Technical University of Cluj-Napoca
Faculty of Electronics, Telecommunications and Information Technology
2024

Computer Aided Design
Project Documentation

Weight Sensor for a shelf

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Group eng_2023

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1. THE ASSIGNMEMT

Design a system for controlling the weight supported by a shelf dedicated to the storage of metal bars. Knowing that the weight sensor used can measure weight linearly in the range specified in the first column, the system will be designed so that the weight of the shelf is maintained within the range specified in the second column. The linear variation of the electrical resistance of the sensor with weight is specified in the third column and must be converted to a voltage variation in the range [0÷(Vcc-2V)]. The weight of the shelf is maintained in the given range by signaling with the help of an LED, having the color specified in the table.

MEASURABLE WEIGHT RANGE (KG)	THE WEIGHT OF THE SHELF (KG)	SENSOR RESISTANCE (KΩ)	VCC (V)	LED COLOR
10…190	14…180	22…50	14	ORANGE

Table 1

2. PROJECT OVERVIEW

This project involves the design and implementation of an analog weight control system intended for a shelf that supports a specific weight range. The system ensures that the weight on the shelf remains within predefined limits, utilizing a combination of a Wheatstone bridge with a weight sensor, an instrumentation amplifier, and an LED indicator to signal when the weight is out of the acceptable range.

2.1 BLOCK DIAGRAM OF THE CIRCUIT

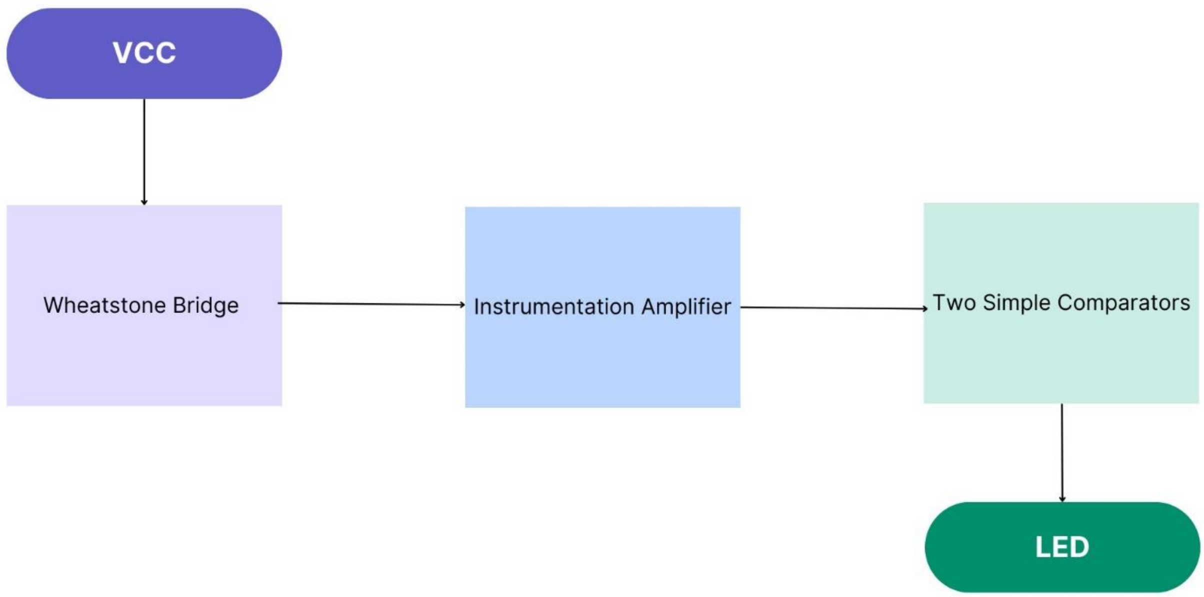
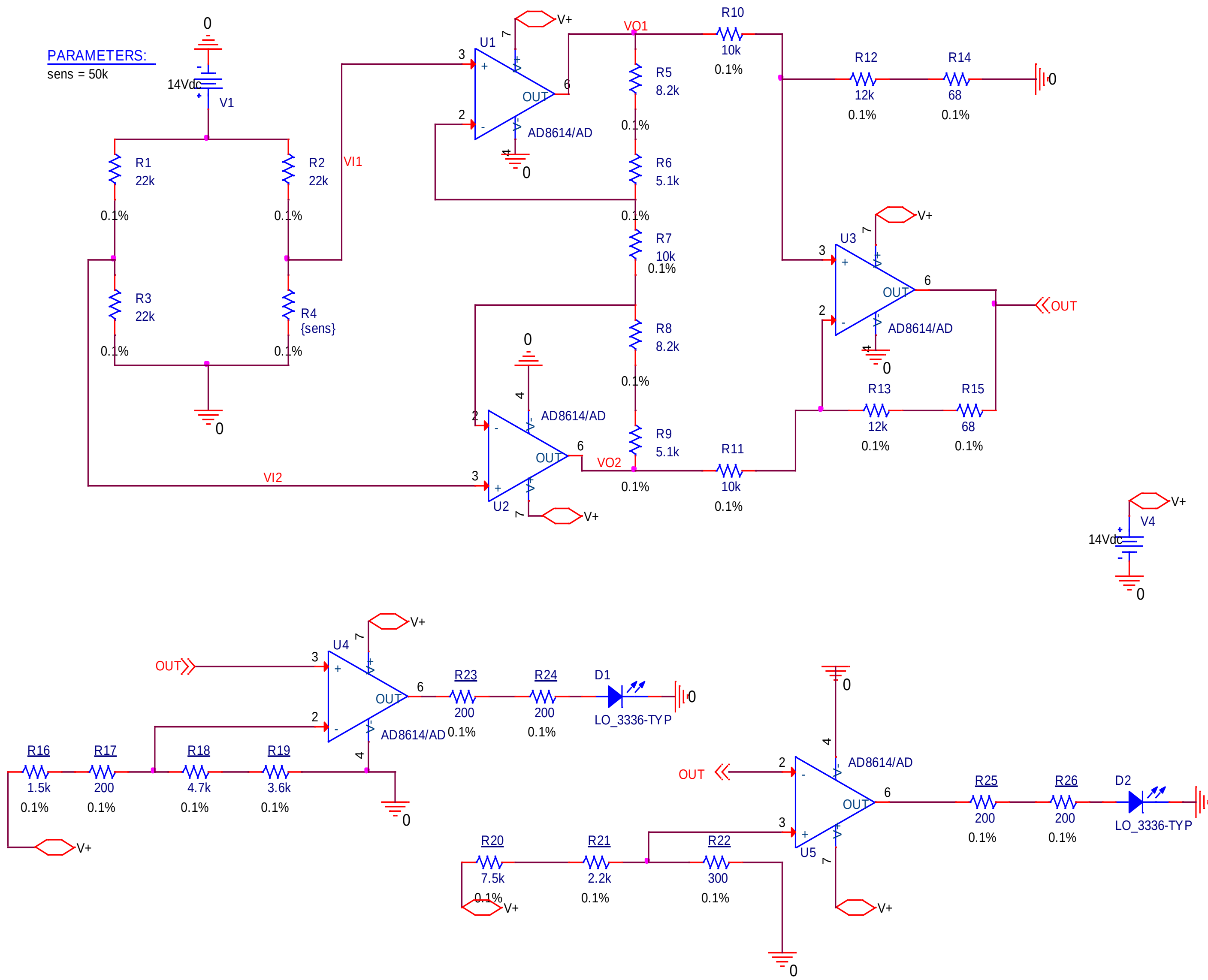


Figure 1

3. THE ELECTRIC SCHEMATIC OF THE CIRCUIT



3.1 THE WHEATSTONE BRIDGE

The Wheatstone Bridge (Figure 2) diamond shaped circuit who's concept was developed by Charles Wheatstone can be used to accurately measure unknown resistance values, or as a means of calibrating measuring instruments, voltmeters, ammeters, by the use of a variable resistance and a simple mathematical formula. The Wheatstone bridge is the basic arrangement of four resistors in making a diamond shape. The bridged voltage source is provided through a voltmeter that is connected between the two opposite points.

