Technical University of Cluj-Napoca
Faculty of Electronics, Telecommunications and Information Technology
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Computer Aided Design
Weight Sensor for a shelf

TECHNICAL UNIVERSITY
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2. The Assigment

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 table column E, the system will be designed so that the weight of the shelf is maintained within the range specified in column F. The linear variation of the electrical resistance of the sensor with weight is specified in column G 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 Colour
2 ... 180	80 ... 160	4 - 20	12	Yellow

3. Electrical Circuit Diagram

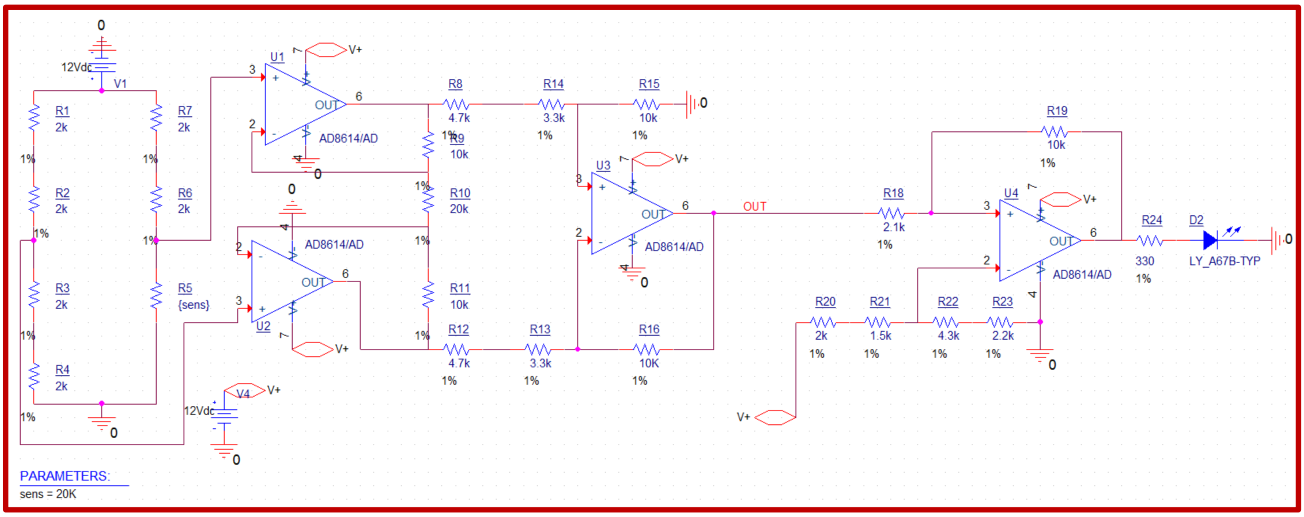


Figure 1

4. Project Overview

This project will involve designing a control system meant to keep the weight of a shelf within a specified range. The sensor used has a linear variation in resistance with weight; the Wheatstone bridge converts this resistance change to a voltage signal. An instrumentation amplifier further processes this signal. This signal shall then be monitored to ensure that it remains within the desired weight range. To indicate the status of the weight, the LED indicator lights up if the weight of the shelf is out of the minimum or maximum range, otherwise, the LED indicator is off.

4.1 Circuit Block Diagram

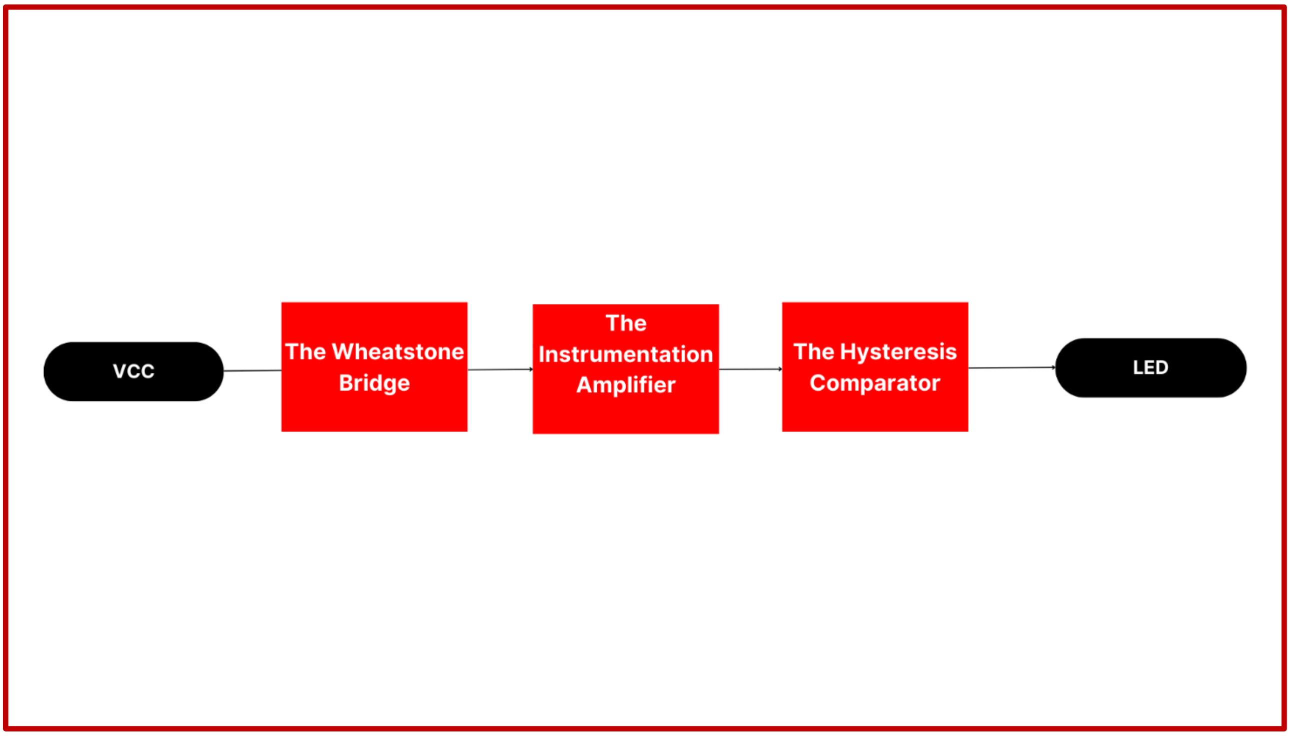


Figure 2

4.2 The Wheatstone Bridge

The Wheatstone Bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two branches of a bridge circuit. The primary components include:

1. **Four Resistors:** Two known resistors (R_1 and R_2), one variable resistor (R_3), and one unknown resistor (Rx).
2. **Voltage Source:** Provides the necessary current through the circuit.
3. **Galvanometer:** Detects the null or zero current condition, indicating balance in the bridge.

Principle of Operation:

The main principle behind the Wheatstone Bridge (Figure 3) is the concept of the voltage balance:

1. **Voltage Division:** Voltage is divided between the two branches based on the resistance values.
2. **Balanced Condition:** When the bridge is balanced, the voltage across the galvanometer is zero, meaning no current flows through it.

Balanced Condition:

In a Wheatstone bridge, when the bridge is balanced (Equation 1), the ratio of the resistances (R_1, R_2) in one pair of opposite branches is equal to the ratio of the resistances(R_3, Rx) in the other pair.

$$\frac{R_1}{R_2} = \frac{R_3}{Rx}$$

Equation 1

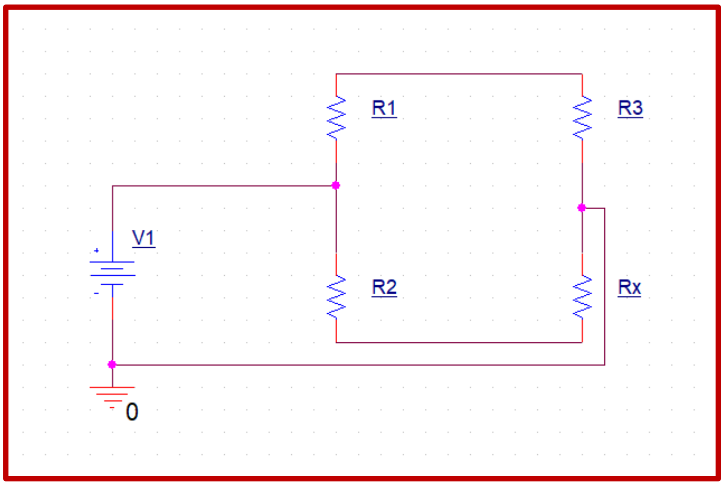


Figure 3

4.3 Instrumentation Amplifier

An instrumentation amplifier is a differential amplifier designed for precise and accurate amplification of low-level signals. The essential components include:

1. **Input Buffers**: The high input impedance of an instrumentation amplifier ensures that there is minimal loading on its signal sources.
2. **Differential Amplifier**: Amplifies the difference between the two input signals.
3. **Gain Resistor**: The amplifier gain can be easily set using a single external resistor for convenience.

