Faculty of Electronics, Telecommunications and Information Technology

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

PROJECT DOCUMENTATION
COMPUTER AIDED DESIGN
Circuit for controlling the concentration of carbon monoxide in an enclosure

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

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1 Project Overview

1.1 Requirements

Design a system using resistive gas sensors to maintain the concentration of carbon monoxide in an enclosure between the limits specified in column E. There is a source in the enclosure that continuously generates carbon monoxide. When the concentration has reached the upper limit (column E), the system will start the fan that will introduce fresh air. When the concentration of carbon monoxide reaches the lower limit (column E) the system will give the command to stop the fan. From the sensor data sheet it is known that at a variation of the gas concentration specified in column F the electrical resistance of the sensor varies linearly in the range specified in column G. The variation of the electrical resistance of the sensor must be converted into a voltage variation in the range [2÷ (Vcc-2V)]. Vcc is specified in column H. The fan is controlled by a hysteresis comparator via a relay which is modeled with a resistor. The state of the fan (on/off) is indicated by an LED of the color specified in column I.

Student name	Indoor carbon monoxide concentration [ppm]	The measurement range of the sensor [ppm]	Sensor resistance [kΩ]	VCC [V]	LED colour
Cantor Lavinia-Denisa	800....16000	20.....18000	94...42	12	yellow

A circuit for controlling the concentration of carbon monoxide (CO) in an enclosure is an electronic system designed to monitor and regulate the levels of CO gas within a confined space to ensure safety and prevent harmful exposure. The core component of the circuit is a carbon monoxide sensor. This sensor detects the concentration of CO in the air and converts this information into an electrical signal.

1.2 Block Diagram

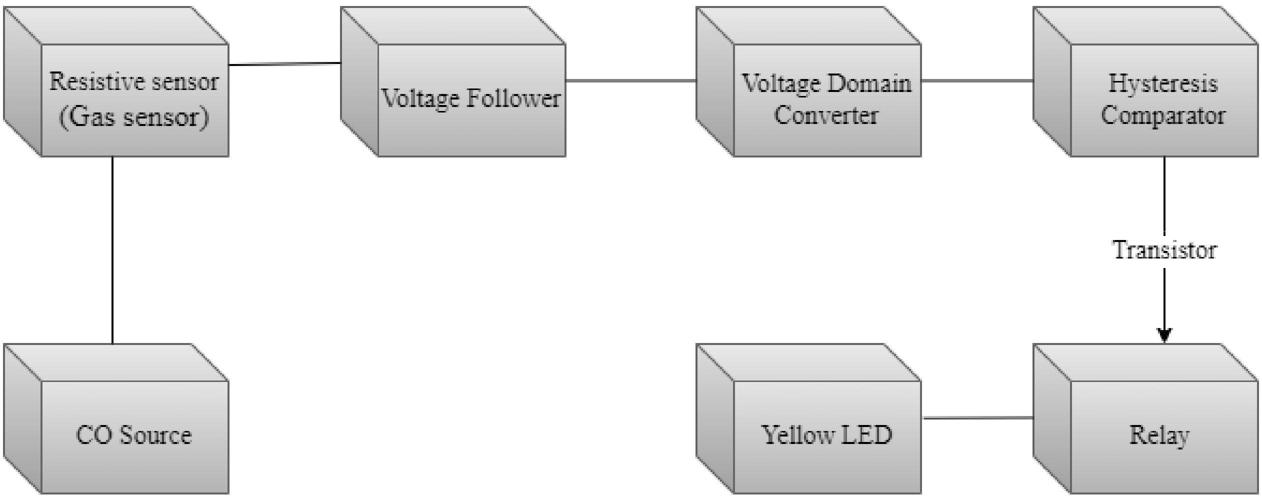

Figure 1. The Diagram

1.2.1 CO Source

The CO source is an entity within the enclosed space that generates carbon monoxide. The circuit is designed to monitor and control the concentration of carbon monoxide emitted by this source, ensuring that it stays within predefined safe limits. The primary goal of the circuit is to detect when the CO concentration reaches dangerous levels and activate a ventilation system to bring in fresh air, thereby maintaining a safe environment within the enclosure.

1.2.2 Resistive Gas Sensor:

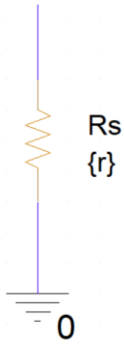

Figure 2. The resistive gas sensor

The resistive gas sensor is crucial for detecting the concentration of carbon monoxide in the enclosure. The sensor's resistance changes in response to varying CO levels; this change is directly proportional to the concentration of CO in the air The resistance of the sensor changes as the CO concentration rises. This resistance change is the primary input to the circuit, allowing it to continuously monitor CO levels. After processing this resistance variation, the circuit initiates the required steps to keep CO concentrations safe.

The resistive sensor is directly connected to the input of the first operational amplifier (U1), which is configured as a voltage follower. The sensor's varying resistance, in response to different levels of carbon monoxide, build a voltage divider network along with fixed resistors R1 and R1.2. This network converts the resistance variation into a corresponding voltage variation.

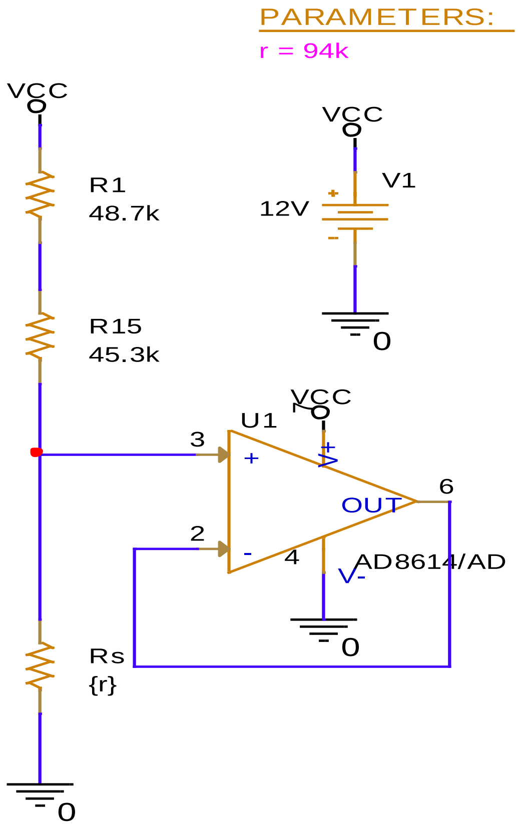

Figure 3.The voltage divider

The primary reason for using a voltage divider with the sensor is to convert the resistance change into a measurable voltage. This voltage can then be processed by next stages of the circuit. The circuit maintains accurate, real-time monitoring of CO levels by arranging the resistive gas sensor in this way, allowing the system to maintain safe concentrations within the enclosure.

1.2.3 Voltage Follower

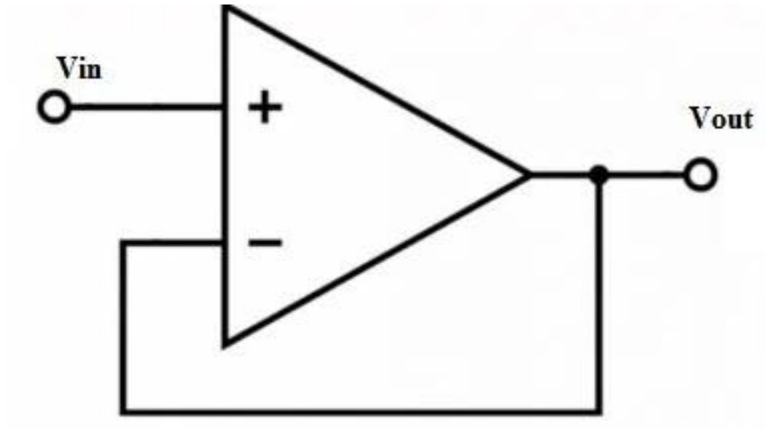

Figure 4. The voltage follower

The voltage follower makes sure that the signal from the resistive gas sensor is accurately transferred to the next stages (voltage domain converter and hysteresis comparator) without any distortion or loss, allowing for reliable monitoring of carbon monoxide levels.

