IOWA STATE UNIVERSITY
ELECTRICAL AND COMPUTER ENGINEERING

EE 230

LAB 4 Project REPORT

9/21/2022

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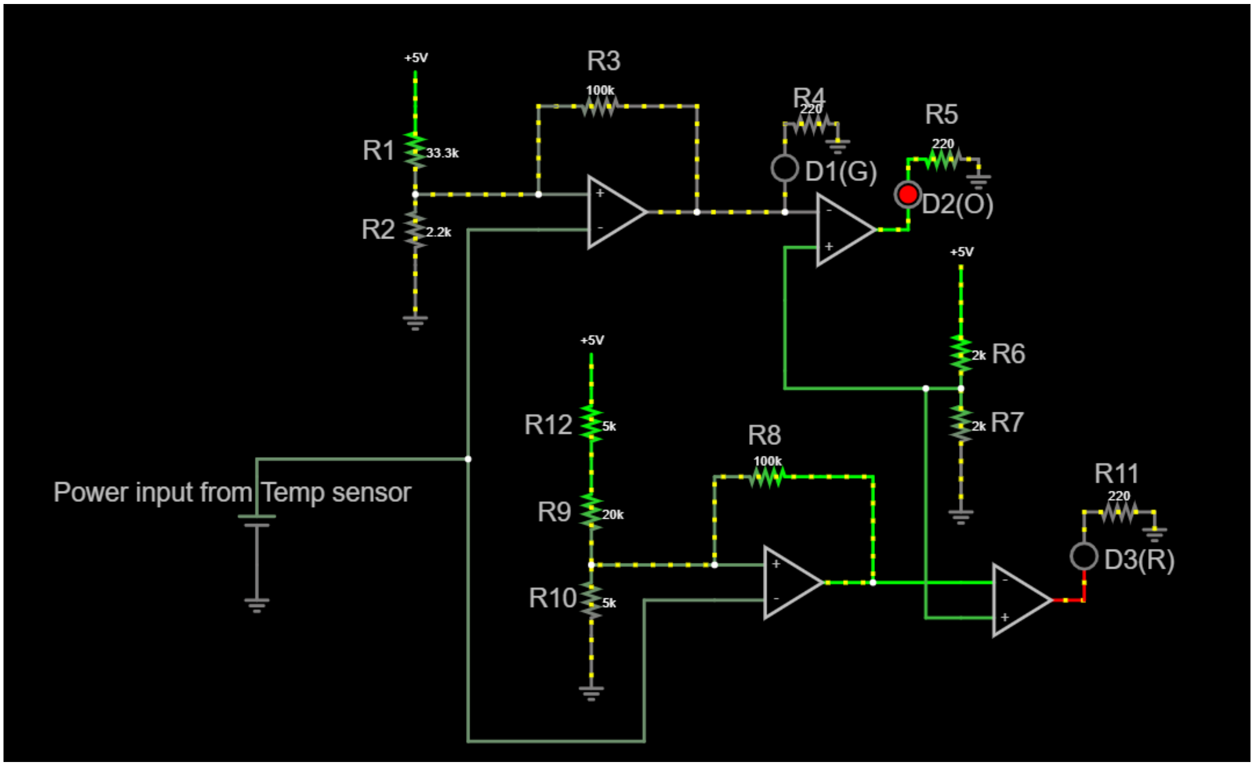
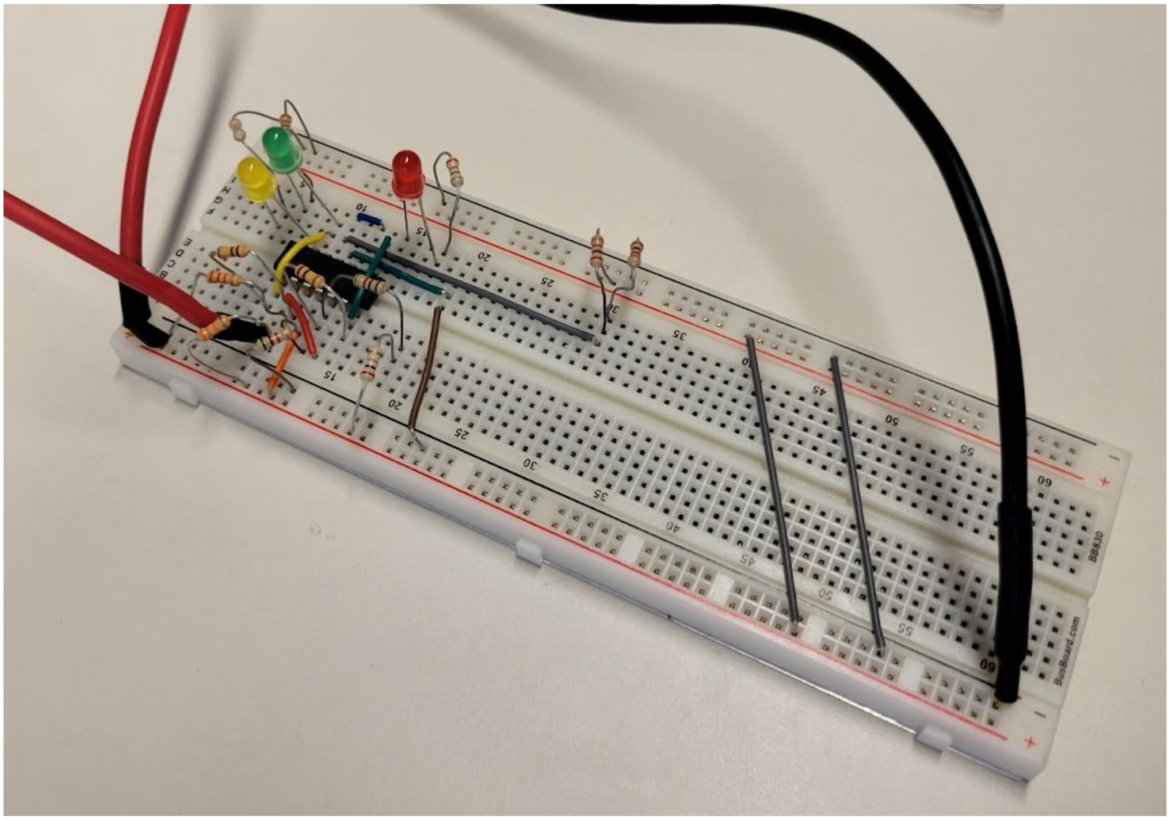