Principle of Operation

The main principle of operation for the instrumentation amplifier (Figure 4) is differential amplification between input signals, along with common-mode noise rejection:

1. **High Input Impedance**: The input buffer stages ensure that the signal sources are not loaded, maintaining signal integrity.
2. **Common-Mode Rejection**: The differential amplifier stage effectively cancels out any noise or interference common to both input signals, ensuring a clean output.
3. **Gain Adjustment**: The gain of the amplifier can be easily set using a single external resistor, providing flexibility for different applications.

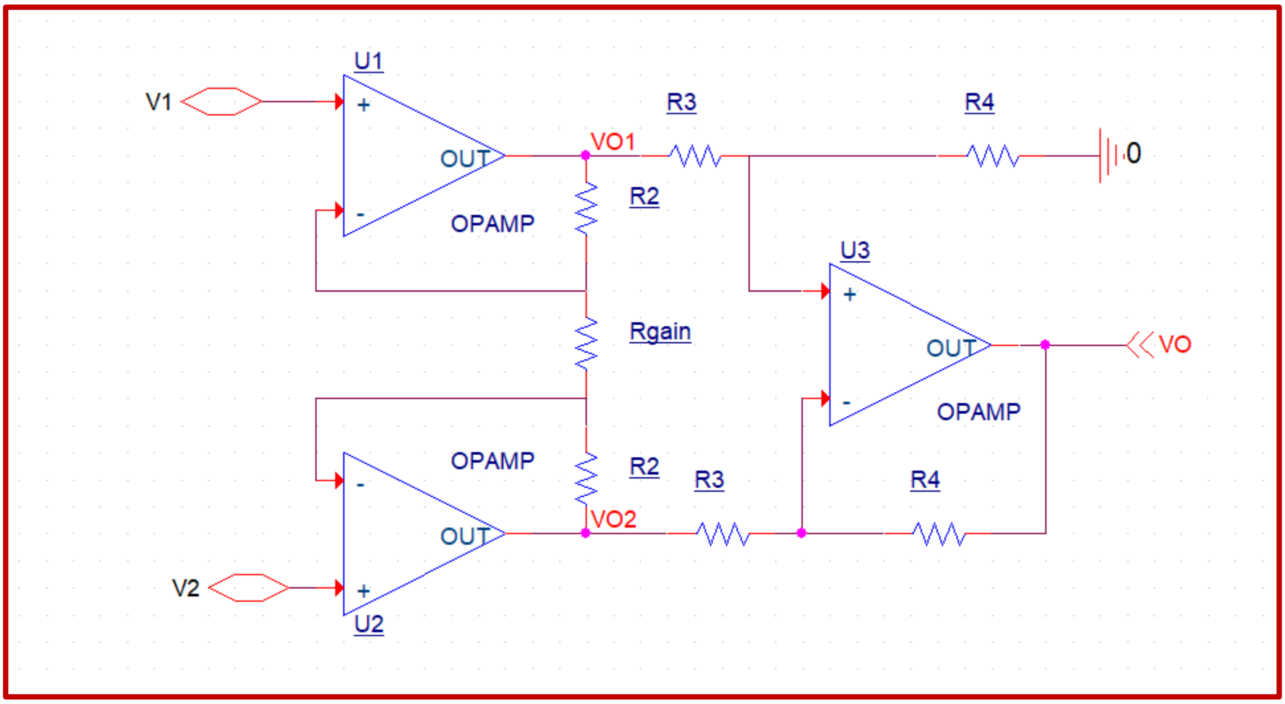


Figure 4

First Stage (Buffer Amplifiers) Outputs:

These equations show the output voltages V_{O1} (Equation 2) and V_{O2} (Equation 3) of the buffer stages. They depend on the input voltages V_{I1} and V_{I2}, and the resistor values R_{gain} and R_2.

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

Equation 2

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

Equation 3

Final Output Voltage:

This formula (Equation 4) shows the final output voltage Vo of the instrumentation amplifier, which is the amplified difference between the input voltages V_1 and V_2. The gain of the amplifier is determined by the resistor values $Rgain$ and R_2.

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

Equation 4

4.4 The Hysteresis Comparator

A hysteresis comparator, is an electronic circuit that provides a clear distinction between high and low logic levels by introducing hysteresis. This means the comparator has two different threshold voltages for rising and falling signals, which helps eliminate noise and provides a stable output. The essential components include:

1. **Operational Amplifier** (Op-Amp).
2. **Four Resistors.**
3. **Reference Voltage Source** (V_{REF}).
4. **Power Supplies:** +Vps,−Vps and V_I.

Principle of Operation:

The Hysteresis comparator (Figure 5) operates by comparing the input voltage (VI) with a reference voltage (V_{REF}). The output of the operational amplifier toggles between +Vps and −Vps based on the input voltage level.

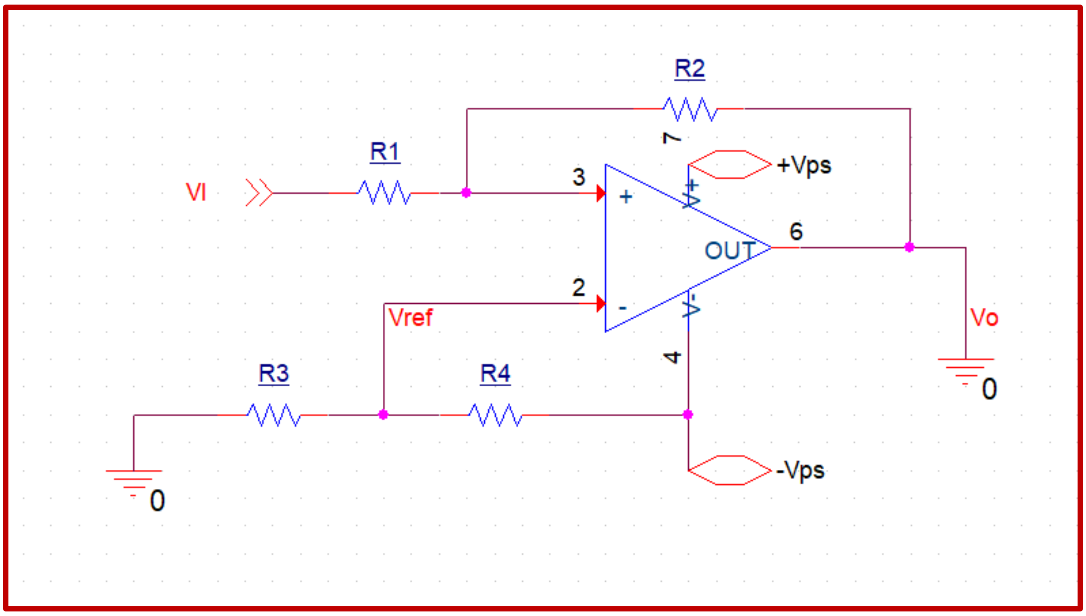


Figure 5

- The hysteresis effect is achieved through positive feedback via the resistor network, creating different threshold voltages for rising and falling edges.