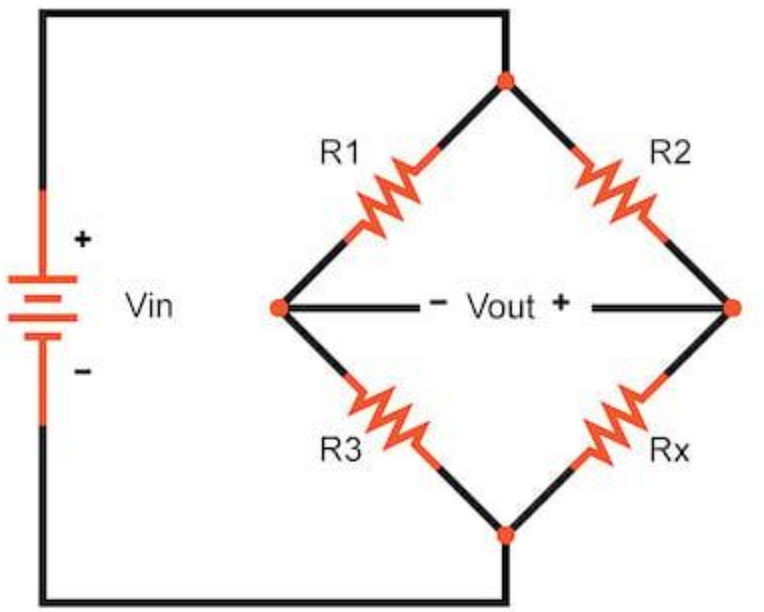


Figure 2

- R1, R2 and R3 are the known resistors.
- Rx (R4) is the unknown resistance – the weight sensor
- V in is the voltage source
- V out is the output voltage (or the voltmeter)

It operates on the principle of null detection, meaning that when the bridge is balanced, no current flows through. This balance condition is achieved when the ratio of the two resistors in one leg is equal to the ratio of the two resistors in the other leg.

$$\frac{R1}{R3} = \frac{R2}{Rx}$$

Equation 1

In this circuit, R4 is a variable resistor that changes its resistance based on the applied weight (it starts with the minimum predefined value of 22kΩ and gradually increases until it reaches the maximum value of 50kΩ). The Wheatstone bridge is initially balanced when there is no weight. This balance condition ensures that the differential voltage across the bridge is a known reference voltage. When weight is applied, R4 changes its resistance, disturbing the balance of the bridge. This creates a differential voltage proportional to the weight.

The small differential voltage generated by the imbalance in the bridge is very low. Hence, an instrumentation amplifier is used to amplify this small signal to a higher level suitable for further processing.

The main purpose of using a Wheatstone bridge is to accurately measure the small changes in resistance due to the applied weight. This method is highly sensitive and provides a precise way to convert physical changes (weight) into an electrical signal.

3.2 THE INSTRUMENTATION AMPLIFIER

An instrumentation amplifier (Figure 3) is a type of differential amplifier that has been suitably optimized for its input impedance to be high, its offset voltage to be low, and its common mode rejection ratio (CMRR) to be high. This means the amplifier effectively rejects noise, ensuring a cleaner output signal. Generally, instrumentation amplifiers amplify small differential signals while at the same time rejecting large common-mode voltages. This makes them ideal for most measurement applications, especially in this assignment of controlling the weight supported by a shelf.

The instrumentation amplifier (IA) consists of three op-amps and several resistors. The standard three-op-amp instrumentation amplifier configuration is designed to amplify the difference between two input voltage signals while rejecting any signals common to both inputs. One of the significant benefits of this method is that it boosts the gain using a single resistor rather than a pair. This avoids a resistor-matching problem and conveniently allows the gain of the circuit to be changed by altering the value of a single resistor.

The operation of this amplifier can be explained as follows:

- Input Stage (Buffering): The first two op-amps (from the left) act as buffers for the input signals, ensuring high input impedance and providing initial amplification.

$$V_{O1} = \left(1 + \frac{R_2}{R_{gain}}\right) * V_{I1} - \frac{R_2}{R_{gain}} * V_{I2}$$

Equation 2

$$V_{O2} = \left(1 + \frac{R_2}{R_{gain}}\right) * V_{I2} - \frac{R_2}{R_{gain}} * V_{I1}$$

Equation 3

- Differential Amplification: The third op-amp amplifies the difference between the outputs of the first two operational amplifiers. The gain of this stage is set by external resistors.

$$V_O = \frac{R_4}{R_3 + R_4} * \left(1 + \frac{R_2}{R_{gain}}\right) * V_{I1} - \frac{R_2}{R_{gain}} * V_{I2}$$

Equation 4

Some key characteristics about the instrumentation amplifier:

- High Input Impedance: Ensures minimal loading on the input signal sources, conserving signal integrity.
- Low Offset Voltage: Minimizes errors in the signal amplification, which is crucial for accurate measurements.
- High CMRR: A high CMRR indicates that the amplifier effectively rejects common-mode signals, which is desirable because it means that it rejects noise and interference.

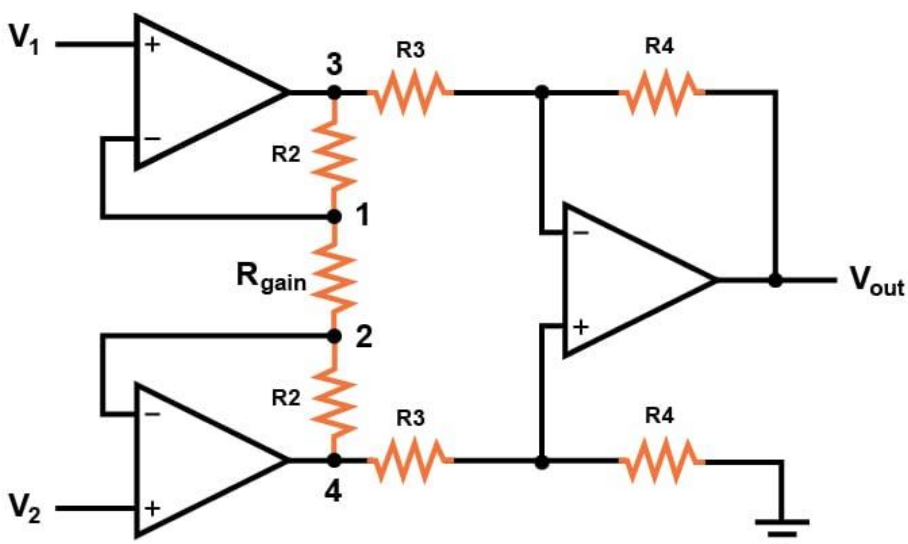


Figure 3 , Instrumentation Amplifier

3.3 THE SIMPLE COMPARATORS

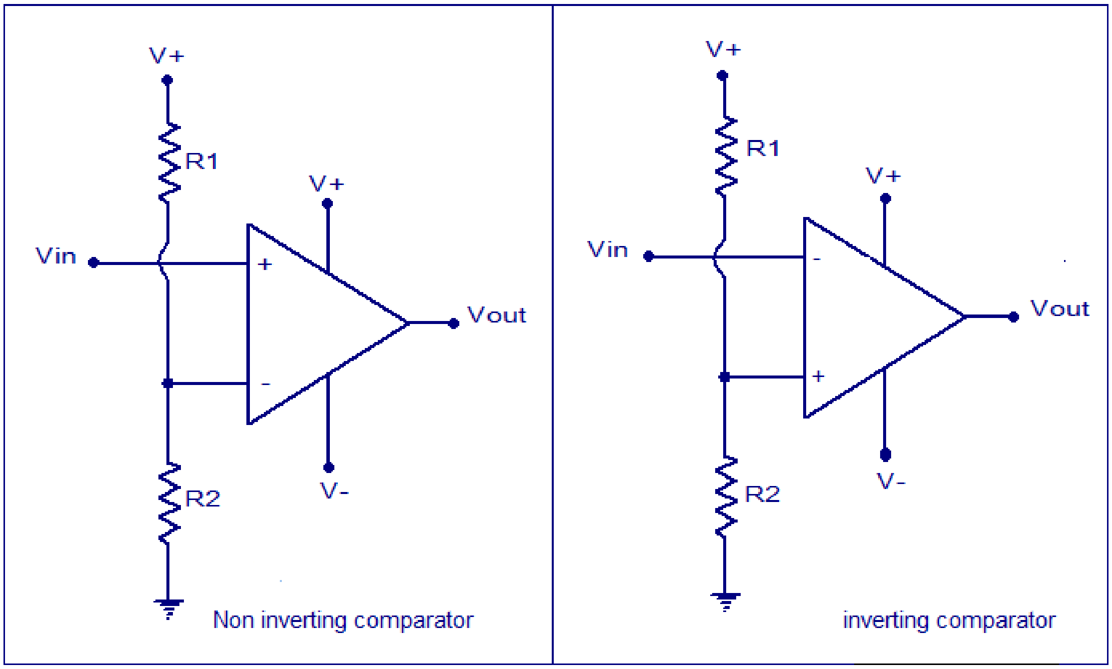


Figure 4

These two simple comparators (Figure 4) are actually an inverting and a non-inverting comparator which are generally used in a circuit for switching between one state to another when a certain threshold is passed.

In a non-inverting comparator, the reference voltage (V_{REF}) is applied to the inverting input (-), and the input voltage is applied to the non-inverting input (+). The output of the comparator depends on the comparison between these two voltages.

