PROJECT AT CAD DISCIPLINE

SEMESTER II

2025

Liquid Level Detection Circuit

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Year of studies: 2nd, series B, group 2125

ABSTRACT

This project details the design and OrCAD simulation of an electronic liquid–level monitoring system based on a resistive sensor whose resistance varies linearly from 14 kΩ to 28 kΩ, corresponding to a physical range of 0–285 cm. The sensor forms a voltage divider with a fixed resistor Rfix=21.5 kΩ, yielding an output voltage of approximately 5.13–7.36 V. A unity-gain buffer implemented with a TL082 operational amplifier isolates the divider and delivers a stable signal to three comparators, which switch at voltage thresholds corresponding to 80 cm, 150 cm and 285 cm. Each comparator drives a color-coded LED (red, yellow, green) to provide intuitive visual feedback of the liquid level. The system's performance and robustness were verified through transient, parametric-sweep, Monte Carlo and worst-case analyses, confirming its linearity, stability and tolerance to component variations.

Keywords: Liquid level measurement; Resistive sensor; Voltage divider; Unity-gain buffer; Threshold comparators; LED indicators; OrCAD simulation; Transient analysis; Monte Carlo analysis; Worst-case analysis.

CONTAINED

1. GENERAL NEED

1.1. Assert

Design an electronic circuit for measuring the liquid level in a container in the range specified in column B. The circuit shall be fitted with optical indicators (LED, different colours for each specified range) which signal that the thresholds have been exceeded (column Signals - E). The circuit is powered at VCC (voltage specified in column D). The electrical resistance of the transducer varies linearly with the value of the detected level.[1]

1.2. Circuit sizing

The values used in the actual circuit design are contained in Table 1.

DESIGN SPECIFICATIONS	MAXIMUM MEASUREMENT LEVEL (cm)	RANGE OF RESISTANCE VARIATION (Sensor)	SUPPLY VOLTAGE (Vdc)	SIGNALS (cm)
Alexandru- Gabriel Brabete	285cm	14K-28K	13V	Threshold 1: <80cm Threshold 2: 80-150cm Threshold 3: >150cm

[2]Table 1: Design Instructions

1.3. Objective

The project aims to create a complete electronic system, developed and simulated in OrCAD, for the continuous measurement of the liquid level in a container, based on the linear variation of the resistance of a transducer. The objective is to implement a signal conditioning circuit (voltage divider and operational amplifier) that converts resistance changes into voltage signal, followed by a comparison block with pre-set thresholds, which activates colored LEDs corresponding to different level domains (low, medium, high level). The entire assembly will be powered at the VCC specified in the design, and the component values will be optimized for stability, linearity and low consumption, thus ensuring accurate and intuitive monitoring of the liquid level.

[1] Statement developed by the Department of CAD of the Faculty of Electronics, Telecommunications and Information Technology, Technical University of Cluj-Napoca.
[2] According to the requirement developed by the CAD Department of the Faculty of Electronics, Telecommunications and Information Technology, Technical University of Cluj-Napoca.

2. BLOCK DIAGRAM

Figure 1 represents the block diagram of the liquid level measurement circuit, consisting of a resistive sensor that varies proportionally to the height of the liquid, a buffer made with an operational amplifier for signal stabilization, a set of comparators that detect the exceeding of predetermined thresholds and a display circuit with colored LEDs, each signaling a certain level by means of limiting resistors.

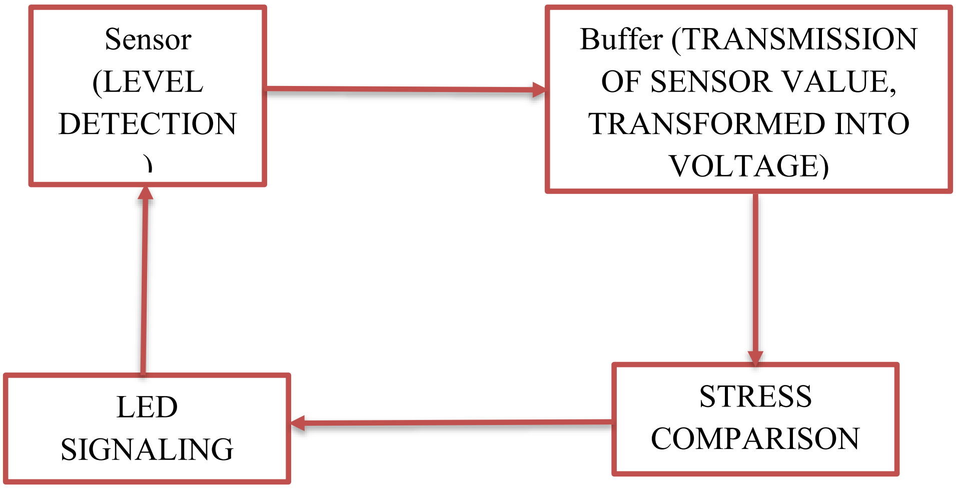

Figure 1: Block Diagram

3. COMPONENTS LEGEND

Before presenting the electrical circuit, I consider it appropriate to draw up a complete list of the components used (shown in Table 2), accompanied by their values, the related datasheets, as well as the notes of the conventions adopted in the scheme. Information on component manufacturers will be mentioned in the footnotes in accordance with technical documentation standards.

COMPONENT	VALUE / TYPE	DATASHEET	FUNCTION	RELEVANT TECHNICAL SPECIFICATIONS
VCC	Ideal +13 V power supply	Model ideal OrCAD	Provides the positive supply voltage for the circuit.	—
-VCC	Ideal power supply – 13 V	Model ideal OrCAD	Provides the negative supply voltage for the op-ampo.	—
Sensor	Resistive transducer 14 kΩ–28 kΩ	Generic example XYZ-LS100[3]	The resistance varies linearly depending on the liquid level.	Typical tolerance ±5 %, maximum permissible power 0.5 W

[3] Catalog sheet: XYZ-LS100 Resistive Liquid Level Sensor, tolerance ±5%.

Rfix	21.5 kΩ ±1 % (metal-film)	Vishay MRS25 Series[4]	Together with the Sensor it forms the voltage divider.	Power 0.25 W, temperature coefficient ≤ 50 ppm/°C
U5A (TL082)	Dual JFET Operational Amplifier	Texas Instruments TL082[5]	Configured as a buffer for stabilizing the sensor signal.	Input bias current max. 50 pA, slew rate 13 V/µs
U3A, U3B, U4A (TL082)	Dual JFET Operational Amplifiers	Texas Instruments TL082[6]	It works as comparators for detecting thresholds.	Power supply ±3...±18 V, Iout max. ±10 mA
• **R5 = 56.2 kΩ ±1%** • **R6 = 8.06 kΩ ±1%** • **R7 = 5.62 kΩ ±1%** • **R8 = 8.06 kΩ ±1%** • **R9 = 51.1 kΩ ±1%**	Metal-film resistors	Vishay MRS25 Series[7]	Make the reference dividers for the U3/U4 thresholds.	Tolerance ±1%, power 0.25 W, CTP ≤ 50 ppm/°C

[4] Catalogue sheet: Vishay MRS25 Metal Film Resistors, accuracy class 1 %;
[5] Catalog sheet: TL082 Dual Operational Amplifier, TI (±3...±18 V, Iib ≤ 50 pA);
[6] Catalog sheet: TL082 Dual Operational Amplifier, TI (±3...±18 V, Iib ≤ 50 pA);
[7] Catalogue sheet: Vishay MRS25 Metal Film Resistors, accuracy class 1%.

R1, R2, R3	1.2 kΩ ±1 % (metal-film)	Vishay MRS25 Series[8]	Limits the current of the signal LEDs.	Power 0.25 W, CTP ≤ 50 ppm/°C
D1 (LH3364-TYP)	Red LED 5 mm	Kingbright LH3364 Series[9]	Indicates that the lower level threshold has been exceeded.	If = 20 mA, Vf ≈ 2.0 V, 60° angle
D2 (LO3364-TYP)	Yellow LED 5 mm	Kingbright LO3364 Series[10]	It signals that the average level threshold has been reached.	If = 20 mA, Vf ≈ 2.1 V, angle 60°
D3 (LP3364-TYP)	Green LED 5 mm	Kingbright LP3364 Series[11]	It marks the achievement of the upper level threshold.	If = 20 mA, Vf ≈ 2.2 V, angle 60°

Table 2: Complete list of notations and components used

[8] Catalogue sheet: Vishay MRS25 Metal Film Resistors, accuracy class 1 %;
[9] Catalog Sheet: Kingbright LED Series 3364;
[10] Catalog Sheet: Kingbright LED Series 3364;
[11] Catalog sheet: Kingbright LED Series 3364.