Voltage difference:

The Voltage difference is the difference between the non-inverting input V+ and the inverting input V- shown in the formula (Equation 5).

$$V_D = V^+ - V^- = \frac{R_1}{R_1 + R_2} V_0 + \frac{R_2}{R_1 + R_2} V_I - V_{REF}$$

Equation 5

Threshold voltages:

The output voltage *Vo* will switch to +Vps when the input voltage V_I rises above the upper threshold (V_{ThH}) (Equation 6) and will switch to −Vps when the input voltage falls below the lower threshold (V_{ThL}) (Equation 7). This behavior ensures that small fluctuations in the input voltage around the threshold values do not cause multiple switching, thereby reducing noise and improving signal stability.

$$V_{ThL} = -\frac{R_1}{R_2} V_{OH} + \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

Equation 6

$$V_{ThH} = -\frac{R_1}{R_2} V_{OL} + \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

Equation 7

5. Sizing the Circuit

5.1 The Wheatstone Bridge

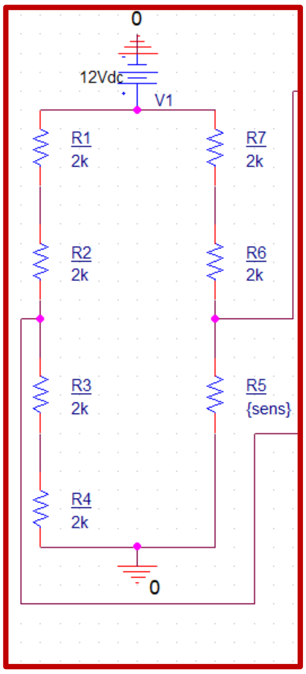


Figure 6

I am choosing the Wheatstone bridge for my case because, despite its non-linearity, it offers significant advantages when properly managed. The Wheatstone bridge can provide highly accurate measurements of resistance changes, especially in applications where precision is crucial. Here are the key reasons for my choice:

1. **High Sensitivity**: The Wheatstone bridge is highly sensitive to small changes in resistance, making it ideal for precision measurement applications. This sensitivity allows for the detection of minute variations in resistance, which is essential for accurate sensor readings.
2. **Balance and Calibration**: When the bridge is balanced, the output voltage is zero, which simplifies the process of detecting changes. By carefully calibrating the bridge, it is possible to achieve high accuracy in the measurements.
3. **Adaptability**: The Wheatstone bridge can be adapted for a wide range of resistance values. By selecting appropriate resistor values and configurations, it can be tailored to suit specific measurement needs, even for high-resistance applications.

I calculated the conversion between ohms to kilograms and I found this formula that worked pretty well (Equation 8) :

$$R_{(M)} = m \cdot M + a$$

Equation 8

a is for slope of the graphic

$R_{(M)}$ is for the sensor Resistance [kΩ]

M is for the weight of the shelf [kg]

m is for measurable weight range [kg]

After that, I created a system with 2 unknows:

$$\begin{cases} 4 = 2m + a \\ 20 = 180m + a \end{cases} \Rightarrow 16 = 178m \Rightarrow m = \frac{16}{178} = 0.089kg$$

I found the unknow slope of the graphic a:

$$4 = 0.0891 \cdot 2 + a \Rightarrow a = 3.822$$

After that, I calculated the values in [kΩ] for the weight of the shelf for 80kg and 160 kg:

$$R_{(M)} = 0.089 \cdot M + 3.822$$
$$M = 80kg \Rightarrow 10.942[\text{k}\Omega]$$
$$M = 160kg \Rightarrow 18.062[\text{k}\Omega]$$

And for the signal, I calculated the Measurable weight range using the formula (Equation 8):

$$R_{(M)} = 0.089 \cdot M + 3.822$$
$$M = 2kg \Rightarrow 4[\text{k}\Omega]$$
$$M = 180kg \Rightarrow 19.842[\text{k}\Omega]$$

I realized if I put all the values for the Wheatstone bridge to be all 4[kΩ] the Wheatstone bridge is balanced means that the voltage that exits both branches of the circuit will be equal and be zero, which means that the circuit is balanced.

The next step is to calculate the Voltage that goes to IA (Instrumentation Amplifier) for two cases when Rsens is equal with the minimum value of the shelf and when is equal with maximum value of shelf.

So first of all we put the value for R_{sens} 10.942 [kΩ] (80kg) and we calculate the voltage divider for both branches:

$$V_{R_5} = \frac{R_5}{R_6+R_7+R_{sens}} Vcc \Rightarrow \frac{10.942}{10.942+2+2} 12 \Rightarrow 8.78\text{V}$$

Equation 9

$$V_{R_3+R_4} = \frac{R_3+R_4}{R_1+R_2+R_3+R_4} Vcc \Rightarrow \frac{2+2}{2+2+2+2} 12 \Rightarrow 6\text{V}$$

For R_{sens} 18.062 [kΩ] (160kg) and we calculate the voltage divider for both branches:

$$V_{R_5} = \frac{R_5}{R_6+R_7+R_{sens}} Vcc \Rightarrow \frac{18.062}{18.062+2+2} 12 \Rightarrow 9.82\text{V}$$

Equation 10

$$V_{R_3+R_4} = \frac{R_3+R_4}{R_1+R_2+R_3+R_4} Vcc \Rightarrow \frac{2+2}{2+2+2+2} 12 \Rightarrow 6\text{V}$$

5.2 The Instrumentation Amplifier

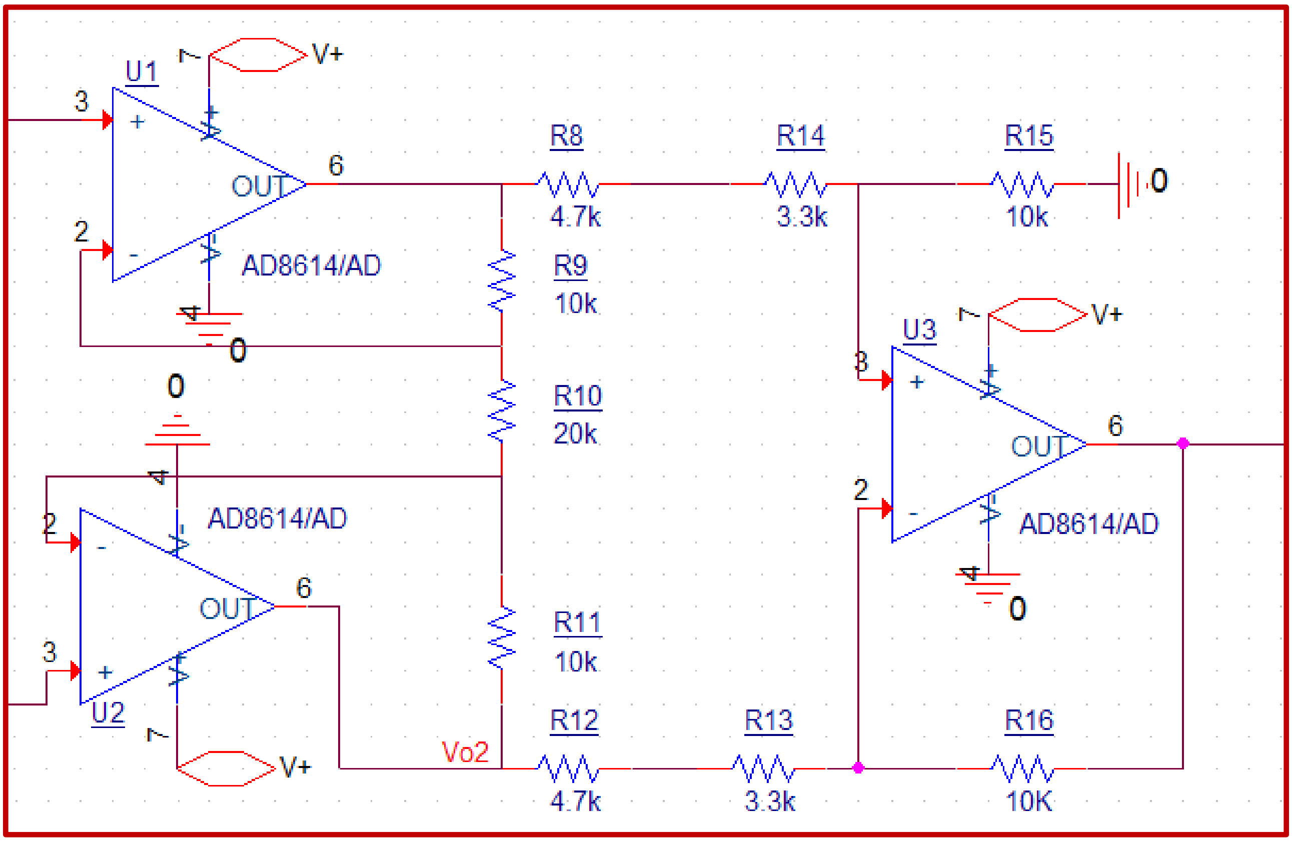


Figure 7

The Operational Amplifier AD8614 Data Sheet:

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
Offset Voltage	V_{OS}			1.0	2.5	mV
		−20°C ≤ T_A ≤ +85°C			3	mV
Input Bias Current	I_B			80	400	nA
		−20°C ≤ T_A ≤ +85°C			500	nA
Input Offset Current	I_{OS}			5	100	nA
		−20°C ≤ T_A ≤ +85°C			200	nA
Input Voltage Range			0		V_S	V
Common-Mode Rejection Ratio	CMRR	V_{CM} = 0 V to V_S	60	75		dB
Voltage Gain	A_{VO}	V_{OUT} = 0.5 V to V_S – 0.5 V, R_L = 10 kΩ	10	150		V/mV

For this part of the circuit I choose the AD8614 operational amplifier because is rail-to-rail input and output amplifier, with low input offset voltage, is more precise and is working really well in low-voltage applications.