1.2.4 Voltage Domain Converter

The voltage domain converter uses the output from the voltage follower, which represents the resistance variation of the gas sensor as a voltage signal. This converter typically includes a bridge circuit and an operational amplifier. The bridge circuit creates a voltage that is proportional to the resistance change in the gas sensor. This signal is then processed by the operational amplifier to make sure it is within a particular voltage range.

It is responsible for converting the resistance changes from the gas sensor into a corresponding voltage signal. This conversion is essential because the later stages of the circuit, such as the hysteresis comparator, need a voltage input to work properly instead of a resistance input.

1.2.5 Hysteresis Comparator

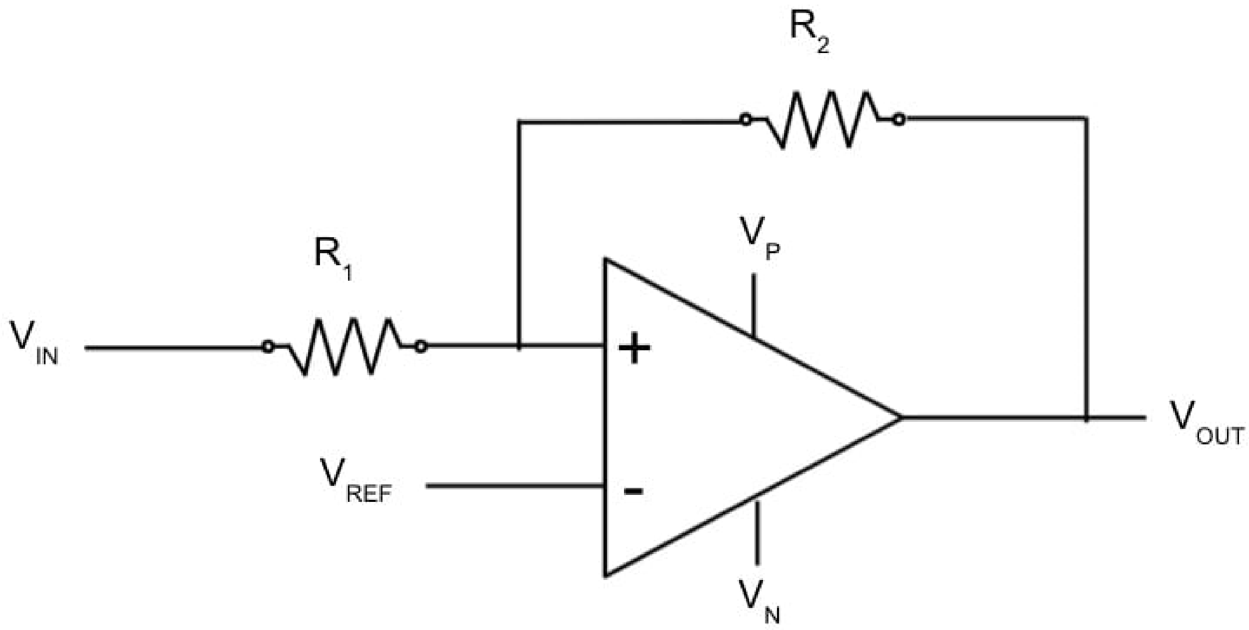

Figure 5. Inverting Hysteresis Comparator

The hysteresis comparator controls the operation of the fan based on the CO levels detected by the sensor. The comparator compares the voltage signal from the voltage domain converter against an upper limit and a lower limit.

When the CO concentration reaches the upper threshold (high limit), the voltage signal triggers the comparator to output a signal that activates the fan. This action introduces fresh air into the enclosure, reducing the CO concentration. When the CO concentration drops to the lower threshold (low limit), the comparator's output signal turns off the fan, no fresh air being introduced in the enclosure.

The comparator's output directly controls the fan, which is essential for regulating the CO concentration within the enclosure. The hysteresis ensures that small variations around threshold values do not cause the fan to switch states repeatedly.

1.2.6 Fan Control (Relay + LED):

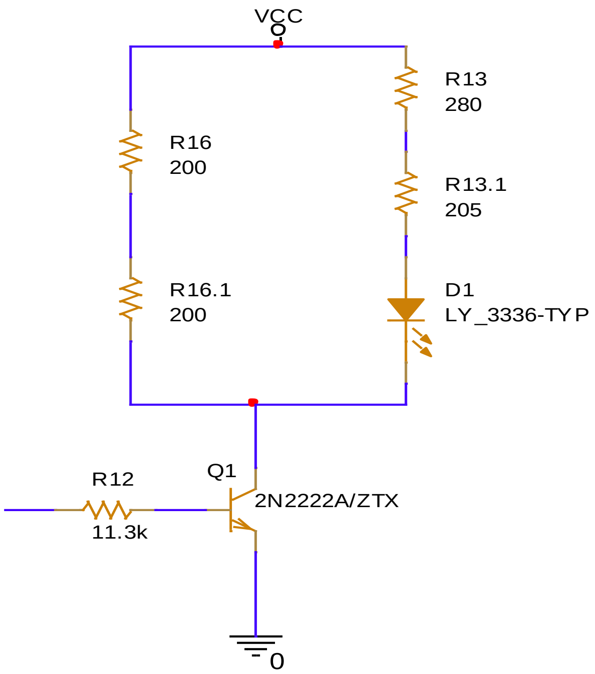

Figure 6. The fan control (Relay + LED)

The fan control system is responsible for turning the fan on and off based on the signals from the hysteresis comparator. The comparator sends a signal to a relay. A relay is like an automatic switch that can turn the fan on and off. When the CO level is too high, the comparator tells the relay to turn on the fan, bringing in fresh air to lower the CO concentration and when the CO level is low enough, the comparator tells the relay to turn off the fan. An LED light is connected to the fan control circuit to show whether the fan is on or off, so the LED lights up when the fan is on.

Resistor R12 is placed before the base of the transistor because it needs to control the current flowing into the base. Too much current could damage the transistor or cause it to operate improperly. The transistor needs a specific amount of current at its base to switch on (enter saturation mode) and allow current to flow from the collector to the emitter. R12 makes sure that this current is in the correct range.