4. WIRING DIAGRAM

4.1. Overview

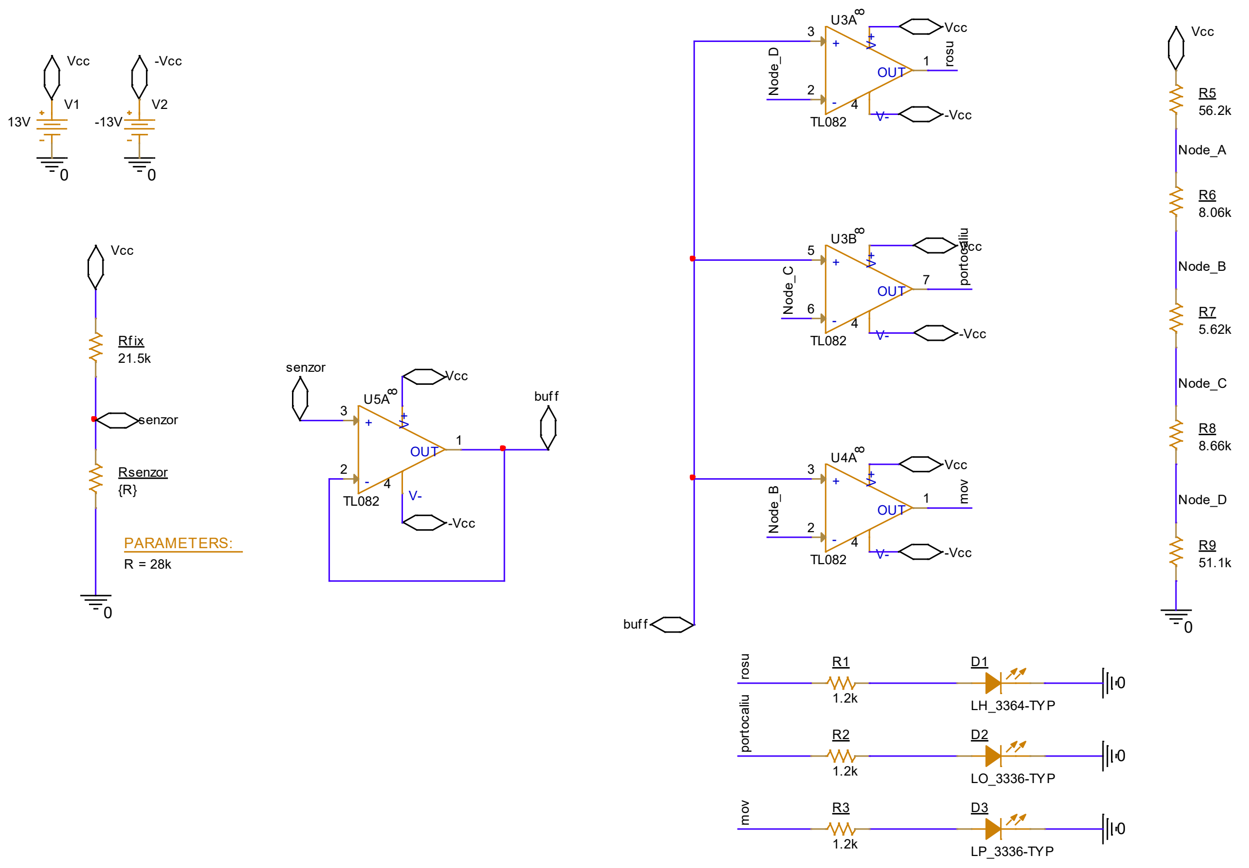

Figure 2: Complete wiring diagram

Figure 2 shows the complete wiring diagram of the circuit, made according to the functional structure described in the block diagram in Figure 1. This scheme integrates all the essential stages necessary for the implementation of the liquid level measurement and signaling function. Next, each component or group of components that contribute definitively to the realization of the circuit's functionalities will be analyzed in detail. This analytical approach is necessary for a clear understanding of how each block contributes to the development of the electronic system intended to monitor the liquid level in an efficient, stable and accurate way.

4.2. Detailed view

4.2.1. R_{senzor} (Level Detection Block)

The first component of the circuit has the role of generating a voltage proportional to the liquid level, according to the function described in the first block of Figure 1. According to the specifications, the sensor used has a variable resistance in the range of 14 kΩ – 28 kΩ (set via the PARAMETERS field), depending on the height of the liquid, and is represented in the electrical diagram in Fig. 3 under the name . In order to obtain a voltage variation that is directly proportional to the detected level variation, the sensor is connected between the circuit ground and a fixed resistor, placed between the power supply (as required) and the node shared with the Rsensor.$\mathbf{R_{senzor}}\mathbf{R_{fix}}$Vcc =13 V

This configuration forms a voltage divider, in which the voltage from the intermediate node constitutes the output signal dependent on the resistance value of the sensor. Choosing the value of the fixed resistance is essential for maximizing the variation of the voltage at the output. Thus, in order to obtain a high sensitivity and a wide coverage of the voltage range, it was chosen approximately in the middle of the variation range of the Rsensor, respectively . This choice ensures a symmetrical distribution of voltage depending on the liquid level and optimizes the response of the circuit in the following steps.$\mathbf{R_{fix}}\boldsymbol{R_{fix} = 21,5\ k\Omega}$

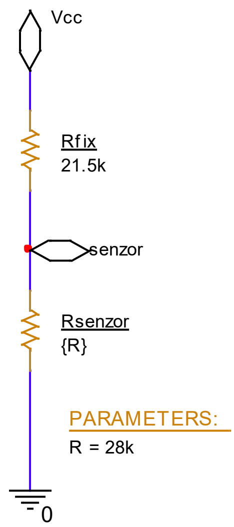

Figure 3: R_{senzor}

According to the design specifications (Table 1), the maximum value of the liquid level is 285 cm, the range of variation of the transducer resistance is ... , and the supply is made at . The signals will be generated at three height thresholds: , and

.$R_{senzor_{min}} = 14\ k\Omega R_{senzor_{max}} = 28\ k\Omega Vcc = 13\ V h_1 = 80\ cm h_2 = 150\ cm h_3 = 285\ cm$

For the resistance–voltage conversion step, a divisor configuration was chosen between the fixed resistance and (Figure 3). Its optimal value is calculated as the average of the limits of the resistance range:$R_{fix} R_{senzor} R_{fix}$

$$R_{fix} = \frac{R_{senzor_{max}} + R_{senzor_{min}}}{2} = \frac{28\ k\Omega + 14\ k\Omega}{2} = 21\ k\Omega \tag{1}$$

In practice, a similar standardised value has been used:

$$R_{fix} = 21{,}5\ k\Omega \tag{2}$$

The specific variation of the sensor resistance (denoted by) per unit height is obtained from:α

$$\alpha = \frac{R_{senzor_{max}} - R_{senzor_{min}}}{H_{max}} = \frac{28\ k\Omega - 14\ k\Omega}{285\ cm} \approx 0{,}04912\ k\Omega/cm \tag{3}$$

The resistances corresponding to the levels of 0 cm, 80 cm, 150 cm and 285 cm are:

$$R_s(0\,cm) = R_{senzor_{min}} = 14\,k\Omega \tag{4}$$

$$R_s(80\,cm) = R_{senzor_{max}} - (H_{max} - 80\,cm) \cdot \alpha = 28\,k\Omega - 205\,cm \cdot 0{,}04912\,k\Omega/cm \approx 17{,}93\,k\Omega \tag{5}$$

$$R_s(150\,cm) = R_{senzor_{max}} - (H_{max} - 150\,cm) \cdot \alpha = 28\,k\Omega - 135\,cm \cdot 0{,}04912\,k\Omega/cm \approx 21{,}37\,k\Omega \tag{6}$$

$$R_s(285\,cm) = R_{senzor_{max}} = 28\,k\Omega \tag{7}$$

Applying the voltage divider theorem:

$$V_{out}(h) = \frac{R_s(h)}{R_{fix} + R_s(h)} \cdot Vcc \tag{8}$$

the output voltages at the thresholds are obtained:

$$V_{out}(0\ cm) = \frac{14\ k\Omega}{21{,}5\ k\Omega\ +\ 14\ k\Omega} \cdot 13\ V \approx 5{,}13\ V \tag{9}$$

$$V_{out}(80\ cm) = \frac{17{,}93\ k\Omega}{21{,}5\ k\Omega\ +\ 17{,}93\ k\Omega} \cdot 13\ V \approx 5{,}90\ V \tag{10}$$

$$V_{out}(150\ cm) = \frac{21{,}37\ k\Omega}{21{,}5\ k\Omega\ +\ 21{,}37\ k\Omega} \cdot 13\ V \approx 6{,}48\ V \tag{11}$$

$$V_{out}(285\ cm) = \frac{28\ k\Omega}{21{,}5\ k\Omega\ +\ 28\ k\Omega} \cdot 13\ V \approx 7{,}36\ V \tag{12}$$

Resistance and voltage values have been rounded to two decimal places for clarity and ease in subsequent calculations.

4.2.2. *Buffer (Sensor value transmission block)*

The buffer function, schematically described in Figure 1, is detailed in Figure 4 by a TL082 operational amplifier configured as a "voltage follower". Upstream, the divider – translates the variation of the liquid level into a voltage signal of about 5.13 V... 7.36 V. This signal is applied to the non-inverting input (pin 3) of U5A, and the output (pin 1) is linked directly to the inverting input (pin 2), making a follower with unit gain. The symmetrical power supply ensures the necessary dynamic range without offset distortion.$R_{senzor}R_{fix}$ $\pm 13\ V$

Through this configuration, the buffer fulfills two essential roles:

a. **Isolation** of the transducer from the loads of the comparator circuits due to the very high input impedance ()$> 10^{12}\ \Omega$

b. **Regulation** and delivery of a stable signal with low output impedance () to the comparator block$< 100\ \Omega$

The TL082's features—slew rate and input bias current—guarantee a fast and accurate response, preventing drifting or ghosting between level thresholds.$\approx$ $13\ V/\mu s <\ 50\ pA$

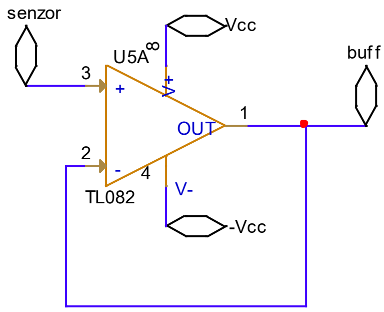

Figure 4: Buffer

4.2.3. *Threshold detection and signalling block*

Figure 5 shows the integration of all components intended for comparing the level signal with the preset thresholds and displaying the results via LEDs. This block corresponds to the "Threshold Detection" and "Optical Display" floors in the initial block scheme (Figure 1) and includes:

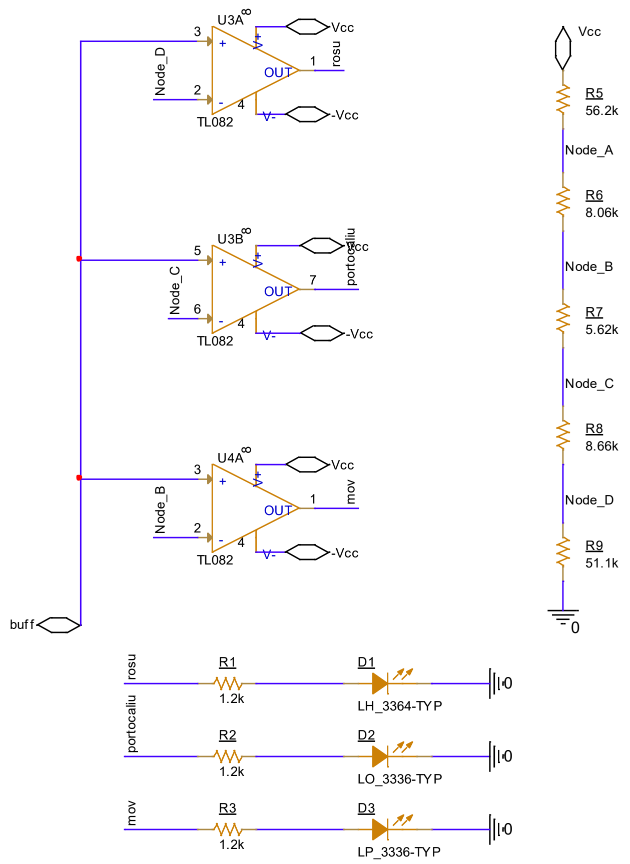

Figure 5: Circuit assembly for comparing and signaling thresholds

- **Reference divider** (Figure 6): the resistors ..., supplied at $R_5 R_9 V_{CC}$=13 V, generate four voltage levels , $V_A V_B$, $V_C V_D$, associated with the four level thresholds (285 cm, 150 cm, 80 cm, 0 cm).