First of all, I tried to find the values for R_9, R_{10},(R_9=R_{11}) and R_{11}, to do that I set the of R_{sens} to 4[kΩ] to make the Wheatstone bridge balanced. The Voltage that goes to both V+ for U1 and U2 will be 6V because of that, to be more specific V_{I1} and V_{I2} = 6V.

I will calculate Vo1 and Vo2 for R_{sens} 4[kΩ] (using Equation 2 and Equation 3)

$$V_{O1} = \left(1 + \frac{R_2}{R_{gain}}\right) V_{I1} - \frac{R_2}{R_{gain}} V_{I2} \Rightarrow V_{O1} = \left(1 + \frac{R_{11}}{R_{10}}\right) V_{I1} - \frac{R_{11}}{R_{10}} V_{I2} \Rightarrow V_{O1} = \left(1 + \frac{R_{11}}{R_{10}}\right) 6 - \frac{R_{11}}{R_{10}} 6 \Rightarrow$$

$$V_{O1} = 6 + 6\frac{R_{11}}{R_{10}} - \frac{R_{11}}{R_{10}} 6 \Rightarrow V_{O1} = 6V$$

$$V_{O2} = \left(1 + \frac{R_2}{R_{gain}}\right) V_{I2} - \frac{R_2}{R_{gain}} V_{I1} \cdots \Rightarrow V_{O2} = 6V$$

So, for the Balanced circuit the formula is:

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

From my trial and error values I observed that from the gain formula:

$$A_v = \left(1 + \frac{2R_2}{R_{gain}}\right)\left(\frac{R_4}{R_3}\right)$$

Equation 11

$$2R_2 = R_{gain}$$

To be able to calculate R4 and R2 without knowing the values for Rgain or R_2.

Let's see if it works:

For R_{sens} = 20[kΩ] (180kg) The Voltage that enters in the First two op-amps are V_{I1}= 10V and for V_{I2}= 6V, and for the circuit to work correctly $Vo = VCC - 2 = 10$.

I will use Equation 4 and Equation 11.

$$\left(1 + \frac{2R_2}{R_{gain}}\right) = 2 \Rightarrow \frac{2R_2}{R_{gain}} = 1 \Rightarrow 2R_2 = R_{gain} \Rightarrow R_{gain} = 20[\text{k}\Omega] \Rightarrow R_2 = 10[\text{k}\Omega]$$

$$Vo = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_{gain}}\right)(V_{I1} - V_{I2}) \Rightarrow Vo = 2\frac{R_4}{R_3}(10 - 6) \Rightarrow Vo = 2\frac{R_4}{R_3}4 \Rightarrow 10 = 8\frac{R_4}{R_3}$$

$$\Rightarrow 10R_3 = 8R_4 \Rightarrow R_3 = 0.8R_4 \Rightarrow R_3 = 10[\text{k}\Omega] \Rightarrow R_4 = 8[\text{k}\Omega]$$

In my circuit case the $R_{gain} = R_{10},\ R_2 = R_9 = R_{11},\ R_{15} = R_{16}, R_{8\,series\,R14} = R_{12\,series\,R13}$

5.3 The Hysteresis Comparator

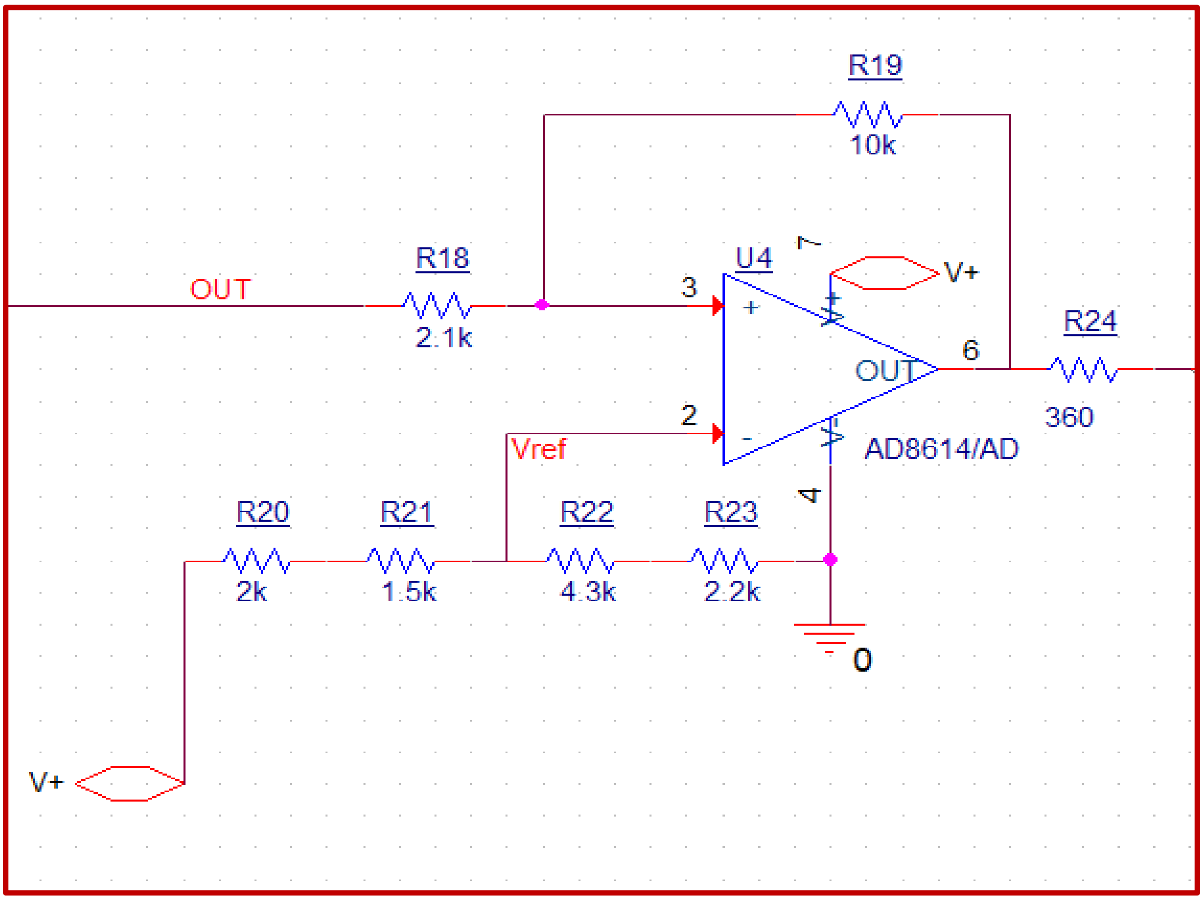


Figure 8

First of all, when I started to make the circuit I used two LM741 operational amplifiers and the circuit worked for the values for of the minimum and maximum of the Measurable weight range[kg]. Led is on for [0...4) and (20...∞).

After some research and finding a better and more professional way to approach the circuit, I changed the LM741 operational amplifier to AD8614. The difference between LM741 and AD8614 is that AD8614 is more precise, rail-to-rail, and is more expensive than LM741.

I created this part of the main circuit using the AD8614 operational amplifier and the application of this part of the circuit is a non-inverting Hysteresis comparator. I used the values from R_{sens} , to calculate V_{ThL} and V_{ThH} (using the Equation 6 and Equation 7, I will make a system).