2 Sizing the circuit

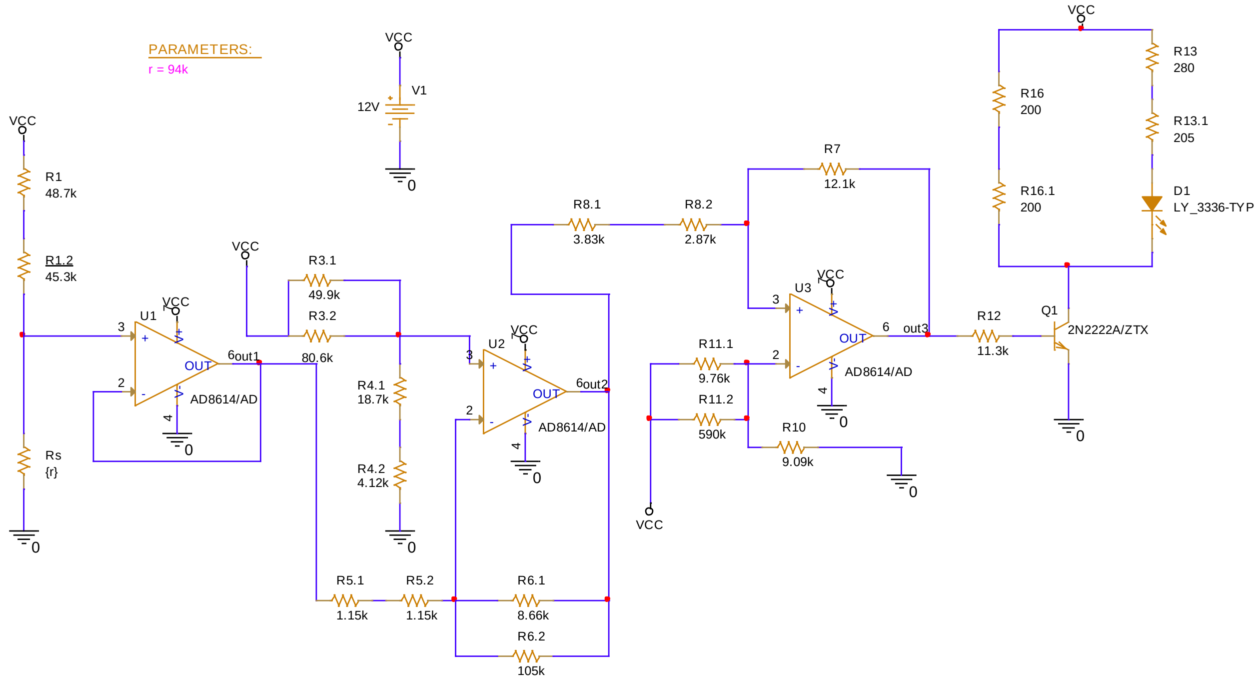

Figure 7. The full circuit for controlling the concentration of carbon monoxide in an enclosure

2.1 Operations

2.1.1 Determining Rs (Gas Sensor Resistance) Range:

Maximum resistance R_{max} of the sensor is $94k\Omega$ and minimum resistance R_{min} is 42kΩ.

2.1.2 Voltage Values for Sensor Resistance Range:

$$R_{max} = 94k\Omega \ \rightarrow \ V_{max} = \frac{R_{max}}{R_{max}+R2} \cdot V_{cc} = \frac{94}{94+94} \cdot 12 = 6V \qquad (1)$$

(at maximum sensor resistance, the voltage across the sensor is 6V)

$$R_{min} = 42k\Omega \ \rightarrow \ V_{min} = \frac{R_{min}}{R_{min}+R2} \cdot V_{cc} = \frac{42}{42+94} \cdot 12 = 3.7V \qquad (2)$$

(at minimum sensor resistance, the voltage across the sensor is 3.7V)

$$V_{max} = 6V \;\rightarrow V_{cd_{max}} = 6V \quad (3)$$

$$V_{min} = 3.7V \;\rightarrow V_{cd_{min}} = 3.7V \quad (4)$$

The range $V_{cd_{max}}$ and $V_{cd_{min}}$ helps in designing the voltage domain converter to map the sensor's voltage output to the desired input range of the hysteresis comparator

$$V_o \in [2 \div (V_{cc} - 2)] \text{ (voltage variation)}$$

2.1.3 Choosing the values of the resistors

Determining the appropriate values of R_6 and R_5 that will scale the voltage from the sensor to match the desired voltage variation for the comparator:

$$\frac{R_6}{R_5} = \frac{v_{o_{max}} - v_{o_{min}}}{V_{cdmax} - V_{cdmax}} = \frac{10-2}{6-3.7} = \frac{8}{2.3} \rightarrow R_6 = 8k\Omega;\; R_5 = 2.3k\Omega \quad (5)$$

Voltage domain conversion amplifier formula:

$$V_{Ref} = \frac{v_{o_{min}} + V_{cdmax} \cdot \frac{R_6}{R_5}}{1 + \frac{R_6}{R_5}} = \frac{R_4}{R_3 + R_4} \cdot V_{cc} \rightarrow \frac{2 + \frac{8}{2.3} \cdot 6}{1 + \frac{8}{2.3}} = \frac{R_4}{R_3 + R_4} \cdot 12 \quad (6)$$

(the positive feetback is equal to the negative feedback)

$$\frac{22{,}82}{4.47} = \frac{R_4}{R_3 + R_4} \cdot 12 \rightarrow \frac{22{,}82}{53.64} = \frac{R_4}{R_3 + R_4} \rightarrow R_4 = 22.82\ k\Omega;\; R_3 = 30.82\ k\Omega \quad (7)$$

$$V_{Ref} = 5.1V$$

Determining the threshold voltages V_{Th_H} and V_{Th_L} used in the hysteresis comparator for the fan control system:

$$v_{o_{max}} - \frac{v_{o_{max}} - v_{o_{min}}}{18000 - 20}(800 - 20) = 9.653 \rightarrow V_{Th_H} = 9.653V \quad (8)$$

This formula calculates the upper threshold voltage at which the fan will be activated to reduce the CO concentration.

$$v_{o_{max}} - \frac{v_{o_{max}} - v_{o_{min}}}{18000-20}(16000-20) = 2.89 \rightarrow V_{Th_L} = 2.89V \qquad (9)$$

This formula calculates the lower threshold voltage at which the fan will be deactivated, indicating that the CO concentration has been reduced to a safe level.

By calculating precise upper and lower threshold voltages, the system can accurately detect when the CO concentration is too high and when it has been sufficiently reduced.

Determining the resistor values for the inverting hysteresis comparator:

$$V_{Ref} = \frac{R_{11}}{R_{11}+10} \cdot V_{cc} = \frac{R_{11}}{R_{11}+10} \cdot 12 \qquad (10)$$

$$V_{Th_L} = -\frac{R_8}{R_7} \cdot V_{cc} + \left(1 + \frac{R_8}{R_7}\right) \cdot V_{Ref} \rightarrow 2.89 = -\frac{R_8}{R_7} \cdot 12 + \left(1 + \frac{R_8}{R_7}\right) \cdot \frac{R_{11}}{R_{11}+10} \cdot 12 \qquad (11)$$

$$V_{Th_H} = -\frac{R_8}{R_7} \cdot (-V_{cc}) + \left(1 + \frac{R_8}{R_7}\right) \cdot V_{Ref} \rightarrow 9.653 = -\frac{R_8}{R_7} \cdot 0 + \left(1 + \frac{R_8}{R_7}\right) \cdot \frac{R_{11}}{R_{11}+10} \cdot 12 \qquad (12)$$

$$(11),(12) \rightarrow 2.89 = -\frac{R_8}{R_7} \cdot 12 + 9.653 \rightarrow \frac{R_8}{R_7} = \frac{6.71}{12} \rightarrow R_8 = 6.7k\Omega;\ R_7 = 12k\Omega \qquad (13)$$

$$9.653 = \left(1 + \frac{R_8}{R_7}\right) \cdot \frac{R_{11}}{R_{11}+10} \cdot 12 \rightarrow 9.653 = 18.7 \cdot \frac{R_{11}}{R_{11}+10} \rightarrow R_{11} = 9.6k\Omega;\ R_{10} = 9.1k\Omega \ (14)$$

Calculating the necessary resistor value R_{13} to ensure that the correct current flows through the LED and the transistor when the circuit is operating.

$$R_{13} = \frac{V_{cc} - V_{D1} - V_{CE_{on}}}{I_{D1}} = \frac{12-2-0.3}{20mA} = 485\Omega \qquad (15)$$

I_{D1}: The current through the LED (D1), set to 20mA from the data sheet of the LED.

