BIRZEIT UNIVERSITY

ANALOG ELECTRONICS

Faculty of Engineering and Technology Department of Computer Systems Engineering

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Project NO.2: Water Temperature Controller

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Abstract

The water temperature control circuit consists of four stages, a Wheatstone bridge, an instrumentation amplifier, a comparator level detector, and the last stage is transistors and relays. The fourth stage that we did not touch on in this project, we only need the first three stages, each with a different way of working. Its main function is to control the water temperature as well as indicate it on the LED. It will be designed using electronic components such as rectifiers, OPAMPS, sensors, LEDS, and resistors.

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Theory

Part 1: Description

The circuit presented here controls the temperature of water as well indicates it on an LED bar graph. When the temperature of water is 0°C, none of the bar graph display LEDS glows. But as the temperature starts increasing above approximately 30°C, LEDS from LED1 through LED8 of the bar graph start glowing one after the other. When temperature is around 30°C, only LED1 would be 'on'. For temperature greater than 97 °C, all display LEDS will be 'on'. To detect the temperature of water, commonly used resistance-temperature detector (RTD) PT100 is used.

It is connected to one of the arms of a Wheat- stone bridge as shown in the figure RTD PT100 has a resistance of 100 ohms when surrounding temperature is 0°C. (To cater to resistance tolerances and calibration, resistor R6 (22-ohm) and 1- kilo-ohm preset VR1 were added at EFY lab. During testing.) Ideally, at 0°C, the bridge has to be in balanced condition and, for other temperatures, the bridge will be unbalanced. The unbalanced volt- age of the bridge is converted into suit- able value in the range 0V to 5V (corresponding to temperatures 0°C to 100°C, respectively) by the instrumentation amplifier formed by op- amps IC1 through IC3 (uA741). Output of instrumentation amplifier is given to voltage compactors for driving the display LEDS. Before using this circuit, the following adjustments have to be made.

First, immerse the RTD in ice water (0°C) and adjust preset VR1 such that the bridge becomes balanced and the out- put of IC3 becomes) V. Next, immerse the RTD in boiling water and slightly adjust preset VR2 such that the output of IC3 becomes 6V. Repeat the above two steps four to five times. To control the temperature of water, 'on'/'off' type controller is used. Lower threshold point is set at 97°C. An electric heater coil is used for heating the water. When power supply is switched 'on', the heater starts heating the water. When temperature reaches 80°C, output of IC5(b) goes 'high'. This turns 'on' relay driver transistor T1 to energies relay RL1. In this state, relay RL2. Relay RL2 in energized state cuts off power supply to the heater coil. Re- lay RL2, once energized, remains so due to the latching arrangement provided by its second pair of contacts. Simultaneously, the buzzer also sounds, due to forward biasing of transistor T3. Since the supply to the heater is cut- off, the temperature of water starts decreasing.

Gradually, the buzzer goes 'off, as output of IC5(d) goes 'low'. When temperature goes below 80°C, output of IC5 (b) goes 'low' to turn 'off transistor T1 and relay RL1. As a result, the power supply provided to relay RL2 (via RL1 N/O contacts) is cut off and relay RL2 energizes. This will again turn 'on' the mains electric power supply to the heater coil. Once again, the temperature of water starts increasing and the cycle repeats to maintain water temperature within the limits 80°C to 97°C. This controller can be used to control the temperature of water in water heaters, boilers, etc. The lower and up- per threshold points can be changed by connecting the base terminals of transistors T1 and T2 to different output terminals of voltage comparators (IC4 and IC5). Base terminals of transistors T1 and t2 are meant for lower and up- per threshold points, respectively.

➢ Part 2: Components we used

❖ RECTIFIER DIODES

A rectifier diode is a semiconductor diode, used to rectify AC (alternating current) to DC (direct current) using the rectifier bridge application. The alternative of rectifier diode through the Schottky barrier is mainly valued within digital electronics. This diode is capable to conduct the values of current which changes from mA to a few kA & voltages up to a few kV. [1]

❖ OPAMP

An operational amplifier (often op amp or opamp) is a DC-coupled high- gain electronic voltage amplifier with a differential input and, usually, a single-ended output. [2]

❖ SENSORS

In the broadest definition, a sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics. [3]

❖ RESISTANCE

In electricity, property of an electric circuit or part of a circuit that transforms electric energy into heat energy in opposing electric current. Resistance involves collisions of the current-carrying charged particles with fixed particles that make up the structure of the conductors. Resistance is often considered as localized in such devices as lamps, heaters, and resistors, in which it predominates, although it is characteristic of every part of a circuit, including connecting wires and electric transmission lines. [4]