Component	Nominal Value	Measured Value
R_1	33.3kΩ	32.53kΩ
R_2	2.2kΩ	2.16kΩ
R_3	100kΩ	99.97kΩ
R_4	220Ω	216Ω
R_5	220Ω	220Ω
R_6	2kΩ	1.96kΩ
R_7	2kΩ	1.97kΩ
R_8	100kΩ	99.68kΩ
R_9	20kΩ	19.75kΩ
R_{10}	5kΩ	5.07kΩ
R_{11}	220Ω	219Ω
R_{12}	5kΩ	5.05kΩ
V_s	5V	5V

V_{H1}	.4V	.38V
V_{L1}	.3V	.3V
V_{H2}	1V	.97V
V_{L2}	.8V	.8V



Circuit Description:

Our circuit is built of 4 smaller circuits with an op-amp in each making up the majority of the design. The side closest to the camera on the picture above compares the voltage output of the temperature sensor. We implemented a circuit with positive feedback with the concepts of hysteresis to learn the knowledge we needed in regards to hysteresis. We found a document from TI explaining and giving the equations for an inverting hysteresis circuit. The output of each started saturated with the positive rail (5V) and would switch to the negative (GND) when our desired voltages were hit and vice versa. This directly outputs the green LED with a current limiting resistor. The other two op amps were used just to invert the output of the other amps to properly output the orange(yellow) and red LED with a current limiting resistor again. The orange LED was just a direct inversion of the green LED and the Red LED had its own hysteresis comparator that was inverted. We looked at implementing a non-inverting hysteresis comparator so we would not need an inverter but beings we had experience with the math for the inverting comparator decided to just implement it again with different ratios.

