COMPUTER AIDED DESIGN PROJECT

Circuit for controlling the weight
of a shelf

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Year 2, group: e_2023, semigroup 2

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1. Requirements

1.1 Task

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.

1.2 Design Data

Measurable weight range [kg]: 20 – 110

The weight of the shelf [kg]: 80 – 100

Sensor Resistance [kΩ]: 18 – 47

V_{CC} [V]: 12

LED Colour: Yellow

2. Theoretical support

2.1 Active Bridge

An *active bridge* or a *linear bridge* is an electronic circuit that incorporates active components, such as operational amplifiers, transistors, or other amplifying devices, to enhance the performance of a traditional bridge circuit. Active bridges are used to measure and manipulate signals with improved sensitivity and accuracy.

A crucial aspect of active bridge circuits is the linearization of signals, which ensures that the output accurately reflects the input changes over a wide range. A varying resistance is added, the response being linear for every value of it. Because the output voltage is a small one, this will be amplified with a second amplifier circuit such as the voltage domain converter.

Linearization is the reason why the active bridge is useful in our circuit, being crucial in sensor applications where the relationship between the input (e.g., physical parameter like strain or temperature) and the output voltage should be linear. Non-linearities can arise from the inherent characteristics of the sensors or the circuit components.

2.2 Inverting Voltage Domain Converter

A voltage domain converter is an electronic circuit or device that translates signals between different voltage levels. This is essential in systems where components operate at varying voltage levels and need to communicate effectively without damage or data corruption.

Voltage domain converters ensure that signals are properly interfaced between these different voltage domains, enabling seamless interaction among components. As its other name specifies, level shifter, it shifts signals from one voltage level to another, such as from a certain voltage logic level, to a higher or a lower voltage logic level.

In our circuit, it brings the voltage signal from the value range at the output of the active bridge, to the range [0V – (V_{CC}-2)V] or [0V – 10V], for this specific circuit.

2.3 Simple Comparators

2.3.1 Inverting

A simple inverting comparator is a basic electronic circuit used to compare two input voltages and produce an output based on their relative magnitudes. It consists of an operational amplifier (op-amp) configured in an inverting amplifier configuration with a reference voltage applied to one input terminal and the input signal applied to the other.

When the input voltage exceeds the reference voltage, the output of the comparator switches to a low state; otherwise, it remains high. This configuration creates a binary output, commonly used in applications such as digital logic circuits, voltage detection, and triggering mechanisms.

Thus, in the designed circuit it adjusts the voltage, in order to control the state of the LED.

2.3.2 Non-Inverting

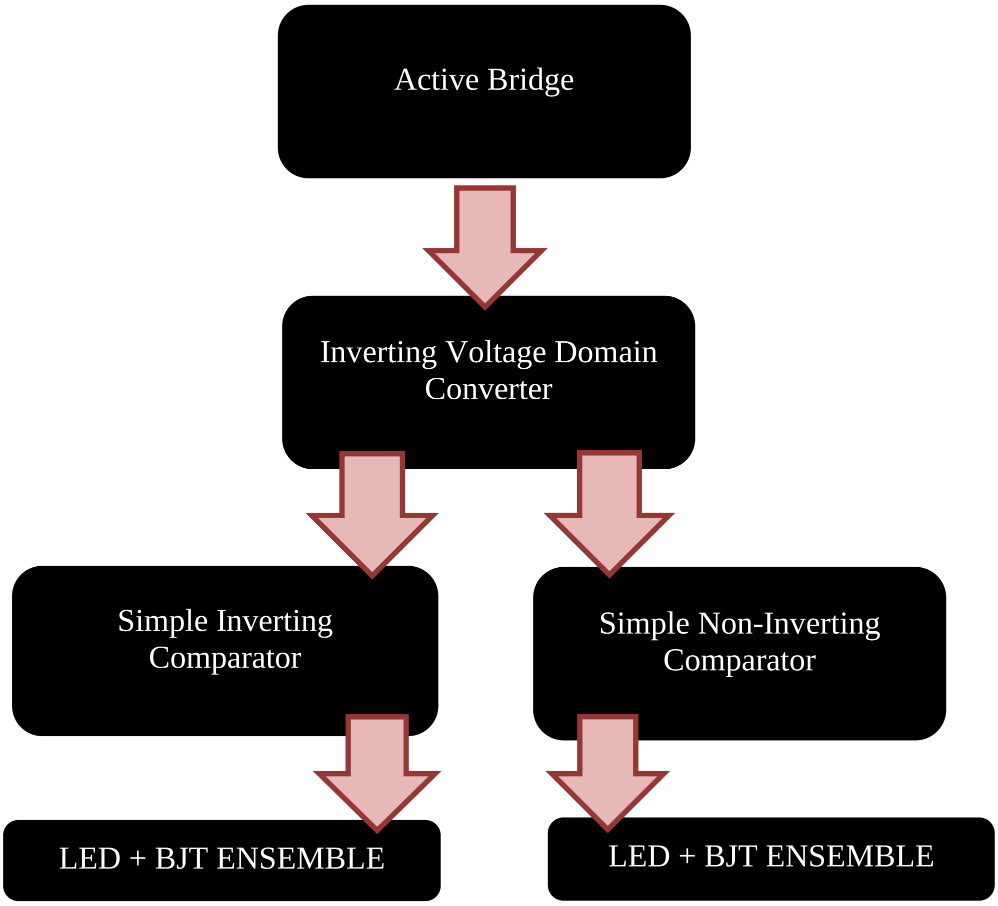
A simple non-inverting comparator is a fundamental electronic circuit used to compare two input voltages and generate an output based on their relative values. It typically consists of an operational amplifier (op-amp) configured in a non-inverting amplifier configuration. In this setup, one input of the op-amp is connected to the input voltage, while the other input is connected to a reference voltage. When the input voltage exceeds the reference voltage, the output of the comparator switches to a high state; otherwise, it remains low.

Similarly to the inverting comparator, it also adjusts the voltage to control the LED’s state.

2.4 LED and BJT Ensembles

These ensembles receive the signals from the comparators and, with the help of the BJT transistor, the LEDs switch between the ON and OFF states. The resistors help in maintaining a correct current through the yellow LEDs, so that it does not get burnt out.

3. Block Diagram



4. Electrical Schematic

4.1 Active Bridge

The circuit started with an active bridge (Figure 1), which encompasses the weight sensor, modelled as the varying resistance R1. The values of the other 3 resistances , which must be equal, were first the maximum value of the sensor, 47 kΩ, but then, the output of the circuit had a small distortion at the end (Figure 2), which meant that a higher resistance was needed. Thus, through iterations, the 75 kΩ resistance was chosen. This resistance is good enough to get a fully linearized output.

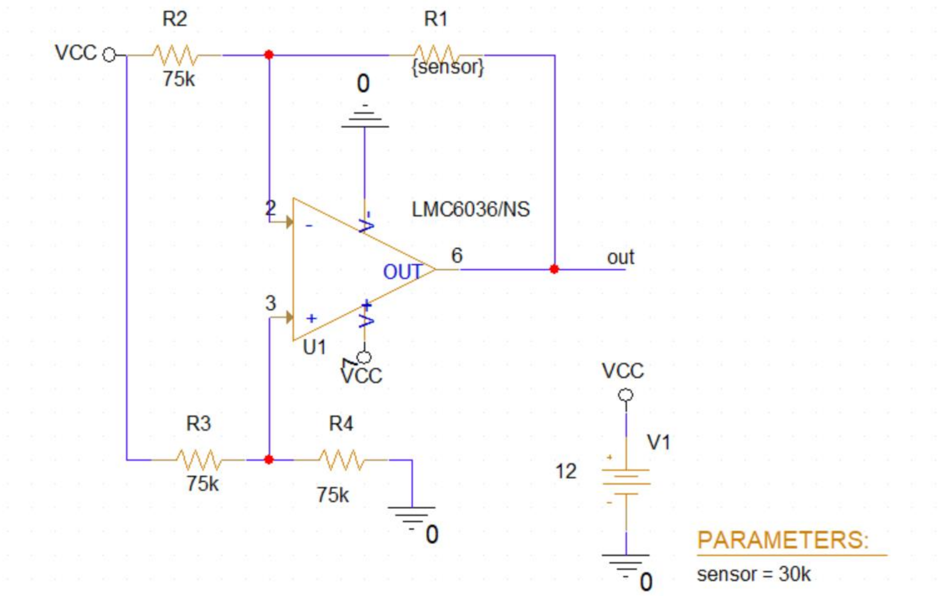


Figure 1 - Active Bridge Circuit

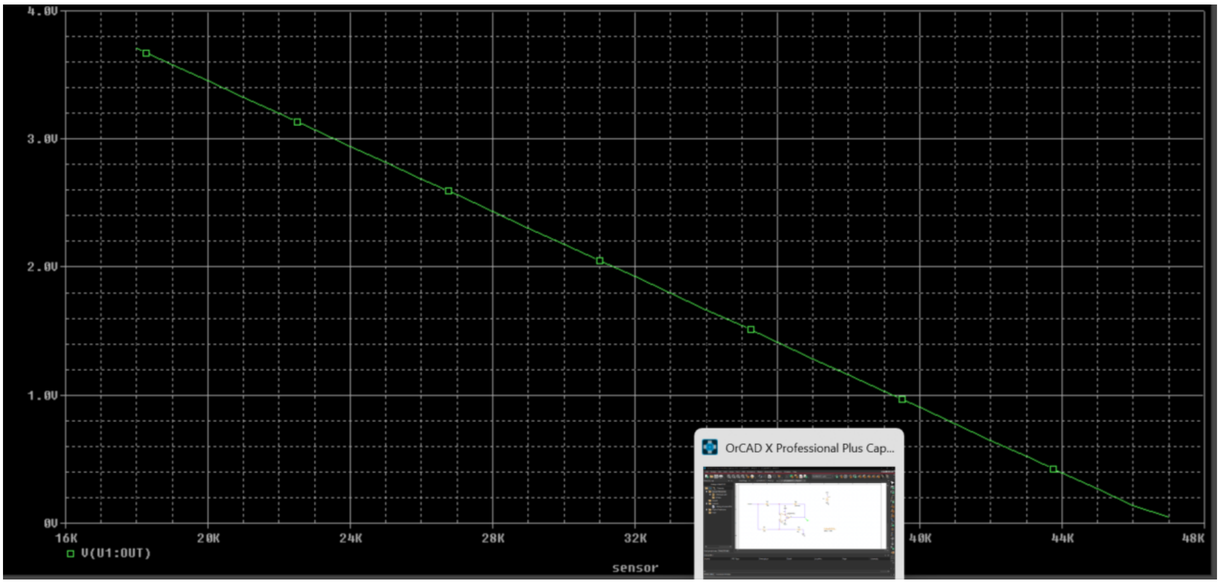


Figure 2 - Active Bridge output for 47kΩ resistances

4.2 Addition of the Inverting Voltage Domain Converter

The voltage signal at the output of the active bridge was linearized, but it was inverse to what was needed, its variation range was too small and the values were not the desired ones, so, in order to bring the range to the one of [0V – 10V], I placed an inverting voltage domain converter at the output of the bridge (Figure 3). This brought the voltage signal to the optimal range, while also inverting it (Figure 4).