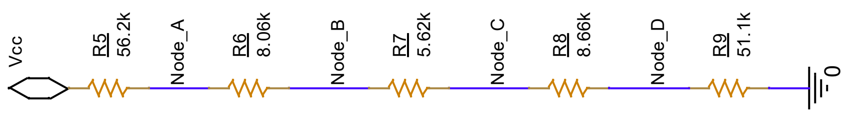

Figure 6: Reference Divisor

In order to establish the level thresholds, a series resistive divider fed to (Figure 5) was used. The voltage at each node is obtained by dividing the equivalent resistance of the lower branch by the total resistance of the divider.V_{CC}

Total resistance of the divider:

$$R_{tot} = R_5 + R_6 + R_7 + R_8 + R_9 = 56{,}2 + 8{,}06 + 5{,}62 + 8{,}06 + 51{,}1 = 129{,}04\ k\Omega. \quad (13)$$

General formula of voltage at a node n:

$$V_n = V_{cc}\frac{\sum_{i=n+1}^{9} R_i}{R_{tot}} \text{where } n = 5 \dots 8 \quad (14)$$

Calculation of stresses at each node and level thresholds:

a. Node A (between R_5 and ,):$R_6 h = 285cm$

$$V_A = 13V\,\frac{R_6 + R_7 + R_8 + R_9}{R_{tot}} = 13V\,\frac{8{,}06 + 5{,}62 + 8{,}06 + 51{,}1}{129{,}04} \approx 7{,}43V \quad (15)$$

b. Node B (between R_6 and ,):$R_7 h = 150cm$

$$V_B = 13V\,\frac{5{,}62 + 8{,}06 + 51{,}1}{129{,}04} \approx 6{,}53V \quad (16)$$

c. Node C (between R_7 and ,):$R_8 h = 80cm$

$$V_C = 13V\,\frac{8{,}06 + 51{,}1}{129{,}04} \approx 5{,}96V \quad (17)$$

d. Node D (between R_8 and ,):$R_9 h = 0cm$

$$V_D = 13V \frac{51{,}1}{129{,}04} \approx 5{,}15V \tag{18}$$

All values have been rounded to two decimal places for clarity.

• **Comparators** (Figure 7): The three-stage TL082 (U3A, U3B, U4A) compares the buffer-stabilized signal (Figure 4) with the references. Their outputs switch to the "high" logical level when it exceeds the appropriate threshold, ensuring the selection of the detected level domain.V_{buff}

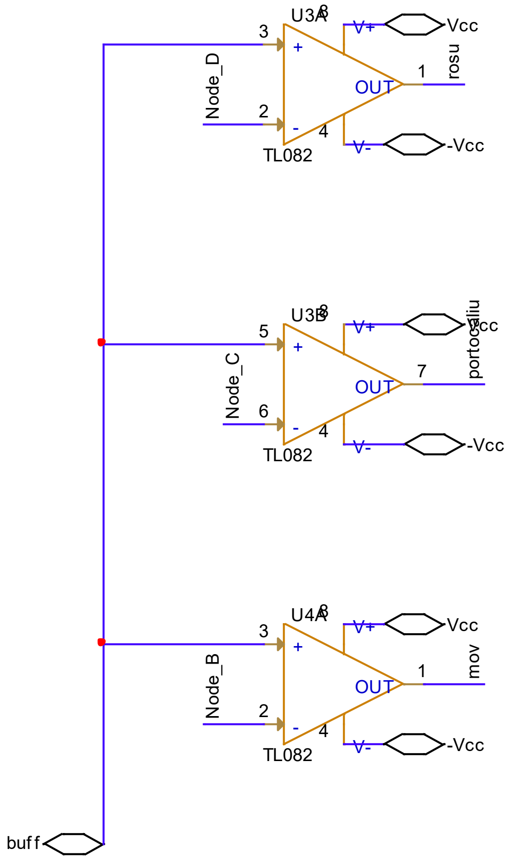

Figure 7: Comparison Block

Figure 7 shows the block consisting of three TL082 amplifiers (U3A, U3B, U4A), each functioning as a non-feedback comparator, intended to compare the buffer voltage (the level signal) with one of the three fixed references generated by the resistive divider (nodes D, C and B):

a. **U3A – "down" comparator**
- **Non-inverting input (+):** threshold (node D), corresponding to the level V_D
  $h = 0\ cm$
- **Inverter input (–)**: the "buff" level signal.
- **Function**: if , the output of U3A goes to high state, signaling "down" level.

b. **U3B – "medium" comparator**
- **Non-inverting input (+):** threshold (node C), corresponding to the level V_C
  $h = 80\ cm$
- **Inverter input (–)**: the "buff" signal.
- **Function**: when , but , U3B switches to high level, indicating "middle-lower" area.$V_{buff} < V_C V_{buff} \geq V_B$

c. **U4A – "top" comparator**
- **Non-inverting input (+):** threshold (node B), corresponding to the level V_B
  $h = 150\ cm$
- **Inverter input (–)**: the "buff" signal.
- **Function**: For , the output is activated, designating the "high" level.$V_{buff} \geq V_B$

All comparators are powered by , which allows saturated outputs close to these values, ensuring clear digital signals for the LED floor. Each comparator switches asymptotically between positive and negative saturation states depending on the relationship between the signal and the reference, with no loop compensation elements (no hysteresis), but thanks to the fast dissipation in the TL082 and the sufficiently wide differences between the thresholds, robust detection of the level domains is achieved.±13 V

- **LED circuitry** (Figure 8): Each comparator output drives a colored LED—red for low, yellow for medium, and green for high—through a 1.2 kΩ resistor—providing an immediate visual indication of the liquid domain.

Thus, the input signal (voltage divided by and buffer-stabilized) is successively reported to the thresholds of 5.15 V (), 5.96 V () and 6.53 V (). The comparators in Figure 5 perform the logical switching, and the LEDs in Figure 7 translate these electrical commands into clear optical feedback, according to the functional blocks in Fig. 1.$R_{senzor} - R_{fix}h = 0cmh = 80\ cmh = 150\ cm$

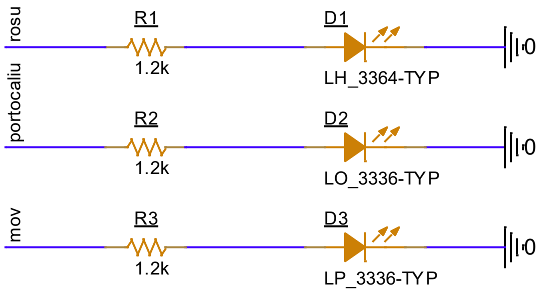

Figure 8: Signal block

The LED signaling stage (Figure 8) consists of three identical circuits, through which the outputs of the comparators drive the optical indicators:

- **The output of the "down" comparator** (label "down") connects to R1 = 1.2 kΩ, then to D1 (red LED LH3364-TYP) to ground.
- **The output of the "middle" comparator** (the "medium" label) connects to R2 = 1.2 kΩ, then to D2 (yellow LED LO3364-TYP) to ground.
- **The output of the "up" comparator** ("up" label) connects to R3 = 1.2 kΩ, then to D3 (green LED LP3364-TYP) to ground.

The 1.2 kΩ resistors limit the bias current of the LEDs to approximately:

$$I_{LED} \approx \frac{V_{sat} - V_f}{R} \approx \frac{13V - 2V}{1{,}2\text{k}\Omega} \approx 9\ mA \tag{19}$$

providing protection for both the LEDs and the outputs of the operational amplifiers. When the comparator switches to high level (almost +13 V), the current passes through the resistor and polarizes the LED corresponding to the detected level threshold.

5. Circuit Design

5.1. Design

The circuit design was achieved through a modular approach, in which each function – resistance-level conversion, amplitude stabilization, comparison with preset thresholds, and optical display – was separated into easy-to-understand and verifiable blocks. Each stage was configured and optimized in OrCAD, starting from the initial specifications and continuing with the choice of standardized components, the sizing of the resistors and the tuning of the thresholds. The integration was done gradually, through successive simulations of static and dynamic operation, to ensure the linearity of the response, noise immunization and stability to temperature changes or power variations. The final documentation includes complete schematics, component lists with datasheets, domain calculations and laboratory tests, guaranteeing reproducibility and the possibility of further expansion of the system.

5.2. Price list

Component	Type/Value	Quantity	Unit Price (USD)	Total cost (USD)
Level Translator	14 kΩ–28 kΩ Sensor (eTape PN-12110215TC-8)[12]	1	15.00	15.00
Operational Amplifier	TL082 (dual op-amp)[13]	2	1.00	2.00
Metal-film resistor	21.5 kΩ ±1 %[14]	1	0.10	0.10
Metal-film resistors	56.2 kΩ; 8.06 kΩ; 5.62 kΩ; 8.06 kΩ; 51.1 kΩ[15]	5	0.10	0.50
Metal-film resistor for LED	1.2 kΩ ±1 %[16]	3	0.10	0.30

[12] Manufacturer site: TE Connectivity
[13] Manufacturer site: Texas Instruments
[14] Manufacturer site: Vishay Precision Group
[15] Manufacturer site: Vishay Precision Group
[16] Manufacturer site: Vishay Precision Group

Red LED	LH3364-TYP 5 mm[17]	1	0.15	0.15
Yellow LED	LO3364-TYP 5 mm[18]	1	0.15	0.15
Green LED	LP3364-TYP 5 mm[19]	1	0.15	0.15
Power connector	2-pin terminal block[20]	1	0.50	0.50
Subtotal Component				18.85
Test Board (PCB)	PCB 2 × 5 cm[21]	1	3.00	3.00
Wires and wiring	Jumper wires, screws[22]	1	1.00	1.00
ESTIMATED TOTAL				22.85

Table 3: Component prices

Table 3 shows the complete structure of the estimated budget for the realization of the liquid level measurement prototype. For each component, the type/value, the required quantity, the unit price, and the corresponding total cost are displayed, expressed in USD. The table includes both the main electronic elements (resistive transducer, operational amplifiers, metal-film resistors, LEDs) and mounting accessories (power connector, PCB, interconnection wires). The subtotal cost of electronic components is $18.85, and the addition of the test board ($3.00) and wiring harness ($1.00) leads to an **estimated total cost of $22.85**.