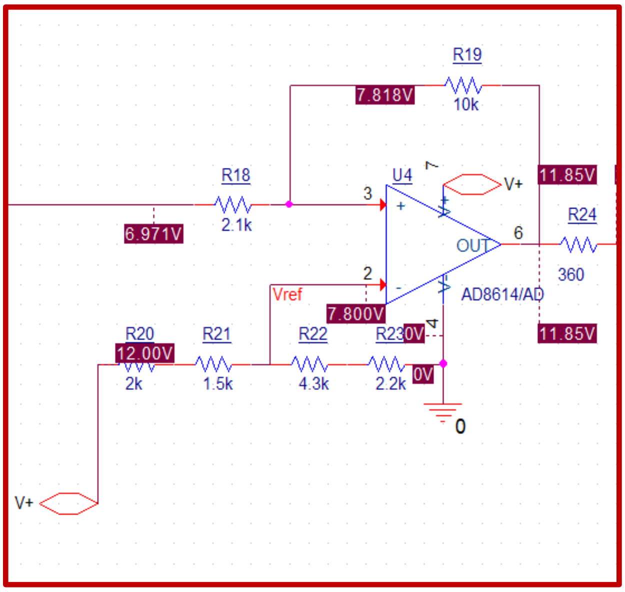


Figure 9

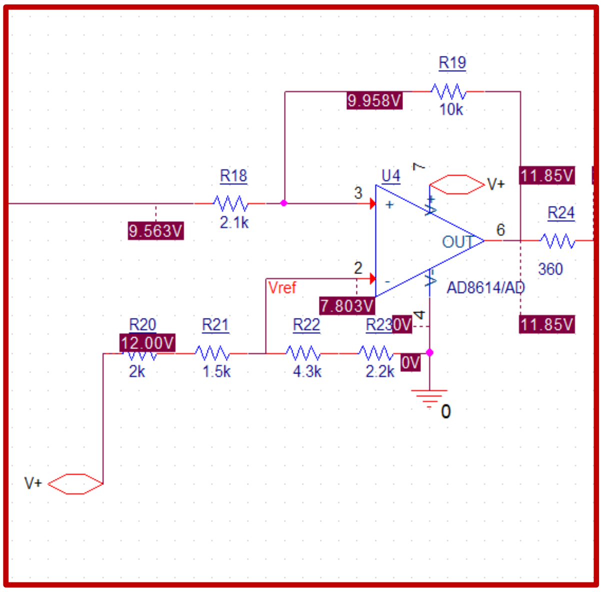


Figure 10

For the Figure 11 V_{ThL} is equal with 6.971V, I used R_{sens}=10.942[kΩ] for minimum value of the shelf $M = 80kg$

For the Figure 12 V_{ThH} is equal with 9.563, I used R_{sens}=18.062[kΩ] for maximum value of the shelf $M = 160kg$

Now I will make the calculus for finding V_{REF}:

$$\begin{cases} V_{ThL} = -\frac{R_1}{R_2} V_{OH} + \left(1 + \frac{R_1}{R_2}\right) V_{REF} \\ V_{ThH} = -\frac{R_1}{R_2} V_{OL} + \left(1 + \frac{R_1}{R_2}\right) V_{REF} \end{cases} \Rightarrow \begin{cases} 6.971 = -\frac{R_1}{R_2} 12 + \left(1 + \frac{R_1}{R_2}\right) V_{REF} \\ 9.563 = -\frac{R_1}{R_2} 0 + \left(1 + \frac{R_1}{R_2}\right) V_{REF} \end{cases}$$

$$\Rightarrow \begin{cases} 6.971 = -\frac{12R_1}{R_2} + V_{REF} + \frac{V_{REF} R_1}{R_2} \\ 9.563 = V_{REF} + \frac{V_{REF} R_1}{R_2} \end{cases} \Rightarrow \; 2.592 = \frac{12R_1}{R_2} \Rightarrow \frac{R_1}{R_2} = 0.213 \Rightarrow \begin{matrix} R_1 = 2.13[\text{k}\Omega] \\ R_2 = 10[\text{k}\Omega] \end{matrix}$$

$$9.563 = V_{REF} + 0.213 V_{REF} \Rightarrow 9.563 = 1.213 V_{REF} \Rightarrow V_{REF} = 7.8V$$

$$7.8V = \frac{R_{21}}{R_{20} + R_{21}} 12 \Rightarrow 0.65 = \frac{R_{22\ series\ R23}}{R_{20\ series\ R21} + R_{22\ series\ R23}} \Rightarrow \begin{matrix} R_{22\ series\ R23} = 6.5[\text{k}\Omega] \\ R_{20\ series\ R21} = 3.5[\text{k}\Omega] \end{matrix}$$

5.4 The LED

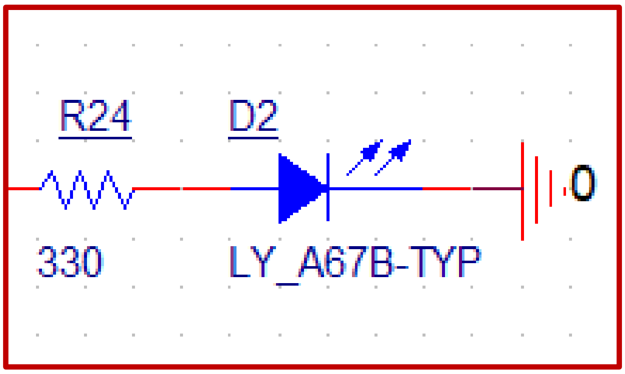
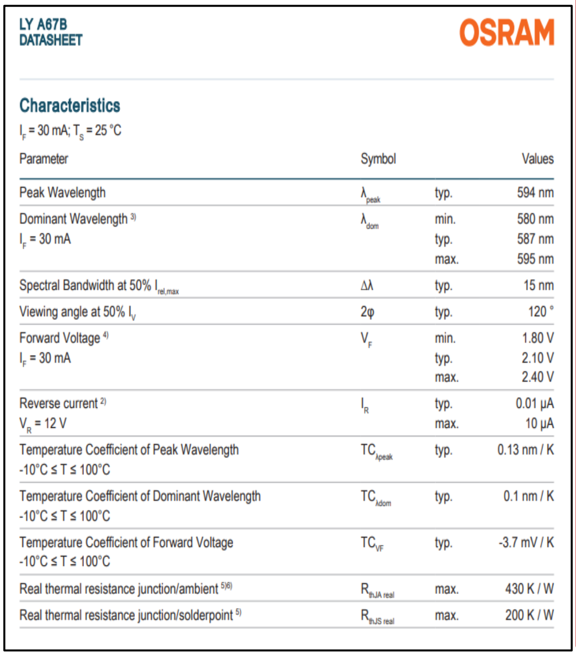


Figure 11

The Yellow LED LY_A67B-TYP Data Sheet:


LY A67B DATASHEET

OSRAM

Characteristics

I_F = 30 mA; T_S = 25 °C

Parameter	Symbol		Values
Peak Wavelength	λ_{peak}	typ.	594 nm
Dominant Wavelength [3] I_F = 30 mA	λ_{dom}	min. typ. max.	580 nm 587 nm 595 nm
Spectral Bandwidth at 50% $I_{rel,max}$	$\Delta\lambda$	typ.	15 nm
Viewing angle at 50% I_V	2φ	typ.	120 °
Forward Voltage [4] I_F = 30 mA	V_F	min. typ. max.	1.80 V 2.10 V 2.40 V
Reverse current [2] V_R = 12 V	I_R	typ. max.	0.01 µA 10 µA
Temperature Coefficient of Peak Wavelength -10°C ≤ T ≤ 100°C	$TC_{\lambda peak}$	typ.	0.13 nm / K
Temperature Coefficient of Dominant Wavelength -10°C ≤ T ≤ 100°C	$TC_{\lambda dom}$	typ.	0.1 nm / K
Temperature Coefficient of Forward Voltage -10°C ≤ T ≤ 100°C	TC_{VF}	typ.	-3.7 mV / K
Real thermal resistance junction/ambient [5][6]	$R_{thJA\ real}$	max.	430 K / W
Real thermal resistance junction/solderpoint [5]	$R_{thJS\ real}$	max.	200 K / W

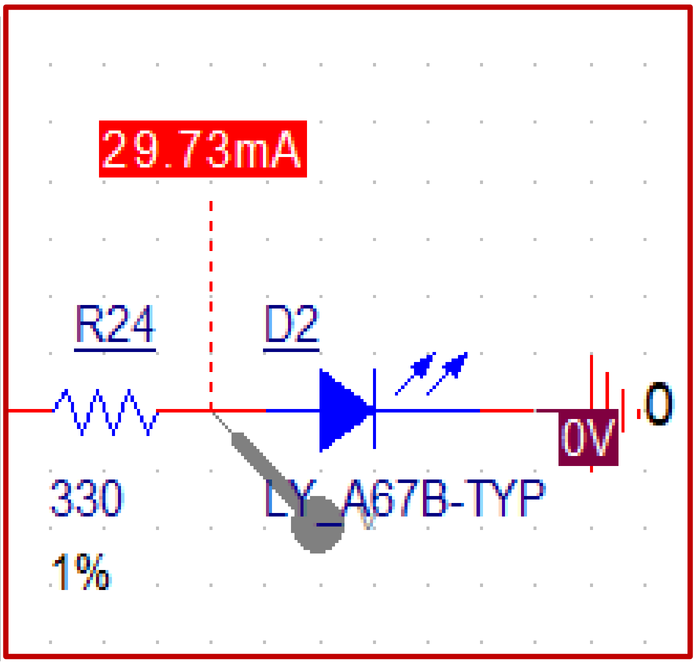


Figure 12 *Figure 13*

The resistance R_{24} is for limiting the current that goes into the LED because if too much current is going to the LED, the LED will emit smoke and it will stop working.