$V_{CE_{on}}$: The voltage drop across the collector-emitter junction of the transistor when it is in the "on" state, which is 0.3V from the data sheet.

V_{D1}: The forward voltage drop across the LED (D1). In this context, set to 2V from the data sheet. It represents the voltage required for the LED to conduct and emit light.

Resistor (R12 - 11.3kΩ) limits the base current of the transistor to protect it from excessive current that could damage it and ensures that the transistor operates within its safe current limits.

The specific value for R16 (400 ohms) were chosen based on data provided in the relay's datasheet and are included in the circuit to model the behavior of the relay.

Component	Calculated Value	Standardized Value	Connection Method
R1	94k	48.7k + 45.3k	Series
R3	30.82k	49.9k // 80.6k	Parallel
R4	22.82k	18.7k + 4.12k	Series
R5	2.3k	1.15k + 1.15k	Series
R6	8k	8.66k // 105k	Parallel
R7	12.1k	12.1k	Single
R8	6.7k	3.83k + 2.87k	Series
R10	9.09k	9.09k	Single
R11	9.6k	590k // 9.76k	Parallel
R12	11.3k	11.3k	Single
R13	485	280 + 205	Series
R16	400	200 + 200	Series

2.2 Formulas used

$$V_{REF} = \frac{R_1}{R_1 + R_2} V_{PS}$$

$$v_{cd_{\min}} \rightarrow v_{O_{\max}}$$

$$v_{cd_{\max}} \rightarrow v_{O_{\min}}$$

$$\boxed{V_{REF} = \frac{v_{O\min} + \frac{R_2}{R_1} v_{cd\max}}{1 + \frac{R_2}{R_1}}}$$

$$\boxed{\frac{R_2}{R_1} = \frac{v_{O\max} - v_{O\min}}{v_{cd\max} - v_{cd\min}}}$$

$$\begin{cases} V_{ThL} = \frac{R_1}{R_1 + R_2} V_{OL} + \frac{R_2}{R_1 + R_2} V_{REF} \\ V_{ThH} = \frac{R_1}{R_1 + R_2} V_{OH} + \frac{R_2}{R_1 + R_2} V_{REF} \end{cases}$$

$$v^{+} = \frac{R_1}{R_1 + R_2} v_O + \frac{R_2}{R_1 + R_2} V_{REF}$$

3 Simulations and Analysis

3.1 Voltage Divider Circuit (voltage follower + resistive sensor)

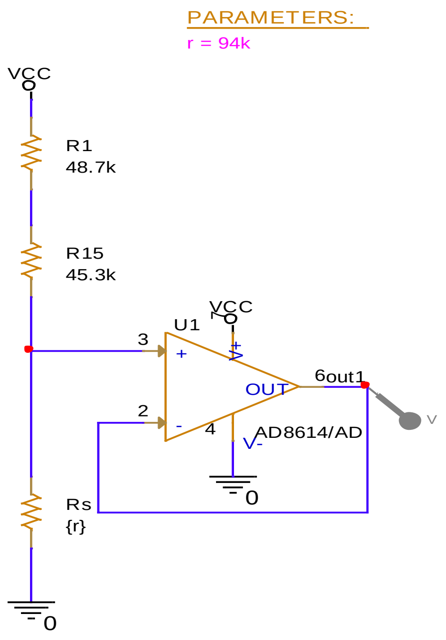

Figure 8.Voltage Divider circuit (voltage follower + resistive sensor) with a level marker for the simulation

This configuration is used to convert the resistance variation of the gas sensor into a voltage variation.

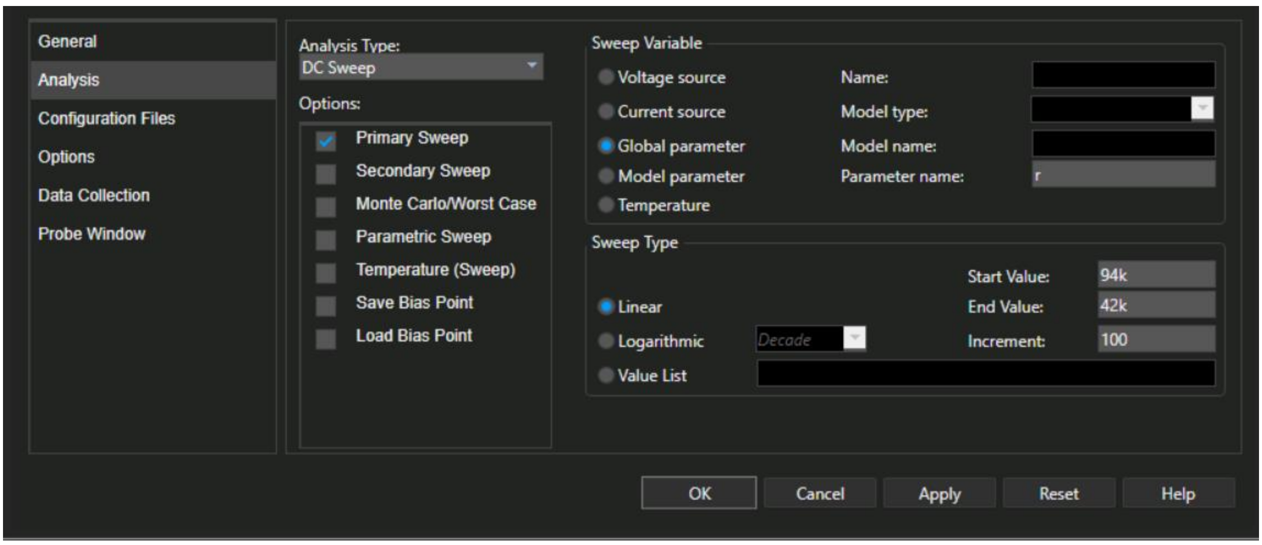

Figure 9.The simulation profile for the voltage divider circuit (voltage follower + resistive sensor)

The simulation is set to perform a DC Sweep analysis, where the parameter "r" (the resistance of the gas sensor, Rs) is varied from 42kΩ to 94kΩ in increments of 100. The purpose of this sweep is to observe how the output voltage of the operational amplifier changes as the resistance of the gas sensor varies within its specified range.

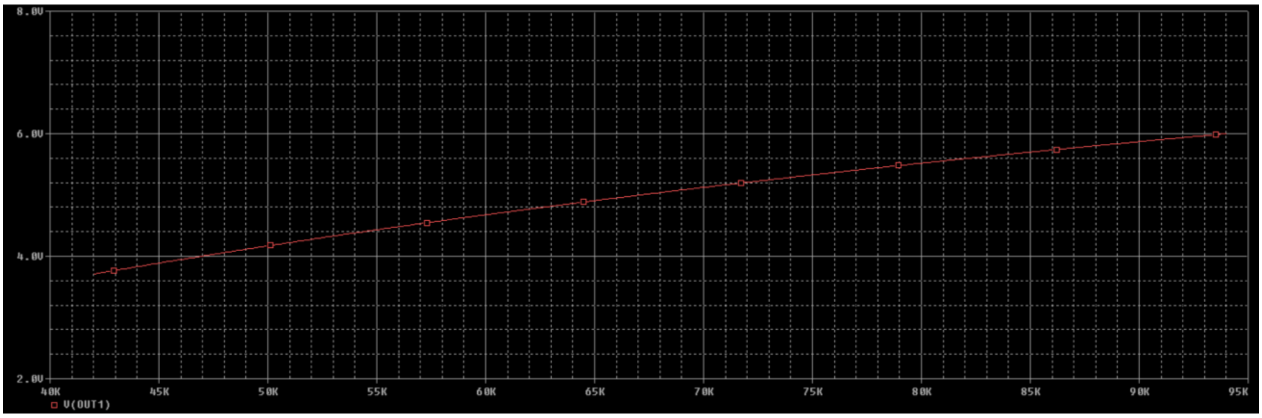

Figure 10.The resulting graph of the voltage divider circuit (voltage follower + resistive sensor)

Graph explanation:

X-Axis (r) represents the resistance value of the gas sensor (Rs) ranging from 42kΩ to 94kΩ. Y-Axis (Vout) Represents the output voltage of the operational amplifier (U1). The graph shows a linear relationship between the resistance of the gas sensor (Rs) and the output voltage (Vout) of the operational amplifier. As the resistance Rs increases from 42kΩ to 94kΩ, the output voltage increases from 3.7V to around 6V(calculated values). The linearity of the graph confirms that the circuit accurately translates the resistance changes of the gas sensor into proportional voltage changes.

