BIRZEIT UNIVERSITY

# ENEE2360

# Project Report

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# Abstract:

This study investigates the design and analysis of a voltage threshold detection circuit using operational amplifiers, diodes, and a transistor. The primary objective is to establish the correct resistor values in the circuit to achieve specific upper and lower threshold voltages ($V_{UT}$ and $V_{LT}$ ).

The circuit was first analyzed using hand calculations to determine the necessary resistor values that would achieve the desired threshold voltages. Following this, the circuit was simulated using PSPICE software to verify the theoretical calculations.
The simulation involved replacing the DC power supply with a pulse voltage source to observe the dynamic behavior of the circuit, particularly focusing on the nodal voltages, diode states, transistor operation, and LED activation.

The results demonstrated a close correlation between the hand calculations and the simulation, validating the accuracy of the design approach. This analysis provides a robust framework for designing similar threshold detection circuits in various electronic applications.

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# 1. Theory:

## i. Operational Amplifiers (Opamps)

An operational amplifier (opamp) is a versatile electronic component often used in analog circuits for signal amplification, filtering, and mathematical operations like addition or subtraction. In this circuit, two opamps are configured as comparators.

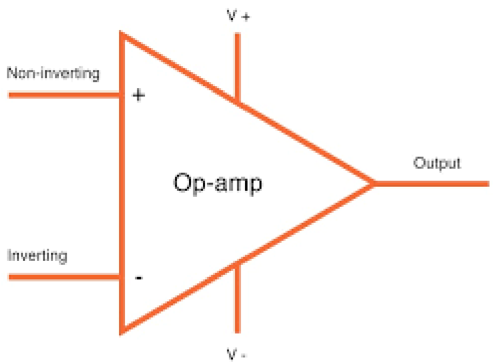


*Figure 1: Operational Amplifiers*

- **Comparator Operation:** A comparator is a device that compares two voltages and outputs a signal indicating which voltage is higher.

- **Linear vs. Saturation Mode:** In a linear region, the opamp output is proportional to the difference between the inverting and non-inverting inputs. However, when configured as a comparator, the opamp operates in a saturation region, where the output is either at the positive or negative supply voltage depending on the input comparison.

## ii. Diode: -

A diode is an electronic device that conducts electricity only in one direction. It is a device which is widely used in modern-day electronics. In this article, we will learn about diodes, their properties, symbols, types and others in detail.

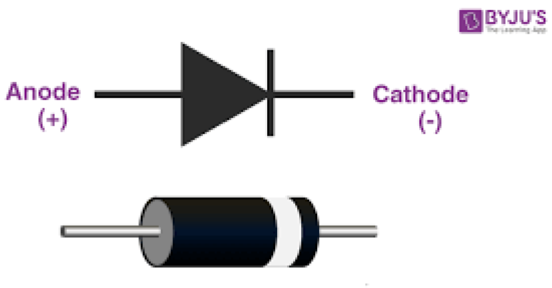


*Figure 2:Diode*

- **Light Emitting Diode (LED):**

When current passes through a light-emitting diode (LED), a semiconductor, it produces light in one direction while blocking current in the other. Doped p-n junctions, or LEDs, release different colors of light depending on the doping dose and material. To allow light to pass through, they are covered with a translucent covering.

*Figure 3:Light Emitting Diode (LED)*

- **Rectifier Diode:**

A rectifier diode is a two-lead semiconductor that allows current to pass in only one direction. Generally, P-N junction Diode is formed by joining together n-type and p-type semiconductor materials.

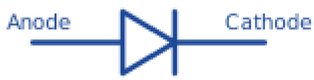


*Figure 4:Rectifier Diode*

## iii. Resistor: -

A transistor is a semiconductor device with three terminals used for amplifying or controlling electrical impulses. It may be used as a switch to regulate current flow by flipping between on and off states, or as an amplifier to increase a tiny input current into a larger output.

*Figure 5:Fixed Resistor and Potentiometer Resistor*

## iv. BJT transistor: -

A bipolar junction transistor (BJT) is a device consisting of three terminals: emitter, collector, and base. By regulating current flow with a tiny input at the base and a larger output at the collector, it amplifies signals. A DC power source that is external is needed for this amplification.