➢ Part 3: Methodology

✓ **This smart art shows the stages of this project.**

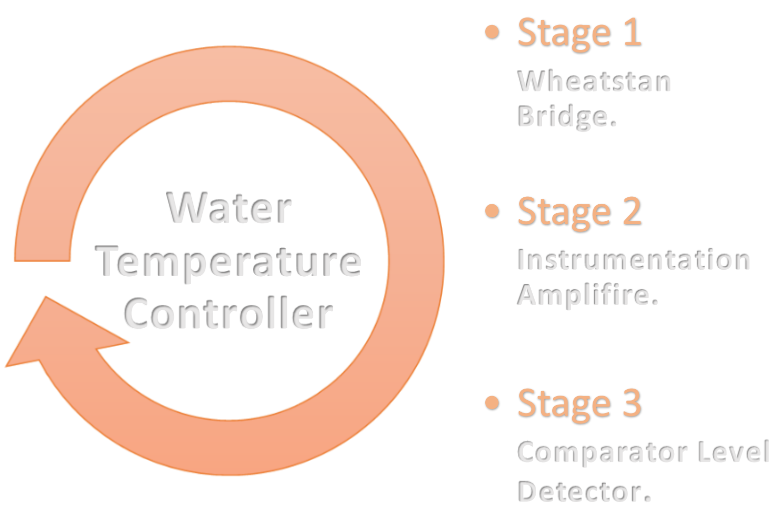


Figure 1: Project Stages

- Stage 1:

The Wheatstone Bridge circuit consists of two simple series-parallel arrangements of resistances connected between a voltage supply terminal and ground producing zero voltage difference between the two parallel branches when balanced. It has two input terminals and two output terminals consisting of four resistors configured in a diamond-like arrangement as shown. It is used to measure very low values of resistances down in the milli-Ohms range also to interface various transducers and sensors to these amplifier circuits.

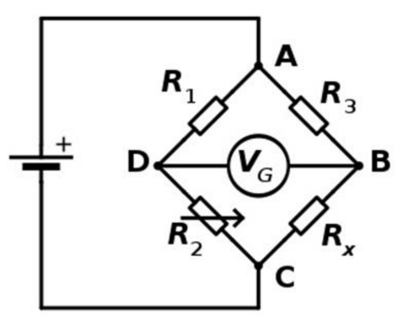


Figure 2: Wheatstone Bridge Circuit

- Stage 2:

Instrumentation amplifiers are precision devices with high input impedance, low output impedance, high common mode rejection ratio, low level of self-generated noise and low drift. The deviation from the current is attributable to the temperature-dependent output voltage. Instrumentation amplifier IC is an essential component in circuit design due to its characteristics such as high CMRR, high open loop gain, low drift as well as low DC, etc. A simple temperature control system can be constructed using the thermistor as the transformer device, in the resistive bridge. The equilibrium of the resistive bridge is maintained at some reference temperature. For any change in this reference temperature, the instrumentation amplifier will produce an output voltage, which in turn drives the relay to turn on / off the heating unit, thereby controlling the temperature.

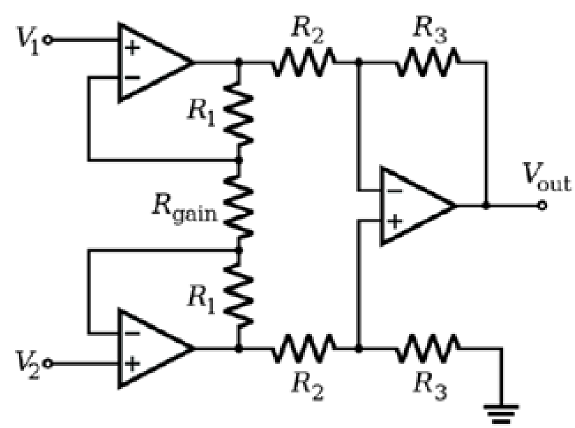


Figure 3: Instrumentation Amplifiers

- Stage 3:

Generally, in electronics, the comparator is used to compare two voltages or currents which are given at the two inputs of the comparator. That means it takes two input voltages, then compares them and gives a differential output voltage. There are very many uses for comparator circuits within electronic circuit design. It is often necessary to be able to detect a certain voltage and switch a circuit according to the voltage that has been detected. One example could be for use in a temperature sensing circuit. This might produce a variable voltage dependent upon the temperature. It may be necessary to switch the heating on when the temperature falls below a given point and this can be achieved by using a comparator to sense when the voltage proportional to the temperature has fallen below a certain value.

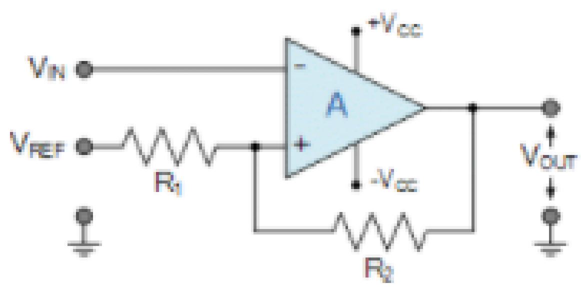


Figure 4: Comparator Level Detector Circuit.

Procedure & Discussion

Part 1: Simulation by OrCad

Stage 1

✓ **Case 1**: When Rx=100 ohm.