In an inverting comparator, the reference voltage is applied to the non-inverting input (+), and the input voltage is applied to the inverting input (-). The output of the comparator is the opposite of the non-inverting configuration.

Both comparators use a reference voltage (threshold voltage) to determine the output state. In a non-inverting comparator, the output switches high when the input voltage exceeds the threshold. In an inverting comparator, the output switches low when the input voltage exceeds the threshold.

$$V_{REF} = \frac{R_2}{R_1 + R_2} * V_{V+}\text{, } where\ V_{REF} = V_{ThL}\text{, for the Inverting Comparator}$$

Equation 5

$$\mathbf{V_{REF} = \frac{R_2}{R_1 + R_2} * V_{V+}\text{, } where\ V_{REF} = V_{ThH}\text{, for the Non} - \text{Inverting Comparator}}$$

Equation 6

4. SIZING THE CIRCUIT

4.1 THE WEIGHT SENSOR AND THE WHEATSTONE BRIDGE

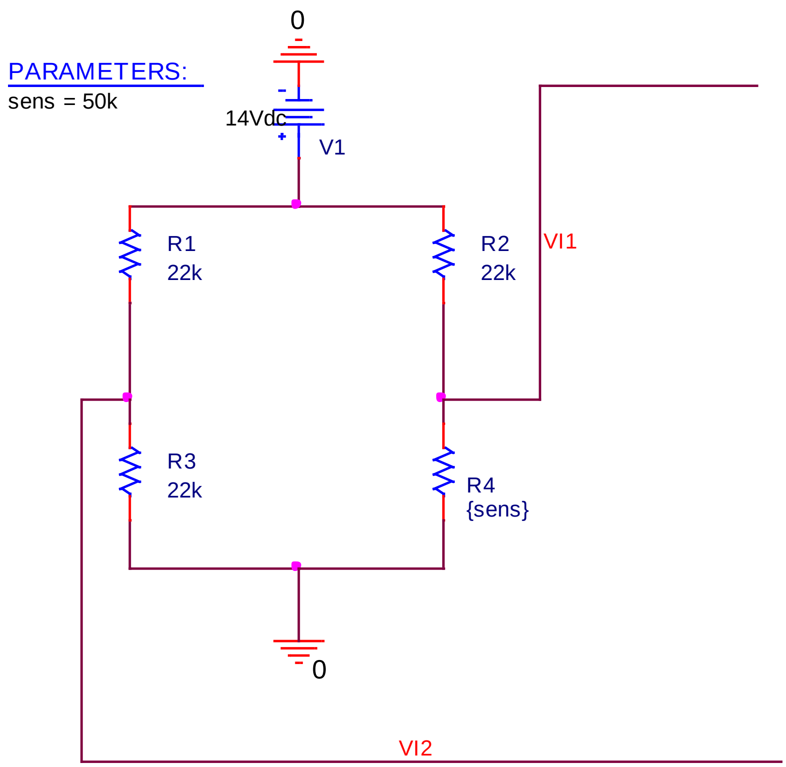


Figure 5

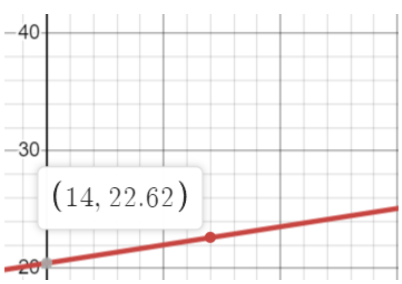
Firstly, I needed to find a relation between weight and resistance. This is very important for finding the Upper and Lower threshold of the comparators used later in this circuit. Knowing two values from the Measurable Weight range and two values from the Sensor Resistance, I was able to connect them on a graph and get a simple mathematical equation describing the line (Equation 7):

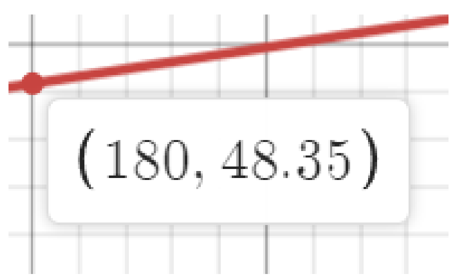
$$R(G) = m * G + x$$

Equation 7

R(G) – the sensor resistance (kΩ**);** m – Measurable Weight Range**;** G – Weight of the Shelf

x – the slope of the equation





Next, I took the minimum and maximum sensor resistance values and the known weight of the shelf and made a system of equations of 2 unknowns to find m and x:

$$\begin{cases} \mathbf{22} = \boldsymbol{m} * \mathbf{10} + \boldsymbol{x} \\ \mathbf{50} = \boldsymbol{m} * \mathbf{190} + \boldsymbol{x} \end{cases} \Rightarrow \mathbf{28} = \mathbf{180} * \boldsymbol{m} \Rightarrow \mathbf{m} = \mathbf{0.155}$$

$$\Rightarrow \mathbf{22} = \mathbf{1.55} + \boldsymbol{x} \Rightarrow \mathbf{x} = \mathbf{20.45}$$

Now, Equation 7 becomes: $\Rightarrow \boldsymbol{R(G)} = \mathbf{0.155} * \boldsymbol{G} + \mathbf{20.45}$

After computing these values, I can find the lowest ($\boldsymbol{R_L}$) and highest ($\boldsymbol{R_H}$) sensor resistance values corresponding to the VTH L and VTH H for both comparators.

For M = 14 $\Rightarrow \boldsymbol{R_L} = \mathbf{0.155} * \mathbf{14} + \mathbf{20.45} \Rightarrow \boldsymbol{R_L} = \mathbf{22.62\ k\Omega}$

Equation 8

For M = 180 $\Rightarrow \boldsymbol{R_H} = \mathbf{0.155} * \mathbf{180} + \mathbf{20.45} \Rightarrow \boldsymbol{R_H} = \mathbf{48.44\ k\Omega}$

Equation 9

Also, when the bridge (Figure 5) is balanced, the sensor resistance R4 is at the minimum predefined value of 22 kΩ. In this state, the voltage difference between the two midpoints of the bridge is zero, meaning there is no differential voltage V_D to be amplified. The voltage across the bridge can be calculated using **the voltage divider formula**:

$$V_{I1} = V1 * \frac{R_4}{R_4 + R_2} = 14\,V * \frac{22k\Omega}{22k\Omega + 22k\Omega} = 7\,V$$

Equation 10

$$V_{I2} = V1 * \frac{R_3}{R_3 + R_1} = 14\,V * \frac{22k\Omega}{22k\Omega + 22k\Omega} = 7\,V$$

Equation 11

$$\Rightarrow \boldsymbol{where\ V_{I1}\ and\ V_{I2}\ are\ the\ inputs\ of\ the\ IA}$$

As the R4 increases from 22 kΩ to 50 kΩ, the bridge becomes unstable, and the differential voltage is no longer zero. For R4 equal to 50 kΩ, V_{I1} (Equation 10) becomes:

$\Rightarrow V_{I1} = 14\,V * \frac{50k\Omega}{50k\Omega + 22k\Omega} = 14 * \frac{50k\Omega}{72k\Omega} = 9.72\,V \Rightarrow$ $\boldsymbol{V_D}$ **varies linearly with the resistance R4**

This Voltage difference between the two voltages is forward sent to the IA.