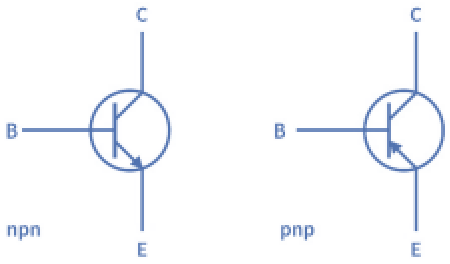


*Figure 6:BJT transistor*

# 2- Explanation of the Function

The circuit in Fig. (1) is designed to detect specific voltage thresholds and respond by controlling an LED. The procedure below outlines the step-by-step explanation

## 1. Components and Connections:

- **Power Supply:** Connect a DC power supply to provide a 12V source to the circuit.

- **Resistors:** The resistors R2, R3, R4, and R5 form two voltage dividers to set reference voltages VBVBVB and VCVCVC for the comparators.

- **Operational Amplifiers (Opamps):** Two 741 opamps are used in a comparator configuration. Their inverting and non-inverting inputs are connected to the voltage dividers and the input voltage VA, respectively.

- **Diodes:** Two diodes D1 and D2 are connected to the outputs of the opamps, directing current to the base of the transistor.

- **Transistor:** An NPN transistor Q1 controls the LED D3, turning it on or off based on the base current supplied through the diodes.

## 2. Circuit Operation

- **Voltage Divider Configuration:**

  ❖ **Reference Voltages:** The resistors in the voltage dividers set the reference voltages VB and VC at the non-inverting inputs of the opamps. These voltages are crucial in determining the circuit's response to the input voltage VA.

- **VB:** is connected to the non-inverting input of the first opamp (Comparator 1).

- **VC**: is connected to the non-inverting input of the second opamp (Comparator 2).

- **Comparing the Input Voltage VA:**

  - **Comparator 1:** The first opamp compares VA to VB (upper threshold VUT).

    1. If VA>VB, the output of Comparator 1 goes high, forward-biasing D1 and allowing current to flow to the base of the transistor.
    2. This turns the transistor on, pulling the collector low, which allows current to flow through the LED, illuminating it.

  - **Comparator 2:** The second opamp compares VA to VC (lower threshold VLT).

    1. If VA<VC, the output of Comparator 2 goes high, forward-biasing D2.
    2. This action is designed to ensure that if VA is below the lower threshold, the LED remains off by preventing base current flow to the transistor.

- **Transistor Switching:**

  ❖ The transistor Q1 acts as a switch, controlling the LED based on the outputs of the comparators.

  ❖ When D1 is forward-biased (due to VA>VUT), the transistor is turned on, and the LED is lit.

  ❖ If D2 is forward-biased (due to VA<VLT), the circuit ensures the transistor is turned off, and the LED is off.

## 3. Expected Circuit Behavior

- **Above Upper Threshold (VA>VUT):**

  → The first comparator output goes high.
  → D1 conducts, turning the transistor on.
  → The LED illuminates, indicating VA is above the upper threshold.

- **Below Lower Threshold (VA<VLT):**

  → The second comparator output goes high.
  → D2 conducts, ensuring the transistor is off.
  → The LED is off, indicating VA is below the lower threshold.

- **Between Thresholds (VLT≤VA≤VUT):**

  → Depending on the design, the LED may remain in its previous state, or the circuit might be designed to turn the LED off, as both comparators could be in a state that prevents the transistor from conducting.