I calculated the desire current that this LED needs from data sheet ($I_F = 30m$).

The V_I is extracted from Figure 11 or 12, that is the output voltage from the hysteresis comparator.

$$V_I = V_O = 11.85V$$

$$R_D = \frac{V_I - V_D}{I_f} = \frac{11.85 - 2}{30 \cdot 10^{-3}} = 328\ [\Omega]$$

Equation 12

6. Analyses

6.1 DC Sweep analysis

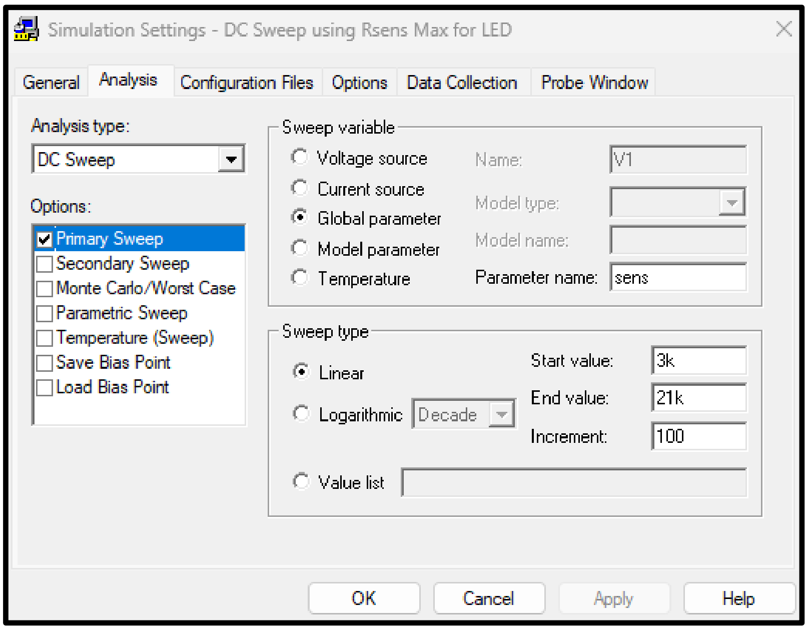


Figure 14

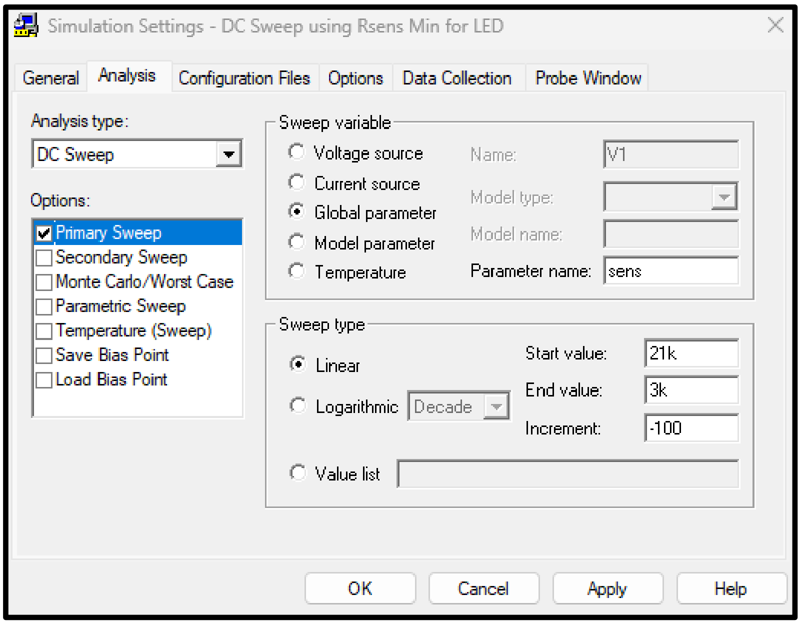


Figure 15

By sweeping the {sens} parameter (Figure 14, 15), we are interacting with the R_{sens} and this allows us to see how the voltage changes between the required resistances levels [kΩ].

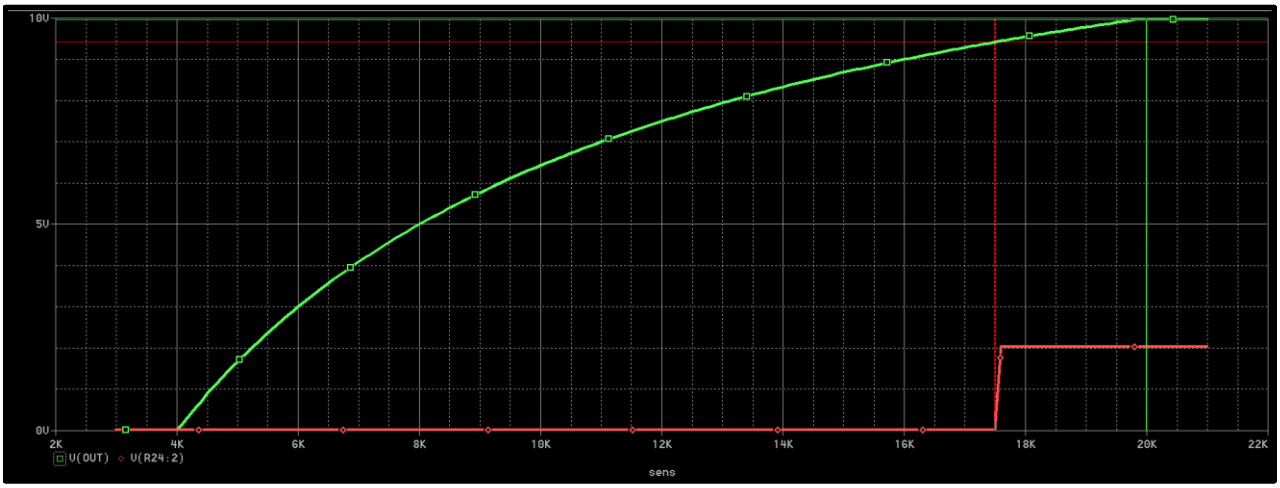


Figure 16

Trace Color	Trace Name	Y1	Y2
	X Values	17.483K	19.989K
CURSOR 1,2	V(OUT)	9.4164	9.963
	V(R24:2)	21.863m	2.0300

Figure 17

We can see that the diode is on For the value of $R_{sens\,max} = 17.483$[kΩ]. is close with a differention of 500[Ω] to the value I calculated above.

Figure 18

Trace Color	Trace Name	Y1	Y2
	X Values	10.899K	19.989K
CURSOR 1,2	V(OUT)	6.9485	9.963
	V(R24:2)	20.840m	2.0300

Figure 19

We can see that the diode is on For the value of $R_{sens\,min} = 10.899[\text{k}\Omega]$. is very close to the value I calculated above.

