BERZIET UNIVERSITY

Faculty of Engineering and Technology
Electrical and Computer Engineering Department

ANALOG ELECTRONICS
ENEE2360
PSpice project part2

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Abstract:

The aim of this project is to know how to use Pspice software to design and simulate the room thermostat to keep the room temperature between two threshold temperatures TH (15 ℃) and TL (13 ℃) that mean the heater turns off when the temperature goes over TH and turns on when the temperature goes below TL. Then, the comparison between the resulting values from the calculation process and the resulting values from the curves to find out the error percentage.

Table of Contents:

1. Procedure and Discussion:

To complete the design of the room thermostat shown in Figure NO.1 to keep the room temperature between two threshold temperatures TH (15 ℃) and TL (13 ℃):

<u>NOTE:</u> The heater turns off when the temperature goes over TH and turns on when the temperature goes below TL.

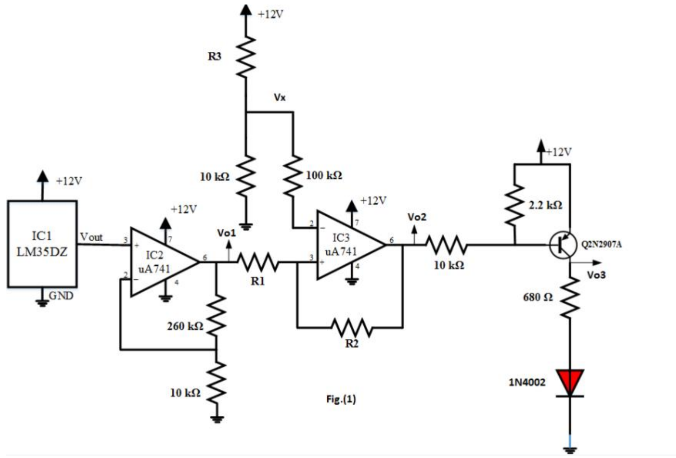


Figure NO.1: Circuit of the room thermostat

<u>The Bipolar Junction Transistor:</u> is a semiconductor device which can be used for switching or amplification. It's a three terminal device: Base, Emitter, and Collector. Also, there are two type of BJT: NPN type and PNP type as shown in Figure NO.2:

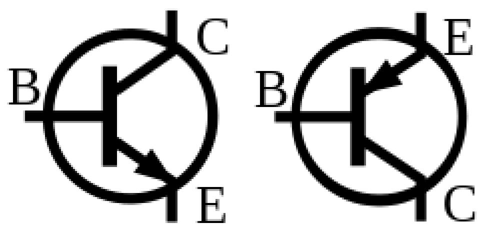


Figure NO.2: BJTs NPN and PNP schematic symbols [1]

<u>The Operational Amplifier:</u> is an integrated circuit that can amplify weak electric signals. An operational amplifier has two input pins and one output pin. Its basic role is to amplify and output the voltage difference between the two input pins as shown in Figure NO.3:

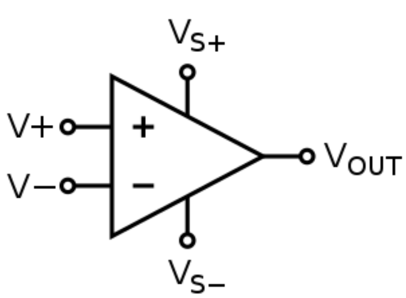


Figure NO.3: Circuit diagram symbol for an Operational amplifier [2]

The calculation before designing the circuit (from the given values):

1. **Non inverting amplifier "Negative feedback":**

- ***Case 1:*** when TL = 13 °C, then V = 10m volt/°C * 13°C = 0.13 volt:

  $V_{o1} = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_+ = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_{out} = 27 * 0.13 = 3.51$ volt.

- ***Case 2:*** when TH = 15 °C, then V = 10m volt/°C * 15°C = 0.15 volt:

  $V_{o1} = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_+ = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_{out} = 27 * 0.15 = 4.05$ volt.

2. **Schmitt trigger (hysteresis) "Positive feedback":**

- No current pass in R7 = 100k ohm, because i7 = i- = 0A.
- 3.51 volt < V_x < 4.05 volt, so assume $V_x = V_- = \frac{3.51 + 4.05}{2} = 3.78$ volt.
- By voltage divider rule "to find the value of R3":

  $V_- = V_x = 12 * \frac{10\ k\ ohm}{R3 + 10\ k\ ohm} = \frac{120\ k\ ohm}{R3 + 10\ k\ ohm} = 3.78$ volt.