# 3- Simulation circuits and results:

## I. The simulation of circuit with monitor a 9V DC power supply and determine all the nodal voltages: -

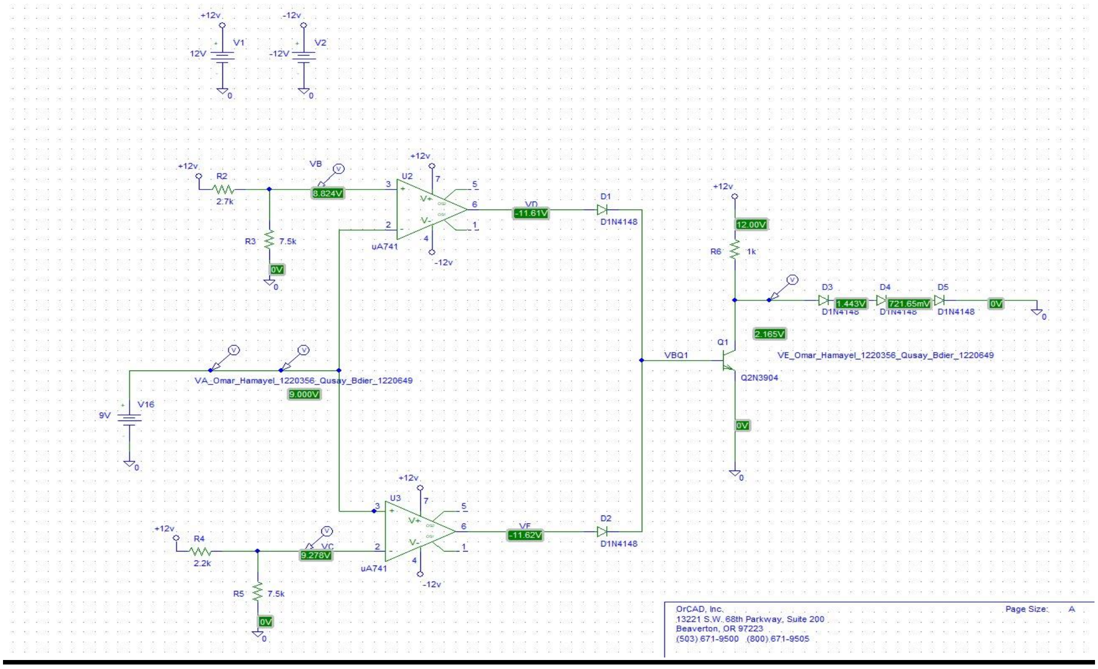

*Figure 7:The circuit with monitor a 9V*

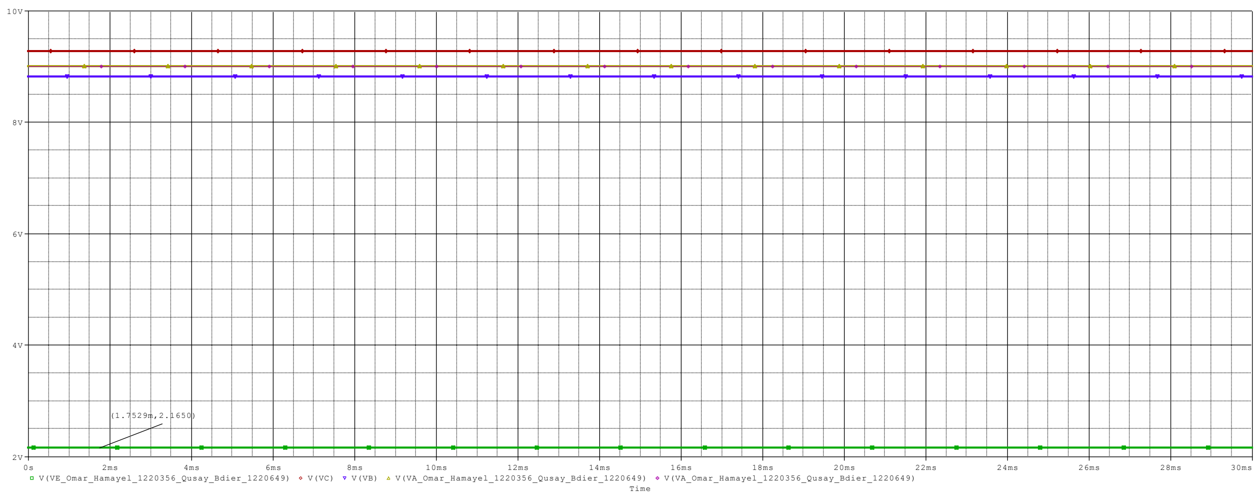

*Figure 8:Ve(t) in DC circuit*

- VB = 8.824 V
- VD = -11.61 V
- VC = 9.278 V
- VF = -11.62 V
- VE = 2.165 V

- **Diodes D1:**
  Both diodes D1 and D2 will be **reverse biased** because the outputs of the op-amps are high. Therefore, they will be **off** (non-conducting).