Circuit Performance:

Our circuit performed quite well with a difference of .02 mV for the Green/Orange LED and .03mV for the Red LED for the . We believe this was caused by imperfections of the resistor values with slight differences from actual value to nominal values. In addition, we found that Op-amps are anything but ideal so assuming they are ideal causes issues when going from simulation to implementation. We were initially using a TL082BCP op-amp and we had many issues which were immediately solved once we swapped to using an LM324 op-amp.

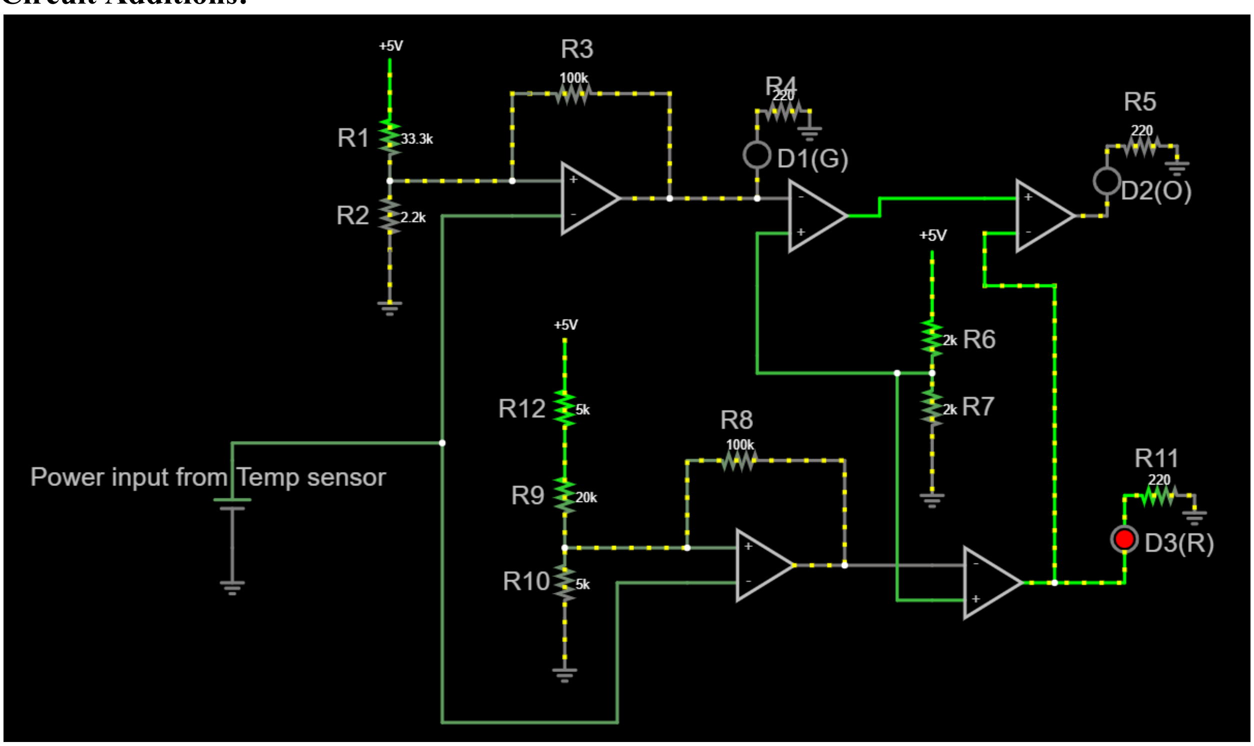
Math of Hysteresis comparator:

The math we used to find desired resistor values for the hysteresis is described below. The premise of hysteresis is it is a comparator with feedback. The op-amp compares the two inputs and outputs with a very high gain. The feedback changes the threshold values depending on which direction it is saturated. This allows there to be two different threshold values for saturation directions.