  ∴ R3 = 21746.03175 ohm = 21.75 k ohm.

- In schmitt trigger (hysteresis) "Positive feedback" $V_o = \mp V_{sat}$:

  I. Let $\mathbf{V_{o2} = +V_{sat}}$ = 11.6 volt, then $V_d = V+ - V- > 0$, $V+ > V- = V_x = 3.78$ volt.
  By superposition:

  A. Kill V_{o1}:

  $V_+ = \frac{R1}{R1 + R2} * V_{o2} = \frac{R1}{R1 + R2} * (+V_{sat}) = \frac{11.6\ R1}{R1 + R2}$.

  B. Kill V_{o2}:

  $V_+ = \frac{R2}{R1 + R2} * V_{o1} = \frac{3.51\ R2}{R1 + R2}$.

  ∴So $V+ = \frac{11.6\ R1 + 3.51\ R2}{R1+R2} > 3.78$…(1)

  II. Let $\mathbf{V_{o2} = -V_{sat}}$ = 0.4 volt, then $Vd = V_+ - V_- < 0$, $V_+ < V_- = V_x = 3.78$ volt.
  By superposition:

  A. Kill V_{o1}:

  $V_+ = \frac{R1}{R1 + R2} * V_{o2} = \frac{R1}{R1 + R2} * (-V_{sat}) = \frac{0.4\ R1}{R1 + R2}$.

  B. Kill V_{o2}:

  $V_+ = \frac{R2}{R1 + R2} * V_{o1} = \frac{4.05\ R2}{R1 + R2}$.

  ∴So $V_+ = \frac{0.4\ R1 + 4.05\ R2}{R1+R2} < 3.78$…(2)

  By subtracting equation number 2 from equation number 1:

  $\frac{11.2\ R1}{R1 + R2} - \frac{0.54\ R2}{R1 + R2} = 0 \rightarrow (\frac{11.2\ R1}{R1 + R2} = \frac{0.54\ R2}{R1 + R2}) * R1+R2$, then $\frac{R2}{R1} = 20.74074074$

  Assume **R1 = 100 k ohm**, then **R2 = 2074.074074 k ohm.**

- When V_{o1} ↓, V_{o1} > 3.51 volt → $V_{o2} = +V_{sat}$. But when V_{o1} < 3.51 volt → $V_{o2} = -V_{sat}$.
- When V_{o1} ↑, V_{o1} < 4.05 volt → $V_{o2} = -V_{sat}$. But when V_{o1} > 4.05 volt → $V_{o2} = +V_{sat}$.

Using PSPICE ,determine Vx,Vo1,Vo2, Vo3, and the status of (the BJT and the diode) at T = 8 ℃ and T =32 ℃ (Vout = 0.08V and Vout = 0.32V):

At T = 8 ℃ and V_{out} = 0.08V:

$V_{o1} = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_{+} = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_{out} = 27 * 0.08 = 2.16$ volt. And V_{o2} = 387.06 mV = 0.38706 V ≅ $-V_{sat}$ = 0.4 V. Then, threshold temperature = 8 ℃ $<$ TL $=$ 13 ℃, so the heater turns on.

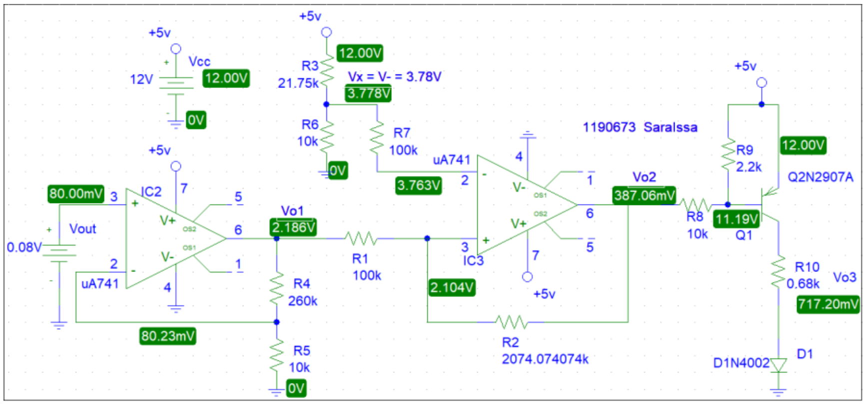


Figure NO.4: Circuit of the room temperature when threshold temperature 8 ℃ in Pspice