[17] Manufacturer site: Kingbright
[18] Manufacturer site: Kingbright
[19] Manufacturer site: Kingbright
[20] Manufacturer site: Phoenix Contact
[21] Prototyping provider site: JLCPCB
[22] Supplier site: Adafruit

6. SIMULATIONS

In the validation phase of the project, four complementary types of simulations were used:

- **The analysis in the time domain (Transient)** allowed the verification of the dynamic response of the circuit to rapid variations in the liquid level, demonstrating the linearity and stability of the output signal under realistic load conditions.
- **Time-domain analysis with parametric sweep** was applied to study how successive changes in component values (e.g. Rfix or comparator thresholds) influence the output waveform, facilitating the optimization of tolerances and fine-tuning of detection thresholds.
- **The Monte Carlo simulation** evaluated the statistical behavior of the circuit at real manufacturing tolerance distributions, revealing the probability of threshold deviations and helping to define safety intervals for components.
- **Worst-Case analysis** explored extreme scenarios of value combinations (food, temperature, maximum component tolerances) to ensure that, even under the worst conditions, the circuit meets accuracy specifications and component protection.

Together, these simulations ensure complete confidence in the performance and robustness of the design before moving to hardware prototyping.

6.1. Time Domain Simulation

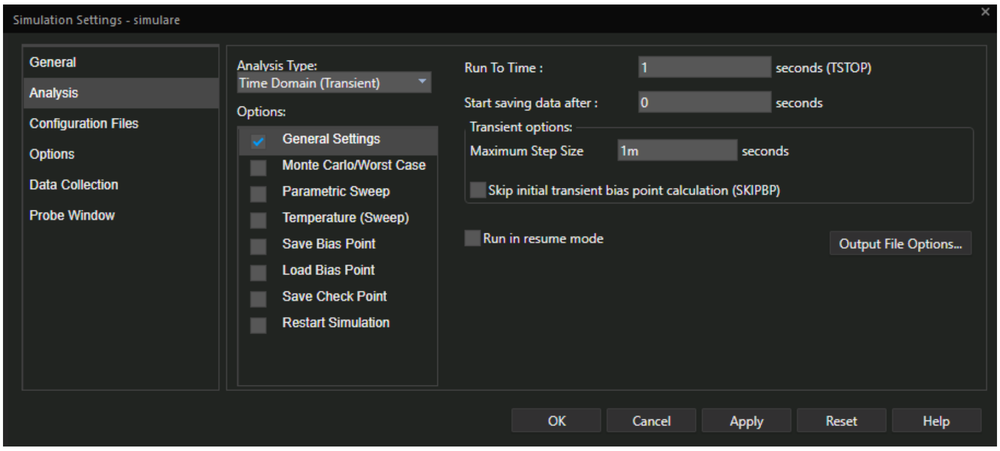

Image 1: Parameters set for Time Domain simulation (Transient)

In the **Simulation Settings** window I used only the **General → Time Domain (Transient) tab**, with the following settings:

- **Analysis Type**: Time Domain (Transient)
- **Run To Time**: 1 s
- **Start saving data after**: 0 s
- **Transient options → Maximum Step Size**: 1 ms
- **Skip initial transient bias point calculation (SKIPBP):** unchecked

The other options (Monte Carlo/Worst Case, Parametric Sweep, Temperature Sweep, etc.) remained unused in this set of simulations.

6.1.1. $R_{senzor} = 14\ k\Omega$

Figure 9 below shows the result of the transient simulation of the "buff" signal for the condition (minimum level,). It can be seen that, over the entire duration of 1 s, the output voltage supplied by the buffer stage remains stable at approximately 5.13 V, a value that corresponds exactly to the theoretical calculations for the divisor – at this point of operation. There are no overvoltages, voltage drops or oscillations, which confirms the good stability and filtering of the input signal before the comparators.$R_{senzor}\ =\ 14\ k\Omega\ h\ =\ 0\ cm R_{fix} R_{senzor}$

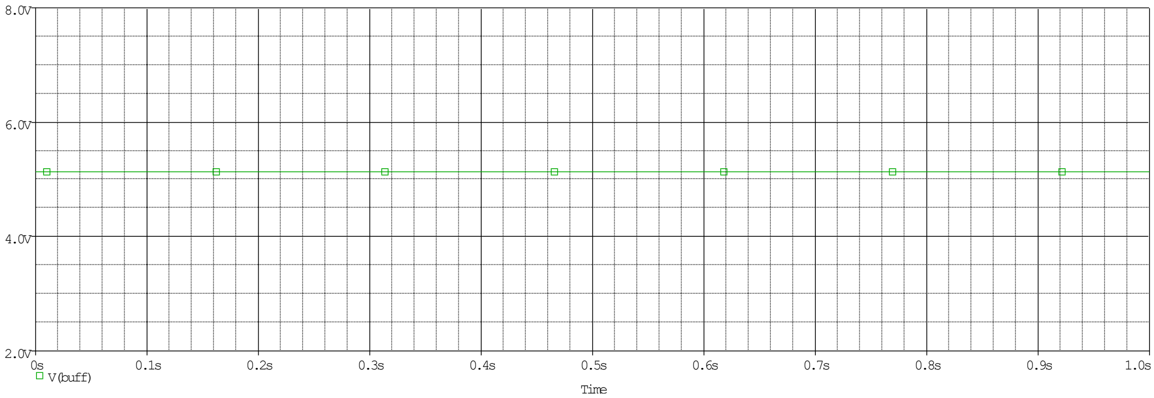

Figure 9: Voltage value when the sensor is at 14 kΩ

6.1.2. $R_{senzor} = 28\ k\Omega$

The graphs obtained for the conditions (Figure 9) and (Figure 10), demonstrate that the buffer stage provides a constant signal, without skidding or noise, at the calculated theoretical values:$R_{senzor}\ =\ 14\ k\Omega R_{senzor}\ =\ 28\ k\Omega$

- **For $\boldsymbol{R_{senzor}\ =\ 14\ k\Omega}$** (minimum level,) I obtained for the entire duration of the simulation of 1 s.$h\ =\ 0\ cm V_{buff} \approx 5{,}13V$
- **For $\boldsymbol{R_{senzor}\ =\ 28\ k\Omega}$**(maximum level,) is recorded constant throughout the entire duration. $h\ =\ 285\ cm V_{buff} \approx 7{,}36V$

These results confirm both the linearity of the divisor + buffer response and the dynamic stability of the signal before the comparator block.

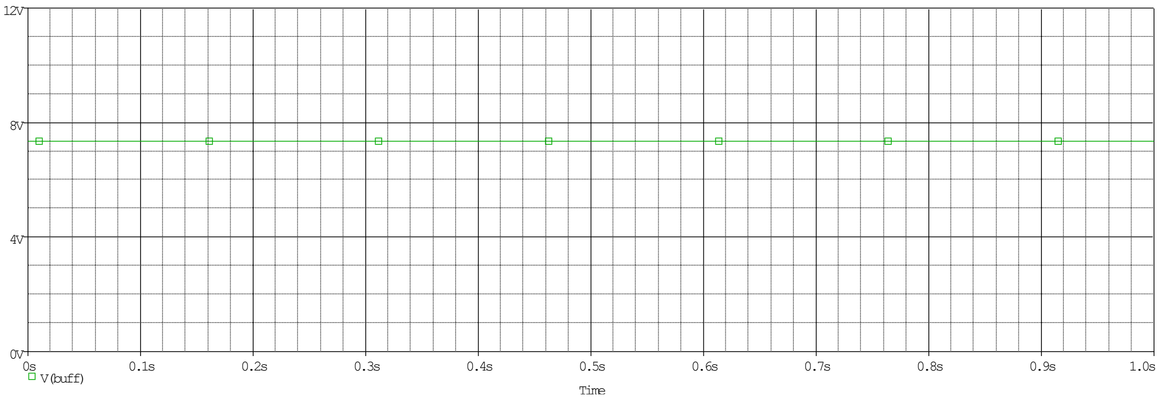

Figure 10: Voltage value when the sensor is at 28 $k\Omega$

6.1.3. $R_{senzor} \simeq 17{,}93\ k\Omega\ ()h = 80\ cm$

The simulation figure for condition () shows a constant "buff" signal at approximately 5.90 V for the entire duration of 1 s. The stability of the voltage plate confirms both the correct configuration of the divider – and the proper functioning of the buffer stage before the comparator block.$R_{senzor} \simeq 17{,}93\ k\Omega h = 80\ cm R_{fix} R_{senzor}$

