CAD TEHNIQUES PROJECT DOCUMENTATION

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Content

1.Requirements

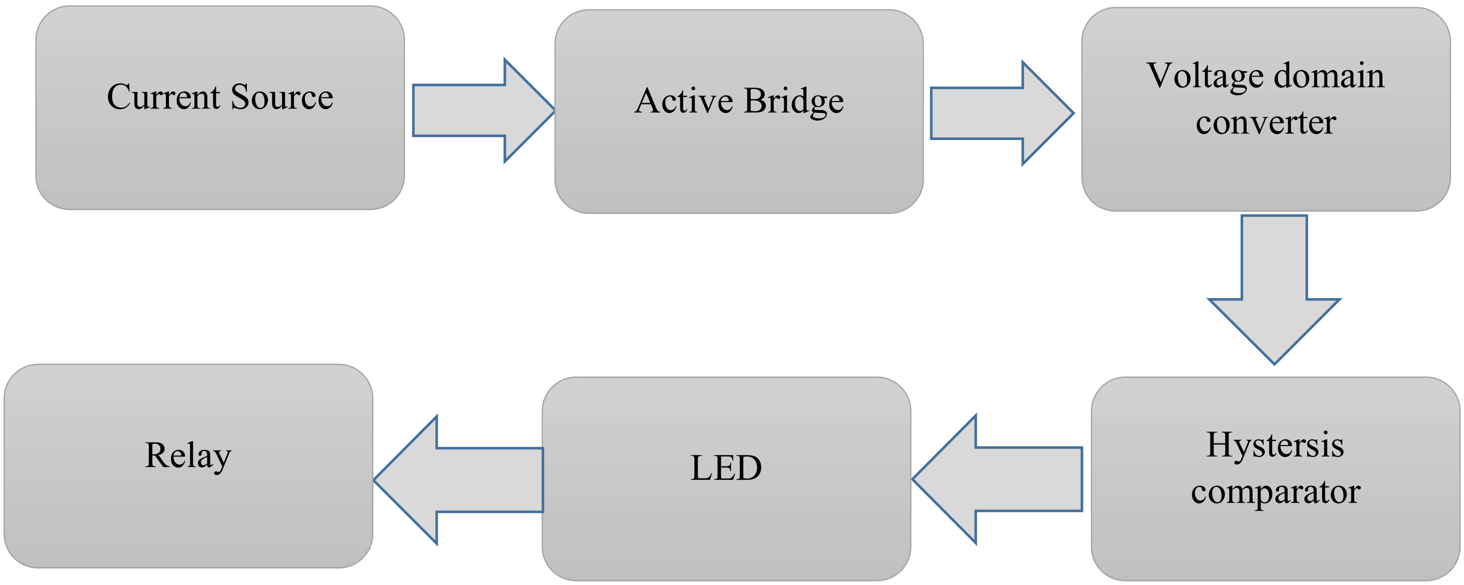
1.1 Circuit for controlling soil moisture levels for plants:

Design an irrigation system that uses resistive moisture sensors to maintain a certain level of relative soil humidity for a plant (moisture level limits are specified in column E). When the soil moisture level has reached the lower limit (from column E), the system will start watering the plant. When the humidity level reaches the upper limit (from column E) the system will give the command to stop watering the plant. From the sensor catalog sheet it is known that at a variation of the humidity level mentioned 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 irrigation pump is controlled by a hysteresis comparator via a relay which is modeled with a resistor. The state of the pump (on/off) is signaled by an LED of the color specified in column I.

Design specifications:

Humidity level to maintain[%]	40-50
Maximum humidity range[%]	10-60
Sensor resistance	80k-380k
Vcc	10V
LED colour	RED