At T = 32 ℃ and V_{out} = 0.32V:

$V_{o1} = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_{+} = (1 + \frac{260\ k\ ohm}{10\ k\ ohm}) * V_{out} = 27 * 0.32 = 8.64$ volt. And V_{o2} = 11.61V ≅ $+V_{sat}$ = 11.6 V. Then, threshold temperature = 32 ℃ $>$ TH $=$ 15 ℃, so the heater turns off.

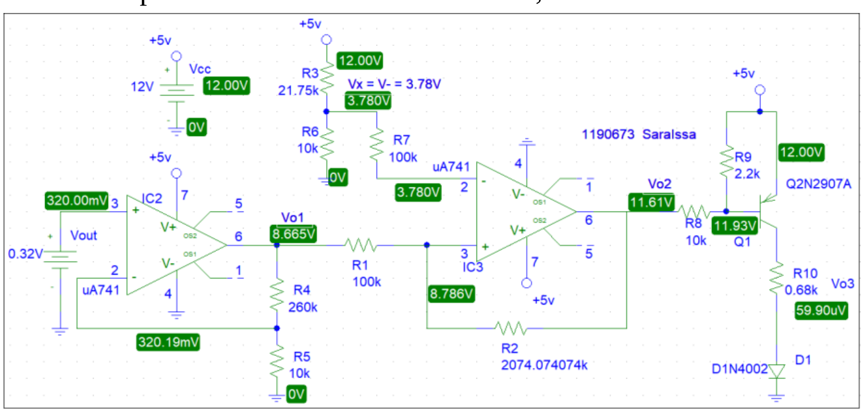


Figure NO.5: Circuit of the room temperature when threshold temperature 32 ℃ in Pspice

The Circuit of the room temperature between two threshold temperatures TH (15 ℃) and TL (13 ℃) in Pspice as shown in Figure NO.6:

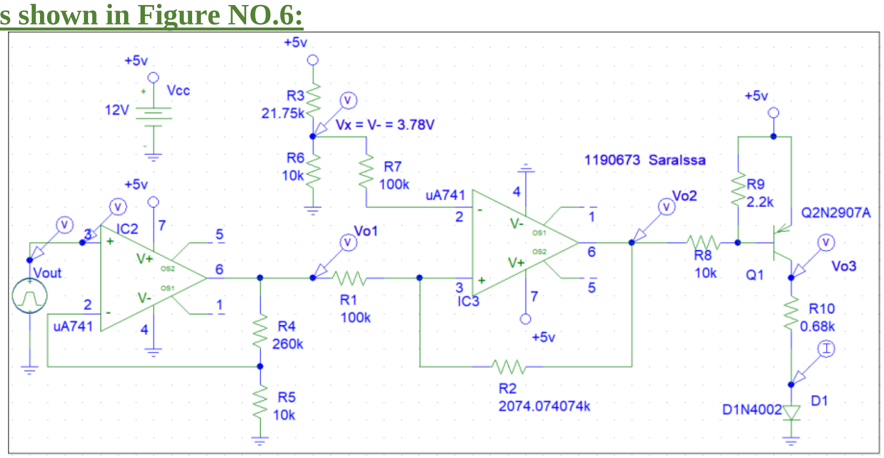
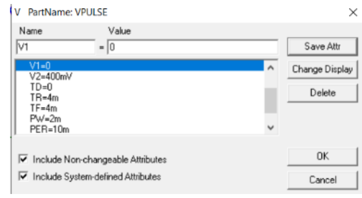


Figure NO.6: Circuit of the room temperature between two threshold temperatures TH (15 ℃) and TL (13 ℃) in Pspice

The output of simulation of Vpulse when the temperature increases from 8 ℃ to 32 ℃, that after set the values in Vpulse as shown in adjacent figure:



The temperature increases from 8 ℃ to 32 ℃.