4.2 RESISTOR VALUES FOR THE INSTRUMENTATION AMPLIFIER

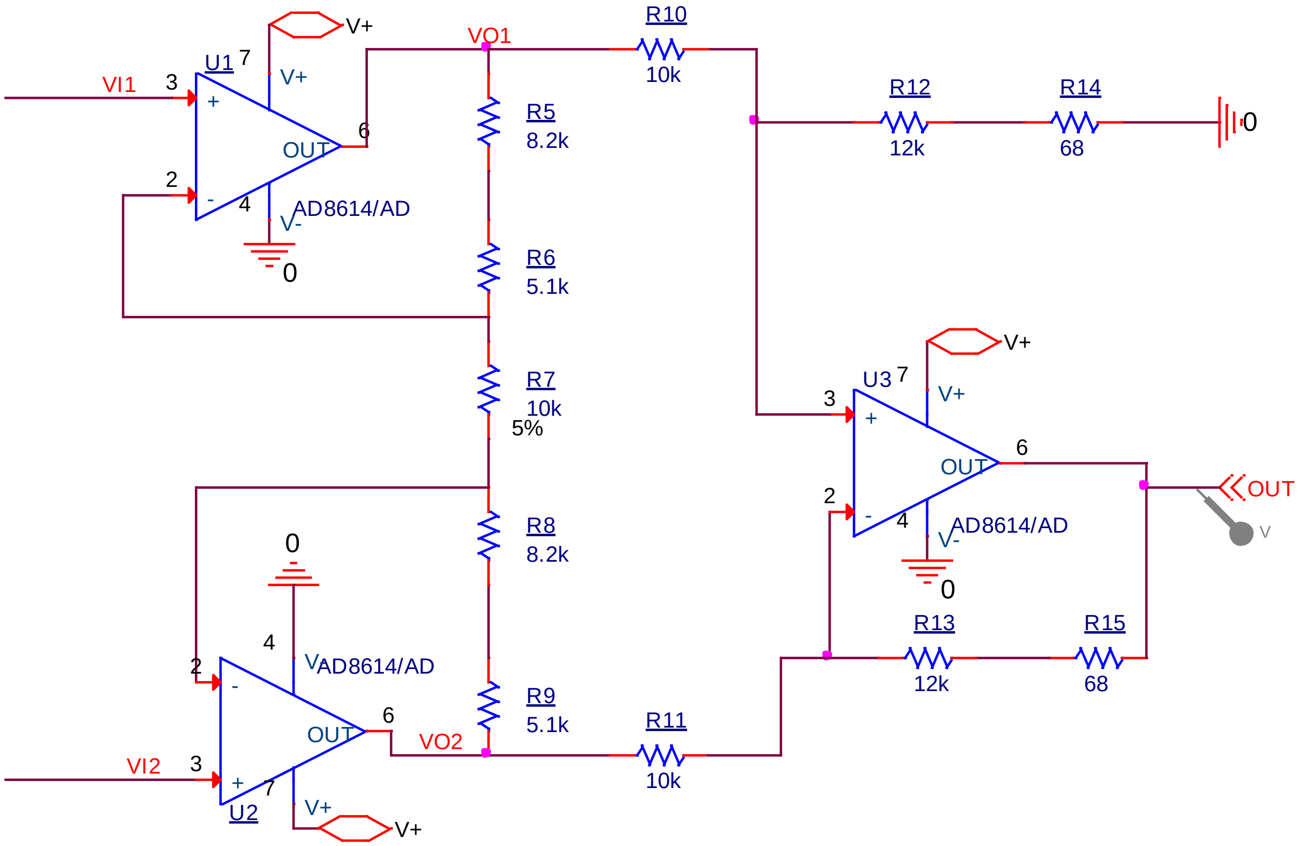


Figure 6

For the Instrumentation Amplifier (Figure 6), I had to size the resistors. The first 2 leftmost operational amplifiers (U1 and U2) which serve as buffers and who will set the high input resistance as well as the gain. The third op amp (U3) will make a conversion from the two voltages coming from the previous op amps to a single voltage and will provide additional rejection of the common mode.

Using Equation 2, when the weight sensor is at the highest point (R4 = 50 kΩ) we know the following values: $V_{I1} = 9.72\ V$ (Equation 10), $V_{I2} = 7\ V$ (Equation 11), $V_{O1} = 13.35\ V$ (from multiple trials and errors, I found the right value for the output voltage V_{O1} so that the output signal is linear and not saturated).

$$V_{O1} = \left(1 + \frac{R_2}{R_{gain}}\right) * V_{I1} - \frac{R_2}{R_{gain}} * V_{I2} \Rightarrow 13.35\ V = 9.72V + \frac{R_2 * 9.72V}{R_{gain}} - \frac{R_2}{R_{gain}} * 7V$$

$$\Rightarrow 3.62 = \frac{2.72 * R_2}{R_{gain}} \Rightarrow \frac{\boldsymbol{R_2}}{\boldsymbol{R_{gain}}} = \mathbf{1.33}$$

So, following this ratio, I picked $\boldsymbol{R_{gain}} = \mathbf{10\ k\Omega}$ **and** $\boldsymbol{R_2} = \mathbf{13.3\ k\Omega}$.

With the first set of resistors figured out, I moved on the size the resistor network around U3, which is a standard differential amplifier. Our goal is to amplify $V_{I1} - V_{I2}$, so I used the following formula:

$$V_{OUT} = \frac{R_4}{R_3} * (V_{I1} - V_{I2}) \Rightarrow 12{,}05 = \frac{R_4}{R_3}(13.35 - 3.37) \Rightarrow \frac{R_4}{R_3} = 1.207$$

Furthermore, following this ratio, I picked $\boldsymbol{R_4 = 12.07\ \mathrm{k\Omega}}$ **and** $\boldsymbol{R_3 = 10\ \mathrm{k\Omega}}$.

In designing the instrumentation amplifier circuit, I initially used precise resistor values calculated to achieve the desired gain and performance. However, in practical applications, it is necessary to use standardized resistor values available in on the market. I used the E24 resistor series and my new resistances (as shown in Figure 6) became:

$$R_{gain} = 10\ \mathrm{k\Omega} \Rightarrow R_7 = 10\ \mathrm{k\Omega}\ ;\ R_2 = 13.3\ \mathrm{k\Omega} \Rightarrow R_{6,9} + R_{5,8} = 5{,}1\ \mathrm{k\Omega} + 8{,}2\ \mathrm{k\Omega}$$

$$R_3 = 10\ \mathrm{k\Omega} \Rightarrow R_{10,11} = 10\ \mathrm{k\Omega}\ ;\ R_4 = 12.07\ \mathrm{k\Omega} \Rightarrow R_{12,13} + R_{14,15} = 12\ \mathrm{k\Omega} + 68\ \Omega$$

4.3 RESISTOR VALUES FOR THE COMPARATORS

Using the resistances found at Equation 8 and Equation 9, where I found the relation between kΩ and weight for my circuit, I did a bias point analysis with each R_L and R_H instead of the R4 weight sensor in the Wheatstone bridge and found out that: $V_{ThL} = 437\ mV$ and $V_{ThH} = 11.63\ V$. These values indicate the voltages at which the LED should activate, signaling that the weight on the shelf is either greater or smaller than the specified limit.

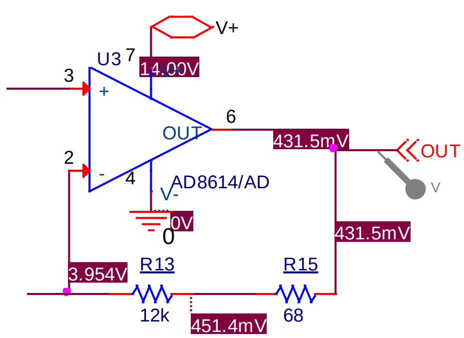


Figure 8, V_{ThL}

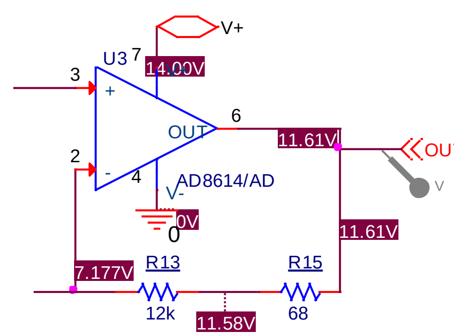


Figure 7, V_{ThH}

Next, I took the thresholds that I just computed and used **Equation 5** and **Equation 6** in order to find out the two resistors, R1 and R2 first for the Inverting Comparator:

$$V_{REF} = \frac{R_2}{R_1 + R_2} * V_{V+}\text{ , where } V_{REF} = V_{ThL} \Rightarrow 0.437\ mV = \frac{R_2}{R_1 + R_2} * 14$$

$$\Rightarrow \frac{R_2}{R_1 + R_2} = 0.03$$

As a result of these calculations, I sized the resistors accordingly: $R_2 = 300\ \Omega$, $R_1 = 9.7\ \mathrm{k}\Omega$

Now, we find the values of the resistances for the Non-Inverting Comparator:

$$V_{REF} = \frac{R_2}{R_1 + R_2} * V_{V+}\text{ , where } V_{REF} = V_{ThH} \Rightarrow 11.63\ V = \frac{R_2}{R_1 + R_2} * 14$$

$$\Rightarrow \frac{R_2}{R_1 + R_2} = 0.83$$

The resistors where sized according to the result obtained above: $R_2 = 8.3\ k\Omega$, $R_1 = 1.7\ \mathrm{k}\Omega$