Fig 5 show the circuit of Wheatstone Bridge when R=100, with all value of voltage and current, and fig 6 show the simulation of it.

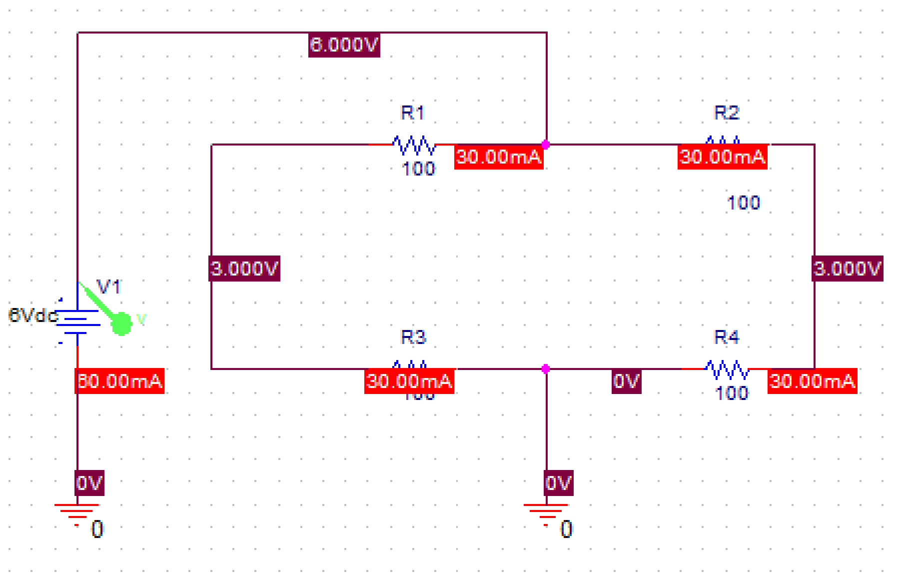


Figure 5: Simulation for Weston Bridge of case 1

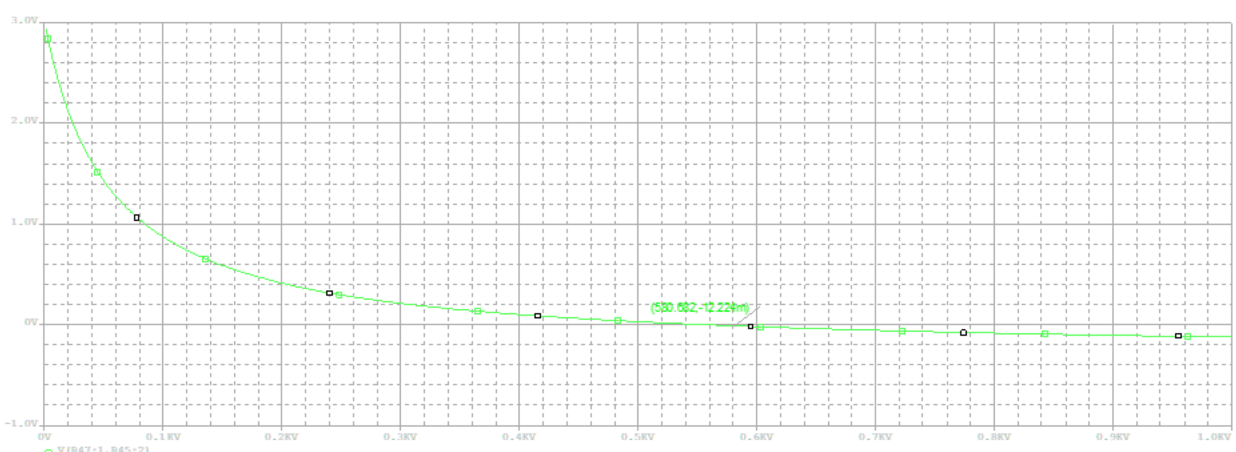


Figure 6: The simulation to find the variable resistors of Weston Bridge

✓ **Case 2**: When Rx=120 ohm.

Same of case 1, see fig 7 to see the simulation of this case.