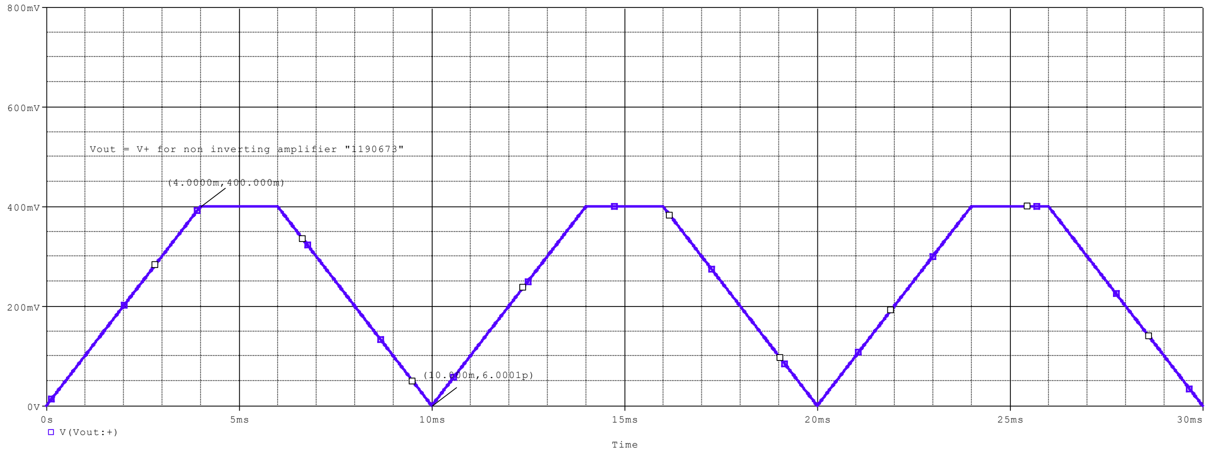


Figure NO.7: The output of simulation of Vpulse in Pspice

Plot V_{o1}(t) from circuit Simulation:

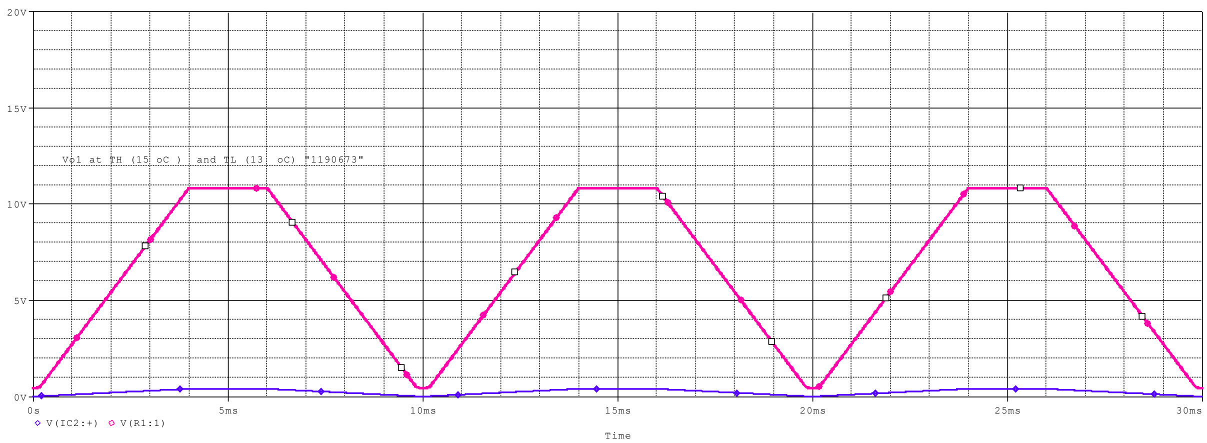


Figure NO.8: Vo1(t) from circuit Simulation in Pspice

Plot V_x = V_- for schmitt trigger (hysteresis) from circuit Simulation:

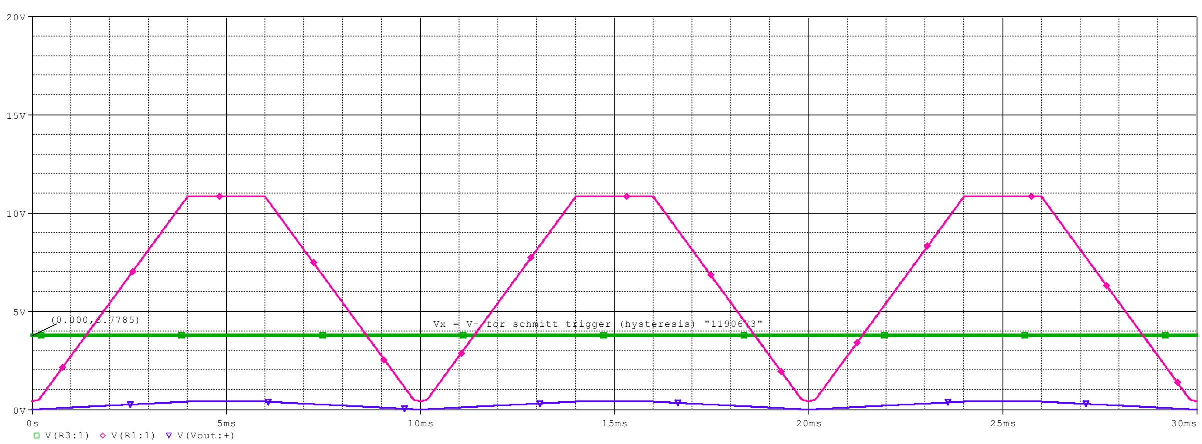


Figure NO.9: Vx = V- for schmitt trigger (hysteresis) in Pspice

Plot V_{o2}(t) from circuit Simulation:

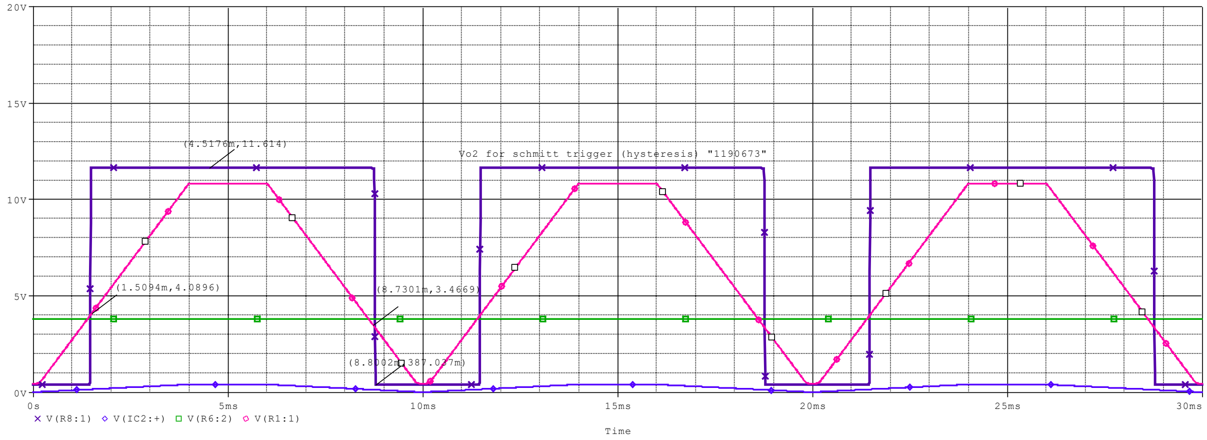


Figure NO.10: Vo2(t) from circuit Simulation in Pspice

Plot V_{o3}(t) from circuit Simulation:

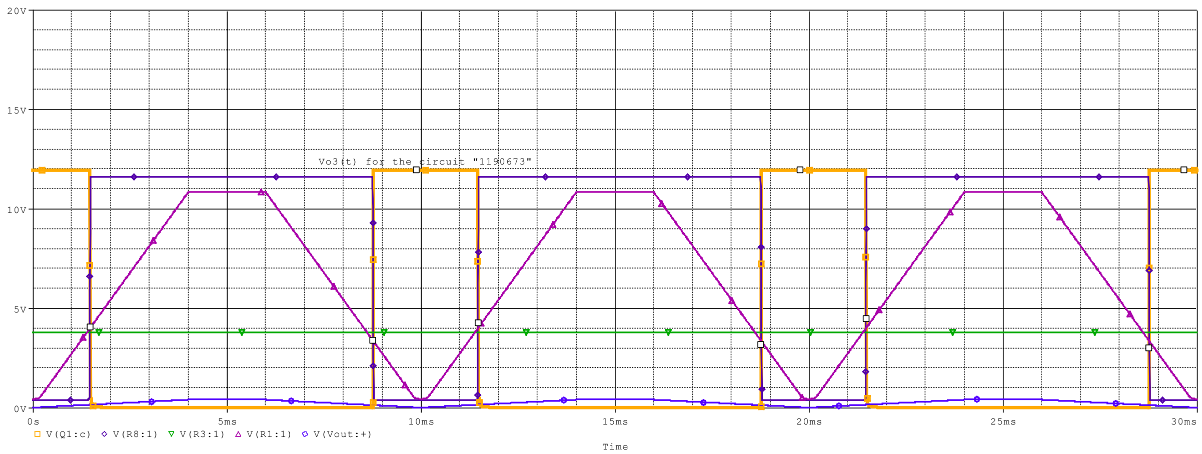


Figure NO.11: Vo3(t) from circuit Simulation in Pspice

Plot I_D from circuit Simulation:

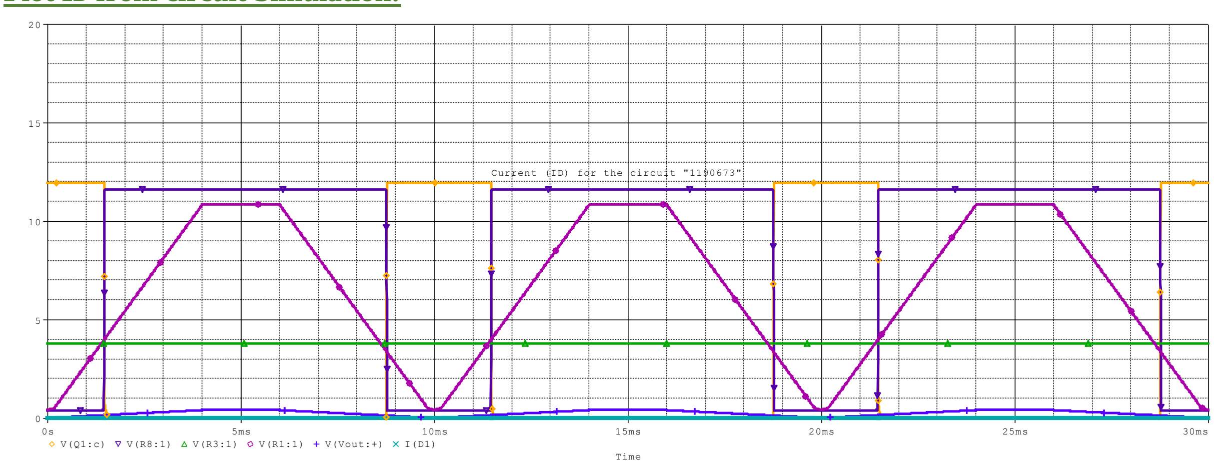
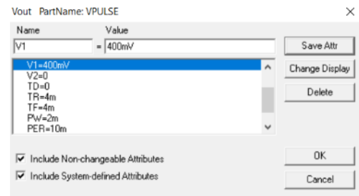


Figure NO.12: ID from circuit Simulation in Pspice

The output of simulation of Vpulse when the temperature decreases from 32 ℃ to 8 ℃, that after set the values in Vpulse as shown in adjacent figure:



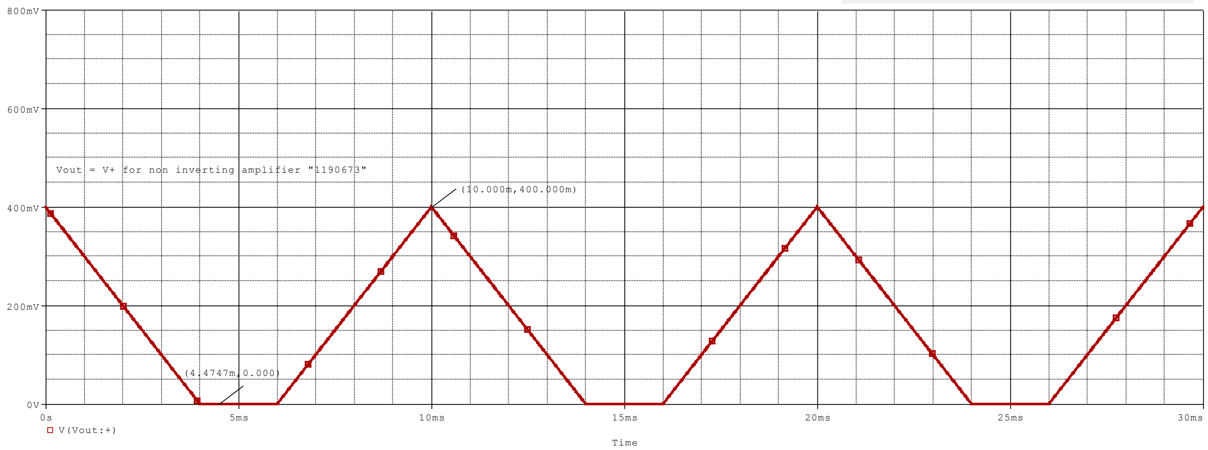


Figure NO.13: The output of simulation of Vpulse in Pspice

Plot V_x,V_{o1},V_{o2}, V_{o3} from circuit Simulation as the temperature decreases from 32 ℃ to 8 ℃:

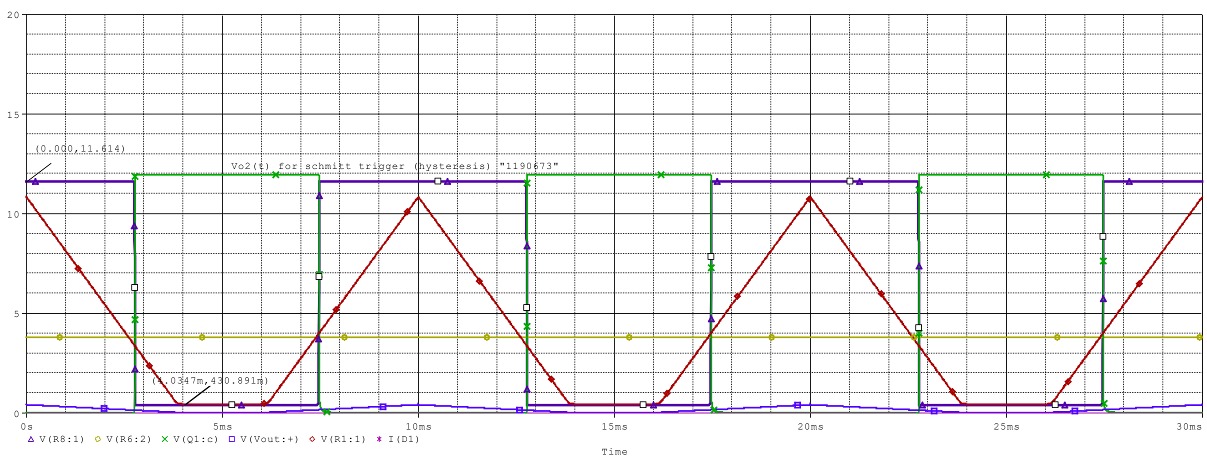


Figure NO.14: The output of plot Vx,Vo1,Vo2, Vo3

The calculation after designing the circuit (from the curves):

From the previous curves:

- At temp = TH = 15 oC, then **V_{o1} = 4.0896 volt**.
- At temp = TL = 13 oC, then **V_{o1} = 3.4669 volt**.
- When **V_{o2} = +V_{sat} = 11.614 volt**.
- When **V_{o2} = -V_{sat} = 387.037 mV = 0.387037 volt.**
- **V_x = V_-** for schmitt trigger (hysteresis) **= 3.7785 volt**.