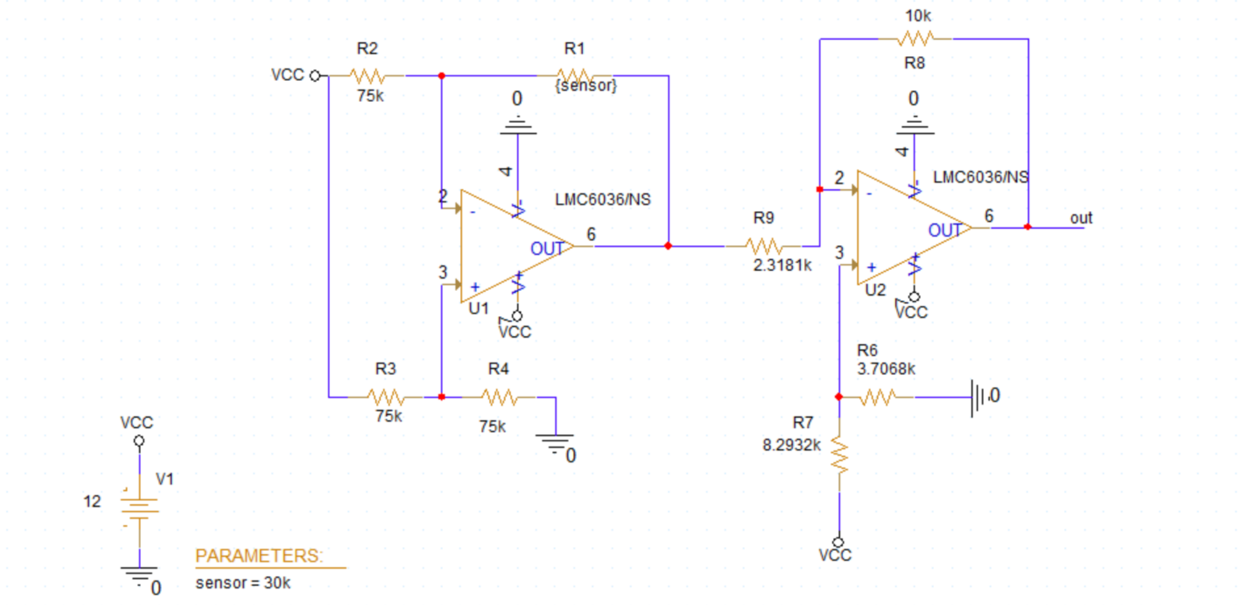


Figure 3 - Active Bridge + Voltage Domain Converter

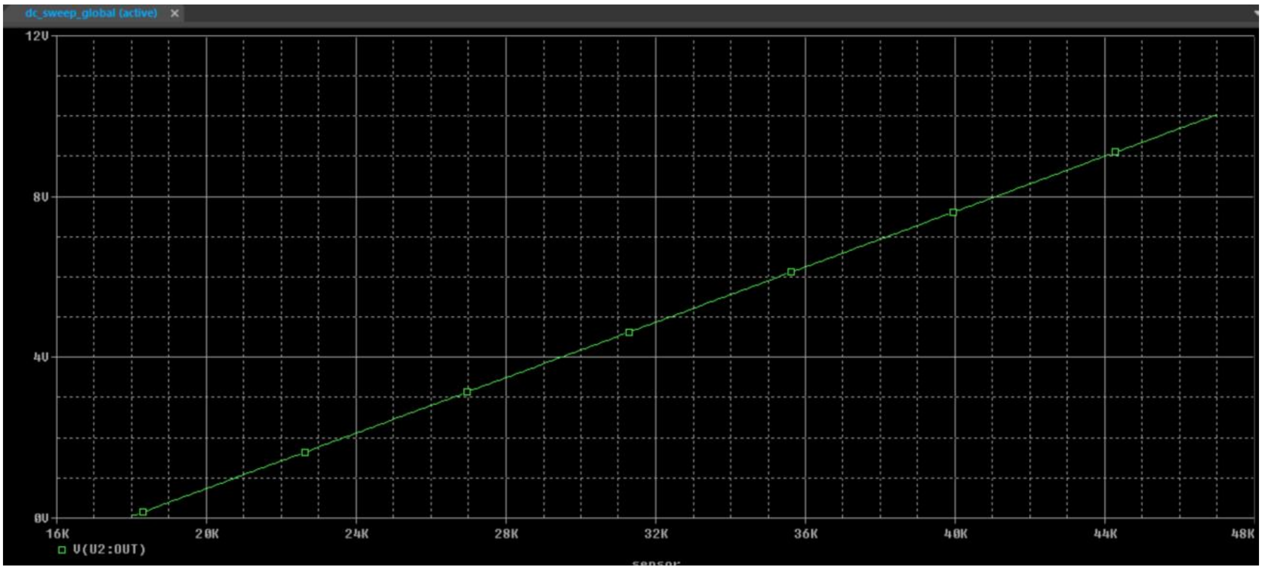


Figure 4 - Voltage Domain Converter output

4.3 Addition of the Simple Comparators

For the LED to be ON out of our resistance range, 2 simple comparators were needed.

4.3.1 Non-Inverting Simple Comparator

After converting the weight range [20kg – 110kg] into a range of resistance,

[37.333 kΩ – 43.777 kΩ], I needed a non-inverting simple comparator in the circuit with the purpose of keeping the LED ON above the value of 43.777kΩ (Figure 5), or the superior range, this value corresponding to the superior weight value.

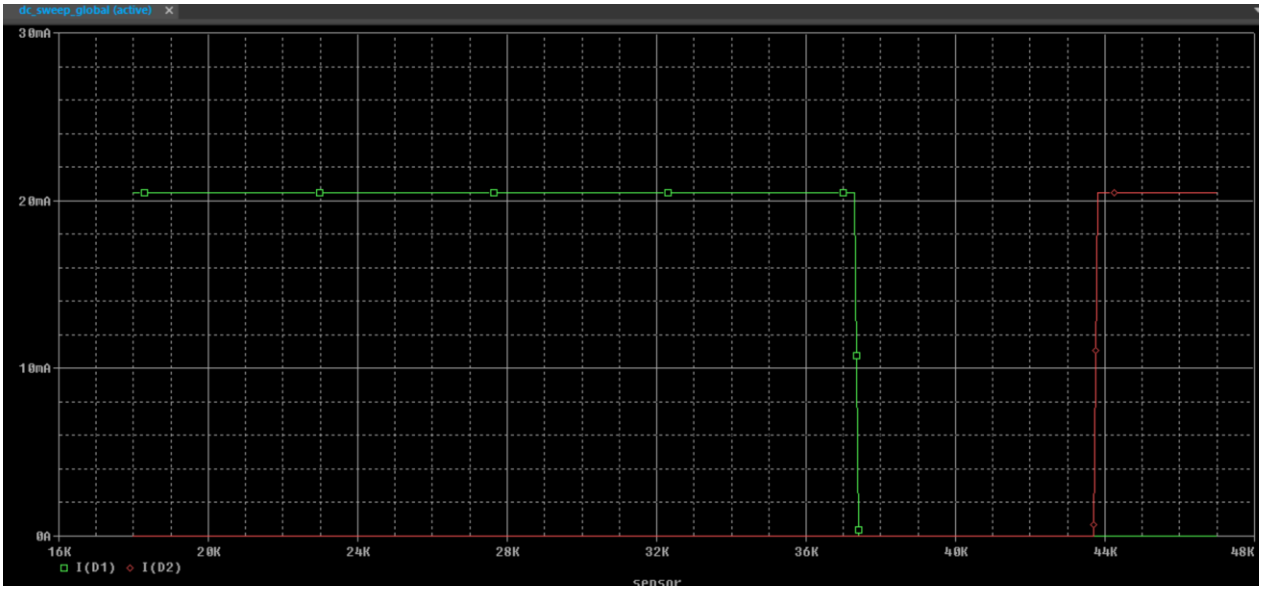


Figure 5 - Comparators output voltages

4.3.2 Inverting Simple Comparator

Similarly, I needed an inverting simple comparator in the circuit with the purpose of keeping the LED ON in the range of [0 kΩ – 37.333 kΩ] (Figure 5), or the inferior range, 37.333kΩ corresponding to the inferior weight.

4.4 Addition of the LED+BJT ensembles

I added the 2 BJT transistors, Q1 and Q2, because the forward current through the yellow LEDs, LY_N971, is of 20mA, and the current at the outputs of the comparators was even lower than 10mA, so that amplifying capabilities of the BJT transistors were needed. In this way, the current is amplified to about 20.45mA.

I chose to use the LMC6036/NS op-amp, due it being rail-to-rail and to the range being enough for my desired output. It allows up to 15.5V, while I only need 10V.

4.5 Electrical scheme BEFORE standardization

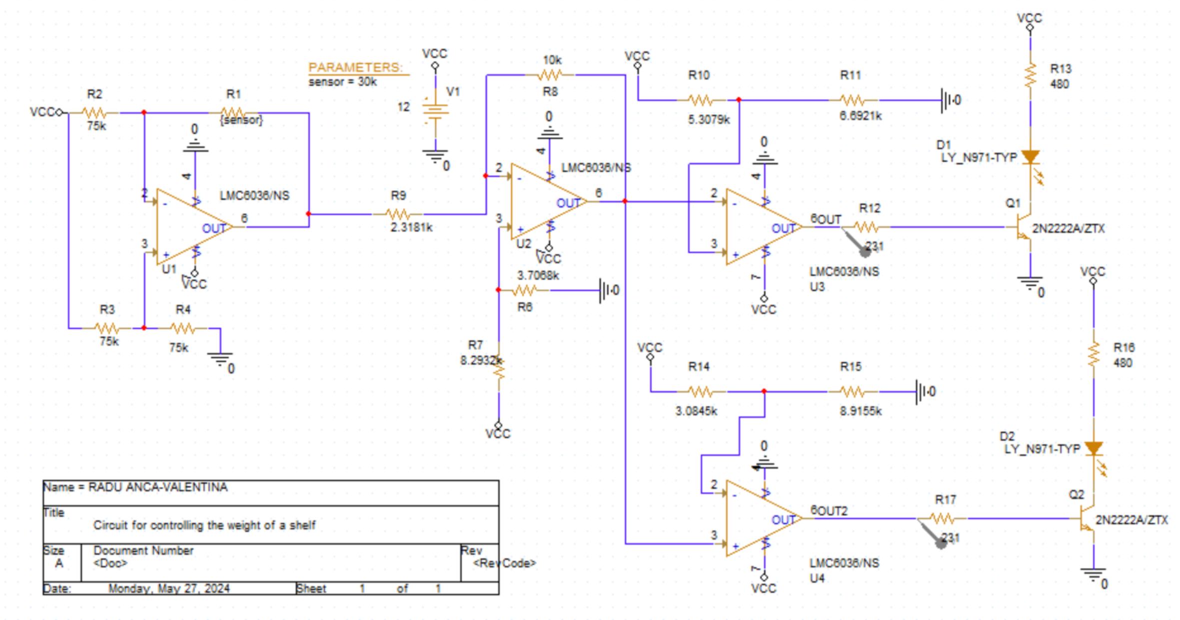


Figure 6 - Electrical scheme BEFORE standardization

4.6 Electrical scheme AFTER standardization

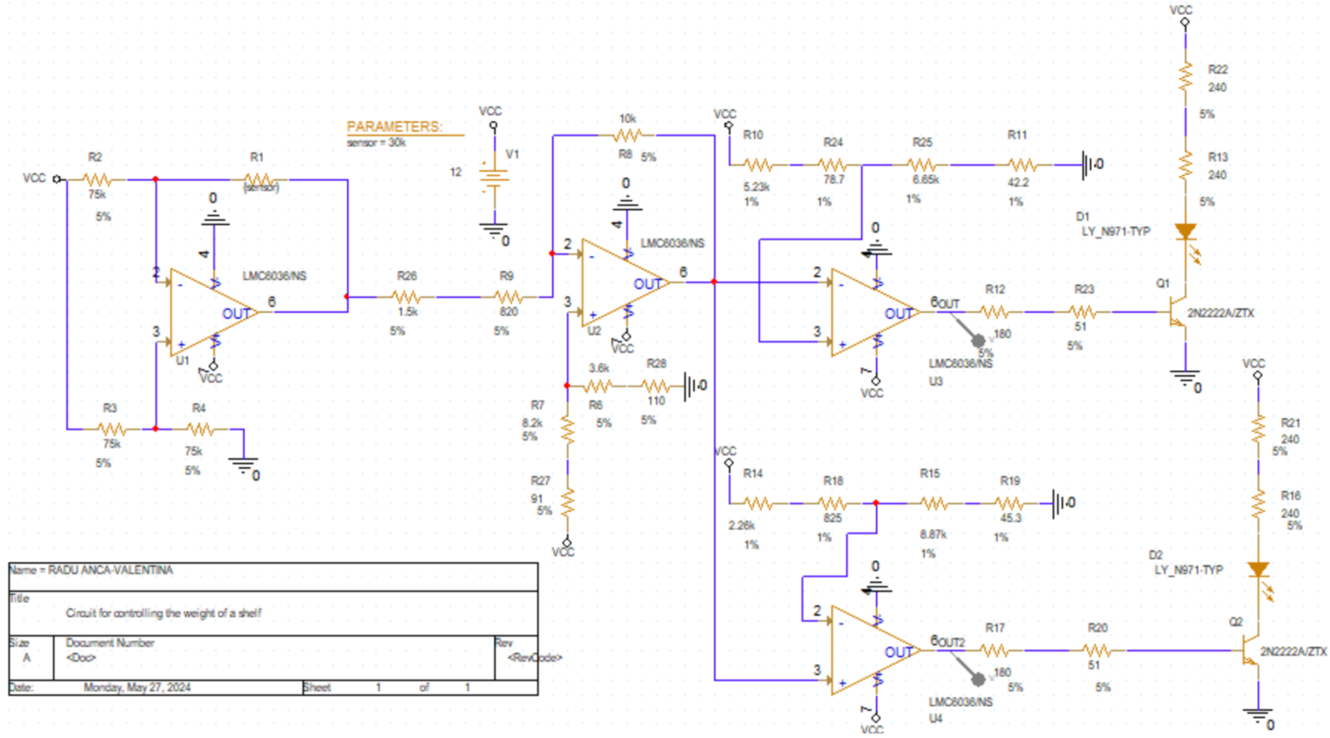


Figure 7 - Electrical scheme AFTER standardization

5. Summary of Calculations (Before standardization)

5.1 Active Bridge

No calculations were needed for the active bridge, I only set the resistance R1 as a parameter named "sensor", taking values in the [18kΩ – 47kΩ] range and, as specified before, through iterations, the 75 kΩ resistance was chosen, after realizing that the output was distorted at the end when a smaller value for the resistances R2, R3 and R4 was set.