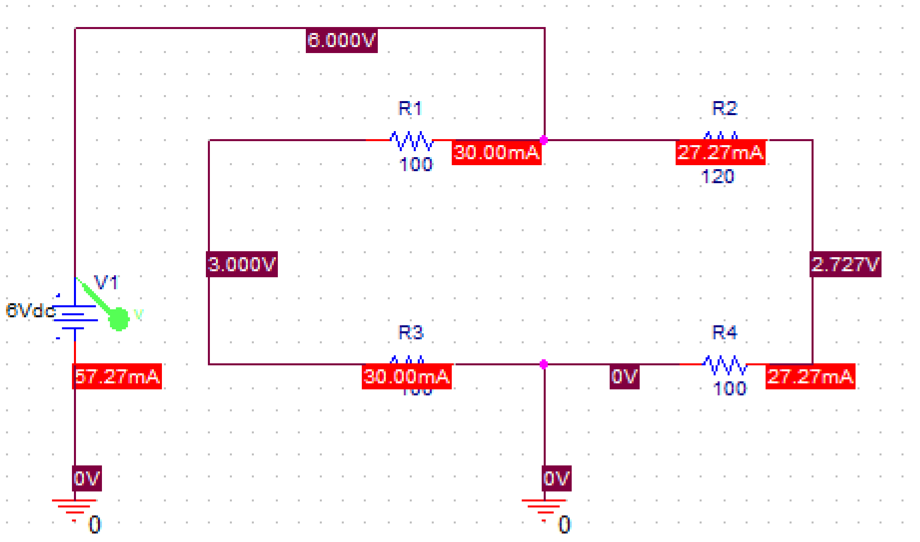


Figure 7: Simulation for Weston Bridge of case 2

✓ **Case 3**: When Rx=138.5 ohm.

Same of previous case, fig 8 show the simulation of this case.

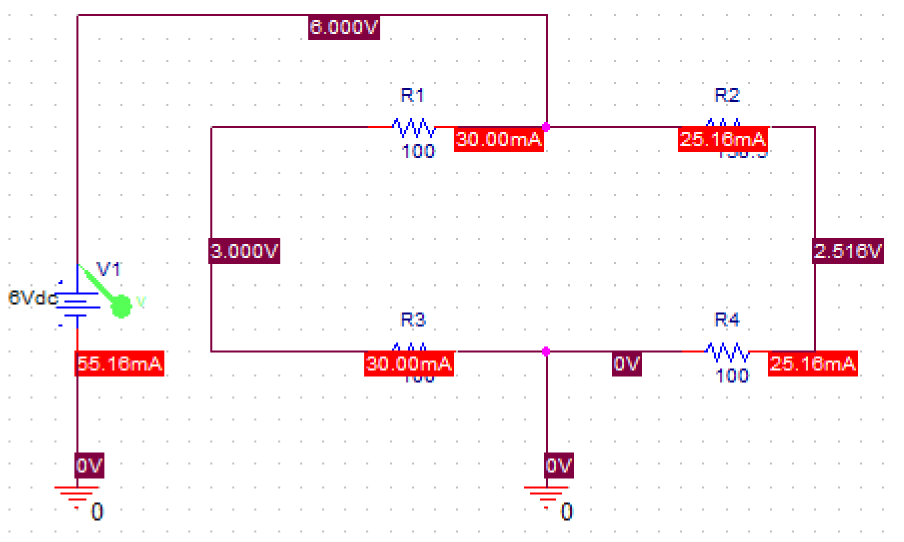


Figure 8: Simulation for Weston Bridge of case 3

- Stage 2

✓ **Case 1**: Rx = 100 ohm.

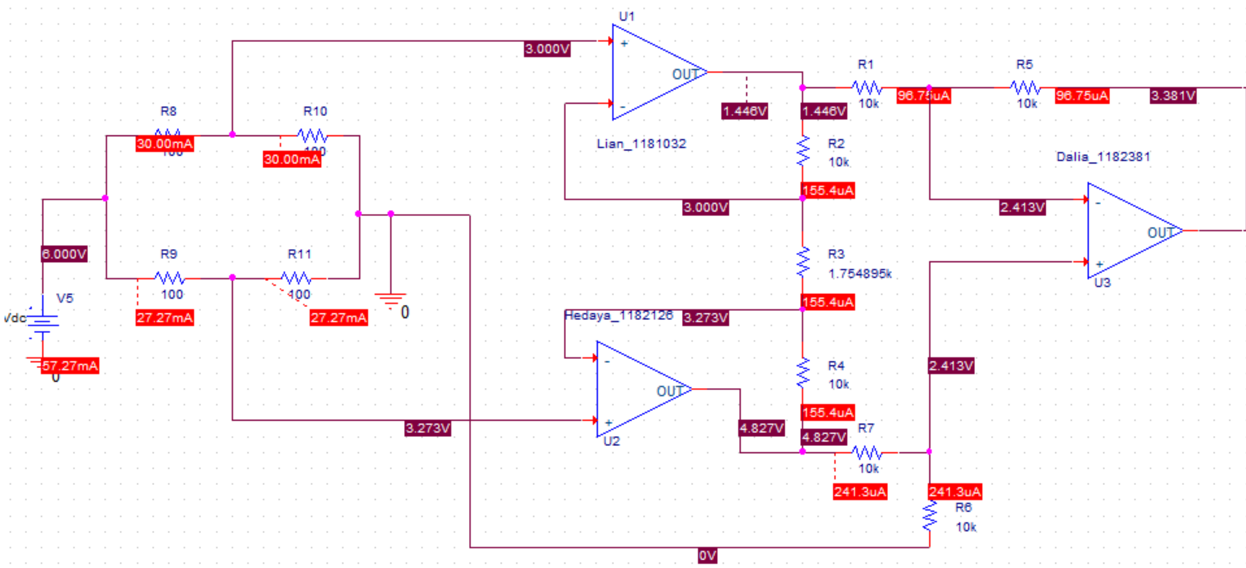


Figure 9: Simulation for Instrumentation Amplifier of case 1

✓ **Case 2**: Rx = 120 ohm.