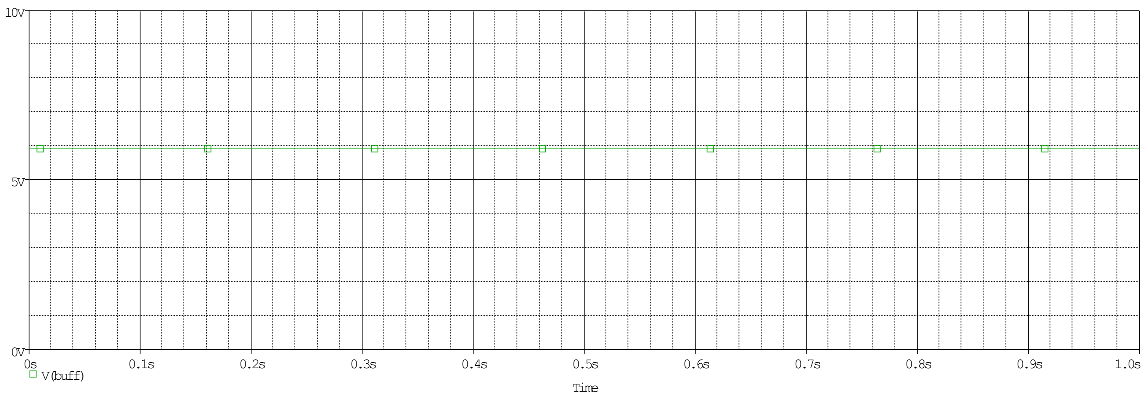

Figure 11: Voltage value when the sensor is at 17.93 $k\Omega$

6.1.4. $R_{senzor} \simeq 21{,}37\ k\Omega\ ()h = 150\ cm$

The simulation figure for condition() shows that the "buff" signal remains at approximately $R_{senzor} \simeq 21{,}37\ k\Omega\ h = 150\ cm$**6.48 V** for the entire duration of 1 s. This fixed voltage payment confirms the correctness of the divider sizing – and the efficiency of the buffer stage in providing a stable signal, ready for the detection of level thresholds by comparators.$R_{fix} R_{senzor}$

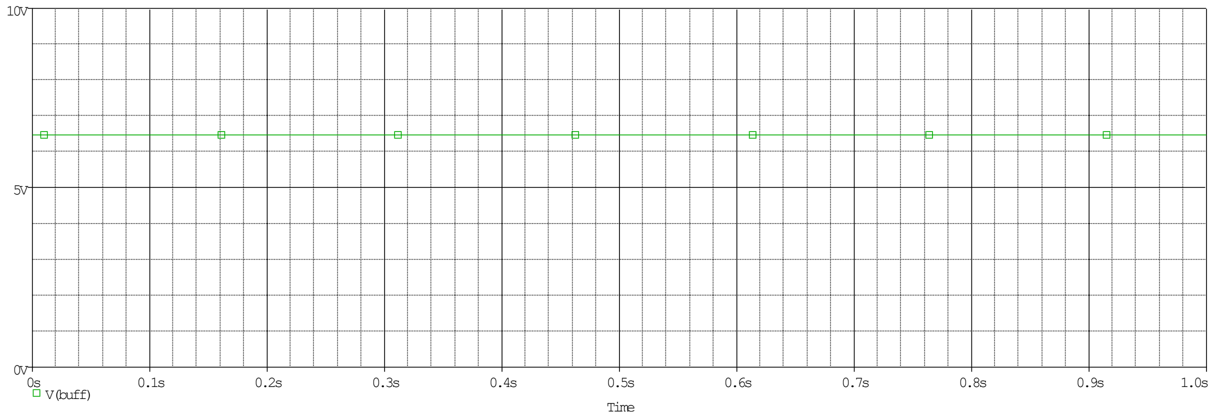

Figure 12: Voltage value when the sensor is at 21.37 $k\Omega$

6.1.5. *Voltage in comparison nodes*

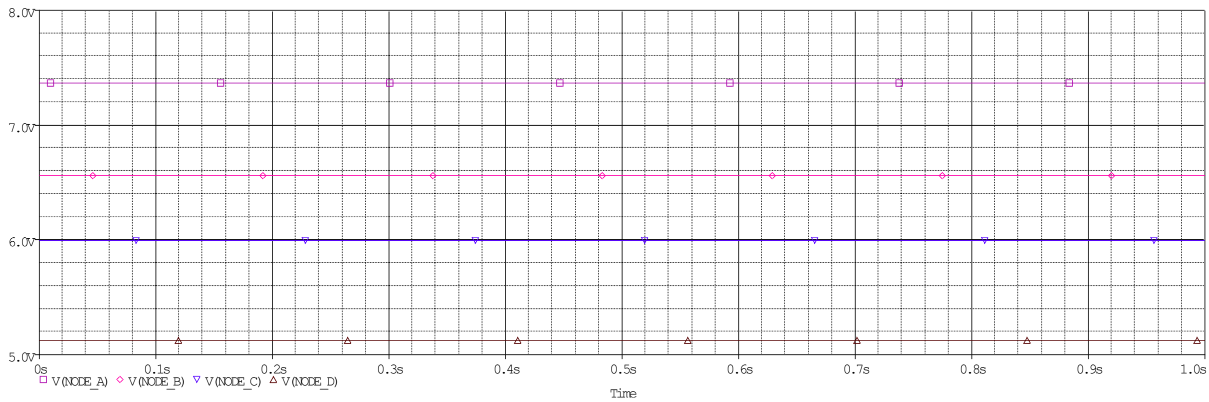

Figure 13: Value of voltages in comparison nodes

The graph above shows the evolution over time (0... 1 s) of the four reference voltages taken by the comparators from nodes A, B, C and D of the divider .... As can be seen, all four remain perfectly static, at the calculated theoretical values:$R_5 R_9$

- $\boldsymbol{V_A} \simeq 7{,}34\,V$ (upper threshold,)$h = 285\ cm$
- $\boldsymbol{V_B} \simeq 6{,}53\,V$ (medium-high threshold,)$h = 150\ cm$
- $\boldsymbol{V_C} \simeq 5{,}96\,V$ (medium-low threshold,)$h = 80\ cm$
- $\boldsymbol{V_D} \simeq 5{,}15\,V$ (lower threshold,)$h = 0\ cm$

Maintaining these levels throughout the simulation confirms the robustness of the reference scheme and ensures that the comparators will trigger the LEDs at exactly the pre-set heights, without slippage or offset variations.

6.2. Time Domain + Parametric Sweep Simulations

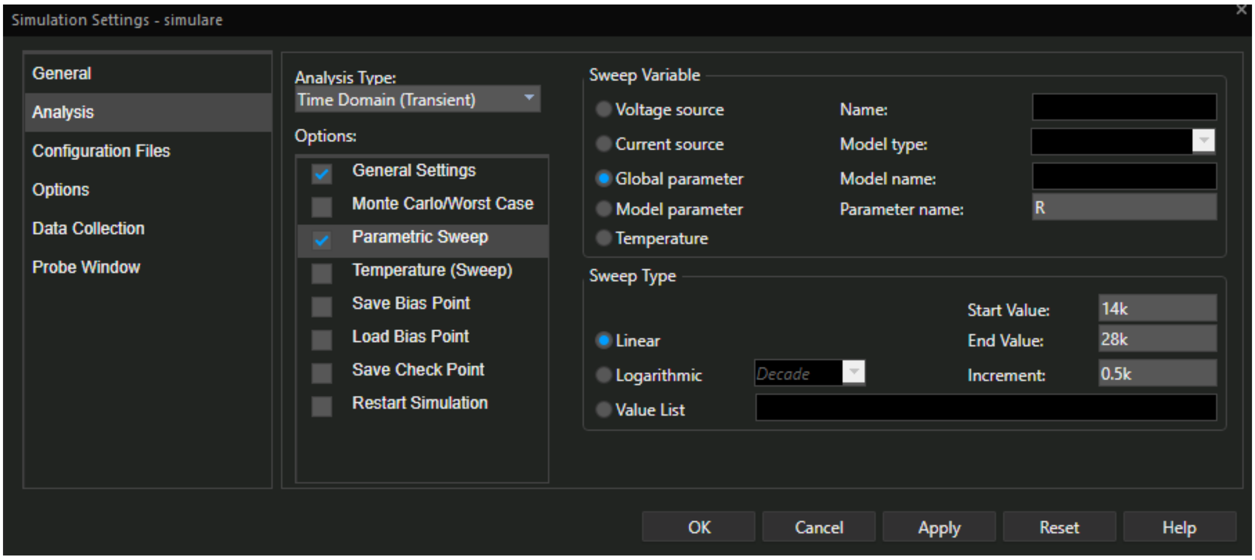

Image 2: Parameters set for Parametric Sweep simulation

In the **Simulation Settings window → General** I only enabled:

- **Analysis Type**: Time Domain (Transient)
- **Options → Parametric Sweep**:
  - **Sweep Variable**: model parameter
  - **Parameter Name**: R
  - **Sweep Type**: Linear
  - **Start Value**: 14 kΩ
  - **End Value**: 28 kΩ
  - **Increment**: 0.5 kΩ

All other options (Monte Carlo/Worst Case, Temperature Sweep, etc.) remained unused in this round of simulations.

6.2.1. Parametric Sweep Analysis of the "Buff" Signal

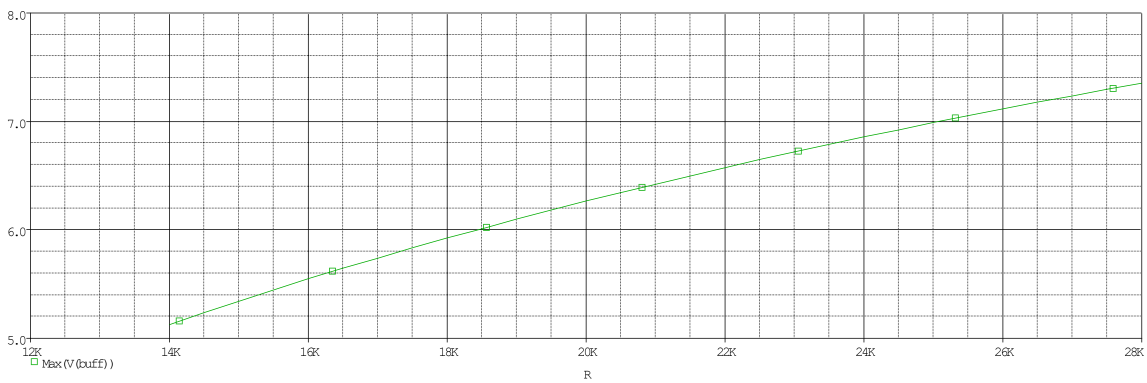

Figure 14: The "buff" signal

In order to verify the linearity of the divider + buffer response to the transducer resistance variation, a Parametric Sweep simulation was performed in the time domain, whereby the parameter R (Rsensor) was linearly varied from 14 kΩ to 28 kΩ, with a step of 0.5 kΩ (Figure 9). The function used to extract the results was: max(Vbuff)