5.2 Voltage Domain Converter

Analyzing the output of the bridge, we get:

$$v_{cd\ max} = 4.5662V$$

$$v_{cd\ min} = 2.2481V$$

The desired output:

$$v_{o\ max} = 10V$$

$$v_{o\ min} = 0V$$

To calculate V_{REF}, we need the values for R_8, R_9:

$$\frac{R_8}{R_9} = \frac{v_{o\ max} - v_{o\ min}}{v_{cd\ max} - v_{cd\ min}} = \frac{10}{2.3181}$$

$$=> R_8 = 10k\Omega$$

$$R_9 = 2.3181k\Omega$$

$$V_{REF} = \frac{v_{o\ min} - \frac{R_8}{R_9} * v_{cd\ max}}{1 + \frac{R_8}{R_9}}$$

Finally,

$$V_{REF} = 3.7068V$$

In order to have a single supply in the circuit, V_{CC}, a voltage divider will be used to get V_{REF}.

$$V_{REF} = V_{CC} * \frac{R_6}{R_7 + R_6}$$

$$3.7068 = 12 * \frac{R_6}{R_7 + R_6}$$

We get:

$$R_6 = 3.7068k\Omega$$

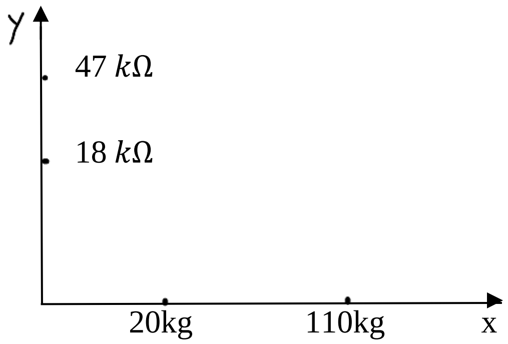
$$R_7 = 8.2932k\Omega$$

5.3 Simple Comparators

To compute the values for these circuits, I needed to make the correspondence between the weight range supported by the shelf and its equivalent resistance range. This allows calculating the resistances in order to form the reference voltages.

$$V_{REF3} = \frac{R_{11}}{R_{10} + R_{11}} * V_{CC}$$

To find V_{REF}, we calculate the slope using



$$y = m * x + n$$

$$y = \frac{\delta y}{\delta x}$$

$$y = \frac{29}{90}$$

We use:

$$y = m * (x - 20) + 18 = \frac{29}{90} * (x - 20) + 18$$

For the superior value: $y = \frac{29}{90} * (100 - 20) + 18$

$$y = 43.777\ k\Omega$$

We look for the $43.777k\Omega$ value with a cursor on the output of the domain converter (Figure 8), and we get:

$$V_{REF2} = 8.9155V$$

We create a voltage divider for V_{REF2}, using the NON-INVERTING comparator

We use the formula:

$$V_{REF2} = \frac{R_{15}}{R_{14}+R_{15}},$$

and we get:

$$R_{14} = 3.0845k\Omega$$

$$R_{15} = 8.9155k\Omega$$

For the inferior value: $y = \frac{29}{90} * (80 - 20) + 18$

$$y = 37.333k\Omega$$

We look for the $37.777k\Omega$ value with a cursor on the output of the domain converter (Figure 8), and we get

$$V_{REF3} = 6.6921V$$

We create a voltage divider for V_{REF3}, using the INVERTING comparator:

We use the formula:

$$V_{REF3} = \frac{R_{11}}{R_{10}+R_{11}},$$

and we get:

$$R_{10} = 5.3079k\Omega$$

$$R_{11} = 6.6921k\Omega$$

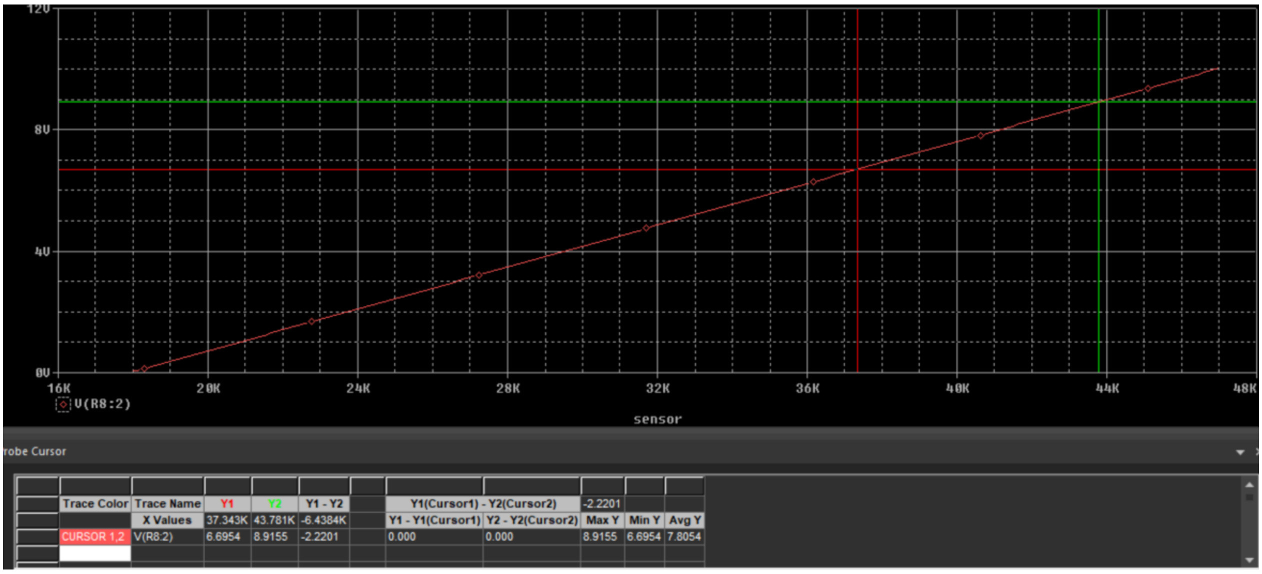


Figure 8 – Resistance and weight correspondence

5.4 LED+BJT ENSEMBLE

To size R_{12} and R_{17}, we use Ohm's law. At that moment, the voltage through the resistance R_{12} was 4.62V. (Since then, I have found that I had done a mistake in making one of the correspondences, which resulted in a circuit that, ultimately, had to be changed, but after that change, I left the value of the resistance R_{12} the same, and it works perfectly.)

Thus, using Ohm's law, $R = \frac{V}{I}$

having the *forward current* of the LED, $I_F = 20mA$

we get

$$R_{12} = R_{17} = 231\Omega$$

Using KVL, we compute R_{13} and R_{16}:

The forward voltage of the LED is $V_F = 2.2V$

The saturation voltage of the BJT is $V_{CE\,SAT} = 0.2V$

$$R_{13} = R_{16} = \frac{V_{CC} - V_{CE\,SAT} - V_F}{I_F}$$

$$R_{13} = R_{16} = 480\Omega$$

6. Standardization

Table 1

Name	Initial Value [Ω]	Final Value [Ω]	Tolerance [%]
R_1	{sensor}	{sensor}	-
R_2	75k	75k	5
R_3	75k	75k	5
R_4	75k	75k	5
R_6	3.7068k	3.6k + 110	5
R_7	8.2932k	8.2k + 91	5
R_8	10k	10k	5
R_9	2.3181k	820 + 1.5k	5
R_{10}	5.3079k	5.23k + 78.7	1
R_{11}	6.6921k	6.65k + 42.2	1
R_{12}	231	180 + 51	1

R_{13}	480	240 + 240	5
R_{14}	3.0845k	2.26k + 825	1
R_{15}	8.9155k	8.87k + 45.3	1
R_{16}	480	240 + 240	5
R_{17}	231	180 + 51	1

Bill of Materials

Table 2

NAME	QUANTITY	CODE	PRICE/unit [RON]
U1,U2,U3,U4	4	LMC6036IMX/NOPB	7.82
R2, R3, R4	3	RSF100JB-73-75K	1.29
R6	1	RSF-50JT-52-3K6	0.87
R7	1	ROX05SJ8K2	0.827
R9	1	MOSX1CT528RR82J	1.94
R10	1	MBA02040C5231FC100	2.95
R8	1	ROX05SJ10K	1.10
R11	1	MRS25000C4229FRP00	1.84
R12, R17	2	3430A3F180RTDF	3.64
R13, R16, R21, R22	4	MBE04140C2400FC100	2.99
R14	1	CCF552K26FKE36	1.38
R15	1	MBA02040C8871FRP00	1.80
R18	1	CCF55825RFKE36	0.965
R19	1	CCF5545R3FKE36	1.38
R20, R23	2	3430H2F51RTDF	2.86
R25	1	CRCW12106K65FKEA	1.01
R24	1	ERJ-8ENF78R7V	0.554
D1,D2	2	LT Q99G.01-R2T1-25-1	1.2
Q1,Q2	2	2N2222A	0.644
TOTAL			80.414

7. Simulation Results

7.1 Active Bridge output – 75kΩ resistances

In this simulation (Figure 9), it is noticeable that the distortion of the output disappeared by changing the 47kΩ resistances to 75kΩ ones.

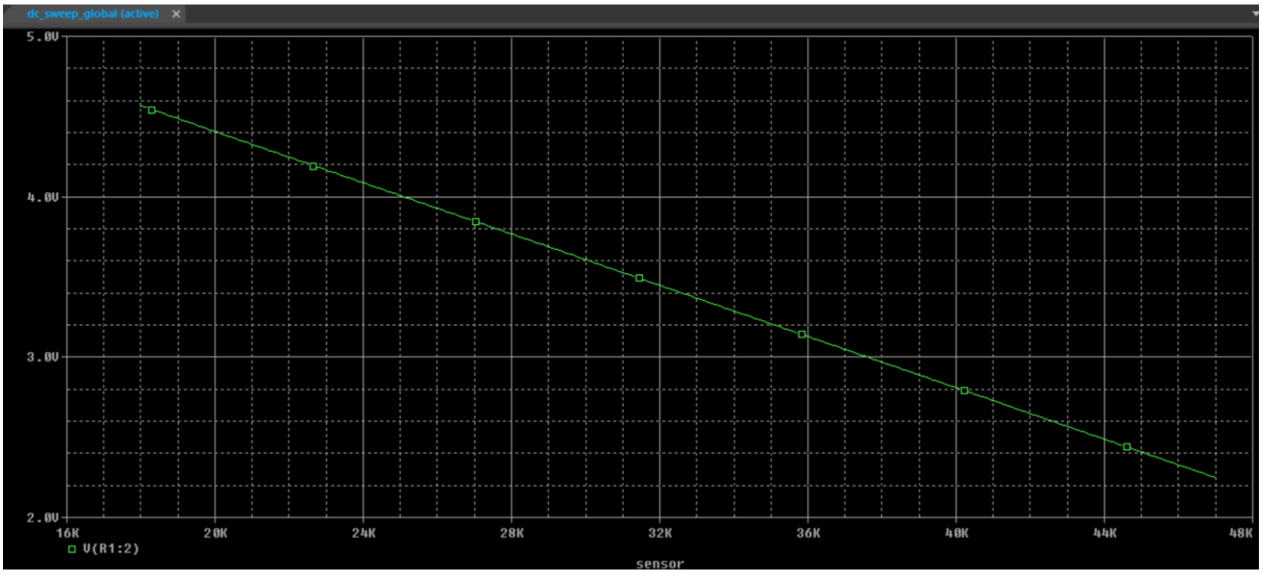


Figure 9 - Active Bridge output for 75 kΩ resistances

7.2 DC SWEEP – Global parameter

This simulation sweeping the value of the global parameter “sensor”, serves to demonstrate the thresholds at which the LED turns off, having a window where the shelf holds a weight in the desired range (Figure 10). The values of the thresholds are presented in Figure 11.

Moreover, the current through both LEDs is at approximately 20.45mA the forward current of the LY_N971 LED being 20mA (Figure 12).

