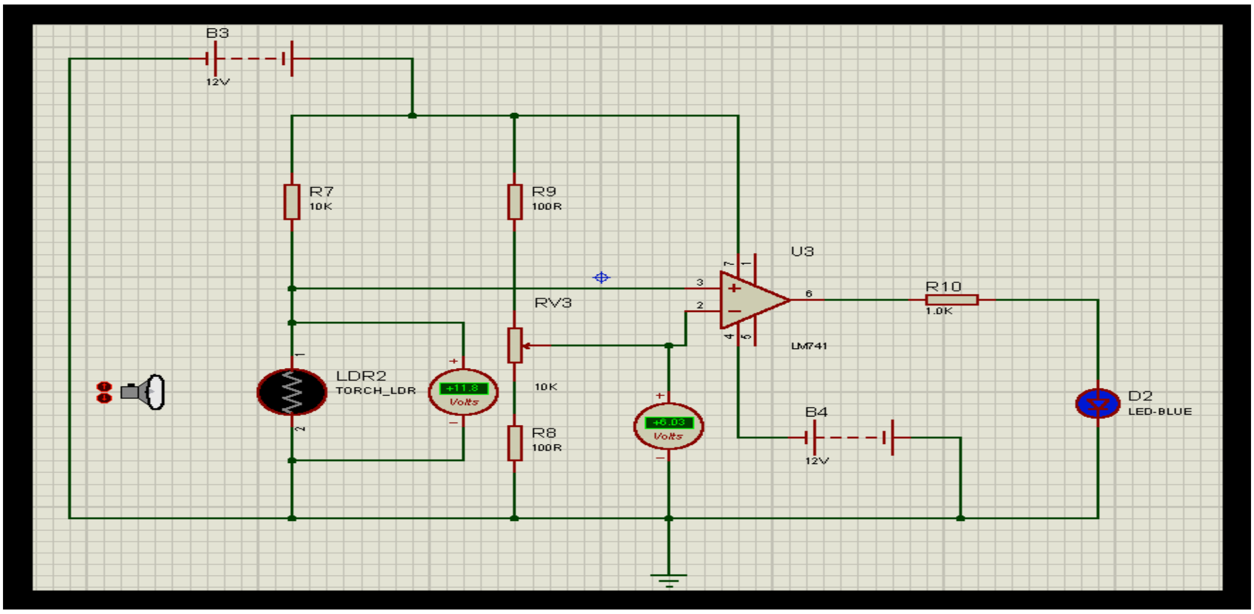

Figure 4.4.5: Voltage level detector application II.