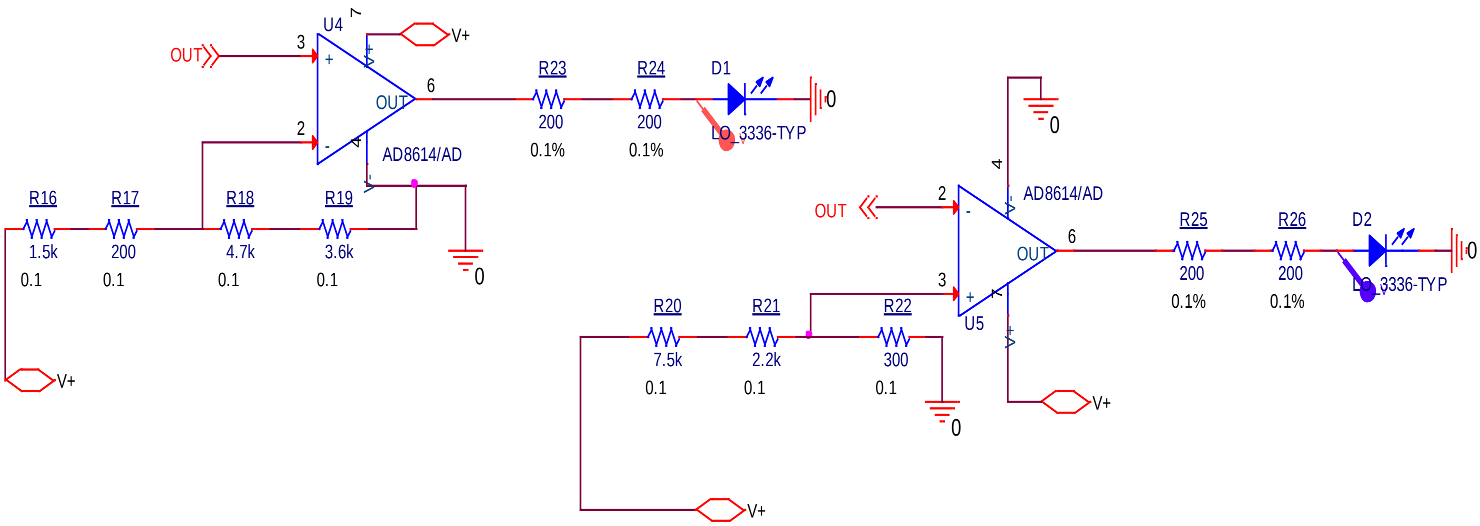


Figure 9, The Comparators

$$R_1 = 9.7\ k\Omega \Rightarrow R_{20} + R_{21} ;\ R_2 = 300\ \Omega \Rightarrow R_{22} \Rightarrow \text{for the Inverting Comparator}$$

$$R_1 = 1.7\ k\Omega \Rightarrow R_{16} + R_{17} ;\ R_2 = 8.3\ k\Omega \Rightarrow R_{18} + R_{19} \Rightarrow \text{for the Non} - \text{Inverting Comparator}$$

4.4 LED AND THE OPERATIONAL AMPLIFIER

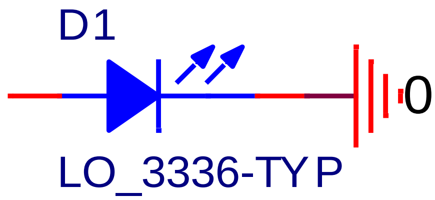


Figure 11

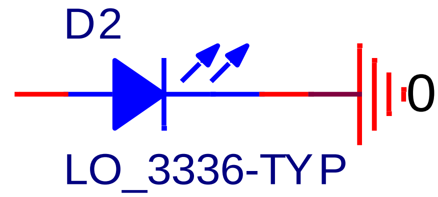


Figure 10

In the design of the comparators circuit, two orange LEDs (Figure 10, Figure 11) were required in order to provide visual indication when both of the comparator outputs are active, meaning the weight applied on the shelf has surpassed the predefined thresholds specified in the assignment. To meet this requirement, I chose the LO 3336-TYP orange LED from the PSpice model library. This LED was selected based on its color specification, ensuring it met the design criteria for visual signaling.

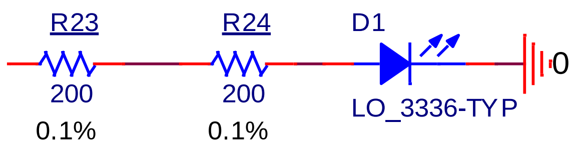
LS 3336, LO 3336, LY 3336

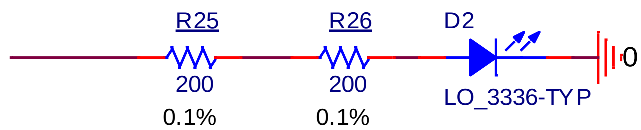
Grenzwerte
Maximum Ratings

Bezeichnung **Parameter**		**Symbol** **Symbol**	**Werte** **Values**			**Einheit** **Unit**
			LO, LS		**LY**	
Betriebstemperatur Operating temperature range		T_{op}	– 55 … + 100			°C
Lagertemperatur Storage temperature range		T_{stg}	– 55 … + 100			°C
Sperrschichttemperatur Junction temperature		T_j	+ 100			°C
Durchlassstrom Forward current (T_A=25°C)		I_F	30			mA
Durchlassspannung[7) Seite 12]	(min.)	V_F	1.8	1.85	1.9	V
Forward voltage[7) page 12]	(typ.)	V_F	2.0	2.0	2.0	V
I_F = 20 mA	(max.)	V_F	2.3	2.35	2.4	V

Figure 12 , The LED data sheet

The resistors R23, R24 and R25, R26 in series with the LEDs serve to limit the current flowing through the LEDs, preventing them from burning out and ensuring operation within the specified range. For sizing the resistances, I used Kirchhoff's voltage law in a closed loop, where we know that $V_{IN} \cong 14\ V$ and $V_D = 2V$ (from data sheet):





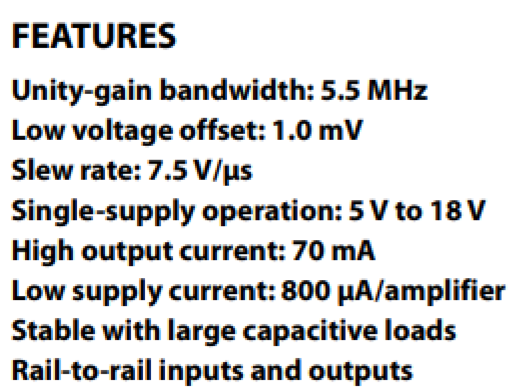
$$\begin{cases} \mathbf{V_{IN} = V_R + V_D} \\ \mathbf{V_D = 2V} \end{cases}$$

$$\Rightarrow \begin{cases} \mathbf{V_R = 12V} \\ \mathbf{I * R = 12V} \end{cases}$$

$$\Rightarrow \begin{cases} \mathbf{I = 30\ mA} \\ \mathbf{R = \frac{12}{30}\ k\Omega} \end{cases} \Rightarrow \mathbf{R_{23} + R_{24} = 400\ \Omega} \Rightarrow \mathbf{R_{25} + R_{26} = 400\ \Omega}$$

When choosing the operational amplifier for a specific condition, it is essential that it aligns with the requirements of the circuit. Here are some key features of why I decided to use the **AD8614/AD** in my circuit:

- **Low Offset Voltage**: This Op-Amp features a low input offset voltage(1mV), vital for precision applications, perfect for this instrumentation amplifier and comparator circuit, where any offset can lead to errors in measurement.
- **Single-supply operation**: The project specifies a single supply voltage (V cc=14V), so there is no need of using an Op-Amp with dual supplies. Also, it operates from supplies of 5 V to as high as 18 V.
- **Rail-to-rail inputs and outputs**: The AD8614 offers rail-to-rail input and output capabilities, which is very helpful in single supply applications. This feature allows the op-amp to utilize the entire voltage range from 0V (ground) to the supply voltage ($V_{CC} - 2$), maximizing the dynamic range and improving signal processing performance.


FEATURES

Unity-gain bandwidth: 5.5 MHz
Low voltage offset: 1.0 mV
Slew rate: 7.5 V/µs
Single-supply operation: 5 V to 18 V
High output current: 70 mA
Low supply current: 800 µA/amplifier
Stable with large capacitive loads
Rail-to-rail inputs and outputs

Figure 13, The AD8614 features

5. THE ANALYSIS

5.1 DC SWEEP

The primary goal of the DC sweep is to ensure that the output voltage (V OUT) varies linearly with the changes in the sensor resistance (sens). I started with $R4 = 22\ \mathrm{k\Omega}$ to the maximum value of the resistance $R4 = 50\ \mathrm{k\Omega}$, with the step size of 100. From the simulation (Figure 15), we can clearly see that the voltage V OUT varies linearly from $[0V,\ VCC - 2] \Rightarrow [0V,\ 12V]$.