Math of Inverting comparator:

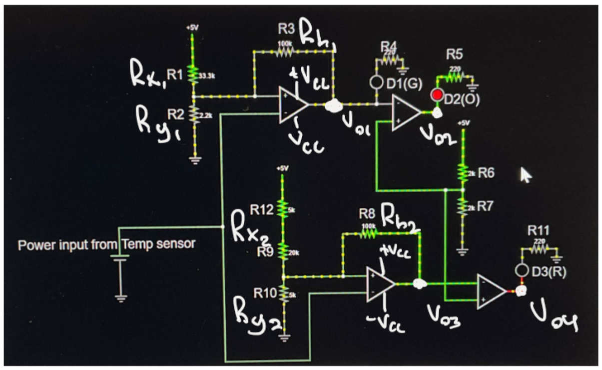
The inverting to output the red LED and the orange LED was just a basic comparator. We had a 2k pull-up and a 2k pull-down to give 2.5 volts compared to the output of the first op-amp so it saturates to 5V when the output from the first op amp is less than 2.5 and saturates to 0V when the op-amp output is greater than 2.5. This is because the op amp outputs a gain(V+ - V-). We assumed this gain was very high so it just saturated the rails. This caused our circuit to invert to output the opposite of the initial op amp.

Circuit Additions:



Adding a single op-amp to our original design as shown above makes it so the orange LED turns off whenever the red LED turns on. It takes the output of our original orange inverter and the output of the red LED. The output of this op-amp is Gain(V+-V-) with the gain being very high. the output of the two op-amps are the same at 5V so when they are both output 5V it outputs 0 V but when the V+ pin is 5V and red LED is off it outputs 5V and when they both are 0V it outputs 0V.

Annotated Circuit:



Below is the ideal equation for hysteresis given resistor values or voltages. Here V_H represents our voltage trigger going up and V_L is our voltage trigger going down.

Hysteresis

$$\frac{R_h}{R_x} = \frac{V_L}{V_H - V_L}, \qquad \frac{R_y}{R_x} = \frac{V_L}{V_{cc} - V_H}$$

Below shows the math for our given design A_1 is our first opamp controlling the green and orange LEDs and A_2 is the third opamp controlling the red LED. What matters for our circuit is ensuring that our resistor values were selected correctly and that the math matches the experimental results.

For A_1

Resistors

$\frac{R_3}{R_1} =$

Nominal

$\frac{100k\Omega}{2.2k\Omega} = 3.003$

Measured

$\frac{99.97k\Omega}{2.16\ k\Omega} = 3.073$

$\frac{R_2}{R_1} =$

Nominal

$\frac{2.2\Omega}{33.3\Omega} = 0.066$

Measured

$\frac{2.16k\Omega}{32.53k\Omega} = 0.066$

Voltages

Predicted

$\frac{300mV}{400mV - 300mV} = 3$

Measured

$\frac{300mV}{380mV - 300mV} = 3.75$

Predicted

$\frac{300mV}{5v - 400mV} = 0.065$

Measured

$\frac{300mV}{5v - 38mV} = 0.064$

For A_2

Resistors

$\frac{R_8}{(R_{12} + R_9)}$

Nominal

$\frac{100k\Omega}{2.2k\Omega} = 3.003$

Measured

$\frac{99.97k\Omega}{2.16\ k\Omega} = 3.073$

$\frac{R10}{(R_{12} + R_9)}$

Nominal

$\frac{2.2\Omega}{33.3\Omega} = 0.066$

Measured

$\frac{2.16k\Omega}{32.53k\Omega} = 0.066$

Voltages

Predicted

$\frac{800mV}{1v - 800mV} = 4$

Measured

$\frac{800mV}{970mV - 800mV} = 4.7$

Predicted

$\frac{800mV}{5v - 1V} = 0.2$

Measured

$\frac{800mV}{5v - 970mV} = 0.1985$

Sources:
Information and calculations for implementing hysteresis:
https://www.ti.com/lit/ug/tidu020a/tidu020a.pdf