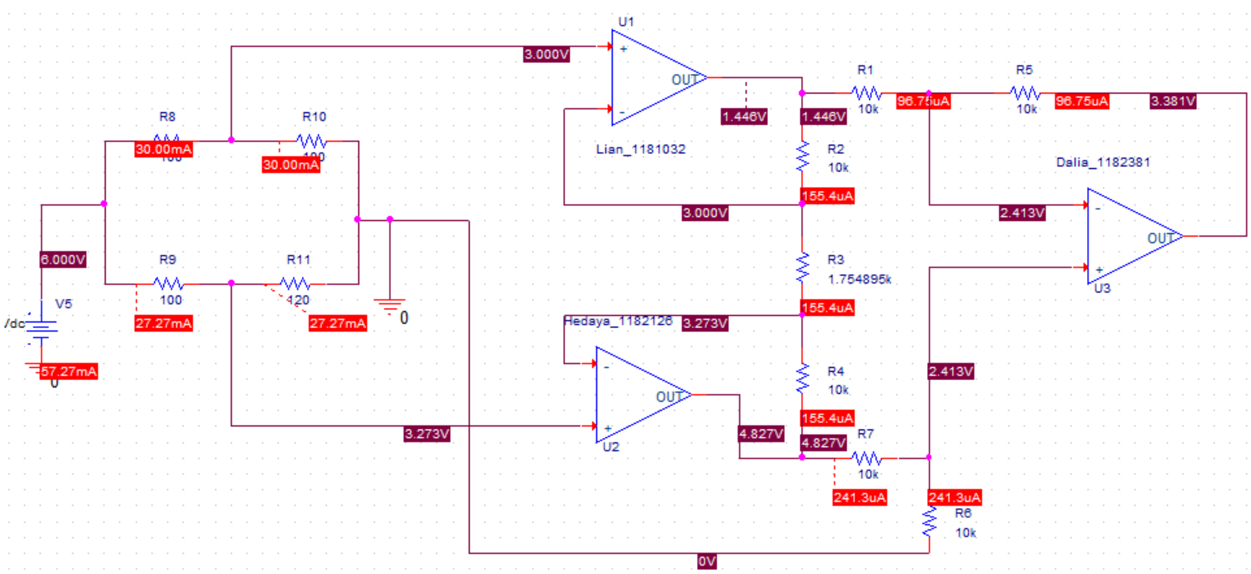


Figure 10: Simulation for Instrumentation Amplifier of case 2

- ✓ **Case 3**: Rx = 138.5 ohm.

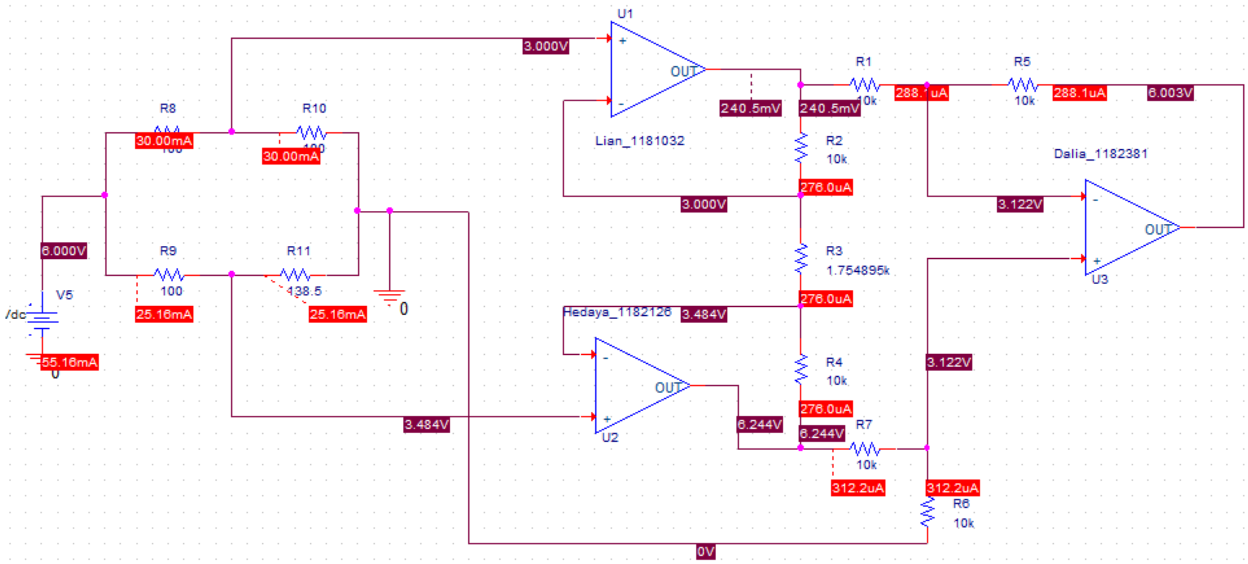


Figure 11: Simulation for Instrumentation Amplifier of case 3

- Stage 3

✓ **Case1**: When Rx=100 ohm.