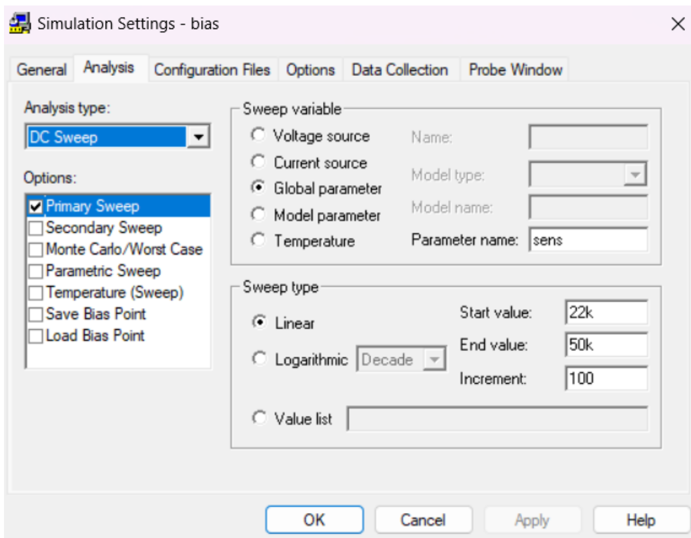


Figure 14, The simulation settings

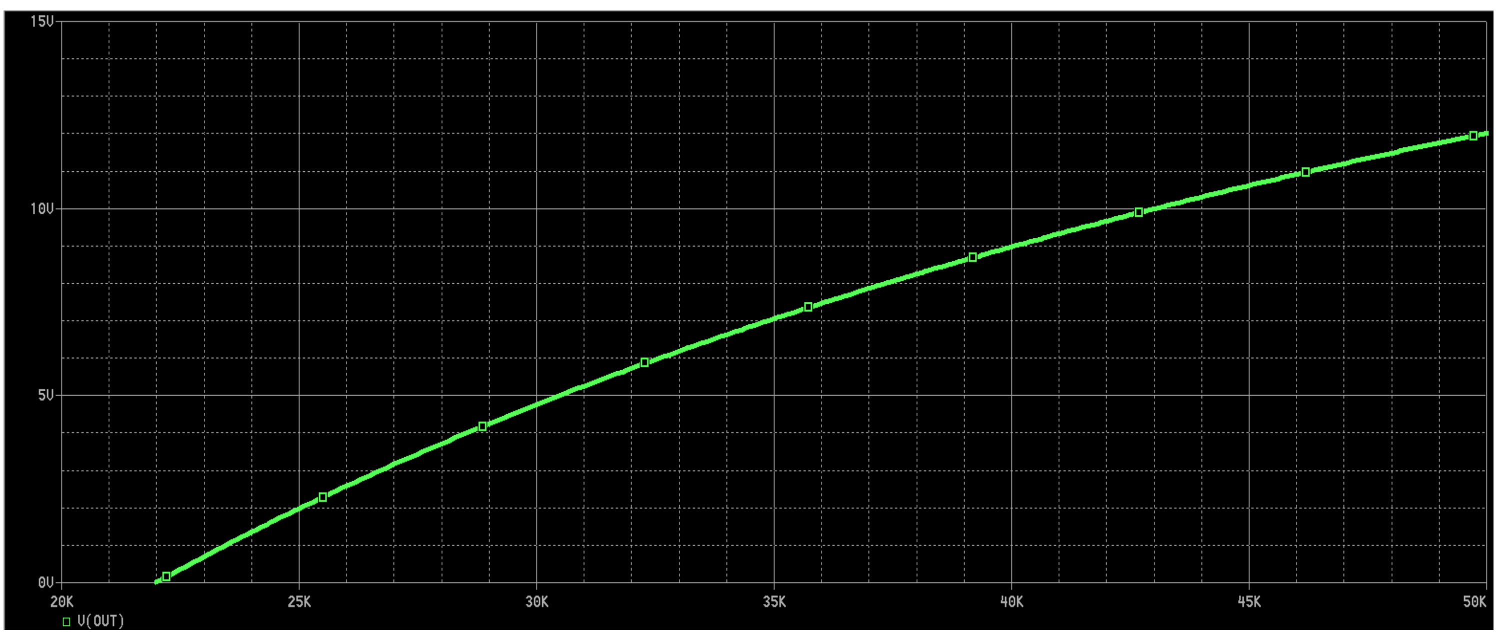


Figure 15

In the following simulation (Figure 15), we can observe a slight curvature of the output voltage that can be attributed to the Wheatstone Bridge. This is due to the fact that the variation of the resistance is very high. In a standard Wheatstone Bridge, to have a linear variation of the parameter, there are used smaller variations of the resistance and the curvature of the output voltage is closer to zero.

Therefore, the behavior of the output voltage from the instrumentation amplifier aligns with the expectations due to the reasons mentioned above.

Next, I used the Dc Sweep in order to spot the two thresholds, in order to see the low and high threshold where the LEDs turn on. By using the same simulation settings from Figure 14 and a voltage marker at the anode of the diodes, the VTH H and VTH L will be:

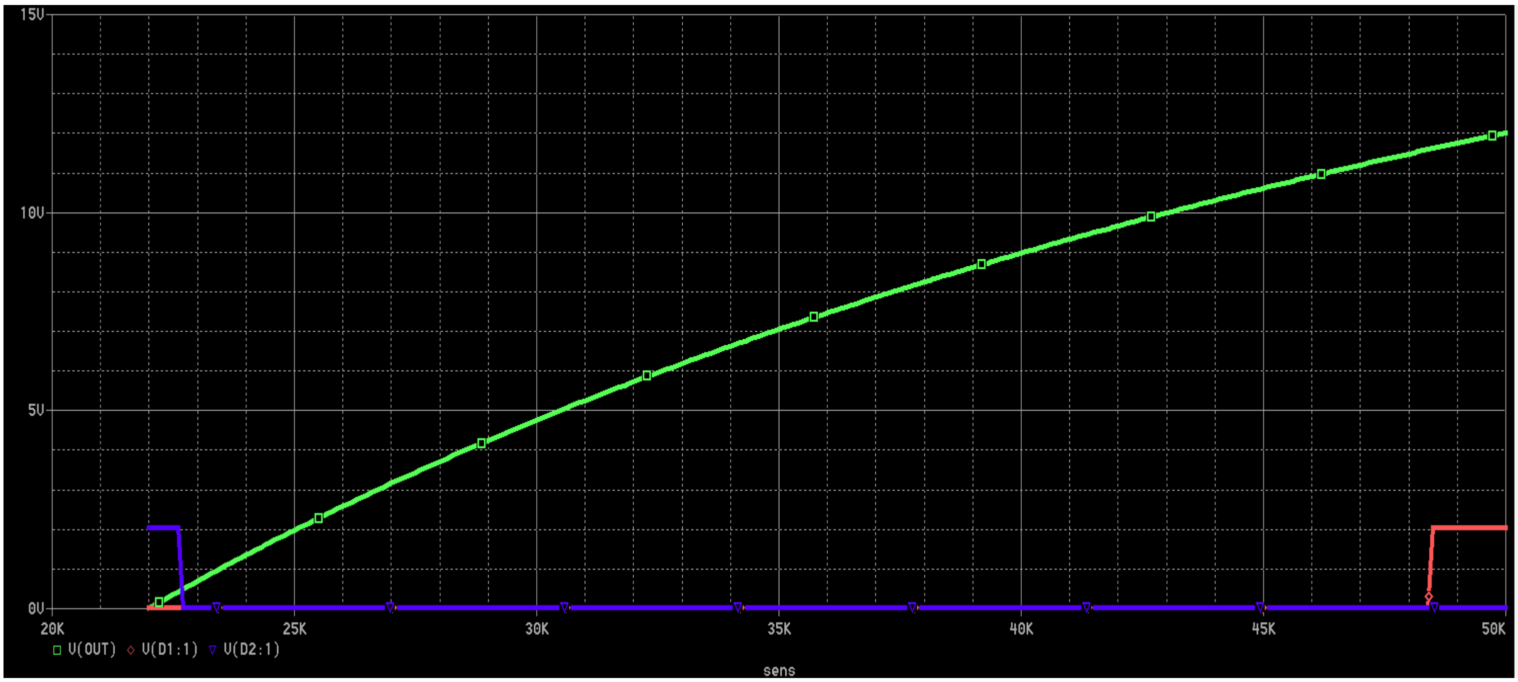


Figure 16

Trace Color	Trace Name	Y1
	X Values	22.618K
CURSOR 1,2	V(OUT)	430.306m
	V(D1:1)	17.982m
	V(D2:1)	1.6865

Figure 17

Trace Color	Trace Name	Y1
	X Values	48.412K
CURSOR 1,2	V(OUT)	11.597
	V(D1:1)	255.537m
	V(D2:1)	17.982m

Figure 18

We can clearly see from Figure 16 and from the two cursors (Figure 17, Figure 18) that the upper threshold is almost the exact same value calculated at Equation 9 and Equation 8, confirming the correct functionality of the LEDs.