3.2 Voltage Domain Converter

The second part of the circuit involves another operational amplifier (U2 - AD8614/AD) configured with resistors R3.1, R3.2, R4.1, R4.2, R5.1, R5.2, R6.1, and R6.2. This configuration processes the signal from the first operational amplifier (U1) to further condition the voltage output.

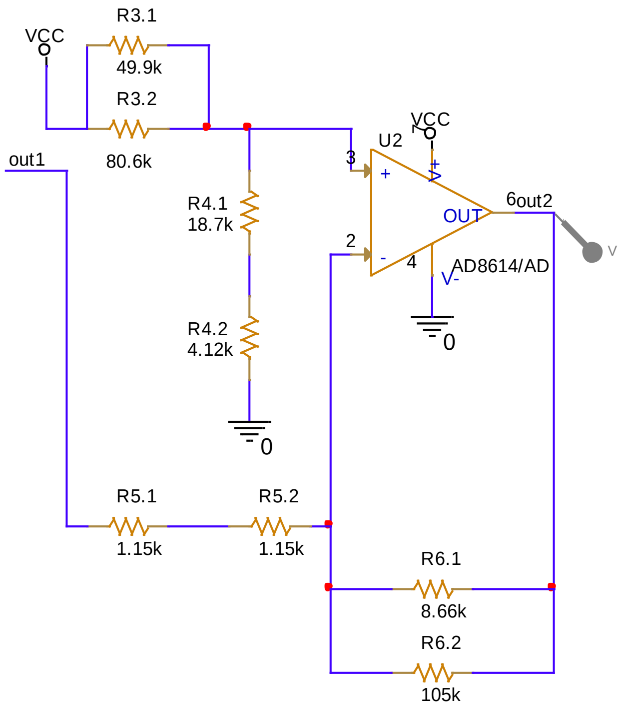

Figure 11. The Voltage Domain Converter circuit

Similar to the previous simulation, this setup performs a DC Sweep analysis where the parameter "r" (the resistance of the gas sensor, Rs) is varied from 42kΩ to 94kΩ in increments of 100 to observe how the output voltage (Vout2) of the second operational amplifier changes as the resistance of the gas sensor varies within its specified range.

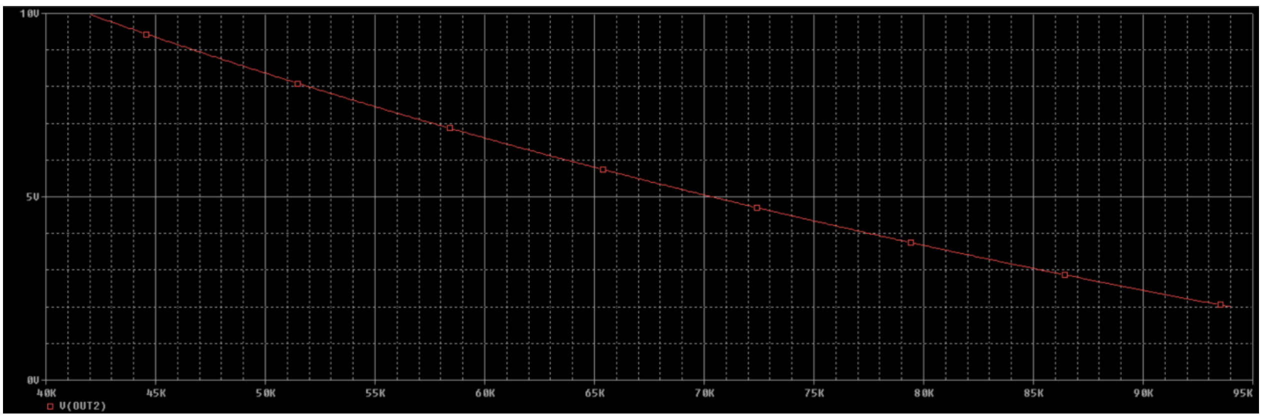

Figure 12. The resulting graph of the voltage domain converter circuit

X-Axis (r) represents the resistance value of the gas sensor (Rs) ranging from 42kΩ to 94kΩ. Y-Axis (Vout2) Represents the output voltage of the second operational amplifier (U2). The graph shows a decreasing relationship between the resistance of the gas sensor (Rs) and the output voltage (Vout2) of the operational amplifier. As the resistance Rs increases from 42kΩ to 94kΩ, the output voltage decreases from 10V(V output max) to around 2V(V output min). The graph confirms that the circuit accurately translates the resistance changes of the gas sensor into a proportional voltage change, in this case showing a decreasing trend. This helps ensure that the CO concentration can be accurately monitored.

3.3 Hysteresis Comparator

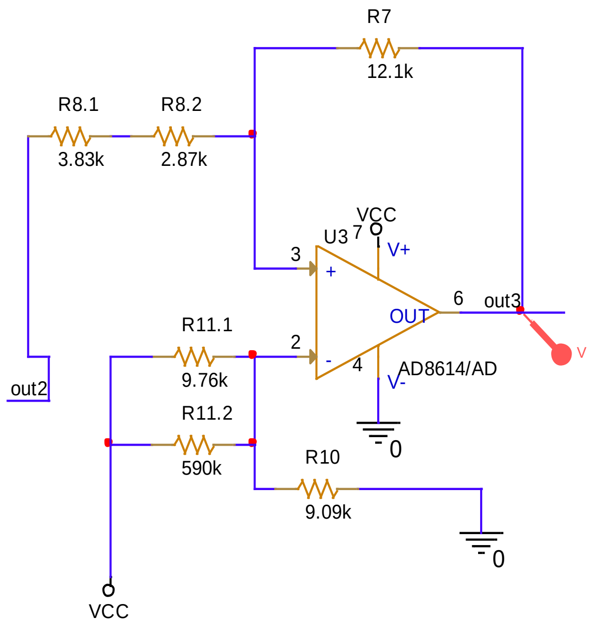

Figure 13. The Hysteresis Comparator circuit

The circuit involves an operational amplifier configured with feedback resistors to create a hysteresis effect, which ensures stable switching between high and low output states. The resistors set the threshold voltages at which the output changes state based on the input signal.