- **Transistor (2N3904):**
  Since both diodes are off, the transistor will not receive base current. Hence, it will be in **cutoff** (non-conducting).

- **LED:**
  The transistor is in cutoff, meaning no current flows through it. As a result, the LED will be **on** since the current through the LED can calculation: -

$$I_{(LED)} = \frac{Vcc - VE}{R5} = \frac{12 - 2.16}{1K\Omega} = 9.84 \text{ mA}$$

## II. The simulate of circuit with VPULSE and determine all the nodal voltages: -

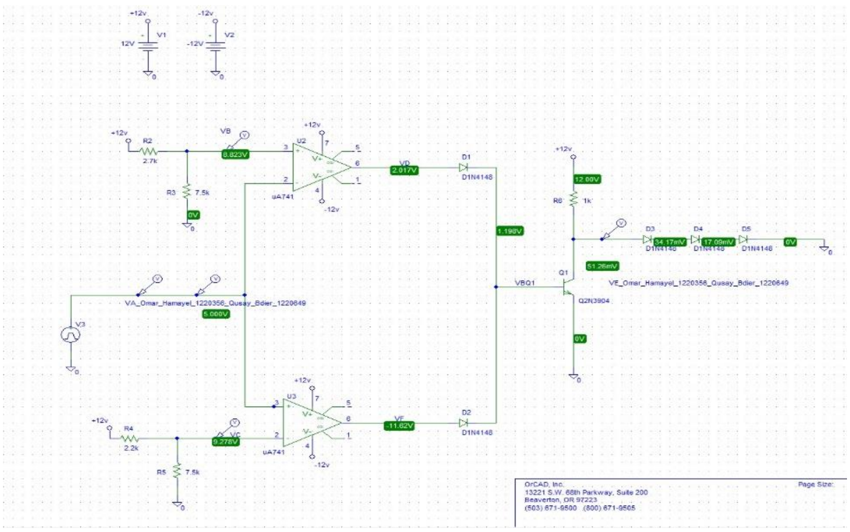


*Figure 9:The circuit with VPULSE*

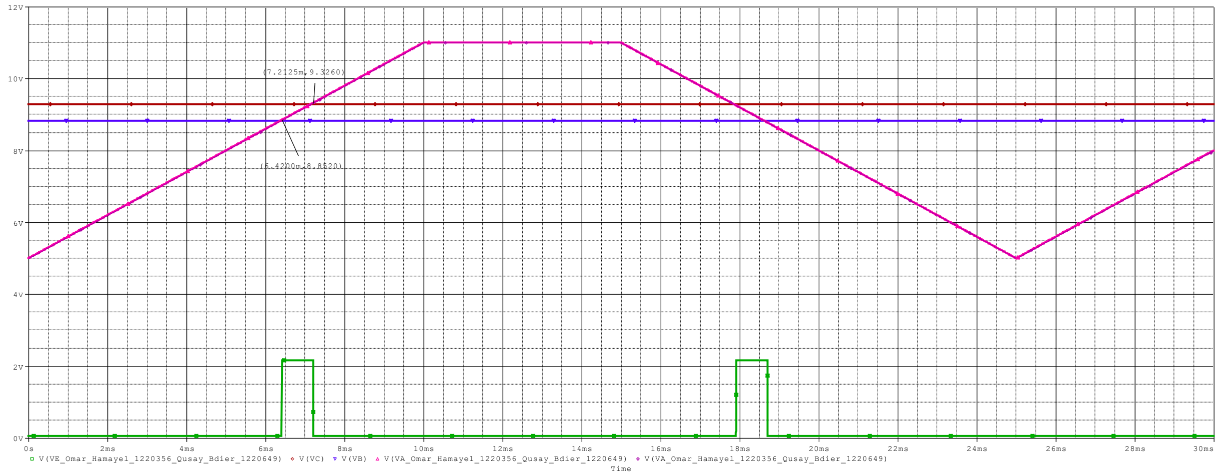


*Figure 10:Ve(t) in VPULSE circuit*

## Estimation from the Plot:

- From plot image, the key points where VE(t) changes state can be identified visually:

  1) **Lower Threshold Voltage VLT:** At the point on the horizontal axis (time) where the transition from low to high happens.