Figure 19 shows that the LEDs don't exceed the 30mA maximum current, further clarifying that the LEDs works as expected in the desired range.

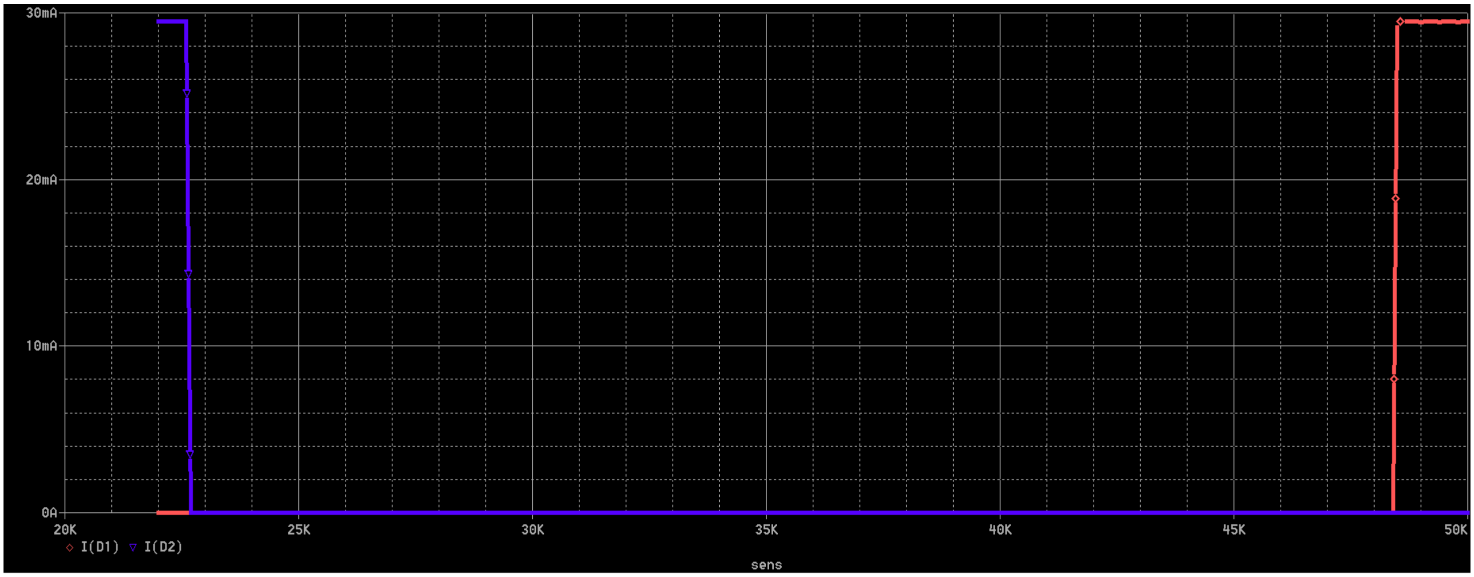


Figure 19

5.2 WORST CASE ANALYSIS

Worst-case analysis is used to find the worst probable output of a circuit or system given the restricted variance of its parameters. This analysis, involves multiple runs, varying one parameter at a time.

It begins with a sensitivity analysis on each component with assigned tolerances. Each component is adjusted towards its tolerance limits by a small percentage to figure out which impacts the worst case output the most. Once sensitivities are known, all parameters are varied to find the worst case. The Figure 20 will provide us with information regarding which of the components are most sensitive to the correct functioning of the circuit:

WORST CASE ALL DEVICES

****

Device	MODEL	PARAMETER	NEW VALUE	
R_R14	R_R14	R	1.001	(Increased)
R_R8	R_R8	R	1.001	(Increased)
R_R15	R_R15	R	1.001	(Increased)
R_R6	R_R6	R	1.001	(Increased)
R_R23	R_R23	R	1	(Unchanged)
R_R11	R_R11	R	.999	(Decreased)
R_R9	R_R9	R	1.001	(Increased)
R_R7	R_R7	R	.999	(Decreased)
R_R2	R_R2	R	.999	(Decreased)
R_R24	R_R24	R	1.001	(Increased)
R_R3	R_R3	R	.999	(Decreased)
R_R4	R_R4	R	1.001	(Increased)
R_R12	R_R12	R	1.001	(Increased)
R_R1	R_R1	R	1.001	(Increased)
R_R5	R_R5	R	1.001	(Increased)
R_R10	R_R10	R	.999	(Decreased)
R_R13	R_R13	R	1.001	(Increased)
R_R26	R_R26	R	.999	(Decreased)
R_R25	R_R25	R	.999	(Decreased)
R_R16	R_R16	R	1.001	(Increased)
R_R17	R_R17	R	.999	(Decreased)
R_R18	R_R18	R	1.001	(Increased)
R_R19	R_R19	R	1.001	(Increased)
R_R20	R_R20	R	1.001	(Increased)
R_R21	R_R21	R	1.001	(Increased)
R_R22	R_R22	R	.999	(Decreased)

Figure 20

The following simulations (Figure 21, Figure 22) shows us that with the chosen resistance tolerance values of ±0.1, the circuit output voltage will be stable and maintain its properties.

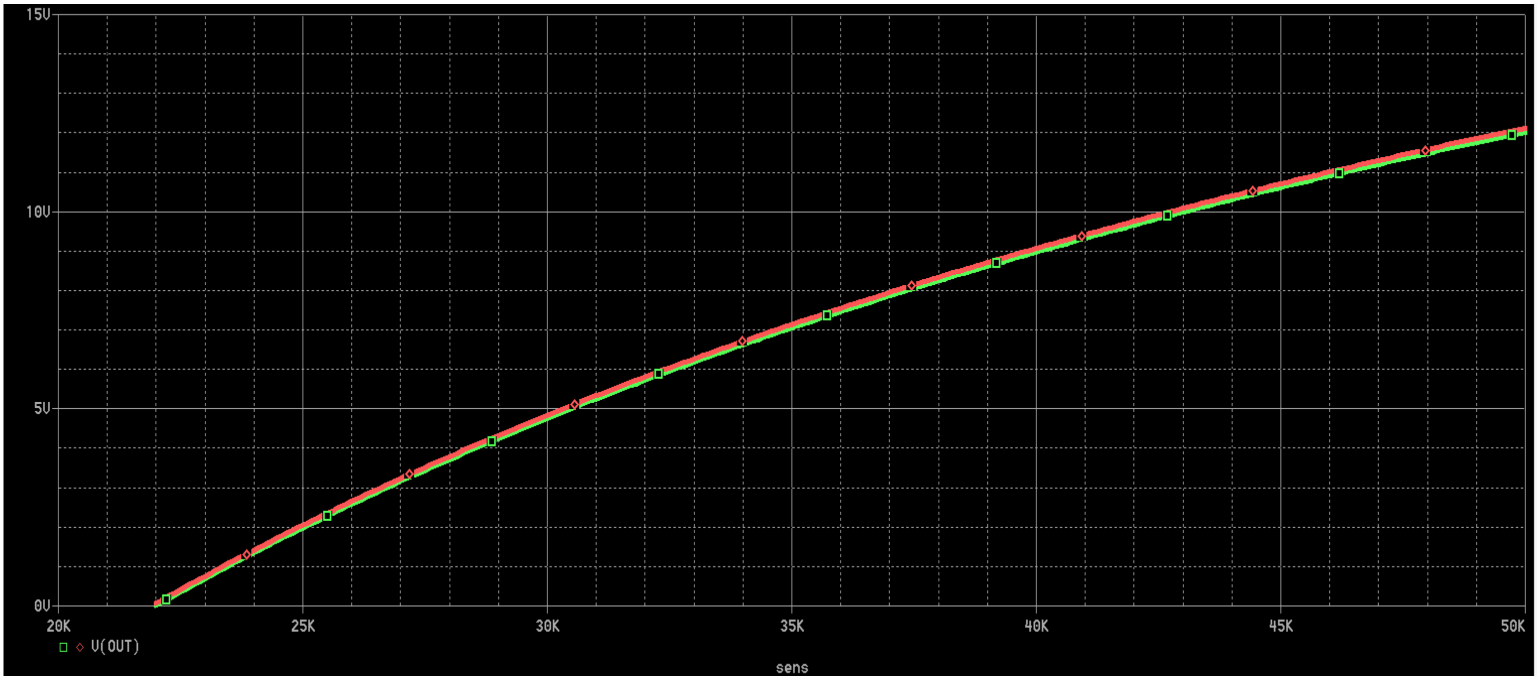


Figure 22

Figure 21

5.3 MONTE CARLO ANALYSIS

Monte-Carlo analysis is an effective statistical method to evaluate circuit behavior under varying component values. It statistically determines circuit performance when component values alter within their tolerance ranges, each time using a different set of random values from the probability functions.