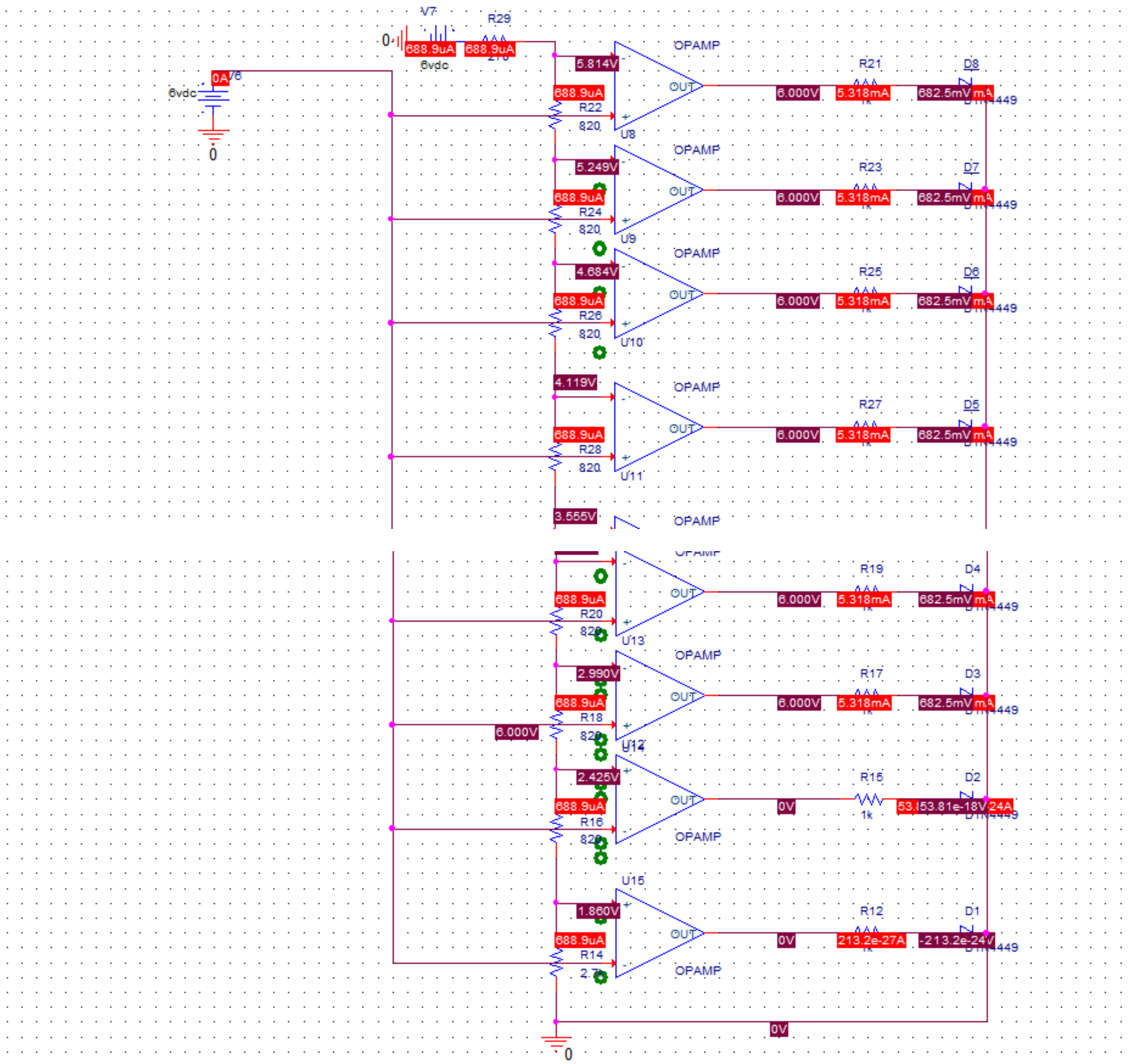


Figure 12: Simulation for Comparator Detector of case 1

✓ **Case 2**: When Rx=120 ohm.