2. Conclusion:

The heater turns off when the temperature goes over TH (temp > 15℃), this means that no current passes through the diode (therefore, if the place of the diode was a led, it will be turn off), ID (when temp = 32 ℃) = 16.60pA ≅ 0 A, as shown in Figure NO.15:

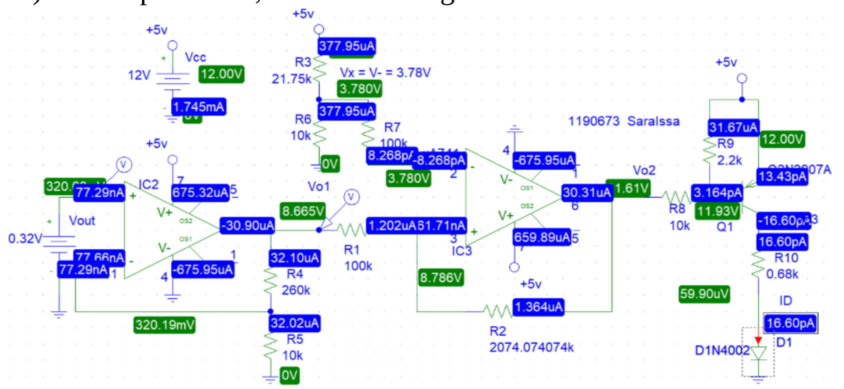


Figure NO.15: The heater turns off when the temperature goes over TH

And the heater turns on when the temperature goes below TL (temp < 13℃), this means that current passes through the diode (therefore, if the place of the diode was a led, it will be turn on), ID (when temp = 8 ℃) = 16.49 mA, as shown in Figure NO.16:

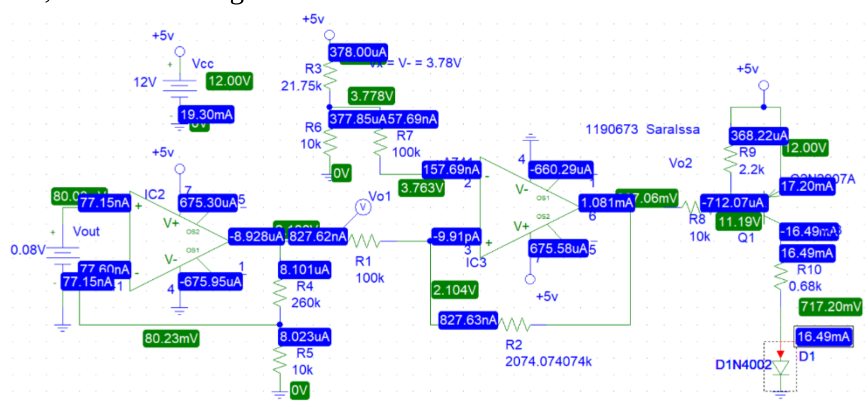


Figure NO.16: The heater turns on when the temperature goes below TL

Note: BJT transistor controls whether the heater turns on or off, so either both of them is On or Off.

Comparison of the results between simulated values of V_x, V_{o1} and V_{o2} to hand calculations, as shown in Table NO.1:

Name of voltage	simulated values	Hand calculations values
V_x	3.7785 volt	3.78 volt
V_{o1} at 13 ℃	3. 4669 volt	3.51 volt
V_{o1} at 15 ℃	4. 0896 volt	4.05 volt
$V_{o2} = +V_{sat}$	11.614 volt	11.6 volt
$V_{o2} = -V_{sat}$	0.387037 volt	0.4 volt

From the previous table, it was found that the values of V_x, V_{o1} and V_{o2} were very similar. Error percentage in the room temperature between two threshold temperatures TH (15 ℃) and TL (13 ℃):

Error percentage = [V_{o2} (simulation) – V_{o2} (given)] / V_{o2} (given) * 100 % = (11.614 – 11.6) / 11.6 * 100 % = 0.120689% very small percentage, and error percentage ≪ 5% so it's accepted.

3. References:

1. "What is an Operational Amplifier?," 30 Dec 2021. [Online]. Available: https://www.ablic.com/en/semicon/products/analog/opamp/intro/.
2. "lecture notes," 20 NOV 2021. [Online]. Available: https://drive.google.com/drive/folders/1BMOtKtk_tsWvnqLaALTTrSv28DYf2cHz
3. "Bipolar junction transistor," 29 Dec 2021. [Online]. Available: https://en.wikipedia.org/wiki/Bipolar_junction_transistor.
4. "Circuit diagram symbol for an Operational amplifier," 30 Dec 2021. [Online]. Available: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.wikiwand.com%2Fen%2FOperational_amplifier&psig=AOvVaw1Jk-waHfXm-l8LL9vibobE&ust=1641551531546000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCLCmipb2nPUCFQAAAAAdAAAAABAD.