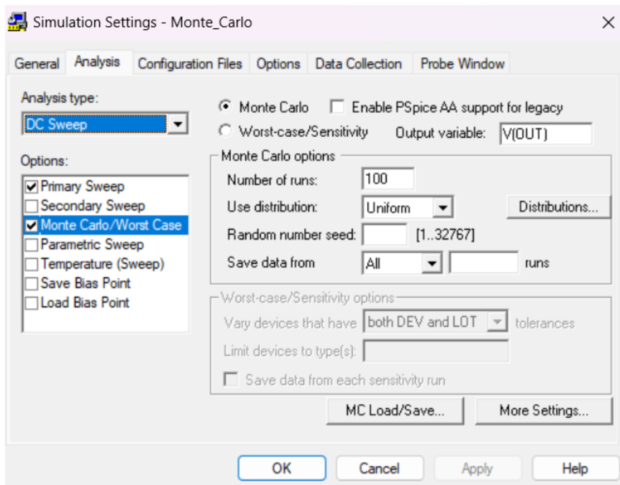


Figure 23, The Monte Carlo settings

In Figure 24 we can see how the output varies as a result of the tolerances in the components:

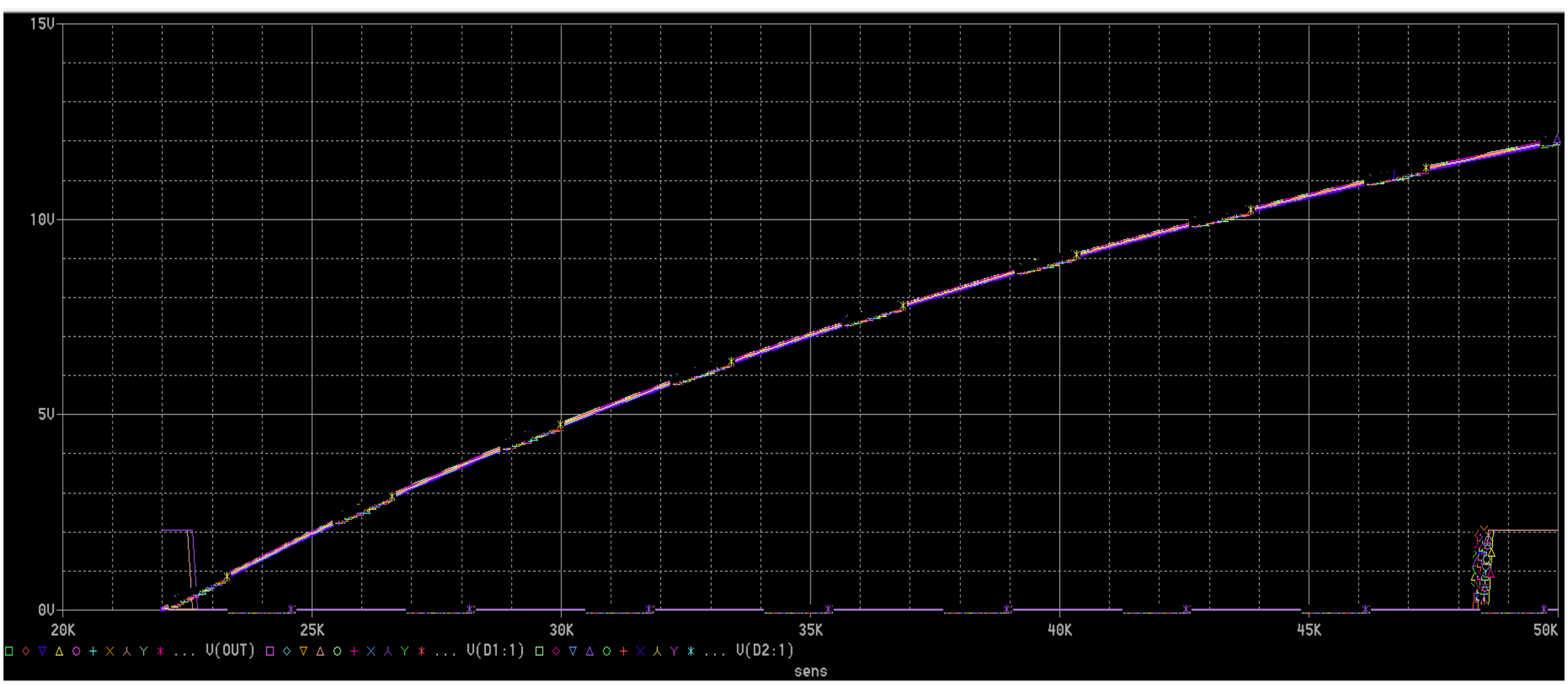


Figure 24

6. BILL OF MATERIALS (BOM)

NR	QUANTITY	REFERENCE	PART	DESCRIPTION
1	4	R	AR03BTCX2202	SMD; 0603; 22kΩ; 0,1W; ±0,1%
2	3	R	AR1206	0.1% REZISTOR SMD 1206 10KOHMI 0.1%
3	2	R	AR03BTCX1202	Resistor SMD; 0603; 12kΩ; 0.1W; ±0.1%;
4	2	R	TC0325B8201T1E	REZISTOR SMD 0603 8.2K 0.1%
5	2	R	TNPW04025K10BYEP	Thin Film Resistors 5.1Kohms 0.1% AEC-Q200
6	2	R	ERJ-H2RD68R0X	Thick Film Resistors 0402 68Ohm 0.5%
7	2	R	RA73F2A200RBTDF	Thin Film Resistors - SMD RA73F 2A 200R 0.1%
8	1	R	TNPW02012K00BEED	Thin Film Resistors - SMD 2Kohms .1%
9	2	R	MCS0402MD3301BE000	Thin Film Resistors - SMD MCS 0402-25 0.1% AT E0 3K3
10	1	R	ERJ-1GJF2201C	Thick Film Resistors 0201 0.05W 1% 2.2KOhm AEC-Q200
11	1	R	TNPW06032K40BEEA	Thin Film Resistors 2.4Kohms .1% 25ppm
12	1	R	TNPW02014K70BEED	Thin Film Resistors 4.7Kohms .1% 25ppm
13	5	OP-AMP	AD8614ARTZ-REEL7	Precision Amplifiers SINGLE 18V LCD DRIVER

Table 2

Total price of this circuit: 29.13 €

7. CONCLUSION

This project involved designing a weight control system for a shelf. The primary components of the system included a Wheatstone bridge, an instrumentation amplifier, and two simple comparators.

The design began with the Wheatstone bridge, which converted the resistance variations from the weight sensor into a corresponding voltage signal. Precision resistors were used to balance the bridge, ensuring accurate voltage output that reflected changes in weight.

An instrumentation amplifier was used to amplify the small differential voltage from the Wheatstone bridge. The AD8614 op-amp was selected for its low offset voltage, high input impedance and a high CMMR. This choice ensured that the small variations in the sensor resistance were translated into a significant voltage range suitable for further processing.

To achieve stable output switching when the certain predefined resistance values are crossed, two simple comparators were used, one Non-Inverting and one Inverting.

An orange LED indicator was added to provide a clear visual signal of the weight status. A current-limiting resistor was calculated to ensure the LED operated within safe current limits, enhancing the system's reliability.

Simulation results confirmed the accuracy of the design calculations, demonstrating the circuits functionality and ensuring that the system met all specified design requirements.

8. BIBLIOGRAPHY

- For calculations and formulas: http://193.226.6.189/dce/didactic/ed/ Electronic Devices, Assistant Professor Laura-Nicoleta IVANCIU, PhD

- For understanding the concept of this circuit:

    1. Wheatstone Bridge

https://www.electronics-tutorials.ws/blog/wheatstone-bridge.html

https://forum.digikey.com/t/analog-bits-wheatstone-bridge-input-and-output-resistance/13342

https://www.allaboutcircuits.com/tools/wheatstone-bridge-calculator/

    2. Instrumentation Amplifier

https://www.allaboutcircuits.com/textbook/semiconductors/chpt-8/the-instrumentation-amplifier/

https://www.elprocus.com/what-is-an-instrumentation-amplifier-circuit-diagram-advantages-and-applications/

    3. The Comparators

https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html

http://193.226.6.189/dce/didactic/ed/C6.%20Simple%20comparators%20with%20OpAmp..pdf

    4. The LED:

https://www.pspice.com/amplifiers-and-linear-ics/operational-amplifiers/cmos

- For the standardization of the circuit: https://jansson.us/resistors.html

- For the components: https://ro.mouser.com/c/passive-components/resistors/

- Data sheets:

https://www.mouser.com/datasheet/2/588/Osram_04302021_LO3336-2891540.pdf

https://ro.mouser.com/datasheet/2/609/AD8614_8644-3120126.pdf