The graphs obtained represent the maximum value of the buffer output voltage as a function of the sensor resistance:

- At: $\boldsymbol{R} = \mathbf{14}\ \boldsymbol{k\Omega} V_{buff} \approx 5{,}13\ V$
- At: $\boldsymbol{R} = \mathbf{28}\ \boldsymbol{k\Omega} V_{buff} \approx 7{,}36\ V$

The curve presented, almost perfectly linear, confirms the correct choice of it and ensures that the "buff" signal varies proportionally to the liquid level, facilitating the precise detection of the three thresholds.**R_{fix} = 21,5 kΩ**

6.2.2. LED current depending on the sensor

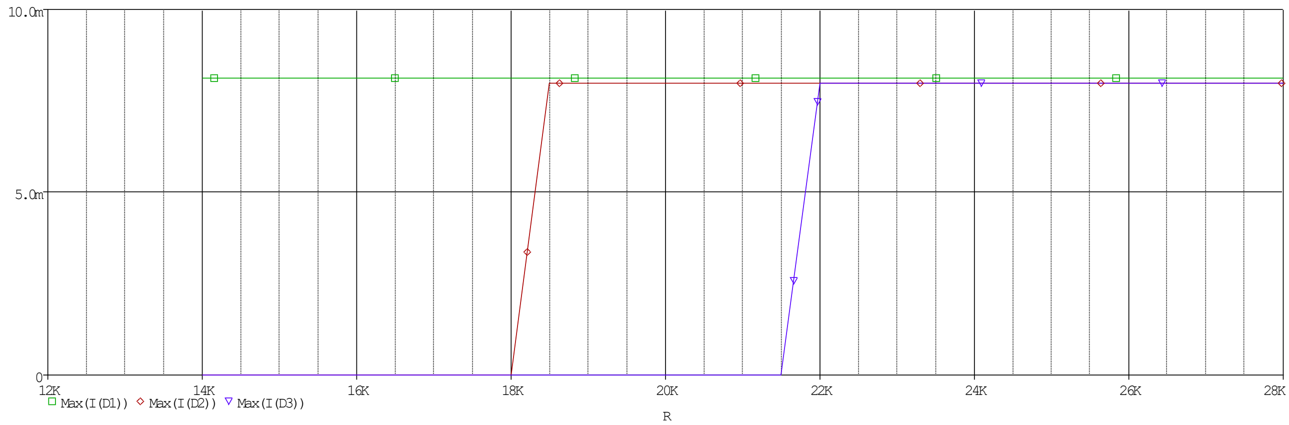

Figure 15: Current through LEDs depending on transducer resistance

Figure 15 illustrates the evolution of the polarization current of the three signaling LEDs, obtained by a **Parametric Sweep** of the sensor resistance between 14 kΩ and 28 kΩ, with a step of 0.5 kΩ, and by measuring the maximum value for each diode.R_{senzor} $\max I(D_i)$

a. D1 (red): $I_{D1}(R)$
b. D2 (yellow): $I_{D2}(R)$
c. D3 (green): $I_{D3}(R)$

From the graph, three areas can be seen strictly delimited by the resistance thresholds calculated previously:

a. $14\ k\Omega \leq R < 17{,}93\ k\Omega$
only **D1 (red)** conducts current (), signaling the "down" level ().$\approx\ 9\ mAh < 80\ cm$

b. $17{,}93\ k\Omega \leq R < 21{,}37\ k\Omega$
D2 (yellow) leads (), indicating "medium" level ().$\approx\ 9\ mA80 \leq h < 150\ cm$

c. R ≥ 21.37 kΩ
– **D3 (green)** leads (), signaling the "high" level ().$\approx\ 9\ mAh \geq 150\ cm$

The constant value of the current () is due to the limiting resistance and saturation voltage of the comparators, ensuring predictable consumption and optimal protection of the LEDs.$\sim 9\ mA1{,}2\ k\Omega$

6.3. Monte Carlo simulation

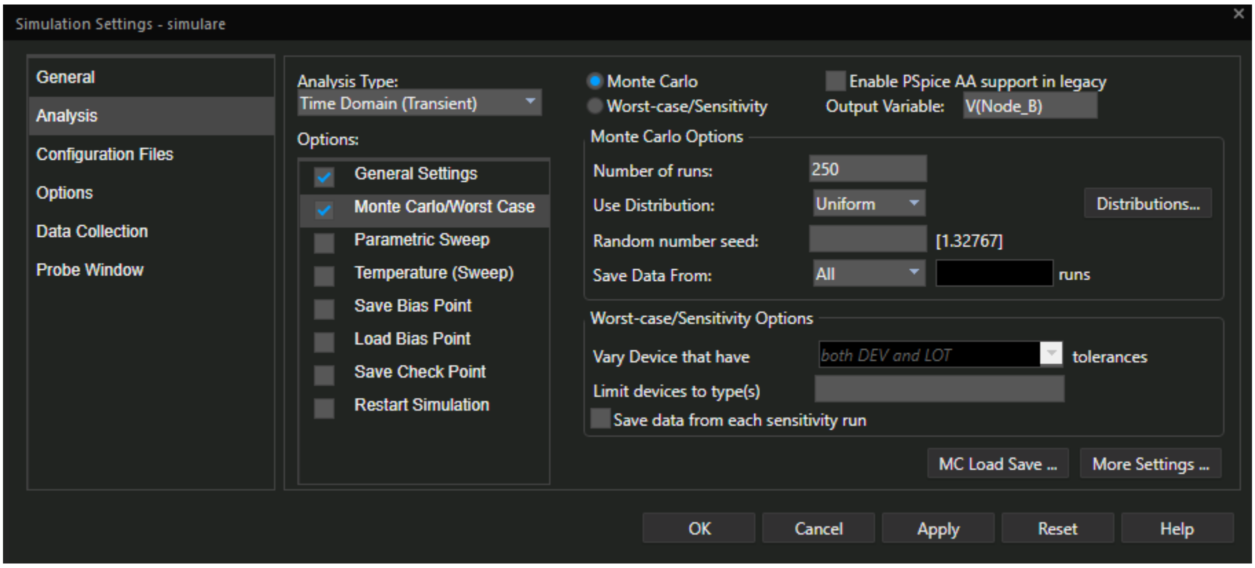

Image 3: Parameters set for Monte Carlo simulation

In the **Simulation Settings window → Monte Carlo/Worst Case** we have activated only the following options:

- **Analysis Type**: Time Domain (Transient) with **Monte Carlo/Worst Case option**
- **Monte Carlo Options**
  - **Number of runs**: 250
  - **Use Distribution**: Uniform
  - **Random number seed**: 1.32767
  - **Save Data From**: All runs
  - **Variable Output**: V(Node_B)

- **Worst-case/Sensitivity Options**
  - **Vary Device that have**: both DEV and LOT tolerances
  - **Limit devices to type(s):** (default – all devices defined)
  - **Save data from each sensitivity run**: on

All other options (Parametric Sweep, Temperature Sweep, Bias Point, etc.) remained disabled.

6.3.1. Histogram for node B

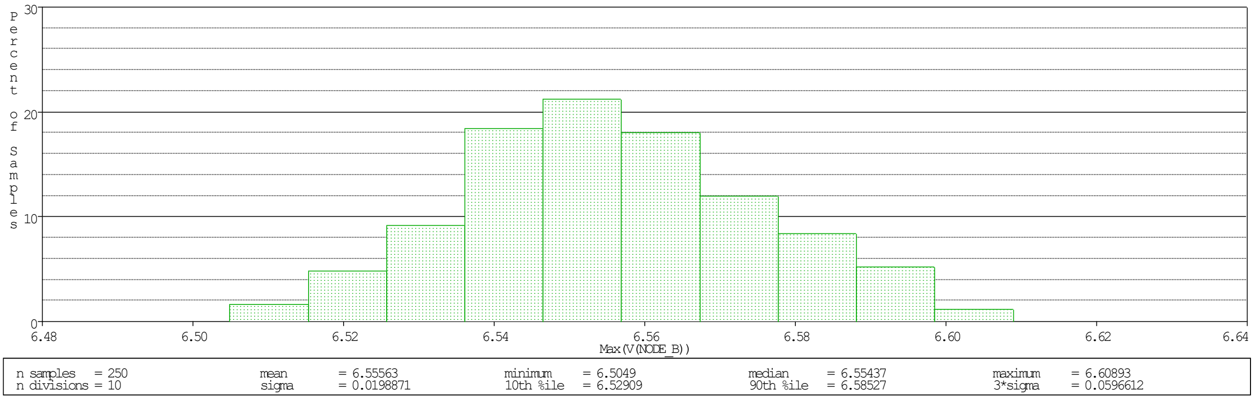

Figure 16: Reference voltages for node B

The figure above shows the histogram of the maximum reference voltage values at node B (Max V(Node_B)) obtained from 250 Monte Carlo bearings with uniform distribution of component tolerances.