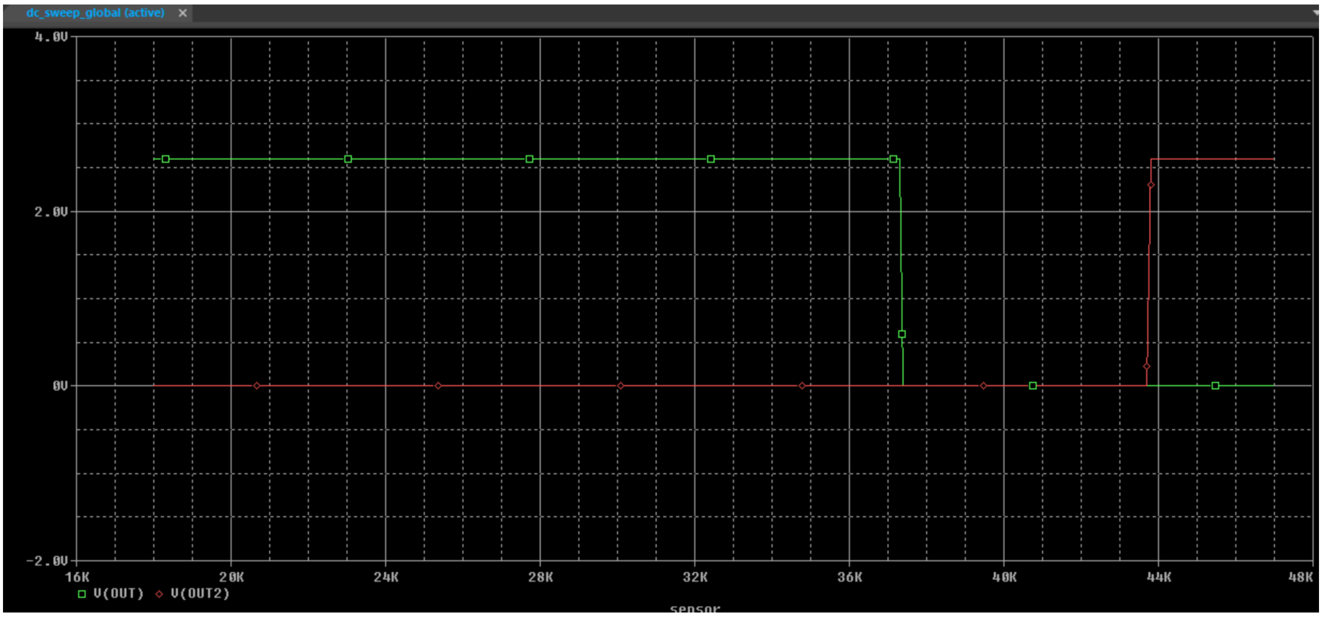


Figure 10 – Voltages at outputs of comparators

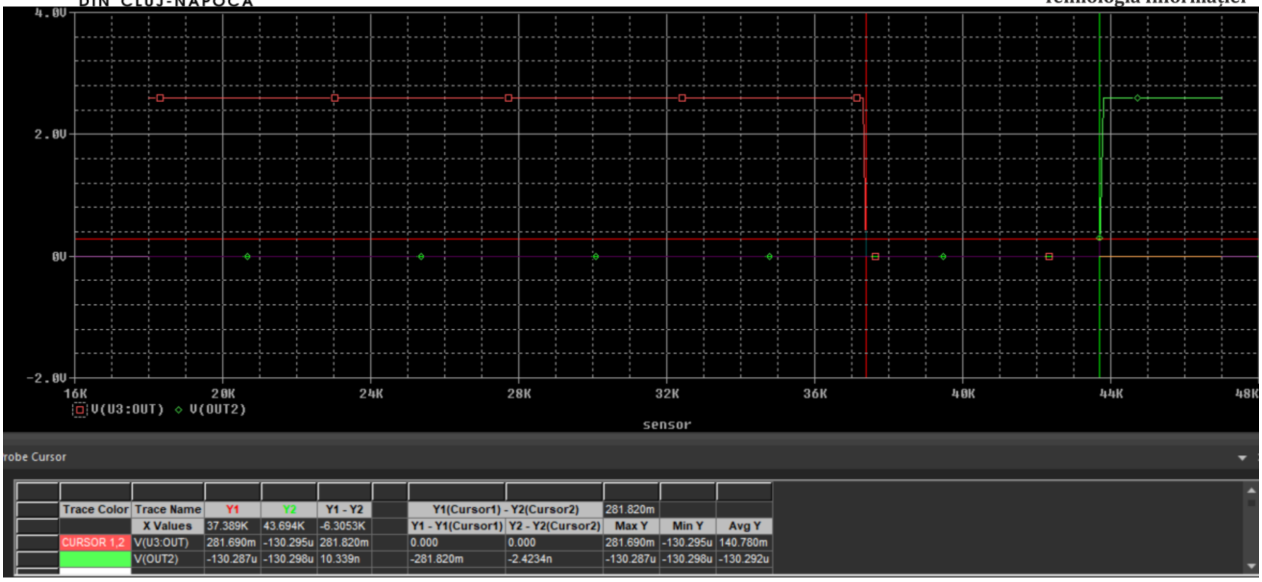


Figure 11 – Threshold voltages values

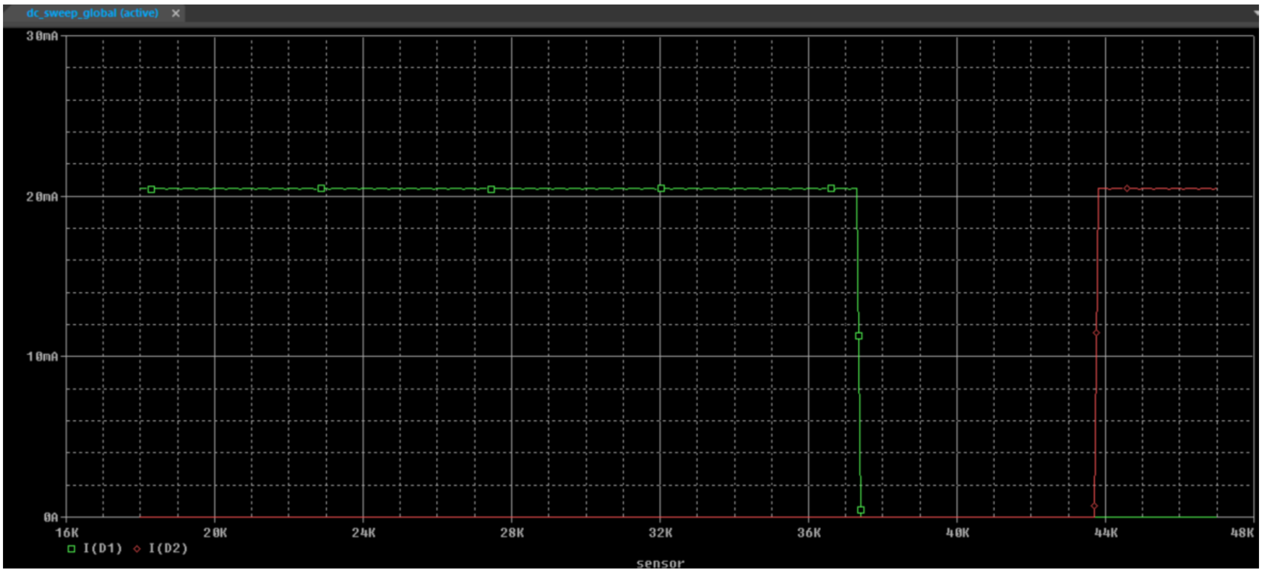


Figure 12 – Currents through LEDs

Simulation settings:

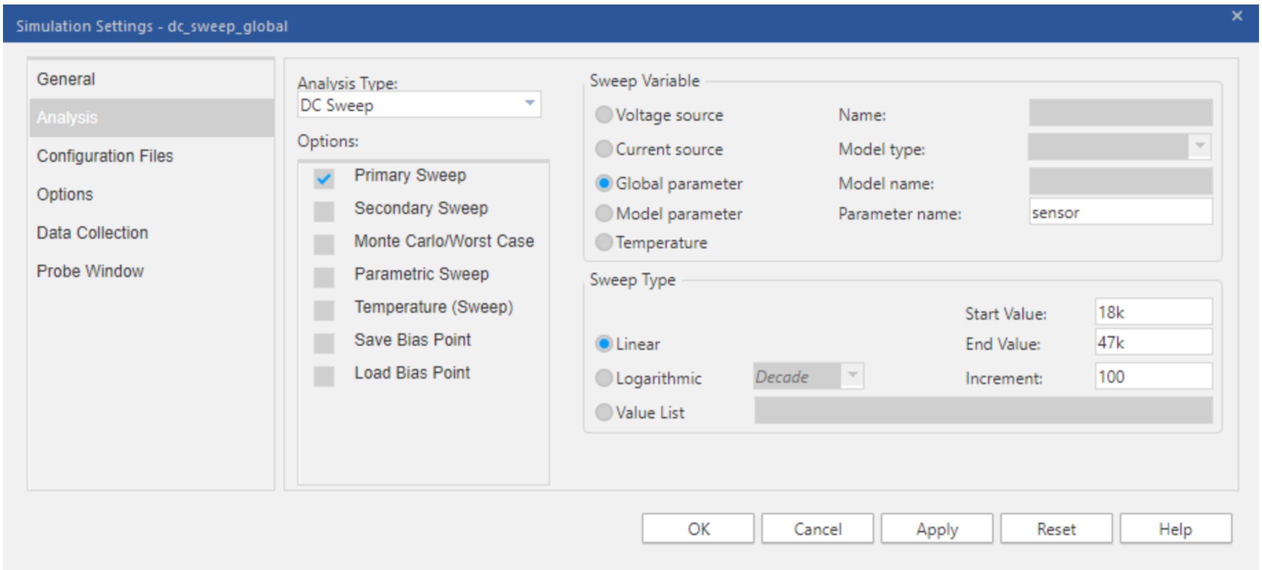


Figure 13 - DC SWEEP Global Parameter Simulation Settings

7.3 DC Sweep –LEDs

In this simulation (Figure 14, Figure 15), we can notice the tight correspondence between the output voltages and the currents through the LEDs.

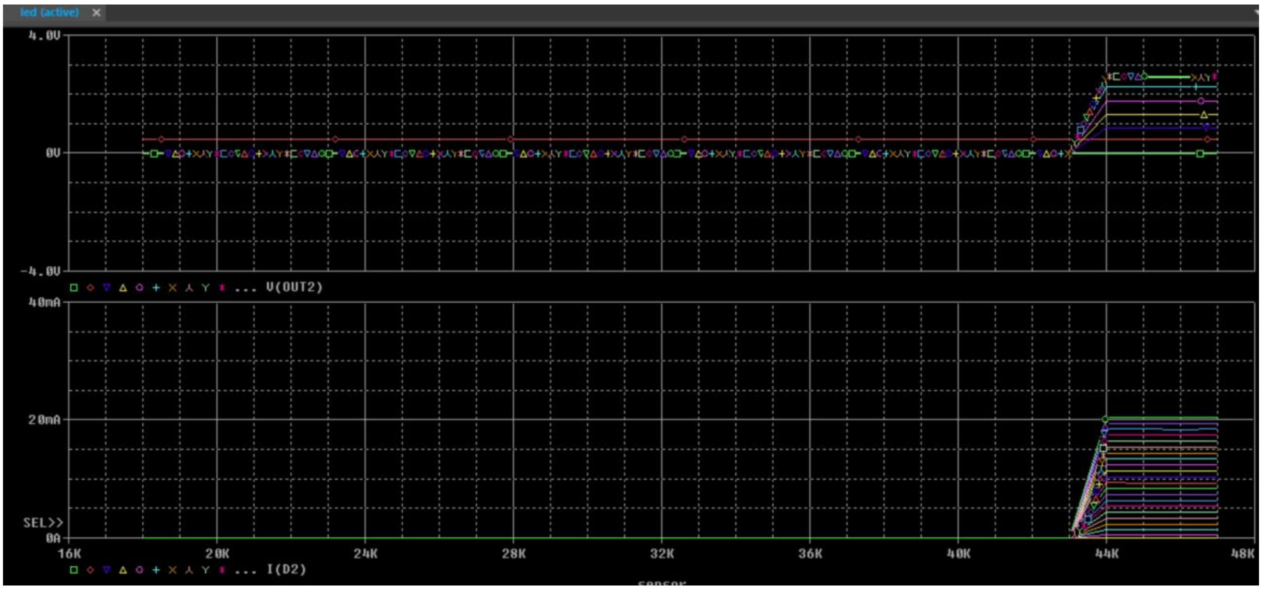


Figure 14 - LED2

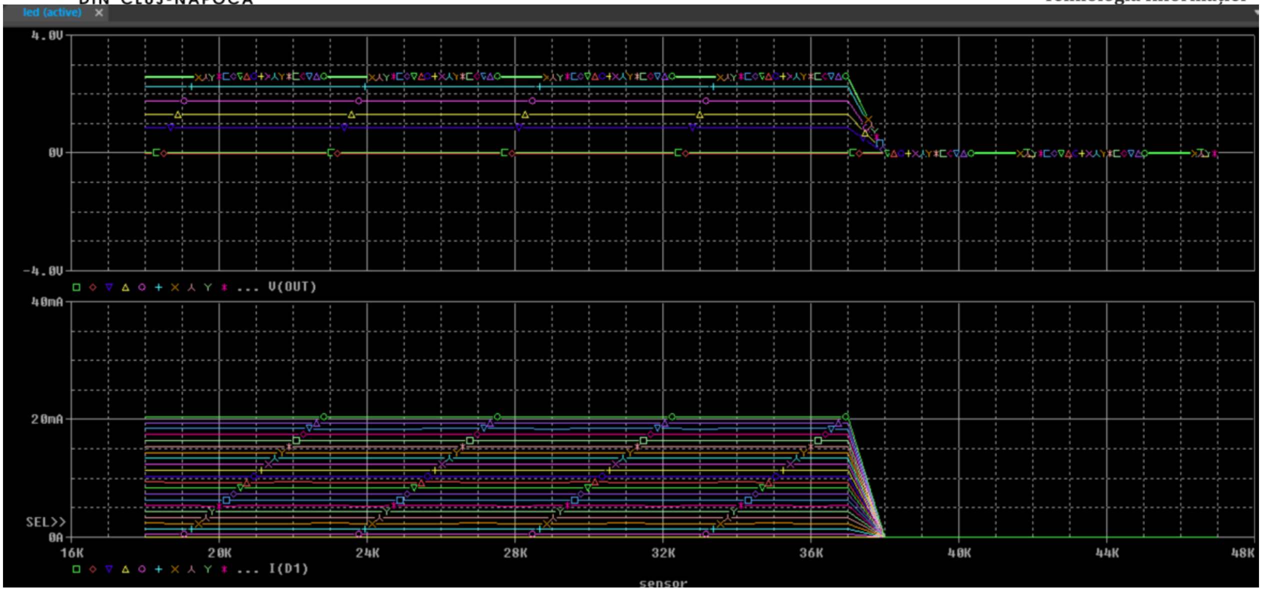


Figure 15 – LED1

Simulation settings:

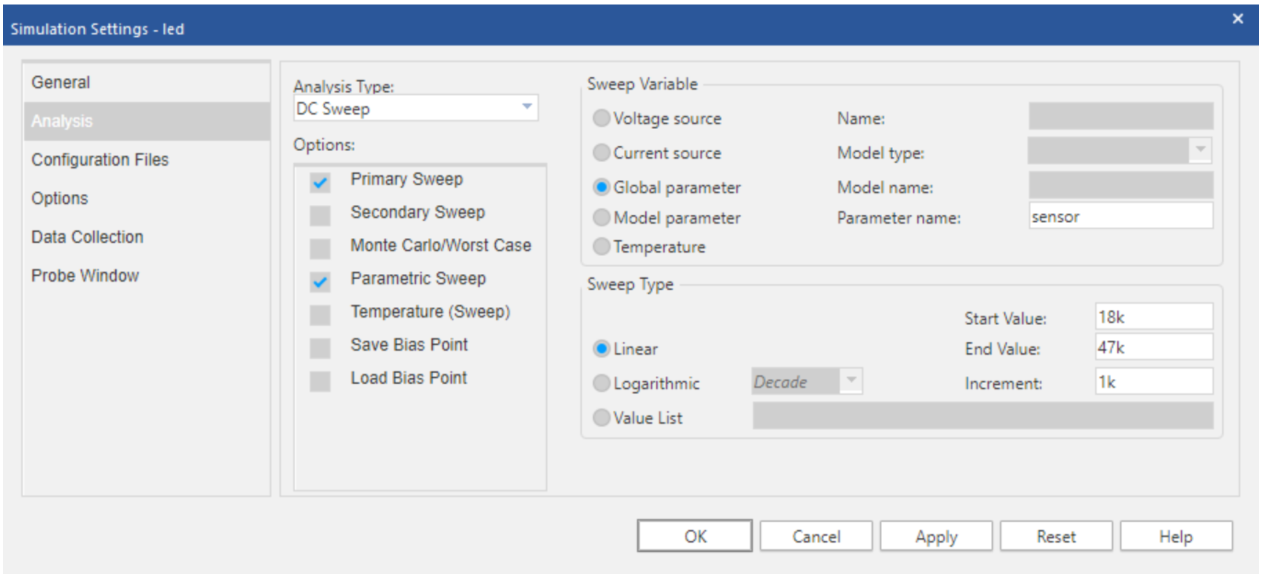


Figure 16 - DC Sweep Simulation Settings 1

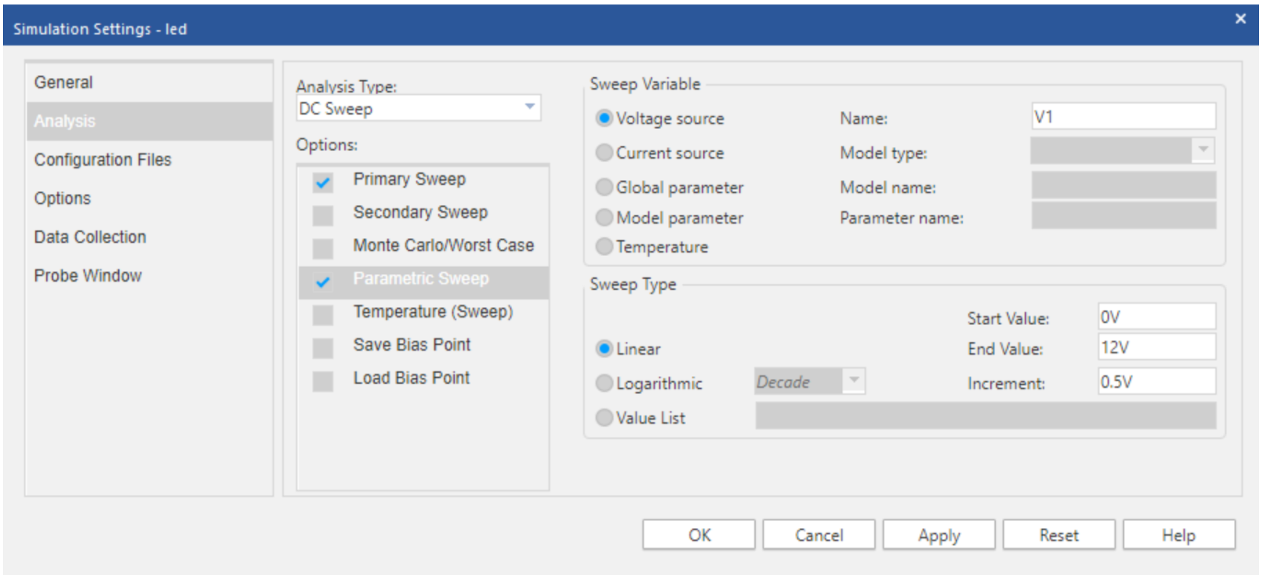


Figure 17 - DC Sweep Simulation Settings 2

7.4 Transient regime

This simulation is useful in demonstrating that the currents through the LEDs, the voltages at the outputs of the comparators and of the voltage domain converter are correct, no matter the sweeping of the resistance.

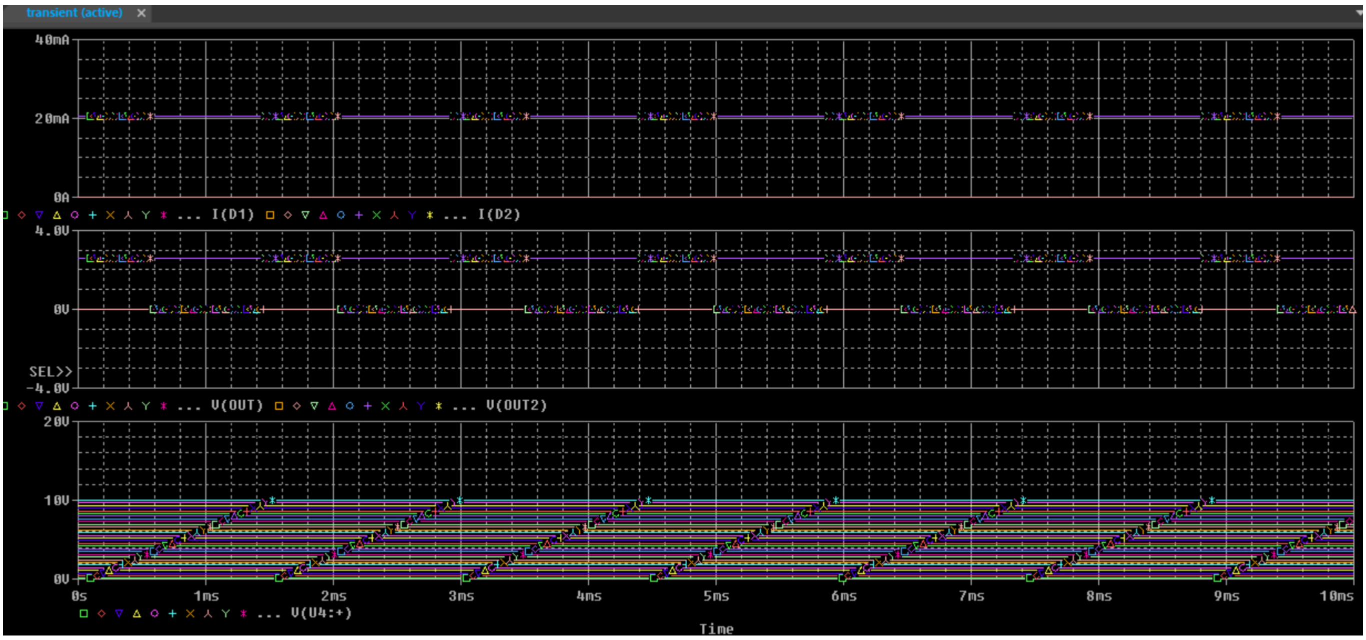


Figure 18 - Transient Regime Simulation

Simulation settings:

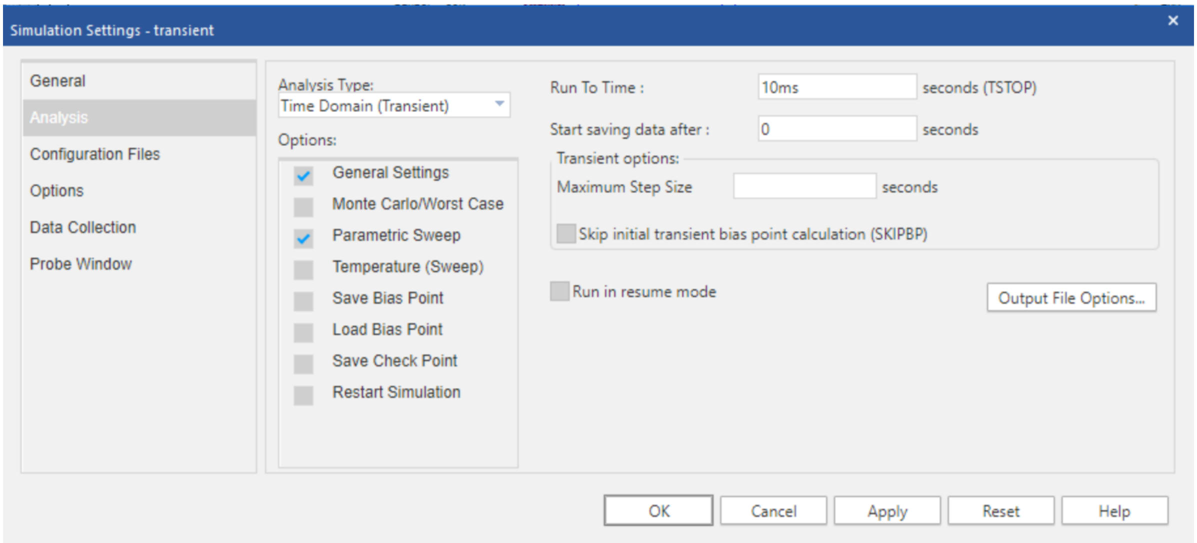


Figure 19 - Transient Regime Simulation General Settings

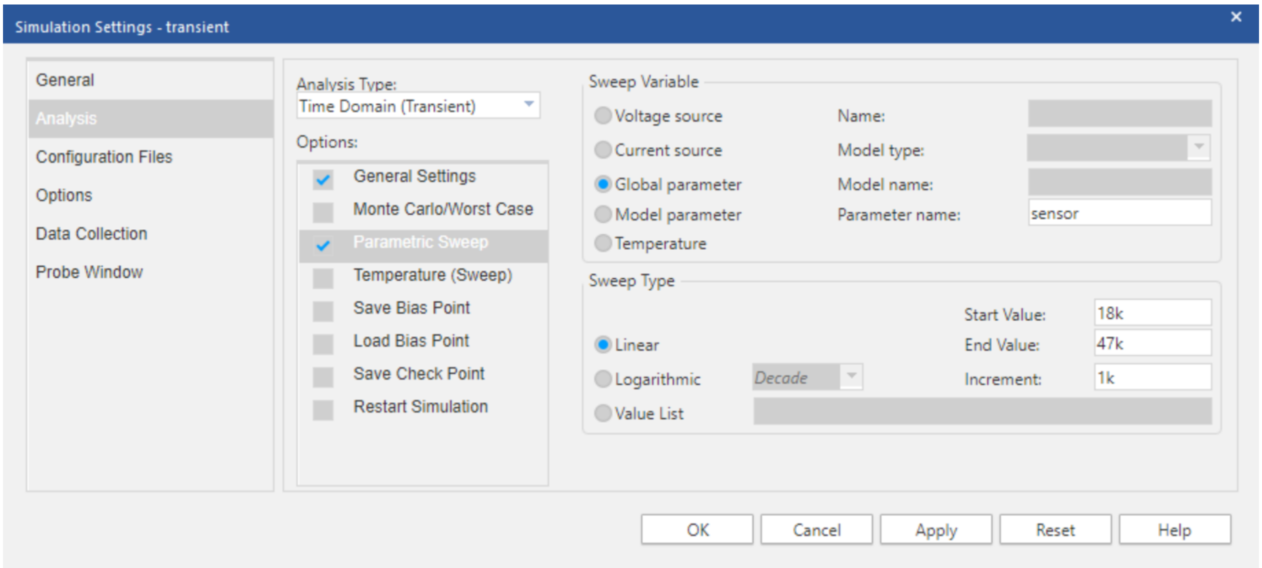


Figure 20 - Transient Regime Simulation Parametric Sweep Settings

7.5 Monte Carlo

This simulation performs a statistical analysis, that determines the impact the standardization had on the circuit. In Figure 21, the histogram represents the total variation of the voltage at the output of the inverting comparator. In Figure 22, it represents the total variation of the voltage at the output of the non-inverting comparator.