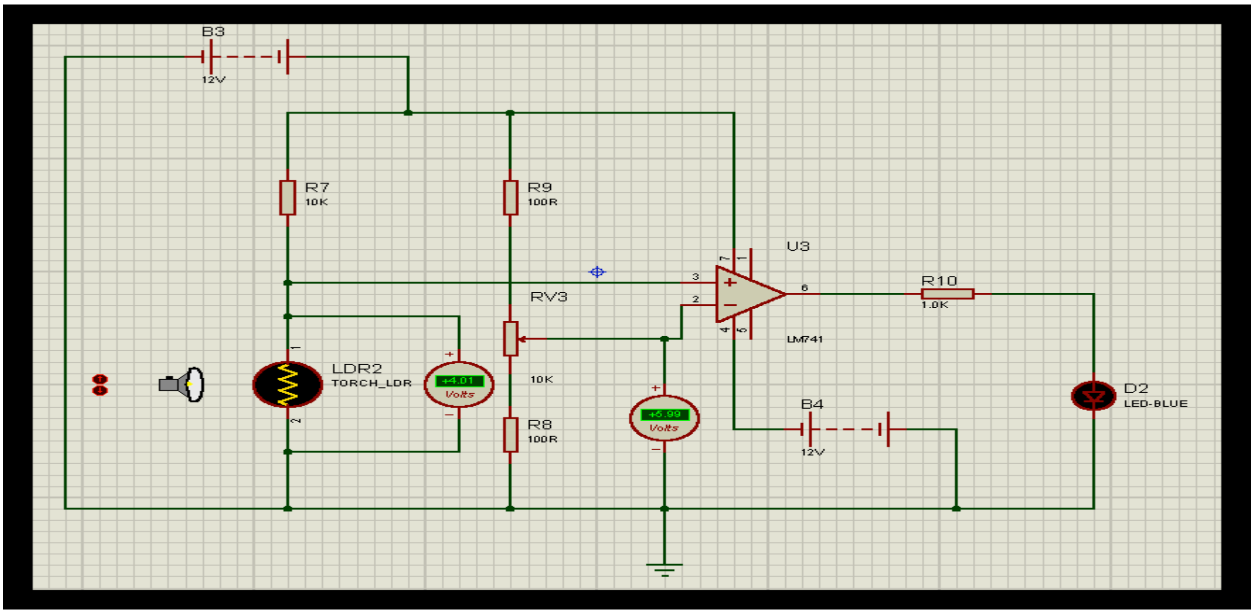

Figure 4.4.6: Voltage level detector application II.

	V_i
V_{ref}	6.03 V
Photocell with light	4.01 V
Photocell without light	11.8 V

Table 5: Figures 4.4.5 and 4.4.6 voltage levels.

4.5 Voltage Level Detector With Hysteresis Applications:

For the circuit in Figure 3.5.0 we simulate it and captured the results in Figures 4.5.0 and 4.5.1, the results of the measures where registered in table 6:

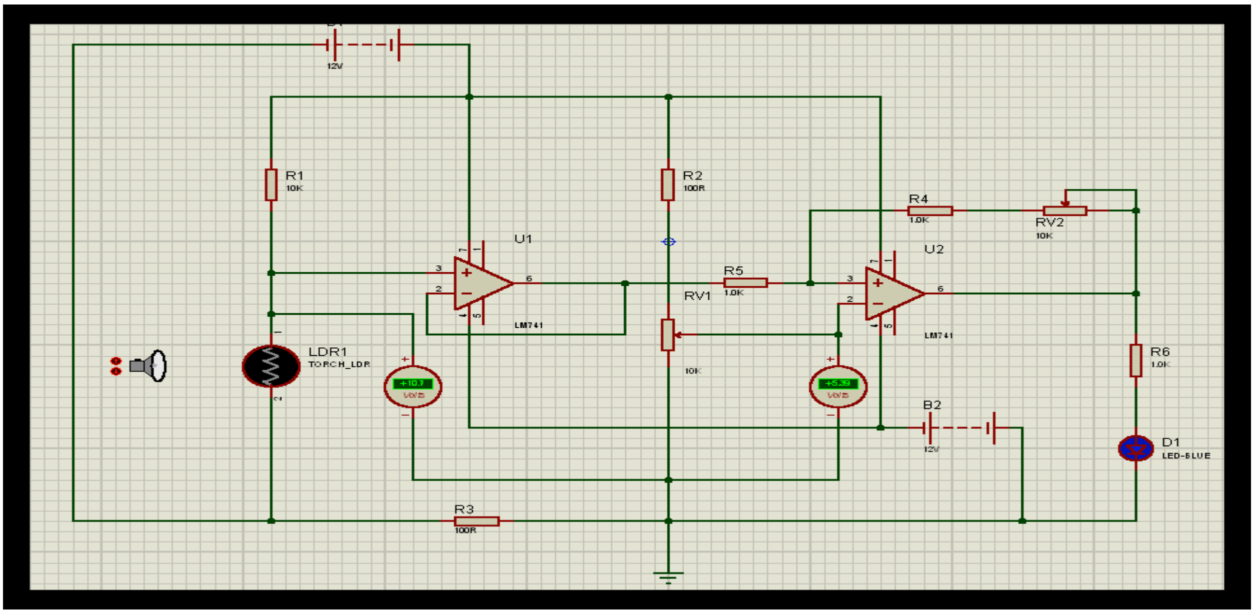

Figure 4.5.0: Level detector with no light near the photocell.