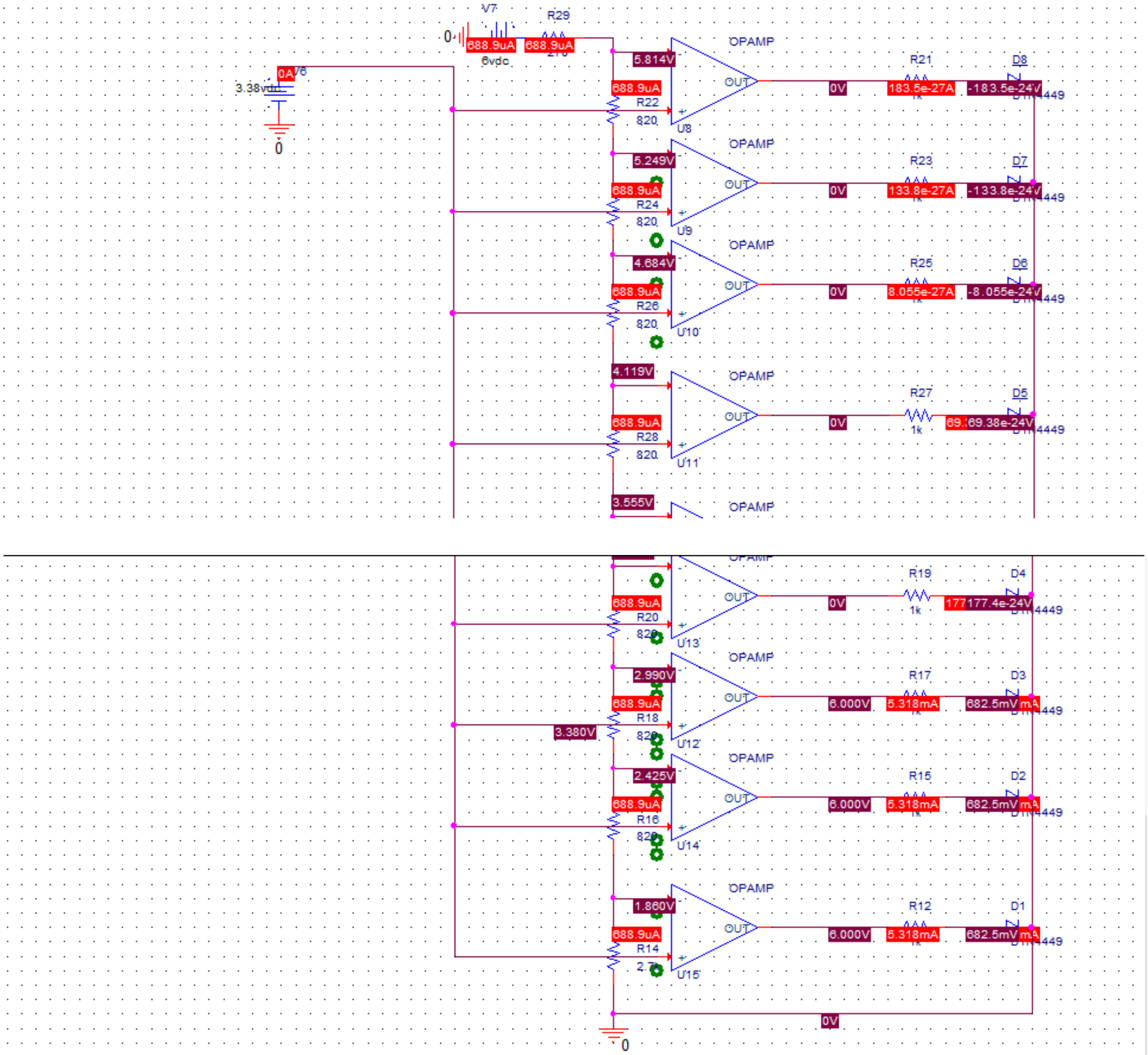


Figure 13: Simulation for Comparator Detector of case 2

✓ **Case 3**: When Rx=138.5ohm

This case the same of case 1, have the same simulation as shown in fig 12.

Because the value of voltage is 6 volts.

➢ Part 2: Analysis

Analysis of this Project

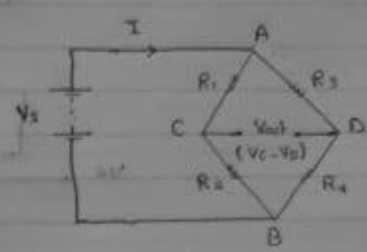
• Part (1) : The equations of stage 1 " Weston Bridge "

→ By using voltage divider at node C

$$V_C = \left(\frac{R_x}{R_x + R_3}\right) * V_{in} \quad \text{.......(1)}$$

At node D

$$V_D = \left(\frac{R_2}{R_2 + R_1}\right) * V_{in} \quad \text{.......(2)}$$



Circuit (1)

(1) - (2) :

$$V_C - V_D = \left(\frac{R_x}{R_x + R_3}\right) * V_{in} - \left(\frac{R_2}{R_2 + R_1}\right) V_{in}$$

But the value of VD & VC = 0 , then

$$\left(\frac{R_x}{R_x + R_3}\right) = \left(\frac{R_2}{R_2 + R_1}\right) \quad \text{.......(3)}$$

By solving (3) the result is :