The next figure, Figure 23, shows how the voltage varies with the tolerance, for the inverting comparator and Figure 24, for the non-inverting one.

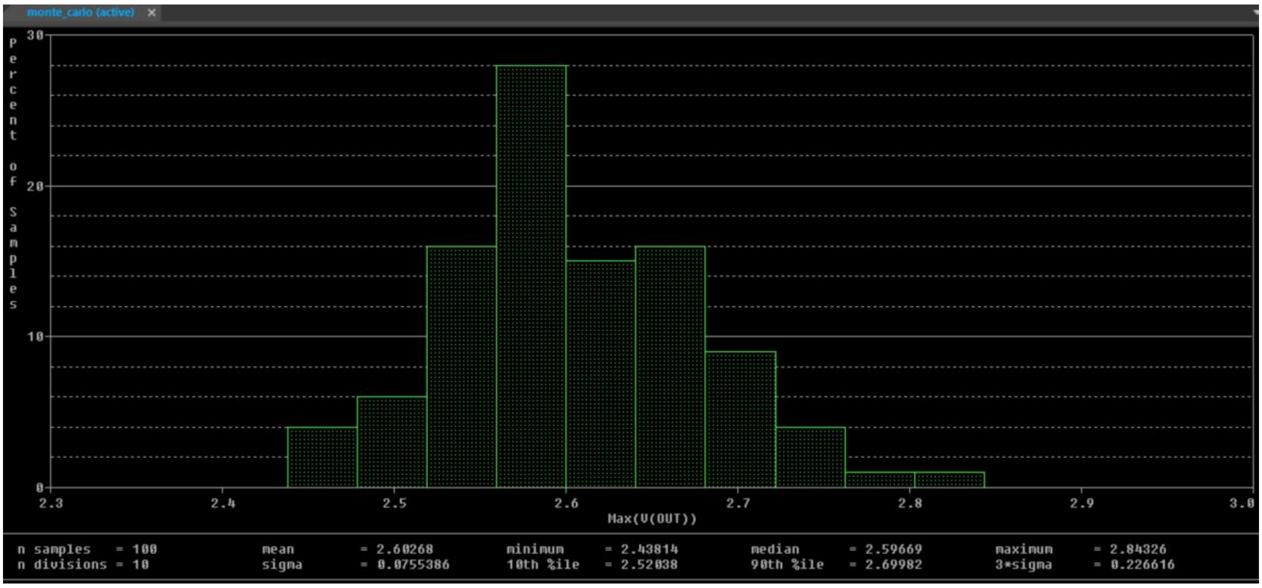


Figure 21 - Histogram for Inverting

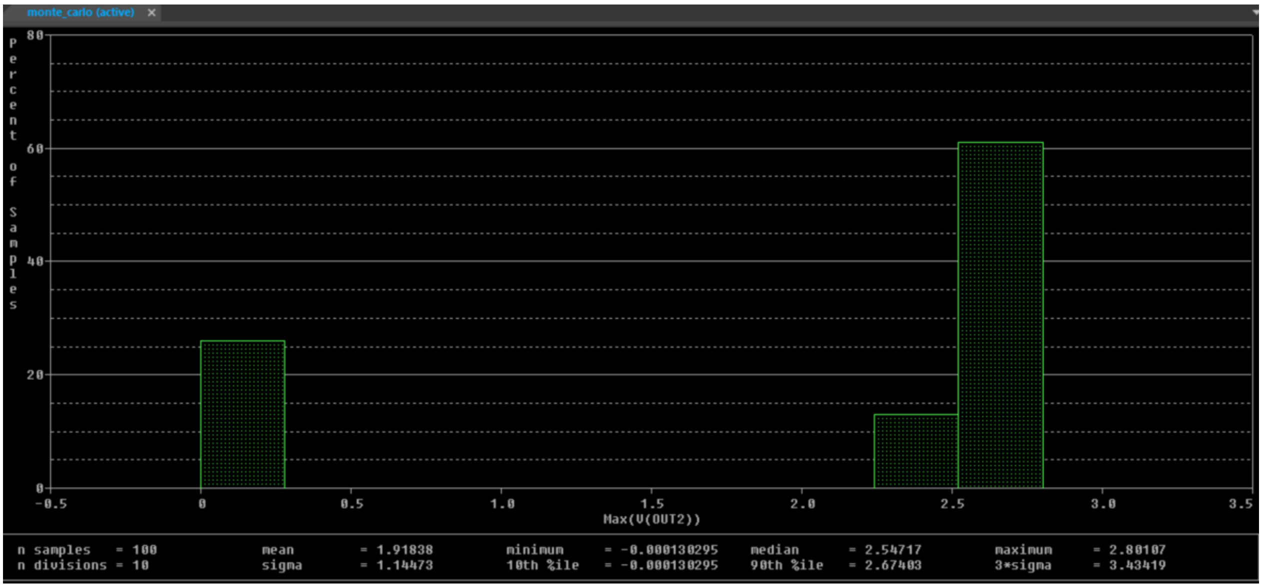


Figure 22 - Histogram for Non-Inverting

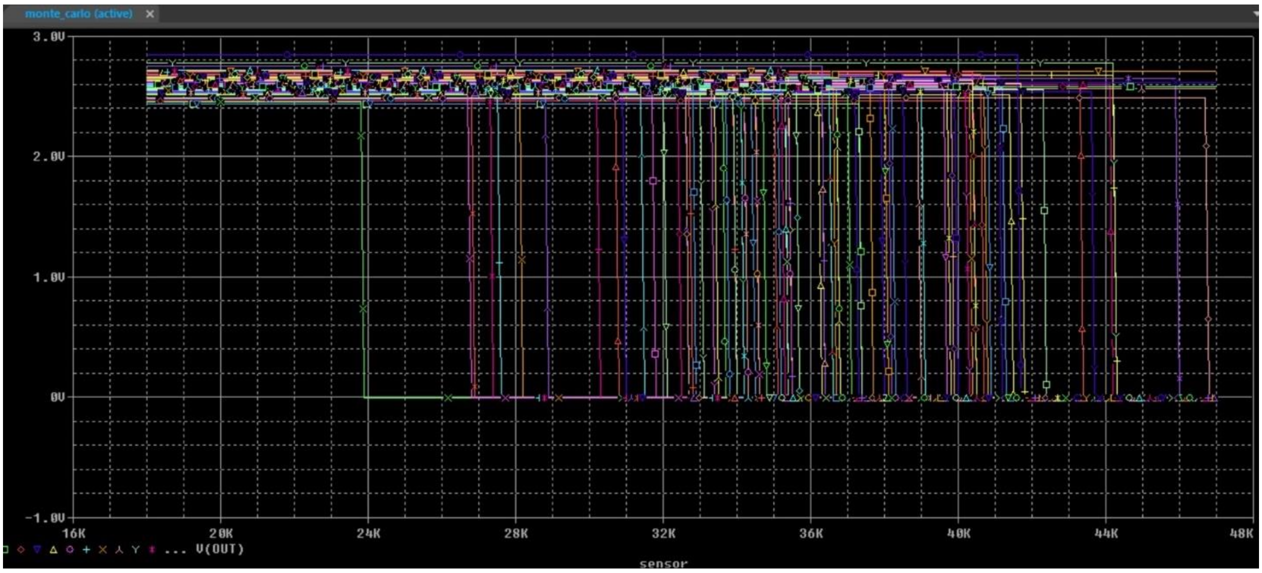


Figure 23 - Voltages Variation for Inverting

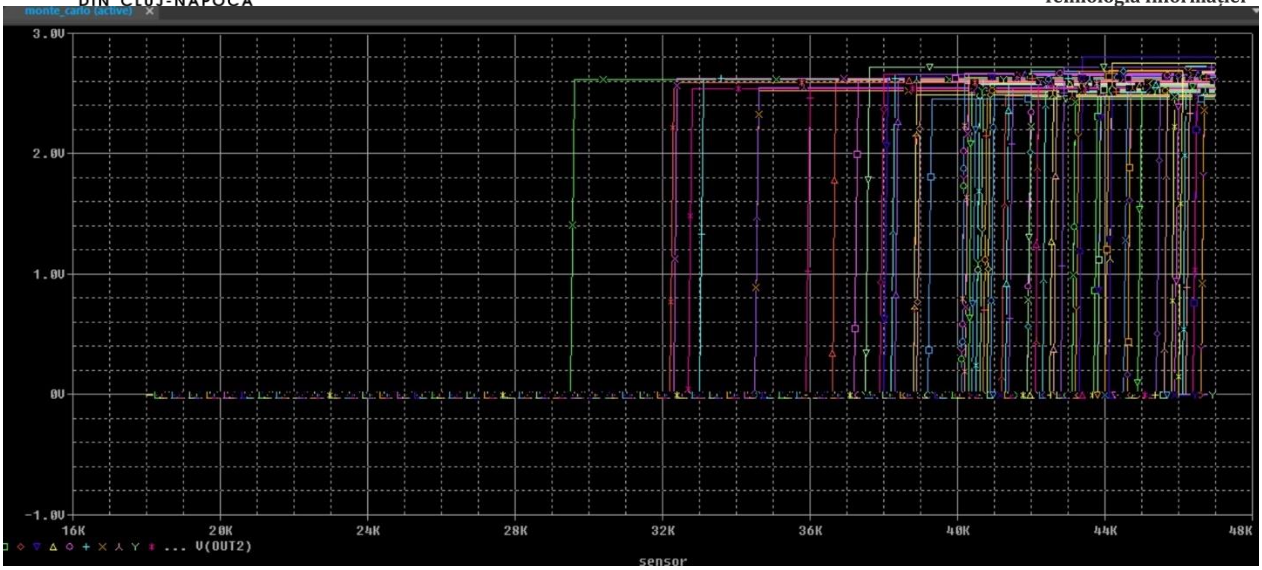


Figure 24 - Voltages Variation for Non-Inverting

Simulation settings:

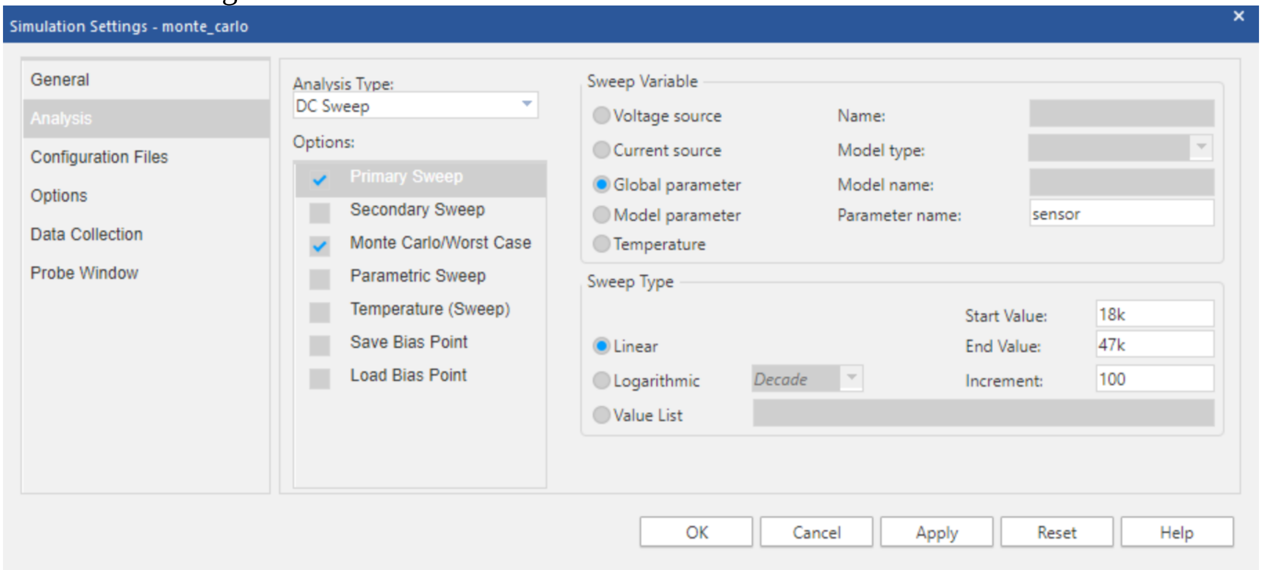


Figure 25 - Monte Carlo Simulation Settings - Primary Sweep

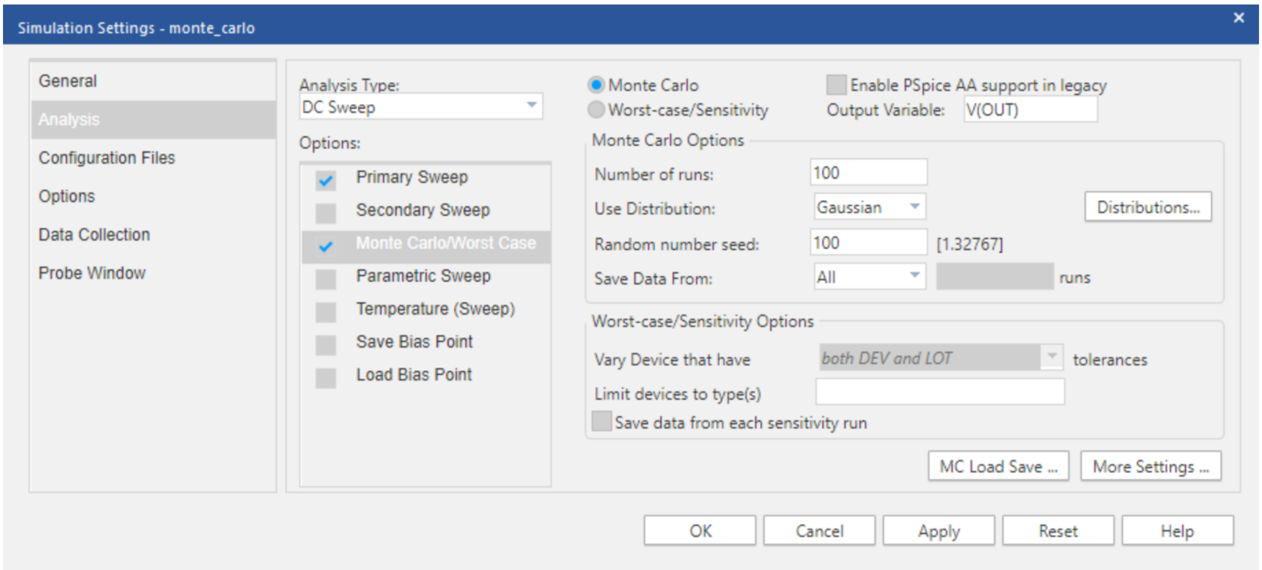


Figure 26 - Monte Carlo Simulation Settings - Monte Carlo Inverting

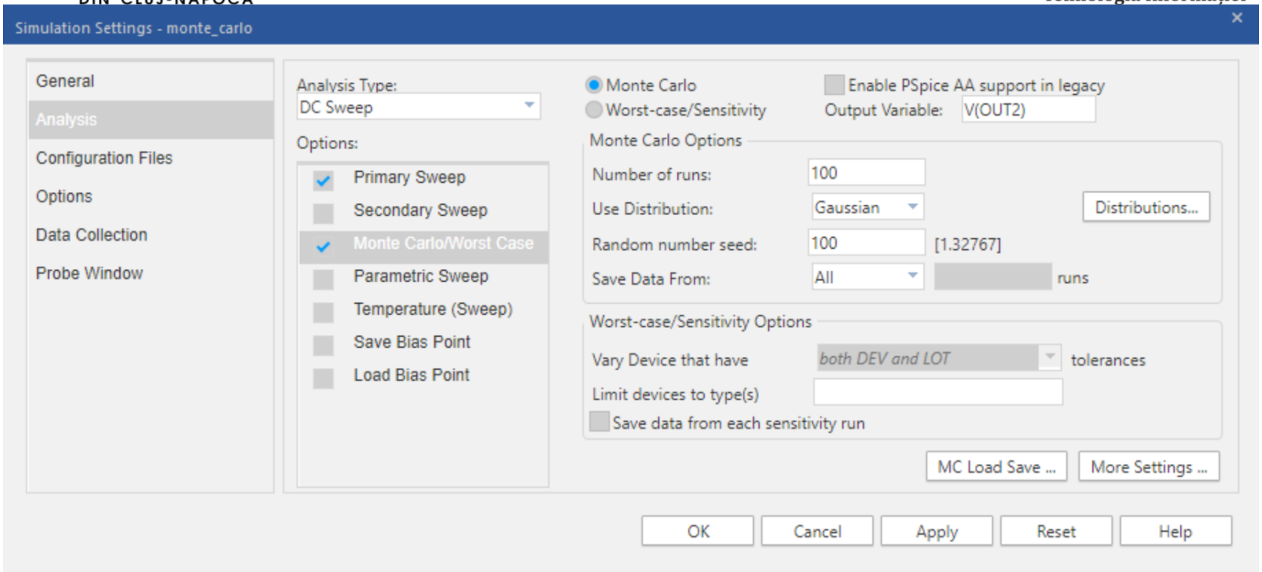


Figure 27 - Monte Carlo Simulation Settings - Monte Carlo Non-Inverting

7.6 Worst-Case Analysis

To find out the worst impact the deviation of tolerances could have on the circuit, we perform a worst-case analysis.

For the output of the inverting comparator, we get:

SENSITIVITY SUMMARY

****

Mean Deviation = -.2261

Sigma = .7329

RUN MAX DEVIATION FROM NOMINAL

R_R3 R_R3 R 2.601 (3.55 sigma) lower at sensor = 37.3000E+03

(-1.0001E+03% change per 1% change in Model Parameter)

R_R6 R_R6 R 2.601 (3.55 sigma) lower at sensor = 37.3000E+03

(-1.0001E+03% change per 1% change in Model Parameter)

R_R12 R_R12 R 1.4536E-03 (.00 sigma) higher at sensor = 18.0000E+03

(.5589% change per 1% change in Model Parameter)

R_R23 R_R23 R 411.9900E-06 (.00 sigma) higher at sensor = 18.0000E+03

(.1584% change per 1% change in Model Parameter)

R_R13 R_R13 R 8.5831E-06 (.00 sigma) lower at sensor = 18.0000E+03

(-3.3000E-03% change per 1% change in Model Parameter)

R_R22 R_R22 R 8.5831E-06 (.00 sigma) lower at sensor = 18.0000E+03

(-3.3000E-03% change per 1% change in Model Parameter)

R_R26 R_R26 R 14.7700E-09 (.00 sigma) higher at sensor = 43.3000E+03

(-.1134% change per 1% change in Model Parameter)

R_R4 R_R4 R 9.1095E-09 (.00 sigma) higher at sensor = 43.0000E+03

(-.0699% change per 1% change in Model Parameter)

R_R25 R_R25 R 3.2742E-09 (.00 sigma) lower at sensor = 43.8000E+03

(.0251% change per 1% change in Model Parameter)

R_R9 R_R9 R 3.1869E-09 (.00 sigma) higher at sensor = 43.7000E+03

(-.0245% change per 1% change in Model Parameter)

R_R8 R_R8 R 2.7212E-09 (.00 sigma) lower at sensor = 37.9000E+03

(.0209% change per 1% change in Model Parameter)

R_R11 R_R11 R 1.5862E-09 (.00 sigma) lower at sensor = 46.2000E+03

(.0122% change per 1% change in Model Parameter)

R_R2 R_R2 R 1.5134E-09 (.00 sigma) higher at sensor = 43.1000E+03

(-.0116% change per 1% change in Model Parameter)

R_R28 R_R28 R 1.5134E-09 (.00 sigma) higher at sensor = 43.1000E+03

(-.0116% change per 1% change in Model Parameter)

R_R27 R_R27 R 1.5134E-09 (.00 sigma) higher at sensor = 43.1000E+03

(-.0116% change per 1% change in Model Parameter)

R_R10 R_R10 R 1.5134E-09 (.00 sigma) higher at sensor = 43.1000E+03

(-.0116% change per 1% change in Model Parameter)

R_R15 R_R15 R 1.5134E-09 (.00 sigma) higher at sensor = 44.1000E+03

(-.0116% change per 1% change in Model Parameter)

R_R7 R_R7 R 1.5134E-09 (.00 sigma) higher at sensor = 43.1000E+03

(-.0116% change per 1% change in Model Parameter)

R_R24 R_R24 R 1.4843E-09 (.00 sigma) higher at sensor = 43.1000E+03

(-.0114% change per 1% change in Model Parameter)

R_R16 R_R16 R 1.4843E-09 (.00 sigma) higher at sensor = 43.3000E+03

(-.0114% change per 1% change in Model Parameter)

R_R18 R_R18 R 1.4843E-09 (.00 sigma) higher at sensor = 43.3000E+03

(-.0114% change per 1% change in Model Parameter)

R_R21 R_R21 R   1.4843E-09 (.00 sigma) higher at sensor =   43.3000E+03

(-.0114% change per 1% change in Model Parameter)

R_R17 R_R17 R   1.4843E-09 (.00 sigma) higher at sensor =   43.3000E+03

(-.0114% change per 1% change in Model Parameter)

R_R14 R_R14 R   0   (0.00 sigma) unchanged at sensor =   0

(0   % change per 1% change in Model Parameter)

R_R19 R_R19 R   0   (0.00 sigma) unchanged at sensor =   0

(0   % change per 1% change in Model Parameter)

R_R20 R_R20 R   0   (0.00 sigma) unchanged at sensor =   0

(0   % change per 1% change in Model Parameter)

**** 05/27/24 01:24:33 ***** PSpice 23.1.0 (17 April 2024) **** ID# 0 ********

** Profile: "SCHEMATIC1-worst_case" [D:\Docs D\OrCAD Projects\FINAL_PROJECT_CAD\FINAL_PROJECT_CAD_STANDARDIZATION-PSpiceFiles\SCHE

****   UPDATED MODEL PARAMETERS   TEMPERATURE =   27.000 DEG C

WORST CASE ALL DEVICES

Device	MODEL	PARAMETER	NEW VALUE	
R_R23	R_R23	R	1.05	(Increased)
R_R9	R_R9	R	1.05	(Increased)
R_R11	R_R11	R	.99	(Decreased)
R_R2	R_R2	R	1.05	(Increased)
R_R14	R_R14	R	1	(Unchanged)
R_R28	R_R28	R	1.05	(Increased)
R_R26	R_R26	R	1.05	(Increased)
R_R24	R_R24	R	1.01	(Increased)
R_R16	R_R16	R	1.05	(Increased)
R_R18	R_R18	R	1.01	(Increased)
R_R21	R_R21	R	1.05	(Increased)
R_R17	R_R17	R	1.05	(Increased)
R_R27	R_R27	R	1.05	(Increased)
R_R13	R_R13	R	.95	(Decreased)
R_R22	R_R22	R	.95	(Decreased)
R_R3	R_R3	R	.95	(Decreased)
R_R8	R_R8	R	.95	(Decreased)
R_R4	R_R4	R	1.05	(Increased)
R_R10	R_R10	R	1.01	(Increased)

R_R15 R_R15 R 1.01 (Increased)

R_R7 R_R7 R 1.05 (Increased)

R_R12 R_R12 R 1.05 (Increased)

R_R25 R_R25 R .99 (Decreased)

R_R19 R_R19 R 1 (Unchanged)

R_R6 R_R6 R .95 (Decreased)

R_R20 R_R20 R 1 (Unchanged)

**** 05/27/24 01:24:33 ***** PSpice 23.1.0 (17 April 2024) **** ID# 0 ********

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**** SORTED DEVIATIONS OF V(OUT) TEMPERATURE = 27.000 DEG C

WORST CASE SUMMARY

****

Mean Deviation = 2.6952

Sigma = 0

RUN MAX DEVIATION FROM NOMINAL

WORST CASE ALL DEVICES

2.6952 higher at sensor = 43.1000E+03

(-2.0684E+06% of Nominal)

JOB CONCLUDED

**** 05/27/24 01:24:33 ***** PSpice 23.1.0 (17 April 2024) **** ID# 0 ********

** Profile: "SCHEMATIC1-worst_case" [D:\Docs D\OrCAD Projects\FINAL_PROJECT_CAD\FINAL_PROJECT_CAD_STANDARDIZATION-PSpiceFiles\SCHE