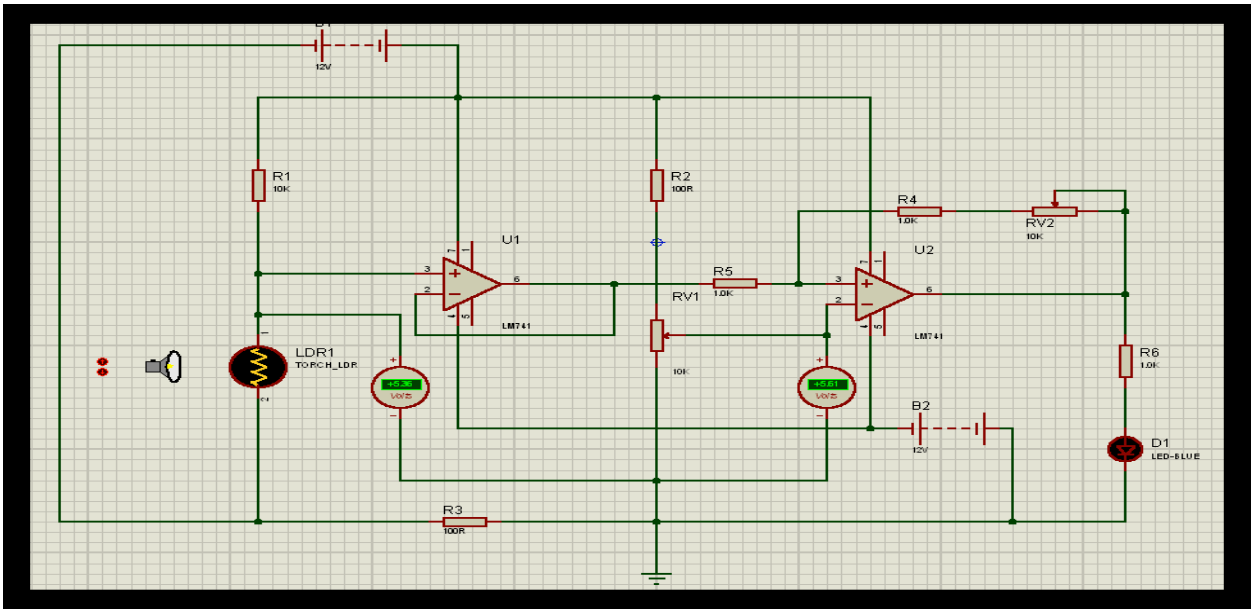

Figure 4.5.1: Level detector with light near the photocell.

	V_i
V_{ref}	6.39 V
Photocell with light	6.3 V
Photocell without light	10.7 V

Table 6: Figures 4.5.0 and 4.5.1 voltage levels.

5 Theoretical Analysis:

For each circuit that we have analyze in the section 3, we calculate each one of them, and we proceeded to make a comparative table with all the theoretical results and the development ones.

5.1 Non-Inverting Zero-Crossing Level Detector:

The circuit that we are going to analyze it's the one in Figure 3.1.0 using the following parameters:

- V_{ent} **= 16** V_{pp}**.**
- V_{ref} **= 0 V.**
- V_{sat} **= 12 V.**

- ***For*** V_{sal} ***in the positive semi-cycle:***

Formula: If $V_{ent} > V_{ref}$ ***then*** $V_{sal} = V_{sat}$***.***

$$Because:\ 8\ V_p\ >\ 0\ V\ then\ V_{sal}\ =\ 12\ V.$$

- ***For*** V_{sal} ***in the negative semi-cycle:***

Formula: If $V_{ent} < V_{ref}$ ***then*** $V_{sal} = -V_{sat}$***:***

$$Because:\ -8\ V_p\ <\ 0\ V\ then\ V_{sal}\ =\ -12\ V.$$

Finally, we can say that V_{sal} ***= 24*** V_{pp}***.***

5.2 Inverting Zero-Crossing Level Detector:

The circuit that we are going to analyze it's the one in Figure 3.2.0 using the following parameters:

- V_{ent} **= 16** V_{pp}**.**
- V_{ref} **= 0 V.**
- V_{sat} **= 12 V.**

- ***For*** V_{sal} ***in the positive semi-cycle:***

Formula: If $V_{ent} > V_{ref}$ ***then*** $V_{sal} = -V_{sat}$***.***

$$Because:\ 8\ V_p > 0\ V\ then\ V_{sal} = -12\ V.$$

- ***For*** V_{sal} ***in the negative semi-cycle:***

Formula: If $V_{ent} < V_{ref}$ ***then*** $V_{sal} = V_{sat}$***:***

$$Because:\ -8\ V_p < 0\ V\ then\ V_{sal} = 12\ V.$$

Finally, we can say that V_{sal} ***= 24*** V_{pp}***.***

5.3 Inverting Zero-Crossing Level Detector With Hysteresis:

The circuit that we are going to analyze it's the one in Figure 3.3.0 using the following parameters:

- V_{ent} = **16** V_{pp}**.**
- V_{sat} = **12 V.**
- R_1 = **2.2 K** Ω**.**
- R_2 = **3.9 K** Ω**.**