6.2 Parametric analysis

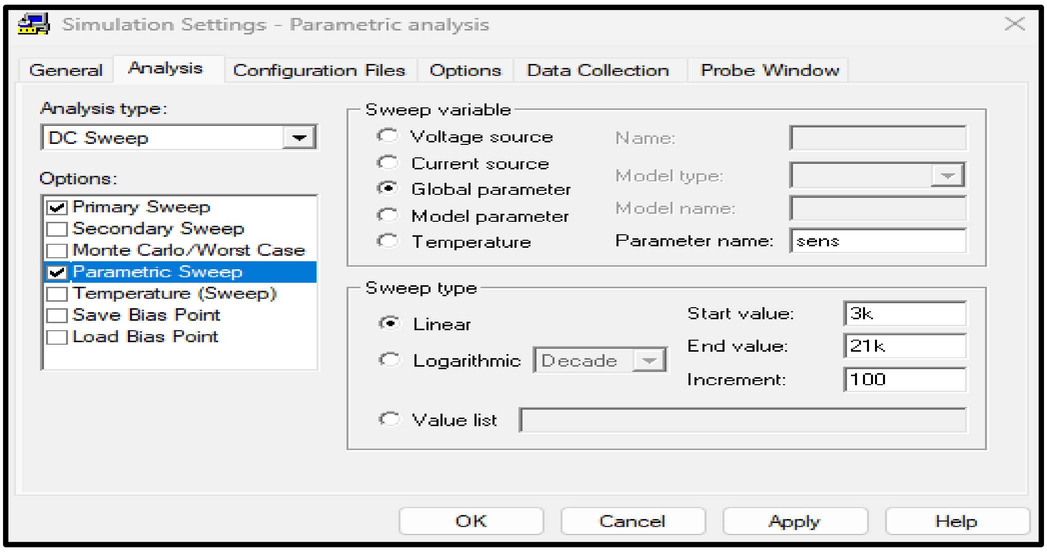


Figure 20

By sweeping the {sens} parameter (Figure 20), we are interacting with the R_{sens} and this allows us to see how the voltage changes between the resistances (3[kΩ]...21[kΩ]) and the voltage across it.

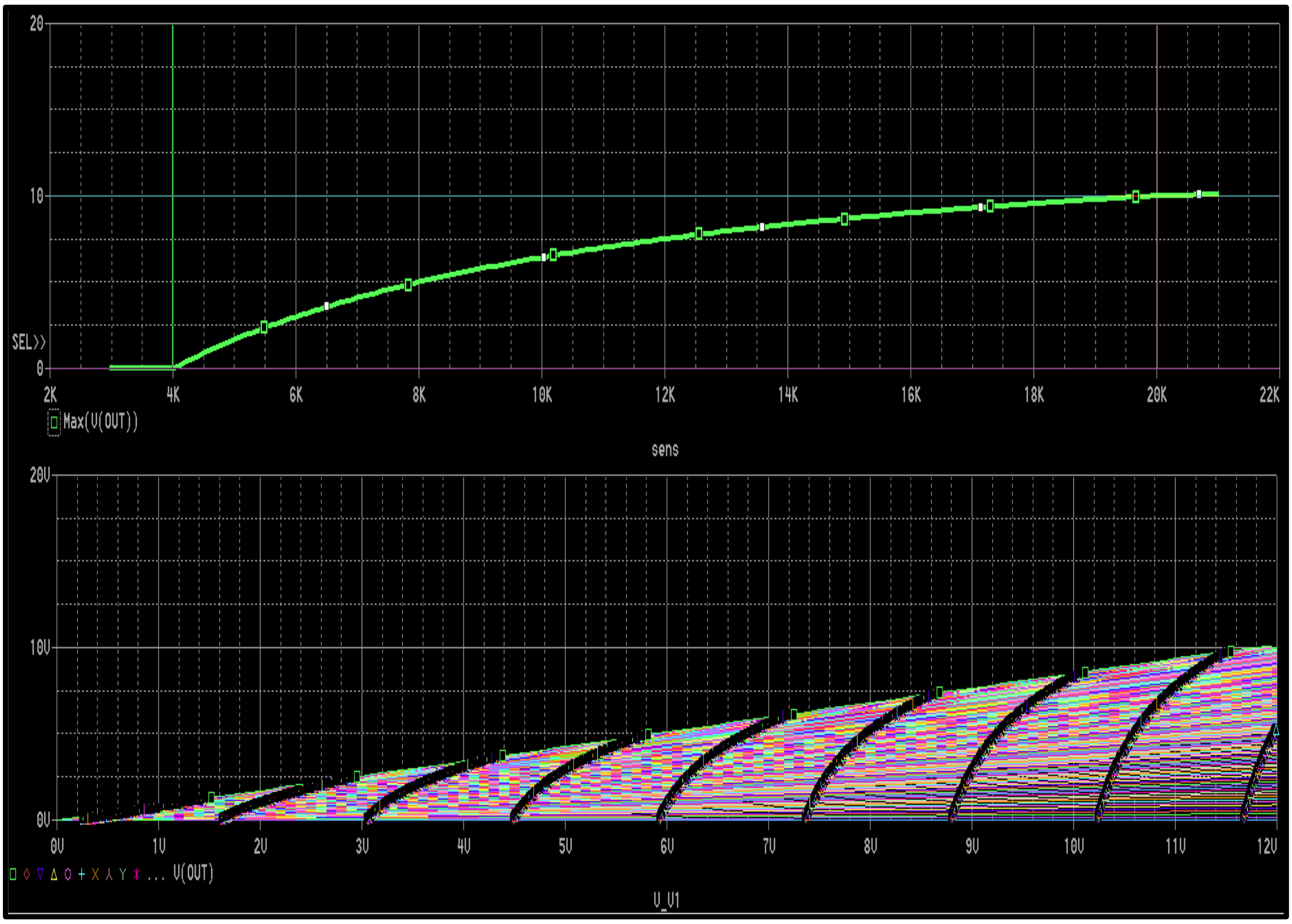


Figure 21

Trace Color	Trace Name	Y1	Y2
	X Values	20.011K	3.9888K
CURSOR 1,2	Max(V(OUT))	9.963	19.705m

Figure 22

We can see in the Figure 22 that the values of the ouput meets the assigment, more exactly for $R_{sens\,min} = 4$ [kΩ] and The value of the ouput $V_O = \sim 0V$

$R_{sens\,max} = 22$ [kΩ] and The value of the ouput $V_O = \sim 10V$

6.3 Monte Carlo analysis

Monte Carlo simulation helps analyze risk by creating models of potential outcomes. Instead of relying on a single value for uncertain factors, it uses a range of values represented by a probability distribution. By repeatedly calculating results with different random values from these distributions, it provides a comprehensive view of possible results.

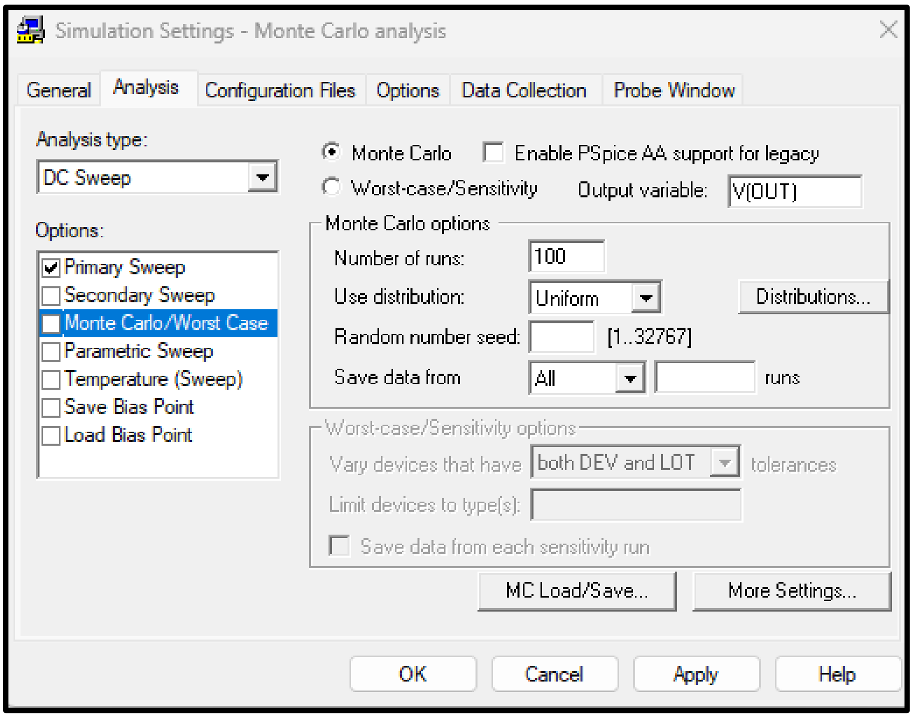


Figure 23

We can see in Figure 24 how the output can vary due to the tolerances in our components:

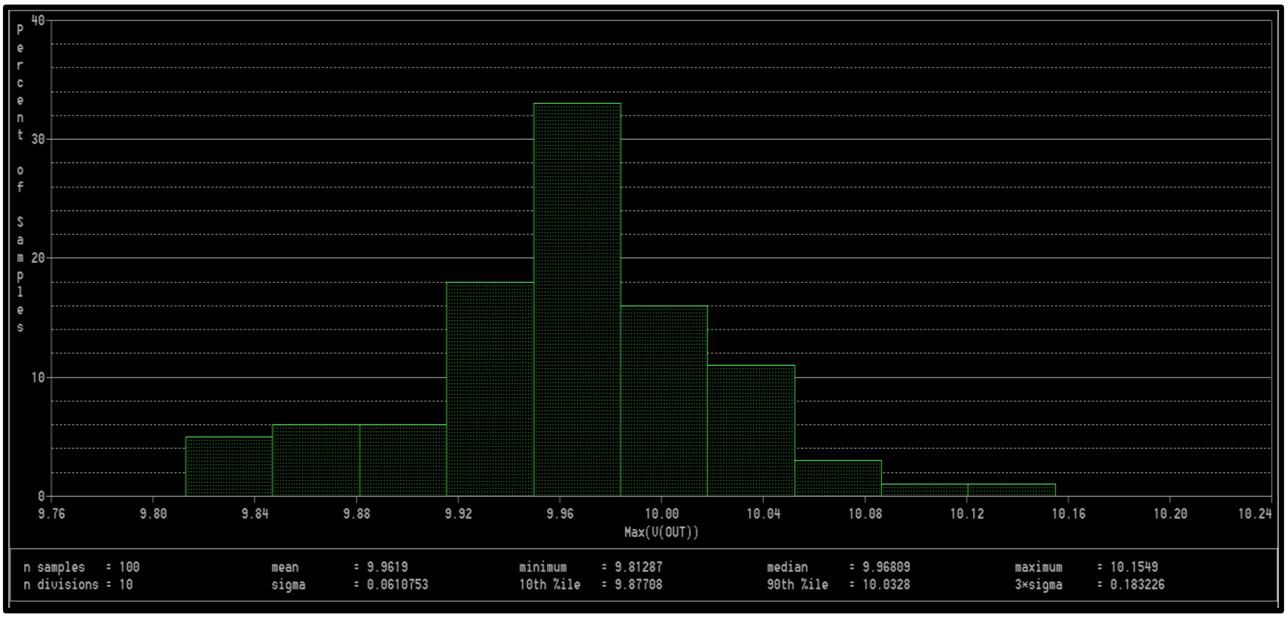


Figure 24

6.4 Worst Case analysis

Worst Case analysis is used to pinpoint the most critical components that impact circuit performance. This begins with a sensitivity analysis for each component that has an assigned tolerance. Each component's value is slightly adjusted towards both ends of its tolerance limits to determine which direction has the greatest effect on the worst-case output. As illustrated in Figure 25, this worst-case analysis reveals which components are most sensitive and crucial for the system's proper functioning, as well as those that deviate the most from their nominal values.

```
                      WORST CASE ALL DEVICES

****************************************************************************


Device       MODEL        PARAMETER   NEW VALUE
R_R5         R_R5         R              1.01          (Increased)
R_R2         R_R2         R              1.01          (Increased)
R_R15        R_R15        R              1.01          (Increased)
R_R11        R_R11        R              1.01          (Increased)
R_R9         R_R9         R              1.01          (Increased)
R_R10        R_R10        R               .99          (Decreased)
R_R24        R_R24        R              1.01          (Increased)
R_R19        R_R19        R              1.01          (Increased)
R_R8         R_R8         R               .99          (Decreased)
R_R14        R_R14        R               .99          (Decreased)
R_R12        R_R12        R               .99          (Decreased)
R_R13        R_R13        R               .99          (Decreased)
R_R1         R_R1         R              1.01          (Increased)
R_R4         R_R4         R               .99          (Decreased)
R_R3         R_R3         R               .99          (Decreased)
R_R7         R_R7         R               .99          (Decreased)
R_R6         R_R6         R               .99          (Decreased)
R_R20        R_R20        R               .99          (Decreased)
R_R21        R_R21        R              1.01          (Increased)
R_R22        R_R22        R               .99          (Decreased)
R_R23        R_R23        R              1.01          (Increased)
R_R18        R_R18        R              1.01          (Increased)
R_R16        R_R16        R              1.01          (Increased)

WORST CASE ALL DEVICES
                                .5403  higher  at sens =   18.8000E+03
                               ( 105.55% of Nominal)
```

Figure 25

7. Bill of materials

Quantity	Reference	Part	Description	Prince	Link
7	R1234567,20	2k	CFR-25JB-52-2K	$0.70	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-2K/649
2	R12,R8	4.7k	CFR-25JB-52-4K7	$0.20	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-4K7/1846
5	R9,10,11,15,16	10k	CFR-25JB-52-10K	$0.50	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-10K/338
1	R10	20k	CFR-25JB-52-20K	$0.10	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-20K/880
2	R13,R14	3.3k	CFR-25JB-52-3K3	$0.20	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-3K3/1455
1	R18	2.1k	CFR-25JB-52-2K1	$0.10	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-2K2/666
1	R21	1.5k	CFR-25JB-52-1K5	$0.10	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-1K5/132
1	R22	4.3k	CFR-25JB-52-4K3	$0.10	https://www.digikey.be/en/products/detail/yageo/CFR-25JB-52-4K3/1827
1	R23	2.2k	CFR-25JB-52-2K2	$0.10	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-2K2/666
1	R24	0.330k	CFR-25JB-52-330R	$0.10	https://www.digikey.com/en/products/detail/yageo/CFR-25JB-52-330R/1636
4	U1,2,3	uAD8614	AD8614ARTZ-REEL7	$21.96	https://www.digikey.com/en/products/detail/analog-devices-inc/AD8614ARTZ-REEL7/621426
1	D2	LY_A67B-TYP	LY A67B-U1V1	$0.71	https://www.digikey.com/en/products/detail//LY-A67B-U1V1-26-0-30-R33-Z/15294667
			TOTAL COST:	$24.87	

8. Conclusion

In conclusion the project demonstrates the design, implementation, and analysis of a weight sensor system for a shelf. The primary objective was to create a system capable of controlling the weight supported by the shelf, ensuring it remains within a specified range. This was achieved by utilizing a sensor that measures weight linearly and converts resistance variations into corresponding voltage changes.

The first part of the design is the Wheatstone Bridge, which was selected for its ability to convert resistance changes from the weight sensor into measurable voltage signals. The Wheatstone Bridge offers high sensitivity to small resistance changes, making it an ideal choice for applications requiring precise measurements.

The Instrumentation Amplifier played a important role in the system by amplifying the small voltage changes from the Wheatstone Bridge. This allowed for accurate and stable signal processing, which is essential for maintaining the integrity of the measurements.

To ensure a clear and stable output signal, the design incorporated a Hysteresis Comparator. This component introduced hysteresis, creating distinct threshold voltages for rising and falling signals. The comparator's output was used to drive a yellow LED, which indicated whether the weight on the shelf was within the desired range.

Calculations were performed to size the circuit components appropriately. These calculations included determining the resistance values for the Wheatstone Bridge, setting the gain for the Instrumentation Amplifier, and establishing the threshold voltages for the Hysteresis Comparator. Simulation results validated these calculations, demonstrating the functionality of the circuits and ensuring that the system met the design specifications.

9. Bibliography

• **For the Wheatstone Bridge circuit**

https://resources.altium.com/p/wheatstone-bridges

• **For the Instrumentation Amplifier**

https://www.allaboutcircuits.com/tools/instrumentation-amplifier-calculator/

• **For the Hysteresis Comparator**

https://fscdn.rohm.com/en/products/databook/applinote/ic/amp_linear/comparator/gpl_cmp_hysteresis-e.pdf

• **For the Components**

https://www.digikey.com

• **For the Data Sheets**

https://www.analog.com/media/en/technical-documentation/data-sheets/AD8614_8644.pdf

https://ams-osram.com/products/leds/color-leds/osram-sideled-ly-a67b

• **Other resources used**

http://193.226.6.189/dce/didactic/ed/, „Electronic devices", Assistant Professor Laura-Nicoleta IVANCIU, PhD.