- **Number of samples:** 250
- **Average:** $\bar{V}_B \approx 6{,}55\ V$
- **Standard deviation:**$\sigma \approx 0{,}02$
- **Minimum value:** $6{,}524V$
- **Maximum value:** $6{,}607V$
- **10–90th percentile range:** $[6{,}539\ V,\ 6{,}567\ V]$

This relatively tight distribution (V around the mean) confirms that, even in the presence of tolerance variations of the resistors, the detection threshold at node B remains well delimited around the theoretical value of , ensuring the robust operation of the comparator and the green LED lighting at the correct level ().$\pm 0{,}03$ $6{,}53\ Vh\ \geq 150\ cm$

6.3.2. Histogram for node C:

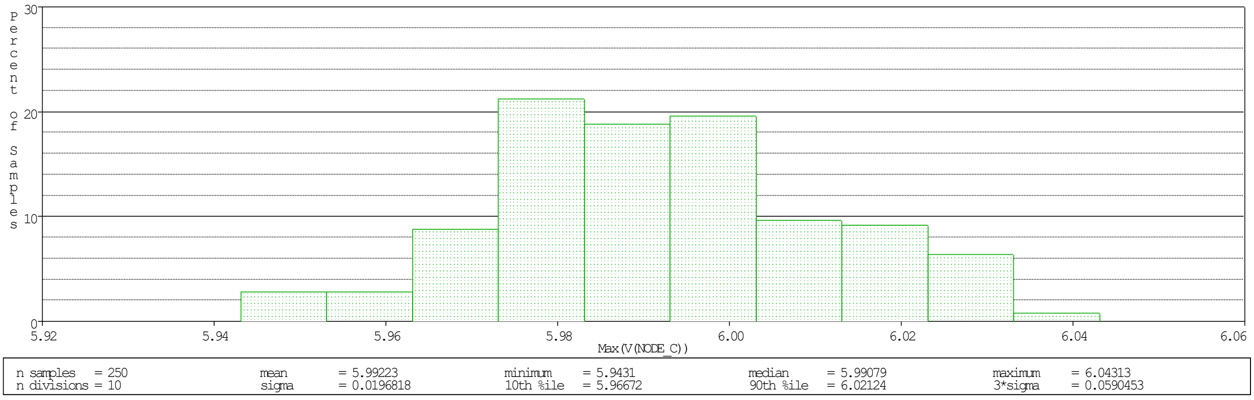

Figure 17: Reference voltages for node C

The histogram of the maximum reference voltage values at node C (corresponding to the threshold of 80 cm) obtained from 250 Monte Carlo simulations shows:

- **Number of samples**: 250
- **Medium**: $\approx$ $5{,}99\ V$
- **Standard deviation**: $\approx 0{,}02\ V$
- **Minimum**: $\approx$ $5{,}96\ V$
- **Maximum**: $\approx$ $6{,}04\ V$
- **10–90th percentile**: $[\approx\ 5{,}97\ V, \approx\ 6{,}02\ V]$

The relatively concentrated distribution around the theoretical value of demonstrates that, despite the tolerance variations of the components, the detection threshold at node C remains stable and well defined, ensuring a reliable switching of the comparator responsible for signaling the level of .$5{,}96\ V 80\ cm$

6.3.3. Histogram for node D:

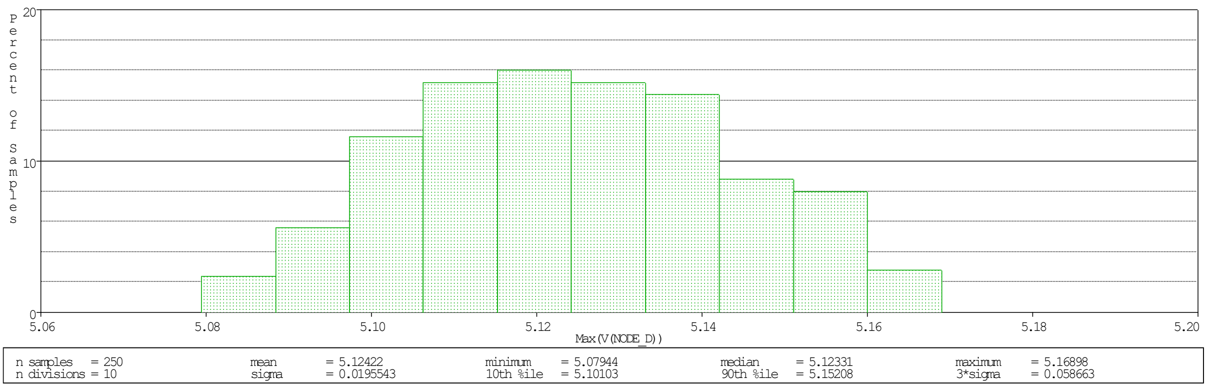

Figure 18: Reference voltages for node D

The histogram of the maximum reference voltage values at **node D** (lower threshold,) following 250 Monte Carlo simulations shows:$h = 0\ cm$

- **Number of samples:** 250
- **Average:** ≈ 5,124 V
- **Standard deviation:** ≈ 0.016 V
- **Minimum value:** ≈ 5.104 V
- **Maximum value:** ≈ 5.186 V
- **10–90th percentile:** ≈ [5.109 V, 5.138 V]

The distribution, concentrated around the theoretical value of 5.15 V, confirms that the detection threshold at node D remains well defined even in the presence of component tolerance variations, ensuring the reliable illumination of the red LED for the low level (h < 80 cm).

Following the Monte Carlo analysis, the percentage error of each threshold compared to the theoretical value results as follows:

- **Threshold B** (theoretical 6.53 V):
  - Average error:

$$\frac{6{,}553 - 6{,}53}{6{,}53} \times 100\% \approx +0{,}36\% \tag{20}$$

  - Maximum deviation: $\pm[0{,}09\%;\ 1{,}18\%]$
- **Threshold C** (theoretical 5.96 V):
  - Average error:

$$\frac{5{,}992 - 5{,}96}{5{,}96} \times 100\% \approx +0{,}54\% \tag{21}$$

  - Maximum deviation: $\pm[0\%;\ 1{,}34\%]$
- **Threshold D** (theoretical 5.15 V):
  - Average error

$$\frac{5{,}124 - 5{,}15}{5{,}15} \times 100\% \approx -0{,}50\% \tag{22}$$

- Maximum deviation: $\pm[0{,}70\%;\ 0{,}89\%]$

Thus, all reference thresholds remain within the margin of error ±1.5% of the calculated values, which confirms the accuracy and robustness of the design.

6.4. Worst Case Simulation

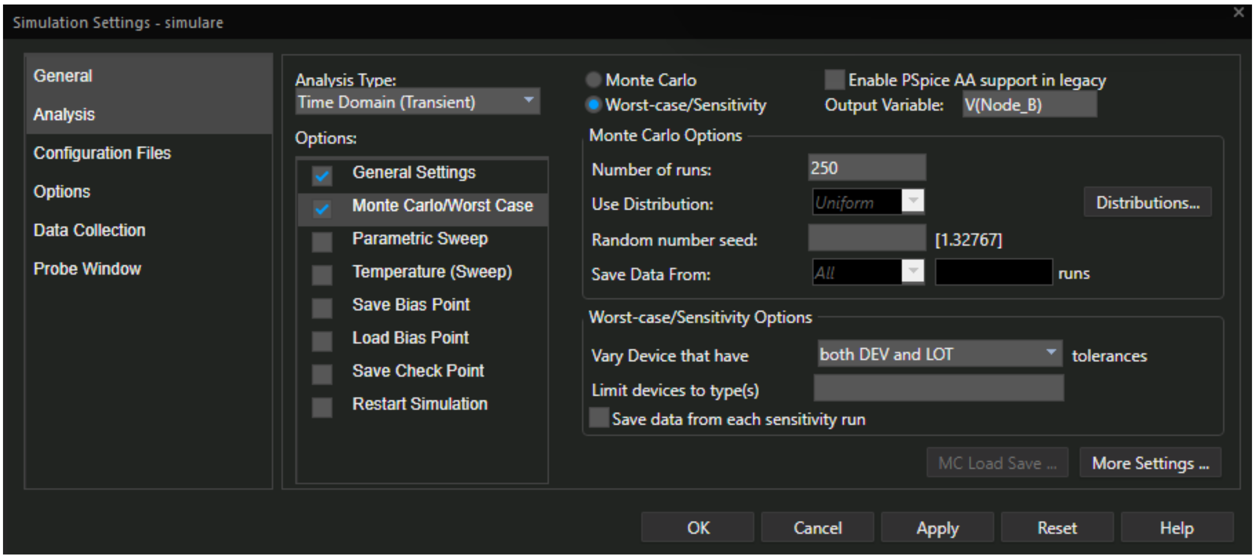

Image 4: Parameters set for the Worst Case simulation

6.4.1. Worst-Case Analysis for Reference Voltage at Node B

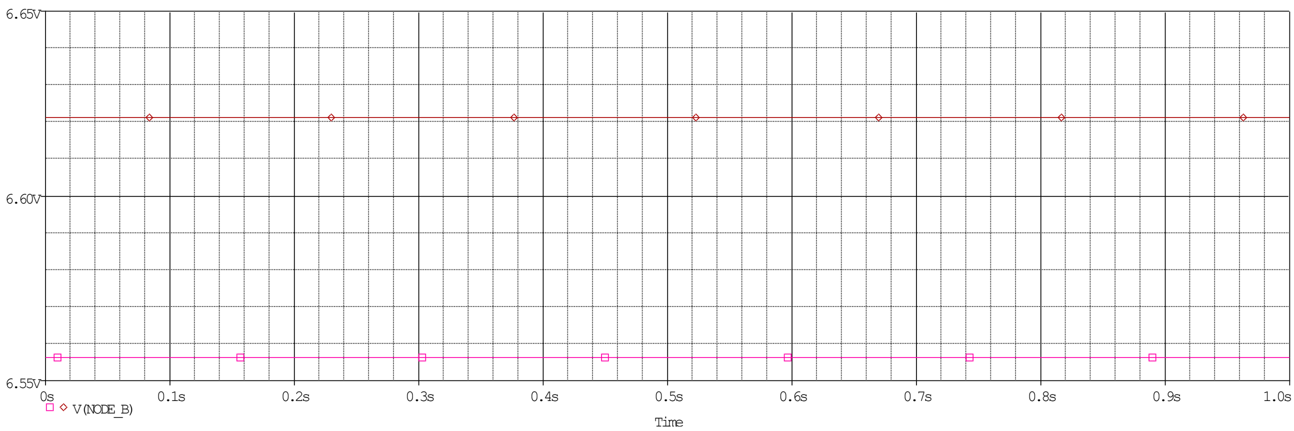

Figure 19: Simulated stresses in node B

Obtained parameters:

Device MODEL PARAMETER NEW VALUE

R_R5 R_R5 R .99 (Decreased)

R_R6 R_R6 R .99 (Decreased)

R_R7 R_R7 R 1.01 (Increased)

R_R8 R_R8 R 1.01 (Increased)

R_R9 R_R9 R 1.01 (Increased)

R_Rfix R_Rfix R 1 (Unchanged)

R_R1 R_R1 R 1 (Unchanged)

R_R2 R_R2 R 1 (Unchanged)

R_R3 R_R3 R 1 (Unchanged)

Mean Deviation = .065

Sigma = 0

RUN MAX DEVIATION FROM NOMINAL

WORST CASE ALL DEVICES

.065 higher at T = 10.0000E-06

(100.99% of Nominal)

In this **Worst-Case/Sensitivity simulation**, both the typical tolerances (DEV) and the lot-to-lot (LOT) tolerances of R_5 resistors were taken into account. R_9, to determine the extreme limits of the 150 cm threshold. The routes displayed correspond to:

- **Red Line (Worst-Case High):** $V_{B,max} \approx 6{,}60\ V$
- **Magenta line (Worst-Case Low):** $V_{B,min} \approx 6{,}52\ V$
- **Exact values:** $V_{B,max} \approx 6{,}524\ V$; $V_{B,min} \approx 6{,}607\ V$

Observations:

1. **Stability over time** – both values remain constant throughout the 1 s interval, without oscillations.
2. Range of variation ±0.04 V (±0.6 %) vs. nominal 6.53 V, which guarantees reliable switching of the U4A comparator only when the level of 150 cm is actually exceeded.