LM324 Datasheet for pinout and op-amp information:
LMx24, LMx24x, LMx24xx, LM2902, LM2902x, LM2902xx, LM2902xxx Quadruple Operational Amplifiers datasheet (Rev. X)

Falstad simulator to test our circuit and draw our diagram to test our circuit you can enter the text below into their import from text option:
https://falstad.com/circuit/circuitjs.html

```
$ 1 0.000005 10.20027730826997 50 5 43 5e-11
v -48 496 -48 416 0 0 40 0.7 0 0 0.5
g -48 496 -48 528 0 0
r 304 80 224 80 0 100000
r 96 160 96 224 0 2200
r 96 160 96 80 0 33300
R 96 80 96 32 0 0 40 5 0 0 0.5
g 96 224 96 272 0 0
w 208 160 96 160 0
w 304 80 352 80 0
```

```
w 352 80 352 176 0
a 208 176 352 176 9 5 0 1000000 0.7 0.30359319952389 100000
w 352 176 432 176 0
r 592 336 592 400 0 2000
g 592 400 592 448 0 0
162 432 176 432 96 2 default-led 1 0 0 0.01
162 544 192 544 128 2 default-led 1 0 0 0.01
r 432 96 480 96 0 220
r 544 128 608 128 0 220
g 480 96 480 112 0 0
g 608 128 608 144 0 0
a 432 192 544 192 8 15 -15 1000000 -0.00003963818004761099 2.5 100000
w 432 256 432 208 0
a 592 528 704 528 8 15 -15 1000000 5.000029997619991 2.5 100000
g 768 448 768 464 0 0
r 704 448 768 448 0 220
162 704 528 704 448 2 default-led 1 0 0 0.01
R 592 272 592 208 0 0 40 5 0 0 0.5
w 512 512 592 512 0
a 368 512 512 512 9 5 0 1000000 0.7 1.0000011999047995 100000
w 512 416 512 512 0
w 464 416 512 416 0
w 368 496 256 496 0
g 256 560 256 608 0 0
R 256 336 256 288 0 0 40 5 0 0 0.5
r 256 496 256 560 0 5000
r 464 416 368 416 0 100000
w 208 192 144 192 0
w 144 192 144 400 0
w 144 400 144 656 0
w 144 656 304 656 0
w 304 656 304 528 0
w 304 528 368 528 0
w 144 400 -48 400 0
w -48 400 -48 416 0
r 592 272 592 336 0 2000
w 432 256 432 320 0
w 592 544 560 544 0
w 560 544 560 336 0
w 560 336 592 336 0
w 560 336 432 336 0
w 432 336 432 320 0
w 368 416 368 496 0
w 208 160 208 80 0
w 208 80 224 80 0
x 48 129 78 132 4 24 R1
```

x 47 200 77 203 4 24 R2
x 252 47 282 50 4 24 R3
x 439 81 469 84 4 24 R4
x 559 96 589 99 4 24 R5
x 620 313 650 316 4 24 R6
x 619 375 649 378 4 24 R7
x 207 456 237 459 4 24 R9
x 199 535 243 538 4 24 R10
x 398 387 428 390 4 24 R8
x 713 422 755 425 4 24 R11
x -233 439 92 442 4 24 Power\sinput\sfrom\sTemp\ssensor
x 450 148 515 151 4 24 D1(G)
x 556 177 621 180 4 24 D2(O)
x 722 500 785 503 4 24 D3(R)
r 256 336 256 400 0 5000
r 256 400 256 496 0 20000
x 195 377 239 380 4 24 R12
o 9 64 0 4099 0.00030517578125 0.00009765625 0 2 9 3
38 0 F1 0 0 5 -1 Voltage