- ***For VUS:***

Formula: VUS $= \frac{(\ V_{sat}\ )(\ R_1\ )}{R_1\ + R_2}$**.**

$$VUS \ = \ \frac{(\ 12\ V\ )(\ 2.2\ K\ \Omega\ )}{2.2\ K\ \Omega\ + 3.9\ K\ \Omega}$$

$$= \ 4.32\ V.$$

- ***For VUI:***

Formula: VUS $= \frac{(\ -V_{sat}\ )(\ R_1\ )}{R_1\ + R_2}$**.**

$$VUS \ = \ \frac{(\ -12\ V\ )(\ 2.2\ K\ \Omega\ )}{2.2\ K\ \Omega\ + 3.9\ K\ \Omega}$$

$$= \ -4.32\ V.$$

- ***For the Hysteresis voltage*** V_H***:***

Formula: $V_H\ = |VUS|\ + |VUI|$**.**

$$V_H \ = \ \left|4.32\ V_p\right| \ + \ \left|-4.32\ V_p\right|$$

$$= \ 8.64\ V.$$

6 Comparisons:

In this sections we will compare the development, simulated and theoretical results for each circuit in each configurations.

6.1 Zero-Crossing Non-Inverting:

Comparison of subsection's 3.1, 4.1 and 5.1 results: The table will illustrate the peak values for input and output voltages.

	V_i	V_o
Practical	8 V_p	12 V_p
Simulated	8 V_p	12 V_p
Theoretical	8 V_p	12 V_p

Table 7: Non-inverting level detector comparison.

6.2 Zero-Crossing Inverting Level Detector:

Comparison of subsection's 3.2, 4.2 and 5.2 results: The table will illustrate the peak values for input and output voltages.

	V_i	V_o
Practical	8 V_p	-12 V_p
Simulated	8 V_p	-12 V_p
Theoretical	8 V_p	-12 V_p

Table 8: Inverting level detector comparison.

6.3 Zero-Crossing With Hysteresis Level Detector:

Comparison of subsection's 3.3, 4.3 and 5.3 results: The table will illustrate the peak values for input and output voltages.

	V_i	V_o
Practical	8 V_p	-12 V_p
Simulated	8 V_p	-12 V_p
Theoretical	8 V_p	-12 V_p

Table 9: Hysteresis inverting level detector comparison.

6.4 Voltage Level Detector Applications:

Comparison of subsection's 3.4, 4.4 Table 1 and Table 4:

LED	Practical V_i	Simulated V_i
1	1.4	1.3 V
2	2.5	2.14 V
3	3.4	3.19 V
4	4.48	4.22 V
5	5.45	5.16 V

Table 10: Comparison voltage levels.

Comparison of subsection's 3.4, 4.4 Table 2 and Table 5:

	Practical V_i	Simulated V_i
V_{ref}	7.17 V	6.03 V
Photocell with light	6.76 V	4.01 V
Photocell without light	4.85 V	11.8 V

Table 11: Comparison voltage levels.

Observation: *I imagine that the measured levels and simulated ones variate because of the resistance in the preset, in the simulation it's ideal i.e 10KΩ, and in the practice we variate this value constantly.*

6.5 Voltage Level Detector With Hysteresis Applications:

Comparison of subsection's 3.5, 4.5 Table 3 and Table 6:

	Practical V_i	Simulated V_i
V_{ref}	7.5 V	6.39 V
Photocell with light	6.9 V	6.3 V
Photocell without light	11.15 V	10.7 V

Table 12: Comparison voltage levels.

7 Conclusion:

The amplifiers, as far, are the most complicated and important device that we think, we analyze in this course, this because, they have a lot of applications and different configuration for a so tiny and simple device. Its functionality it's based on the transistor principle and we have seen and demonstrated that depending of the devices that we connect around of the amplifier it will do a specified operation as a addition, product, subtraction, integration, derivation, inclusive the Fourier Transform. This device has a lot of applications in the industry and in out daily life. Also, the positive and negative inputs can be used to have a level detector by using this voltage as saturation V_{sat}. In every new class we discover that this device has more and more configurations and applications, like the one with hysteresis voltage by feedback the non-inverting input with the V_{sal} output.

8 Bibliographic References:

[1] BOYLESTAD, Robert L. "Electronic Devices and Circuit Theory". Edit. Prentice Hall. 2009.