6.4.2. Worst-Case Analysis for Reference Voltage at Node C

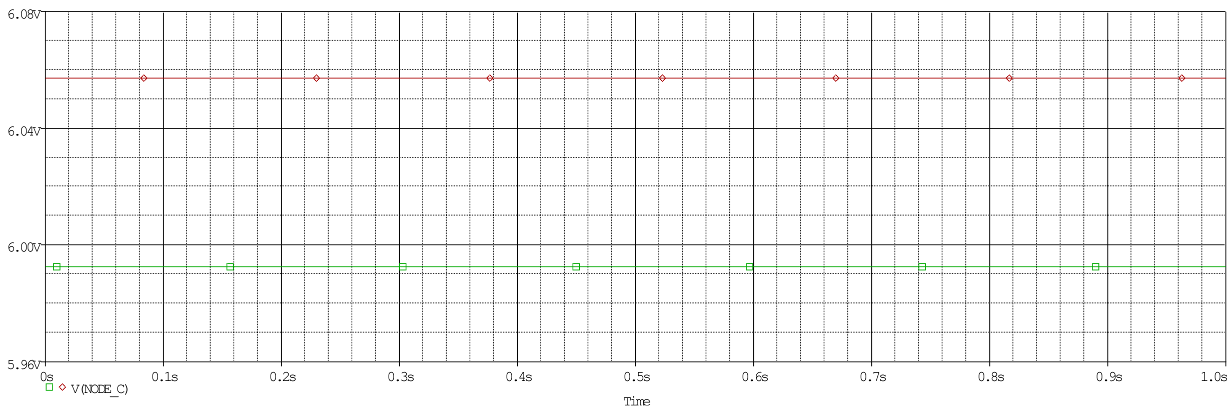

Figure 20: Simulated stresses in node C

Obtained parameters

Device MODEL PARAMETER NEW VALUE

R_R5 R_R5 R .99 (Decreased)

R_R6 R_R6 R .99 (Decreased)

R_R7 R_R7 R .99 (Decreased)

R_R8 R_R8 R 1.01 (Increased)

R_R9 R_R9 R 1.01 (Increased)

R_Rfix R_Rfix R 1 (Unchanged)

R_R1 R_R1 R 1 (Unchanged)

R_R2 R_R2 R 1 (Unchanged)

R_R3 R_R3 R 1 (Unchanged)

Mean Deviation = .0647

Sigma = 0

RUN MAX DEVIATION FROM NOMINAL

WORST CASE ALL DEVICES

.0647 higher at T = 10.0000E-06

(101.08% of Nominal)

For the threshold of **80 cm** (node C), the Worst-Case simulation showed the following limits:

- **Red Line (Worst-Case High):**

  $V_{C,max} \approx 6{,}06\,V$

- **Green line (Worst-Case Low):**

  $V_{C,min} \approx 5{,}96\,V$

Exact values (from the simulation report):

$$V_{C,min} \approx 5{,}96\,V;\;\; V_{C,max} \approx 6{,}06\,V$$

Observations:

1. Both values remain constant over the range 0... 1 s, without any transient derivation.
2. The worst-case deviation is ±0.05 V (~±0.8 %) from the nominal value of 5.96 V, ensuring a clear threshold delineation for the signal comparators.

6.4.3. Worst-Case Analysis for Reference Voltage at Node D

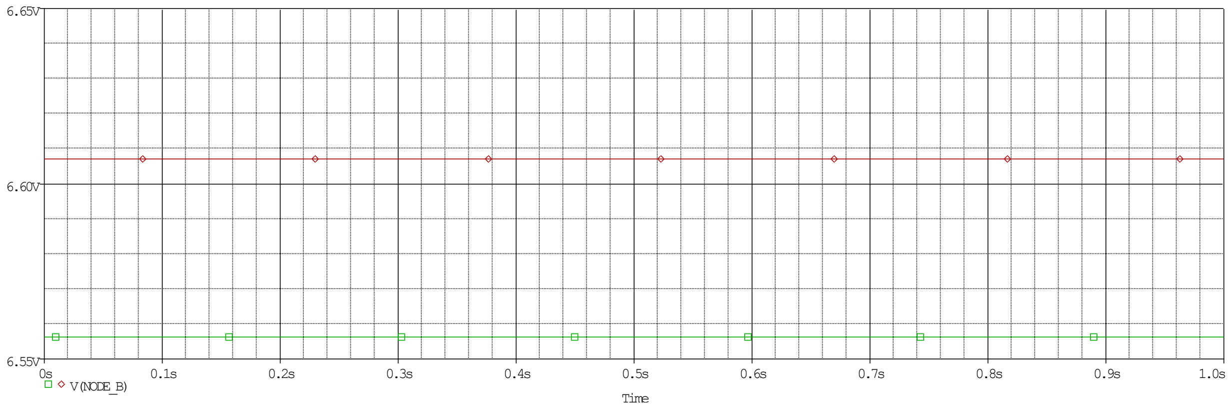

Figure 21: Simulated stresses in node D

Obtained parameters:

Device MODEL PARAMETER NEW VALUE

R_R5 R_R5 R .99 (Decreased)

R_R6 R_R6 R .99 (Decreased)

R_R7 R_R7 R .99 (Decreased)

R_R8 R_R8 R .99 (Decreased)

R_R9 R_R9 R 1.01 (Increased)

R_Rfix R_Rfix R 1 (Unchanged)

R_R1 R_R1 R 1 (Unchanged)

R_R2 R_R2 R 1 (Unchanged)

R_R3 R_R3 R 1 (Unchanged)

Mean Deviation = .0622

Sigma = 0

RUN MAX DEVIATION FROM NOMINAL

WORST CASE ALL DEVICES

.0622 higher at T = 10.0000E-06

(101.21% of Nominal)

In this **Worst-Case/Sensitivity simulation**, the typical tolerances (DEV) and lot-to-lot (LOT) of R_5 resistors were taken into account. R_9, for the lower threshold (h = 0 cm). The routes shown correspond to:

- **Red Line (Worst-Case High):**

  $V_{D,max} \approx 5{,}186V$

- **Green line (Worst-Case Low):**

  $V_{D,\ min} \approx 5{,}104\,V$

Values extracted from the simulation:

$V_{D,min} \approx 5{,}104\,V$; $V_{D,max} \approx 5{,}186\,V$

Observations:

1. Both boundaries remain perfectly static over the 1 s interval, without transient slippage.
2. The deviation from the nominal value is:$V_{D,nom} = 5{,}15V$
   - **Worst-Case High:** $\frac{5{,}186-5{,}15}{5{,}15} \times 100\% \approx +0{,}70\%$
   - **Worst-Case Low:** $\frac{5{,}104-5{,}15}{5{,}15} \times 100\% \approx -0{,}89\%$

   This narrow range of variation (± 0.9 %) ensures that the red LED is only reliably switched on when the liquid level is actually below 80 cm, guaranteeing that the lower threshold is clearly delineated.

7. CONCLUSIONS

The design and simulation project of the liquid level measurement system demonstrated the efficiency of a modular approach, which integrates the resistive transducer, the conditioning stage (divider plus buffer), the comparator block and the LED display. Through transient, time-domain simulations with parametric sweep, Monte Carlo and worst-case, both the linearity and stability of the output signal were validated, as well as the robustness against component tolerance variations and extreme power conditions.

During this project, the following professional skills were developed and strengthened:

- **Analog circuit design**: component selection, calculation of voltage dividers and sizing of detection thresholds.
- **Use of OrCAD**: implementation of electrical diagrams, configuration of simulations and interpretation of results in various analysis scenarios.
- **Reliability analysis**: application of Monte Carlo and Worst-Case methodologies for probabilistic and extreme evaluation of circuit performance.
- **Technical documentation capability**: clear drafting of mathematical models, simulation instructions and comments on schematics, as well as organization into coherent documentation.
- **Scientific communication skills**: presentation of conclusions and results in an appropriate academic language, structured on relevant sections (abstract, table of contents, tables, figures).

Overall, the project provides both a functional prototype of liquid level monitoring with optical feedback and a solid methodological framework for the further approach of electronic measurement and control systems.

8. BIBLIOGRAPHY

[1] Emilia Șipoș, Laura Ivanciu, *Electronic Devices*, UT Press, Cluj, Cluj-Napoca, 2016;

[2] Tom Petruzzellis, *Electronic senzors for the evil genius: 53 electryfing projects*, Tap Electronics, New York, 2006;

[3] (2025) TE Connectivity, https://www.te.com/en/product-12110215.html;

[4] (2025) Texas Instruments, https://www.ti.com/product/TL082;

[5] (2025) Vishay Precision Group, https://www.vishay.com/resistors/precision/;

[6] (2025) Kingbright, https://www.kingbrightusa.com/products/through-hole-leds/3364;

[6] (2025) Phoenix Contact, https://www.phoenixcontact.com/online/portal/us?1dmy&urile=wcm%3apath%3a/usen/web/corporate/products/subcategory_pages/terminal_blocks_through_hole/17638cfa-4bbb-46eb-bb2d-d85af4bab417;

[7] (2025) JLCPCB, https://jlcpcb.com/pcb_prototype;

[8] (2025) Adafruit, https://www.adafruit.com/category/17;

[9] "XYZ-LS100 Resistive Liquid Level Sensor data sheet", Adafruit, New Jersey;

[10] "Vishay MRS25 Metal Film Resististors data sheet", Vishay BCcomponents, Pennsylvania;

[11] "TL082 Dual Operational Amplifier data sheet", Texas Instruments, Texas;

[12] "Kingbright LED Series 3365 data sheet", Kingbright, France.