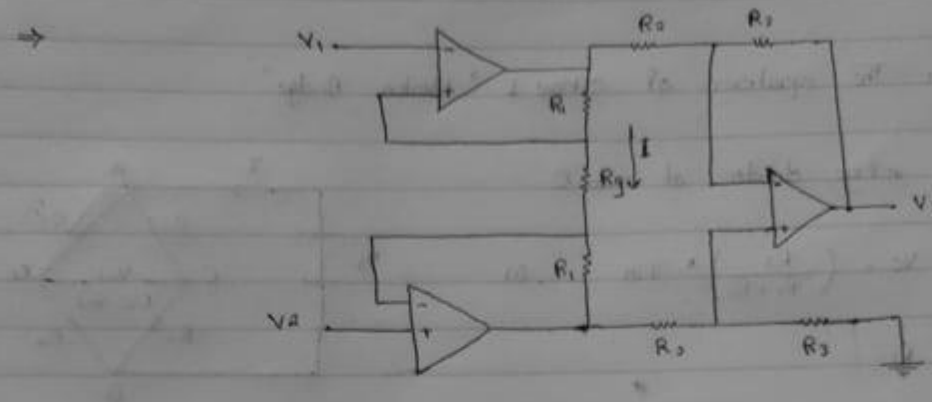
$$R_x = \frac{R_3 \times R_2}{R_1} \quad \text{..........(I)}$$

. Part (2) : The equations of stage 2 " Instrumentation Amplifier :

$$V_o = \frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_g}\right) * (V_2 - V_1)$$

See circuit (2) ∵

→



Circuit (2)

By Using KVL :

$$I = \frac{V}{R_g} = \frac{V_a - V_b}{R_g} \quad \text{------ (1)}$$

$$I = \frac{V}{R_g} = \frac{V_a - V_b}{R_g + 2R_1} \quad \text{------ (2)}$$

Then → (1) = (2)

$$\frac{V_1 - V_2}{R_g + 2R_1} = \frac{V_a - V_b}{R_g} \quad \text{------ (3)}$$

Then we get this equation :

$$V_1 - V_2 = \frac{R_g + 2R_1}{R_g} (V_1 - V_2)$$

$$V_1 - V_2 = \left(1 + \frac{2R_1}{R_g}\right)(V_1 - V_2) \quad \text{------ (4)}$$

& the output voltage is :

$$V_o = \left(\frac{R_2}{R_1}\right)\left(1 + \frac{2R_1}{R_g}\right) * (V_1 - V_2) \quad \text{------- I}$$

→ When $R_1 = R_2$ the output voltage is:

$$V_o = \left(1 + \frac{2R_1}{R_g}\right)(V_1 - V_2) \quad \text{--------- II}$$

. Now we have 3 Cases, In each case we will Calculate the values of V_C, V_D and V_o.

Case [1] : When $R_x = 100\ \Omega$

a. $V_C = \frac{R_x}{R_x + R_3} * V_{in} = \frac{100}{100 + 100} * 6 = 3$ Volts

b. $V_D = V_C$, Because All resistance have same value

c. $V_o = \left(\frac{R_2}{R_1}\right)\left(1 + \frac{2R_1}{R_g}\right)(V_1 - V_2)$

$= \frac{100}{100} * \left(1 + \frac{2*100}{100}\right) * (3.484 - 2.988) = 1.488$ V

Case [2] : When $R_x = 120\ \Omega$

a. $V_C = \frac{R_x}{R_x + R_3} V_{in} = \frac{100}{120 + 100} * 6 = 2.727$ Volts

b. $V_D = \frac{R_2}{R_2 + R_1} V_{in} = \frac{100}{100 + 100} * 6 = 3$ Volts

c. $V_o = \frac{100}{100} * \left(1 + \frac{(2)(100)}{120}\right) * 0.496 = 1.3226$

Case [3] : When $R_x = 138.5\ \Omega$

a. $V_C = \frac{100}{138.5 + 100} * 6 = 2.515$ Volt

b. $V_o = \frac{100}{100 + 100} * 6 = 3$ volt

c. $V_o = \frac{100}{100} * \left(1 + \frac{2*100}{138.5}\right) = 1.2122$

Conclusion

In conclusion, the water temperature controller was designed to measure the temperature of the water using LEDs, if the water temperature was 100oc all the LEDs will shine and that's when the sensor resistor equals 138.5Ω, while if the water temperature was 0, then none of the LEDs will shine (when the sensor resistor equals 100Ω), the last sensor resistor was chosen to be 120 Ω, and only three LEDs shined. There were no major problems in implementing this project, the simulation results were acceptable since the simulation results were similar to the theoretical values calculated and shown before.

This project is a very interesting one, since that we apply some things we learned in the course, and we learned a lot of skills such as how to use ORCAD/ PSPICE to simulate any project or subproject.

Reference

[1] https://www.elprocus.com/rectifier-diode-working-applications/
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[2] https://en.wikipedia.org/wiki/Operational_amplifier
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[3] https://en.wikipedia.org/wiki/Sensor
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[4] https://www.britannica.com/technology/resistance-electronics
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