  2) **Upper Threshold Voltage VUT:** At the point on the horizontal axis (time) where the transition from high to low happens.

From the waveform:

- **VLT :** The transition from low to high seems to occur around 9.32V.
- **VUT :** The transition from high to low seems to occur around 8.85V

## III. The simulation of circuit with new values of R2 and R4: -

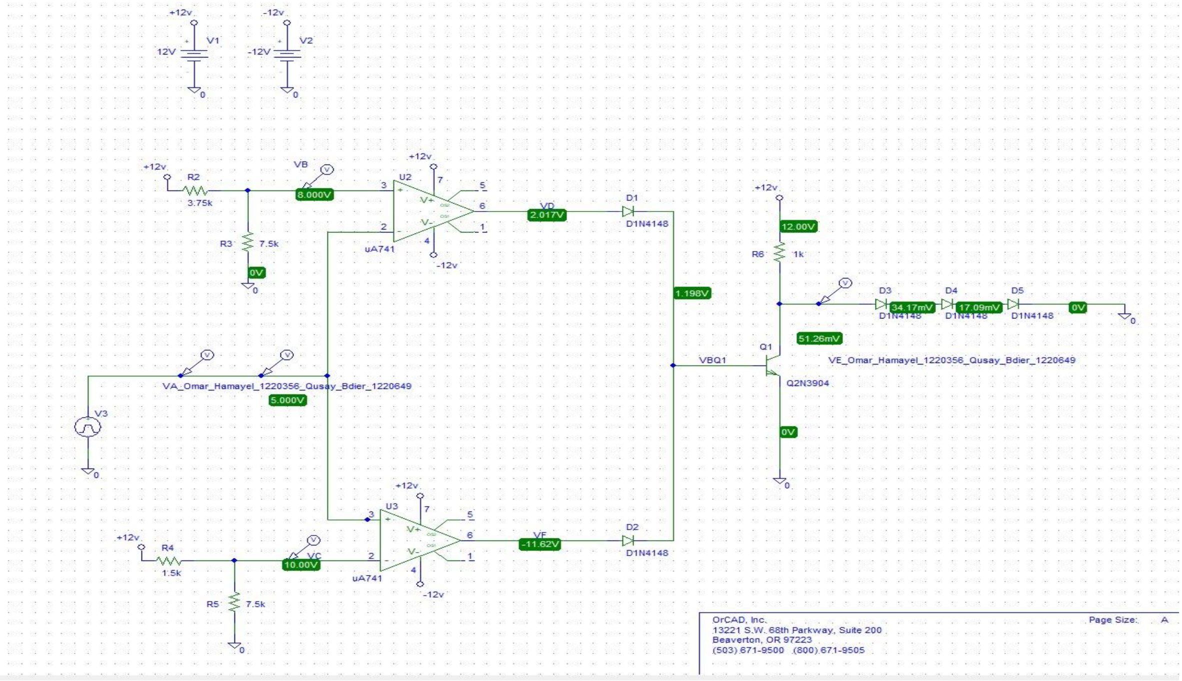

*Figure 11:circuit with new values of R2 and R4*

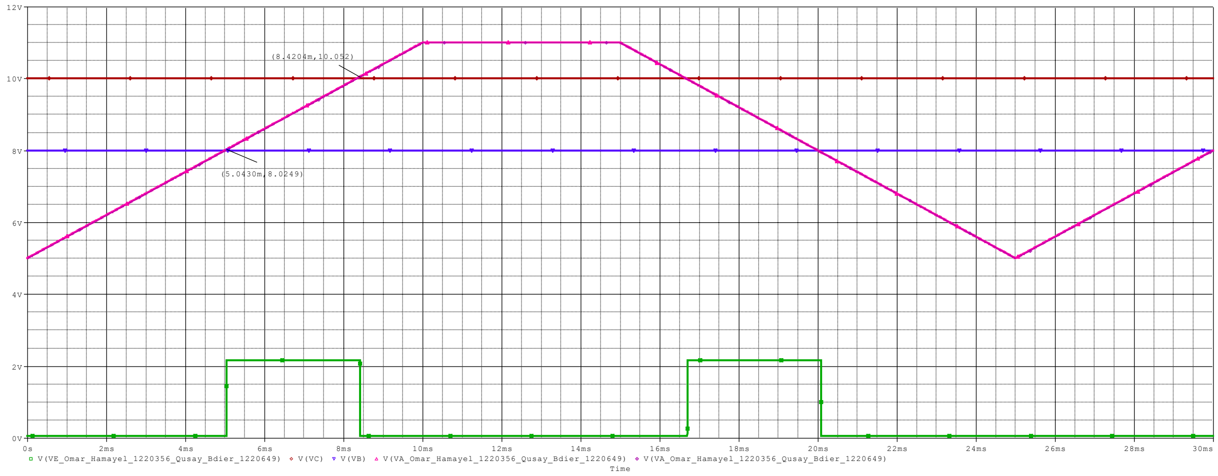

*Figure 12:Ve(t) in DC circuit with new R2, R4.*

From the waveform:

- **VLT :** The transition from low to high seems to occur around 10.05V.
- **VUT :** The transition from high to low seems to occur around 8.02V

# 4- Comparison of simulation results to hand calculation

- Compute all nodal voltages and assess the state of the electrical parts: -

**Calculate VB:**

$$VC = V_{supply} \times \frac{R_2}{R1+R_2}$$

$$VB = 12 * \frac{7.5\ K\Omega}{2.7\ K\Omega + 7.5\ K\ \Omega} = 8.82\ V$$

**Calculate VC:**

$$VC = V_{supply} \times \frac{R_4}{R_3+R_4}$$

$$VC = 12 * \frac{7.5\ K\Omega}{7.5\ K\Omega + 2.2 K\Omega} = 9.28\ V$$

**Calculate VD:**

Since the v (-) > v (+) in the op-amp
$VD = V_{CC(-)} + 2$
$VD = -12 + 2 = -10\ V$