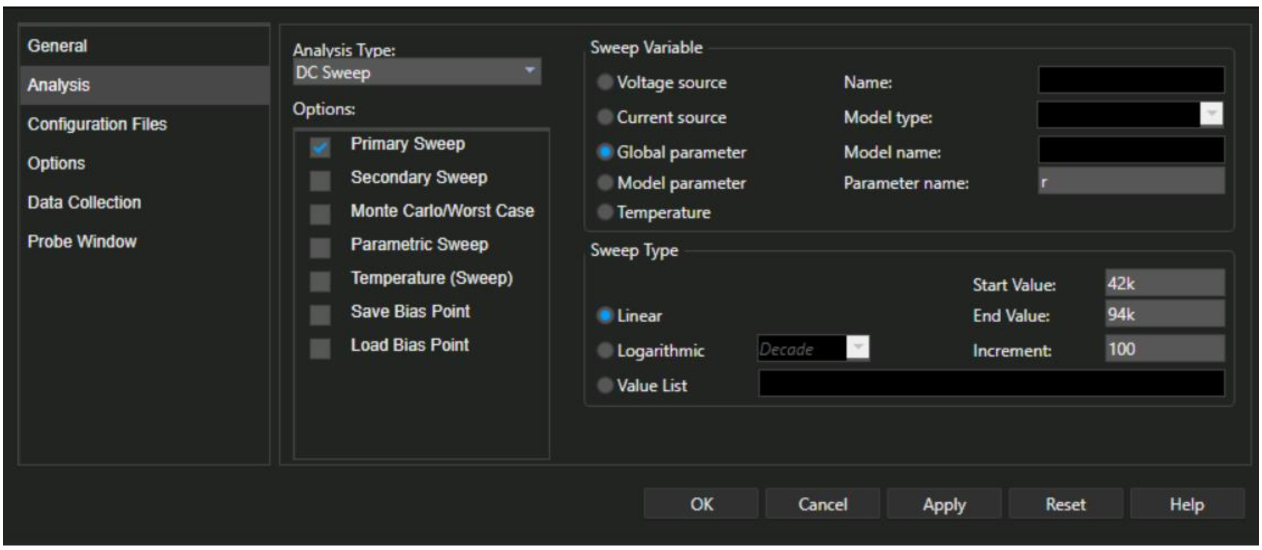

Figure 14. First simulation profile of the Hysteresis Comparator circuit

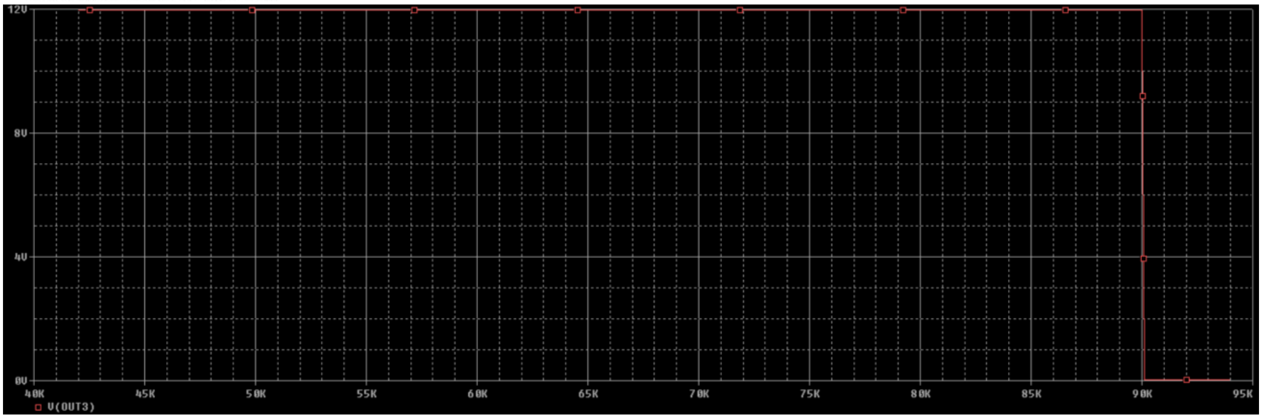

Figure 15.The resulting graph for the first simulation profile of the Hysteresis Comparator circuit

The first simulation is set to perform a DC Sweep analysis where the parameter "r" (the resistance of the gas sensor, Rs) is varied from 42kΩ to 94kΩ in increments of 100. The purpose of this sweep is to observe how the output voltage (Vout3) of the comparator changes as the resistance of the gas sensor varies within its specified range.

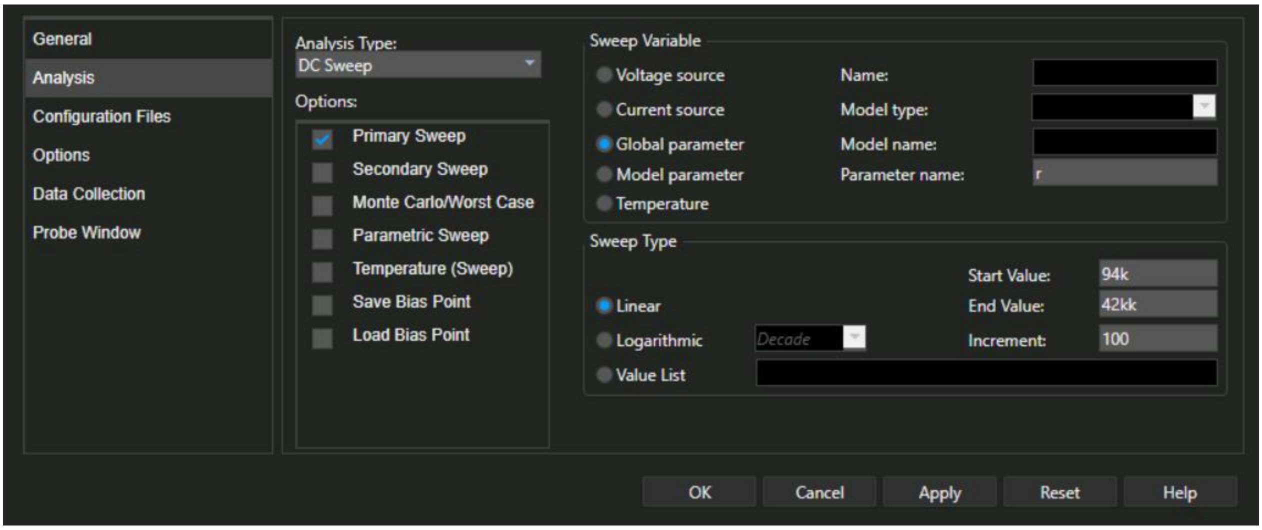

Figure 16. Second simulation profile of the Hysteresis Comparator circuit

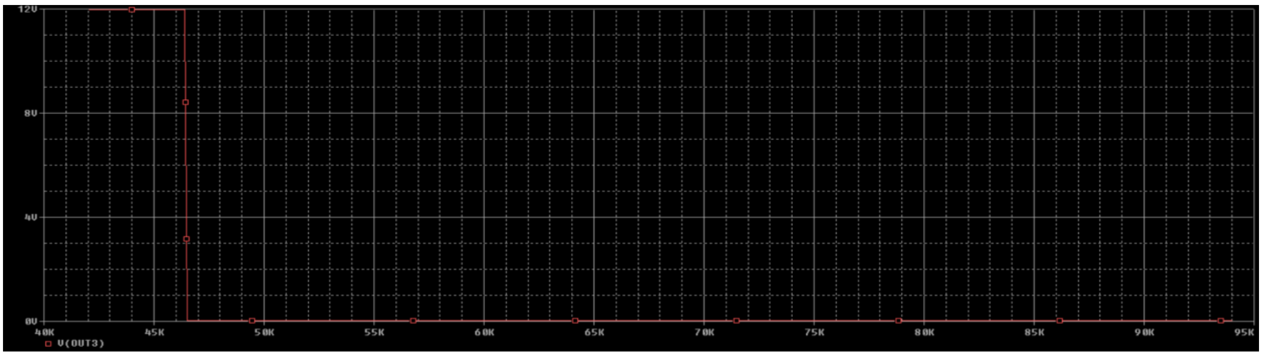

Figure 17. The resulting graph for the second simulation profile of the Hysteresis Comparator circuit

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The second simulation is similar but with the start and end values for the resistance parameter reversed (from 94kΩ to 42kΩ). This setup allows for the observation of how the output voltage (Vout3) changes in the reverse direction, providing insight into the hysteresis effect.