****   JOB STATISTICS SUMMARY

****

Total job time (using Solver 1)   =   6.72

For the output of the non-inverting comparator, we get:

SENSITIVITY SUMMARY

****

Mean Deviation =   .2002

Sigma   =   .6931

RUN   MAX DEVIATION FROM NOMINAL

R_R3 R_R3 R 2.601 (3.75 sigma) higher at sensor = 43.7000E+03

(-19.9630E+06% change per 1% change in Model Parameter)

R_R6 R_R6 R 2.601 (3.75 sigma) higher at sensor = 43.7000E+03

(-19.9630E+06% change per 1% change in Model Parameter)

R_R17 R_R17 R 1.4536E-03 (.00 sigma) higher at sensor = 43.8000E+03

(.5589% change per 1% change in Model Parameter)

R_R20 R_R20 R 411.9900E-06 (.00 sigma) higher at sensor = 43.8000E+03

(.1584% change per 1% change in Model Parameter)

R_R16 R_R16 R 8.5831E-06 (.00 sigma) lower at sensor = 43.8000E+03

(-3.3000E-03% change per 1% change in Model Parameter)

R_R21 R_R21 R 8.5831E-06 (.00 sigma) lower at sensor = 43.8000E+03

(-3.3000E-03% change per 1% change in Model Parameter)

R_R28 R_R28 R 3.8126E-09 (.00 sigma) lower at sensor = 18.3000E+03

(.0293% change per 1% change in Model Parameter)

R_R8 R_R8 R 3.5507E-09 (.00 sigma) lower at sensor = 18.0000E+03

(.0273% change per 1% change in Model Parameter)

R_R26 R_R26 R 3.5361E-09 (.00 sigma) lower at sensor = 18.3000E+03

(.0271% change per 1% change in Model Parameter)

R_R9 R_R9 R 3.4051E-09 (.00 sigma) lower at sensor = 18.3000E+03

(.0261% change per 1% change in Model Parameter)

R_R2 R_R2 R 3.2160E-09 (.00 sigma) lower at sensor = 18.3000E+03

(.0247% change per 1% change in Model Parameter)

R_R7 R_R7 R 2.6193E-09 (.00 sigma) lower at sensor = 18.5000E+03

(.0201% change per 1% change in Model Parameter)

R_R4 R_R4 R 1.1933E-09 (.00 sigma) lower at sensor = 18.8000E+03

(9.1581E-03% change per 1% change in Model Parameter)

R_R22 R_R22 R 873.1100E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.7011E-03% change per 1% change in Model Parameter)

R_R18 R_R18 R 858.5600E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.5894E-03% change per 1% change in Model Parameter)

R_R23 R_R23 R 844.0100E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.4777E-03% change per 1% change in Model Parameter)

R_R27 R_R27 R 844.0100E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.4777E-03% change per 1% change in Model Parameter)

R_R15 R_R15 R 844.0100E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.4777E-03% change per 1% change in Model Parameter)

R_R19 R_R19 R 844.0100E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.4777E-03% change per 1% change in Model Parameter)

R_R13 R_R13 R 829.4600E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.3660E-03% change per 1% change in Model Parameter)

R_R25 R_R25 R 829.4600E-12 (.00 sigma) lower at sensor = 18.0000E+03

(6.3660E-03% change per 1% change in Model Parameter)

R_R11 R_R11 R 742.1500E-12 (.00 sigma) lower at sensor = 18.0000E+03

(5.6959E-03% change per 1% change in Model Parameter)

R_R24 R_R24 R 640.2800E-12 (.00 sigma) lower at sensor = 18.0000E+03

(4.9141E-03% change per 1% change in Model Parameter)

R_R12 R_R12 R 334.6900E-12 (.00 sigma) lower at sensor = 18.0000E+03

(2.5687E-03% change per 1% change in Model Parameter)

R_R14 R_R14 R 261.9300E-12 (.00 sigma) lower at sensor = 18.0000E+03

(2.0103E-03% change per 1% change in Model Parameter)

R_R10 R_R10 R 189.1700E-12 (.00 sigma) lower at sensor = 18.0000E+03

(1.4519E-03% change per 1% change in Model Parameter)

**** 05/27/24 01:28:43 ***** PSpice 23.1.0 (17 April 2024) **** ID# 0 ********

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**** UPDATED MODEL PARAMETERS TEMPERATURE = 27.000 DEG C

WORST CASE ALL DEVICES

****

Device	MODEL	PARAMETER	NEW VALUE
R_R23	R_R23	R	.95 (Decreased)
R_R9	R_R9	R	.95 (Decreased)
R_R11	R_R11	R	.99 (Decreased)
R_R2	R_R2	R	.95 (Decreased)
R_R14	R_R14	R	.99 (Decreased)
R_R28	R_R28	R	.95 (Decreased)
R_R26	R_R26	R	.95 (Decreased)
R_R24	R_R24	R	.99 (Decreased)
R_R16	R_R16	R	.95 (Decreased)
R_R18	R_R18	R	.99 (Decreased)
R_R21	R_R21	R	.95 (Decreased)
R_R17	R_R17	R	1.05 (Increased)
R_R27	R_R27	R	.95 (Decreased)
R_R13	R_R13	R	.95 (Decreased)
R_R22	R_R22	R	.95 (Decreased)
R_R3	R_R3	R	1.05 (Increased)
R_R8	R_R8	R	.95 (Decreased)
R_R4	R_R4	R	.95 (Decreased)

R_R10	R_R10	R	.99	(Decreased)
R_R15	R_R15	R	.99	(Decreased)
R_R7	R_R7	R	.95	(Decreased)
R_R12	R_R12	R	.95	(Decreased)
R_R25	R_R25	R	.99	(Decreased)
R_R19	R_R19	R	.99	(Decreased)
R_R6	R_R6	R	1.05	(Increased)
R_R20	R_R20	R	1.05	(Increased)

**** 05/27/24 01:28:43 ***** PSpice 23.1.0 (17 April 2024) **** ID# 0 ********

** Profile: "SCHEMATIC1-worst_case" [D:\Docs D\OrCAD Projects\FINAL_PROJECT_CAD\FINAL_PROJECT_CAD_STANDARDIZATION-PSpiceFiles\SCHE

**** SORTED DEVIATIONS OF V(OUT2) TEMPERATURE = 27.000 DEG C

WORST CASE SUMMARY

****

Mean Deviation = 2.6952

Sigma = 0

RUN MAX DEVIATION FROM NOMINAL

WORST CASE ALL DEVICES

2.6952 higher at sensor = 32.7000E+03

(-2.0684E+06% of Nominal)

JOB CONCLUDED

**** 05/27/24 01:28:43 ***** PSpice 23.1.0 (17 April 2024) **** ID# 0 ********

** Profile: "SCHEMATIC1-worst_case" [D:\Docs D\OrCAD Projects\FINAL_PROJECT_CAD\FINAL_PROJECT_CAD_STANDARDIZATION-PSpiceFiles\SCHE

**** JOB STATISTICS SUMMARY

****

Total job time (using Solver 1) = 6.80

Simulation settings:

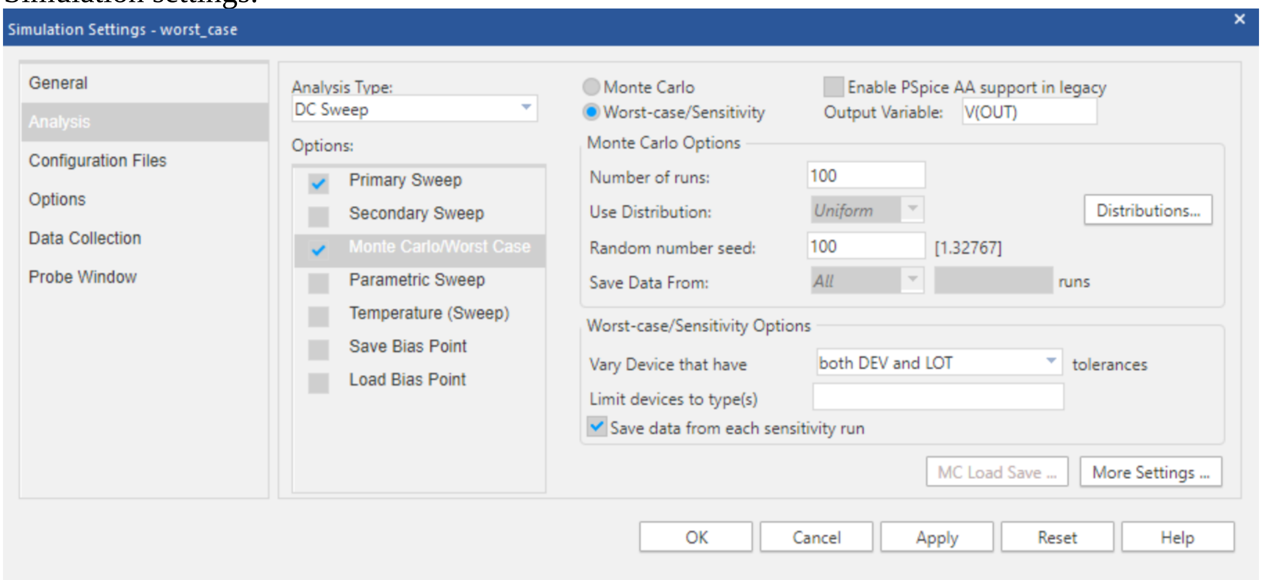

Figure 28 - Worst-Case Simulation Settings - Inverting

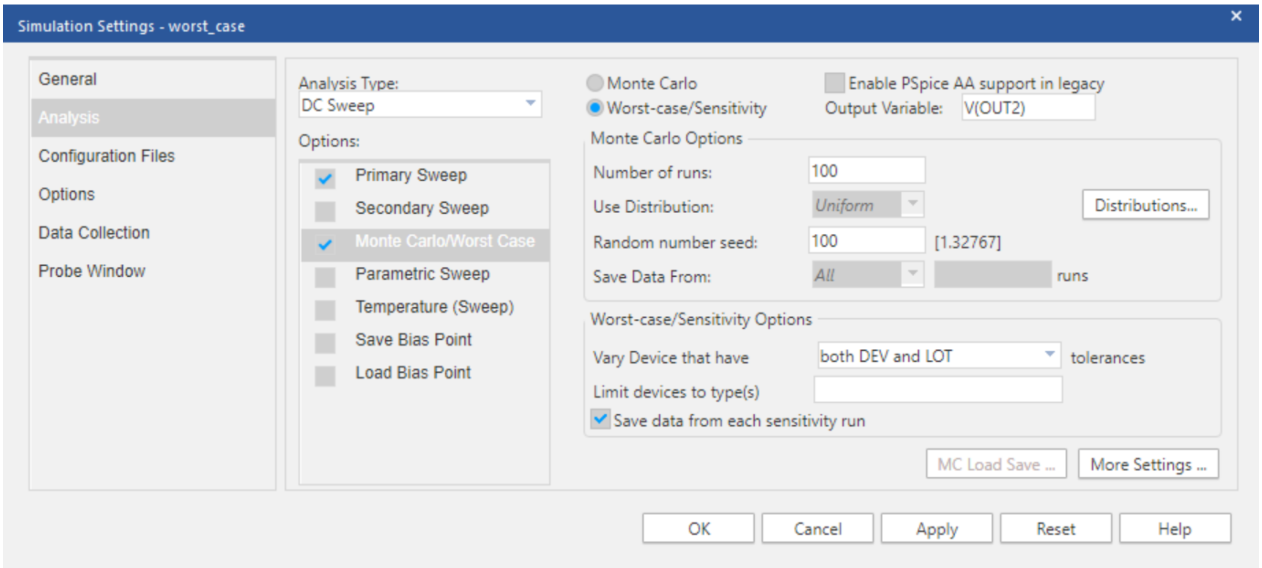

Figure 29 - Worst-Case Simulation Settings - Non-Inverting

For the inverting output, key findings include significant deviations in the resistances of R_R3 and R_R6, which exhibit the highest sensitivity to changes in the sensor parameter, with deviations up to 3.55 sigma. Most other resistors show minimal to no significant deviation, indicating stability. Updated model parameters suggest minor adjustments, with several resistors' values increased by 5% and a few decreased or unchanged, reflecting the worst-case scenario impact on the circuit's performance.

For the non-inverting output, the sensitivity analysis reveals that deviations in resistor values significantly impact the output voltage (V(OUT2)), with R_R3 and R_R6 showing the highest deviations. The report also updates the worst-case model parameters for all devices, reflecting minor decreases in resistance values for components such as R_R23, R_R9, and R_R2 to simulate worst-case conditions.

8. Conclusions

In conclusion, the designed circuit would perform well to alert through its LEDs when the weight on the shelf is out of range, fact noticed in the simulations. While some improvements should be done, especially on the R3 and R6 resistances, as the Worst-Case Analysis has proven, it is still efficiently implemented and it would be able to face its task.

9. References

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