**Calculate VF:**

Since the v (-) > v (+) in the op-amp
$VF = V_{CC\ (-)} + 2$
$VD = -12 + 2 = -10\ V$

| Type of node | Hand Calculation | Simulation |
|---|---|---|
| VB | 8.82 V | 8.824 V |
| VC | 9.28 V | 9.278 V |
| VD | -10 V | -11.61 V |
| VF | -10 V | -11.62 V |
| VE | 2.177 V | 2.165 V |

*Table 1:Simulation Results Vs Hand Calculation*

- Find new values of R2 and R4 so that VUT=10V and VLT=8V: -

$$VLT = \frac{R3}{R3+R2} * 12 \Longrightarrow 8 = \frac{7.5\ K\Omega * 12}{7.5\ K\Omega + R2} \Longrightarrow R2 = 3.75\ K\Omega$$

$$VUT = \frac{R5}{R5+R4} * 12 \Longrightarrow 10 = \frac{7.5\ K\Omega * 12}{7.5\ K\Omega + R4} \Longrightarrow R4 = 1.5\ K\Omega$$

## Conclusion:

The study successfully demonstrated the design and analysis of a voltage threshold detection circuit using both theoretical calculations and PSPICE simulation. The hand calculations provided accurate estimates for the necessary resistor values to achieve the desired threshold voltages.

The simulation results confirmed the accuracy of these calculations, with the circuit functioning as intended across the tested voltage range. This method of combining hand calculations with simulation provides a robust approach to circuit design, ensuring both accuracy and practical functionality.