After running the first simulation, the results are displayed in the graph window. Using the "Append File" feature, the results of the second simulation are added to the same graph window, allowing for a combined view of both simulations.

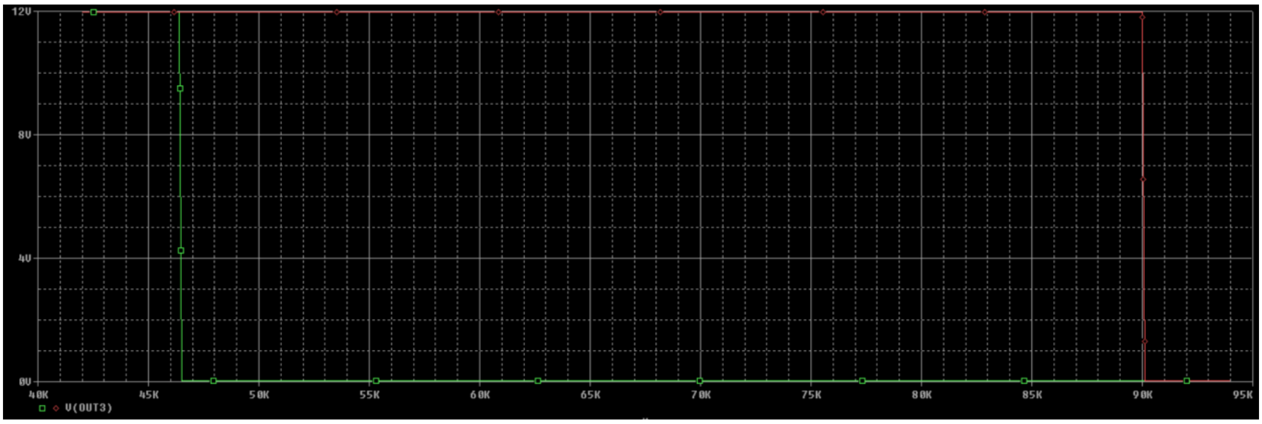

Figure 18. The resulting graph, combined view of both simulations

As the resistance Rs decreases from 94kΩ to 42kΩ, the output voltage switches from 12V (high state) to 0V (low state) at a specific threshold resistance value and as the resistance Rs increases from 42kΩ to 94kΩ, the output voltage switches from 0V (low state) to 12V (high state) at a different threshold resistance value.

The difference in the threshold values between the two simulations confirms the presence of hysteresis. This ensures that the comparator does not rapidly switch between states near a single threshold value, providing stable operation.

3.4 Fan Control (Relay + LED)

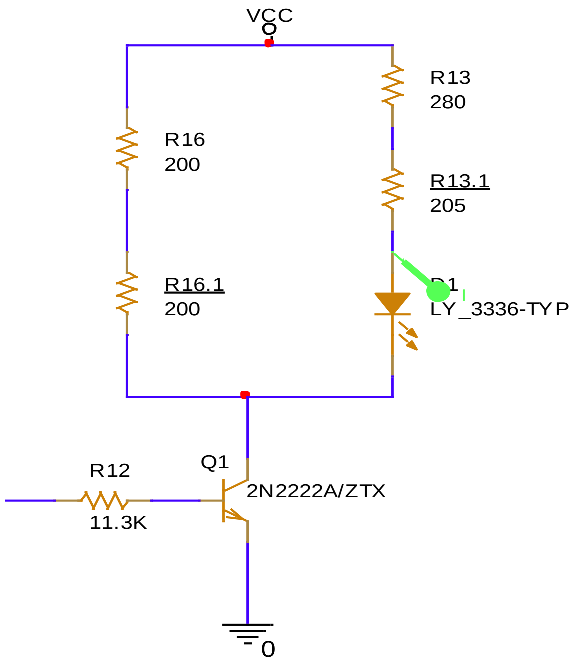

Figure 19.The Fan Control Circuit

The part of the circuit involves a transistor (Q1), an LED (D1), and associated resistors. This section is responsible for controlling the operation of a fan (represented by the relay) and providing a visual indication using the LED.

The transistor acts as a switch that controls the current flow to the relay and the LED. When the base of the transistor receives sufficient voltage (from the output of the hysteresis comparator), it allows current to flow from the collector to the emitter, turning on the relay and the LED.

Resistor (R12 - 11.3kΩ) limits the base current of the transistor to protect it from excessive current that could damage it and ensures that the transistor operates within its safe current limits.

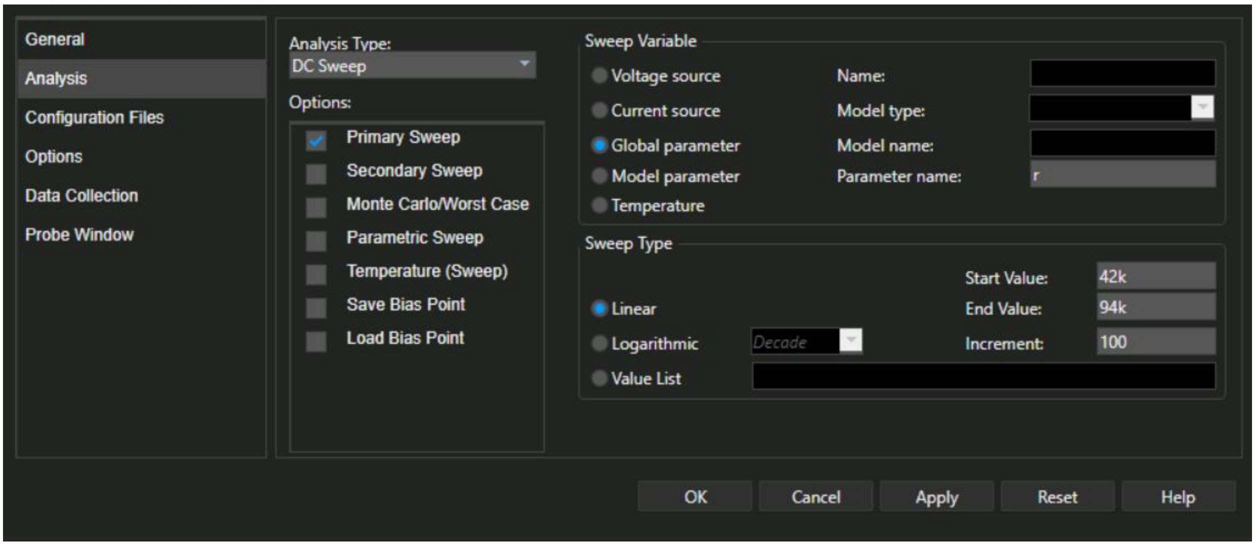

Figure 20. The simulation profile for the Fan Control

The DC Sweep analysis was selected to observe how the current through the LED (D1) and the state of the transistor (Q1) change as the resistance of the gas sensor varies. This helps in understanding the switching behavior of the circuit, specifically how the transistor controls the relay and the LED in response to changes in CO concentration detected by the gas sensor.

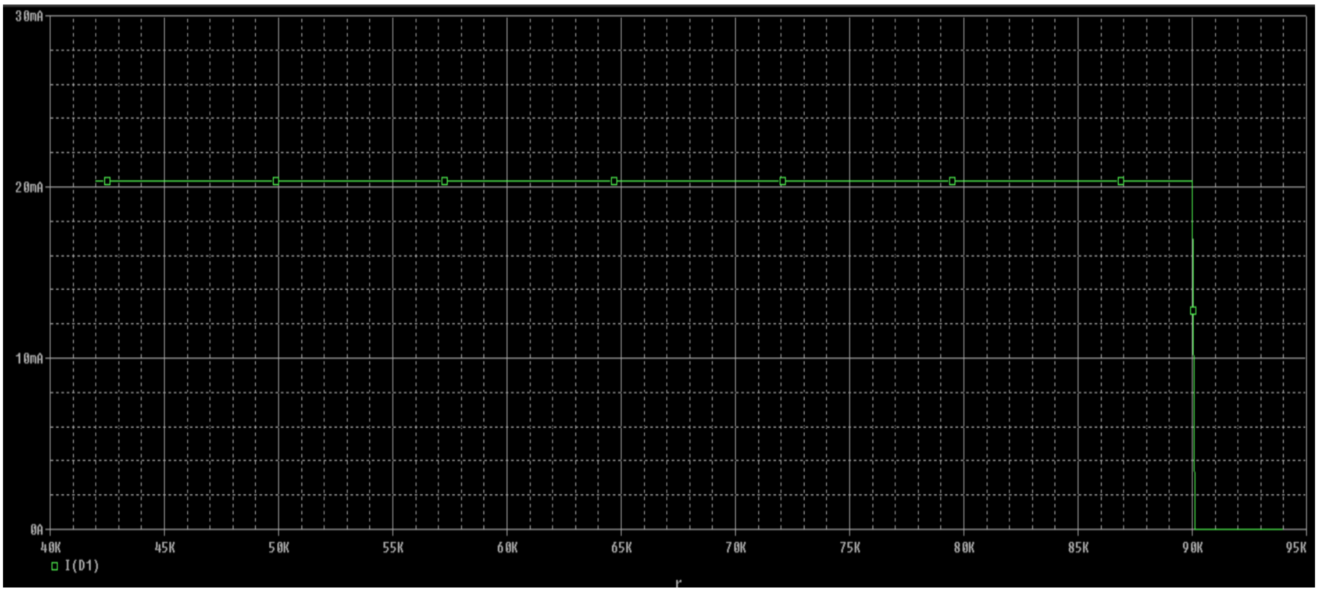

Figure 21. The resulting graph of the Fan Control

The graph displays the current through the LED (D1) as the resistance of the gas sensor (Rs) changes. The x-axis represents the sensor resistance (r), and the y-axis shows the current through the LED. The current remains constant at approximately 20mA until the resistance reaches around 90kΩ. At around 90kΩ, there is a sharp drop in the current, indicating that the transistor has switched off, cutting off the current to the LED and the relay.

4 Bill of materials

Component Name	Value	Quantity	Description	Part Number	Unit Price (Lei)
R1	48.7kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0748K7L	1
R1.2	45.3kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0745K3L	1
Rs	94kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0794KL	2
R3.1	49.9kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0749K9L	1
R3.2	80.6kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0780K6L	1
R4.1	18.7kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0718K7L	1
R4.2	4.12kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-074K12L	1
R5.1	1.15kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-071K15L	1
R5.2	1.15kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-071K15L	1
R6.1	8.66kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-078K66L	1
R6.2	105kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-07105KL	1
R7	12.1kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0712K1L	1
R8.1	3.83kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-073K83L	1
R8.2	2.87kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-072K87L	1
R10	9.09kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-079K09L	1
R11.1	9.76kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-079K76L	1
R11.2	590kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-07590KL	1
R12	11.3kΩ	1	Resistor, 1/4W, 1%	Yageo RC0603FR-0711K3L	1
R13	280Ω	1	Resistor, 1/4W, 1%	Yageo RC0603FR-07280RL	1
R13.1	205Ω	1	Resistor, 1/4W, 1%	Yageo RC0603FR-07205RL	1
R16	200Ω	1	Resistor, 1/4W, 1%	Yageo RC0603FR-07200RL	1

R16.1	200Ω	1	Resistor, 1/4W, 1%	Yageo RC0603FR-07200RL	1
U1	AD8614	1	Op-Amp, Precision, Low Noise	Analog Devices AD8614ARZ	20
U2	AD8614	1	Op-Amp, Precision, Low Noise	Analog Devices AD8614ARZ	20
U3	AD8614	1	Op-Amp, Precision, Low Noise	Analog Devices AD8614ARZ	20
Q1	2N2222A/ZTX	1	NPN Transistor, 40V, 800mA	Zetex ZTX2222A	5
D1	LY_3336-TYP	1	LED, Yellow, 20mA, 2V	Osram LY T676-Q2R2-36	2
V1	12V	1	Power Supply, 12V, 1A	Mean Well GST25A12-P1J	50

5 Conclusion

This circuit is designed to maintain the concentration of carbon monoxide (CO) in an enclosure within specified limits by controlling a fan. The key components and their roles in the circuit are as follows:

1. **Resistive Gas Sensor (Rs)**:
   - The gas sensor detects the CO concentration by varying its resistance. The sensor's resistance changes linearly with the CO concentration, allowing accurate monitoring.
2. **Voltage Divider and Voltage Follower**:
   - The resistive gas sensor is part of a voltage divider network with resistors R1 and R1.2, generating a voltage signal that is proportional to the CO concentration.
   - The voltage follower (U1) isolates this signal to prevent loading effects, ensuring accurate signal transmission.
3. **Voltage Domain Converter**:
   - This stage converts the resistance variation of the gas sensor into a corresponding voltage variation.
   - Using operational amplifier U2 and resistors (R3.1, R3.2, R4.1, R4.2, R5.1, R5.2, R6.1, R6.2), the circuit scales the output voltage to fit in the range [2V, Vcc - 2V].
4. **Hysteresis Comparator**:
   - The comparator (U3) compares the voltage from the voltage domain converter to predefined upper and lower threshold values.
   - When the CO concentration reaches the upper limit, the comparator outputs a signal to activate the fan through a relay and transistor (Q1).
   - When the CO concentration drops to the lower limit, the comparator deactivates the fan, maintaining the desired CO levels without frequent switching due to hysteresis.
5. **Fan Control (Relay + LED)**:
   - The relay, controlled by the transistor Q1, switches the fan on and off based on the comparator's output.
   - An LED (D1) indicates the fan's operational state, providing visual feedback.

Simulations :

1. DC Sweep Analysis:

- For the voltage follower and voltage divider stage, a DC sweep was conducted to verify the output voltage variation with changes in sensor resistance.
- The graphs showed a linear relationship, confirming the proper functioning of the voltage follower and divider network.

2. **Voltage Domain Converter Analysis:**

   - A DC sweep was performed to ensure the voltage domain converter scaled the sensor's resistance variation into the correct voltage range.
   - The output graph confirmed the expected voltage response, validating the design.

3. **Hysteresis Comparator Analysis:**

   - The comparator was analyzed to determine its switching behavior at the defined threshold voltages.
   - The resulting graphs showed the correct switching of the comparator output, making sure the fan control works reliably.

This circuit effectively maintains the CO concentration within safe limits by using a resistive gas sensor, voltage domain converter, and hysteresis comparator to control a fan. The design includes key features like buffering, signal scaling, and hysteresis to ensure accurate and stable operation. The simulations confirmed the proper functionality of each stage, validating the overall design.

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