2.Block Diagram

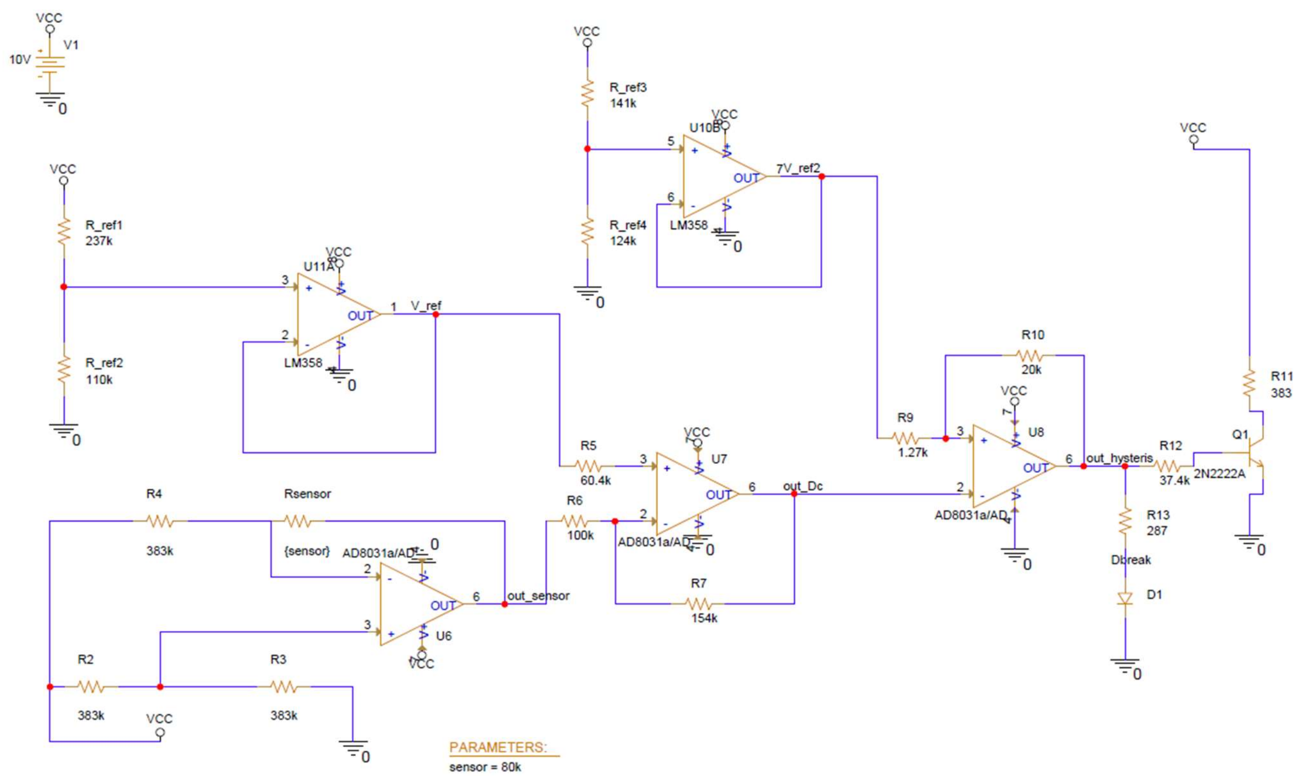


3.Schematic Circuit

3.1 The circuit explained:

For my irrigation system project, I implemented a resistive moisture sensor(Active linear Bridge) to monitor and maintain the soil moisture level for a plant. This sensor functions as a variable resistor based on the soil's humidity. The system is programmed to initiate watering when the soil moisture drops below 40% and to stop watering when it rises above 50%. The circuit is powered by a 10V DC power supply.The resistive moisture sensor is integrated into an Active Linear Bridge Circuit, which translates resistance changes into a linear voltage variation. This voltage is then amplified and scaled to the required range of 2V to 8V using a differential amplifier.A hysteresis comparator estimates the amplified voltage against predefined thresholds corresponding to the lower and upper soil moisture limits. When the moisture level falls below 40%, the system activates the irrigation pump.Besides, when the moisture level exceeds 50%, the system halts the irrigation.The irrigation pump is controlled by the hysteresis comparator and connected to a relay for power switching. Additionally, a red LED provides visual feedback, indicating that the system is operational. The resistors, selected from the E96 series for their precision, have a 1% tolerance. I decided to use Texas Instruments LM741 Op-Amps for V_ref due to their reliability, availability, price and suitability for general-purpose amplification.For the Active Bridge,Voltage Domain Converter and Hysteresis comparator I have used an AD8031a/AD OpAmp because it supported my Vcc and it is a good rail to rail amplifier.For the transistor part I utilized a 2N2222A transistor because it is a common NPN BJT and it is mainly used in the applications of switching & amplifying with less power. This transistor is mainly designed for low power, low to medium current, medium voltage & works at fairly high speeds

3.2 The circuit :



4.The components

4.1 The Active bridge (resistive sensor)

4.1.2.The schematic

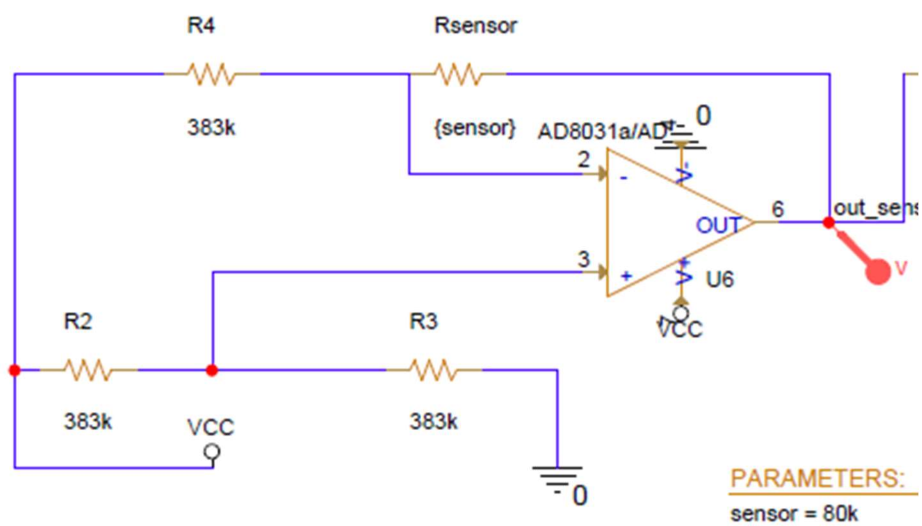


Figure 4.1

I have used an active bridge to determine the voltage on the sensor and for a better linear response with high precision.The active bridge(linear bridge)is capable of detecting very small changes in resistance and offers accurate measurements especially when coupled with high quality op-amps.I connected 3 resistors and gave them real values from the E96 tabel with a tolerance of ±1%(383kΩ).R1 and Rsensor are connected in series and R2 R3 are in series too. To prevent the influence of the voltage on the sensor and to prevent voltage losses, I included a buffer (repeater circuit) that I used as an impedance adapter and which separates the voltage domain converter (differential amplifier).The R1 and Rsensor go to the – of the OpAmp and the R2-R3 to the +.

4.1.2.The equations

$$v^{+} = v^{-} = \frac{R3}{R2 + R3} * Vcc => \frac{383}{766} * Vcc = \frac{Vcc}{2} = 5V$$

$$\frac{Vcc - v^{-}}{R} + \frac{Vo - v^{-}}{Rsensor\_min} = 0 => \frac{5}{383k} + \frac{Vo - 5}{80k} = 0 => 383k * Vo = 1515$$

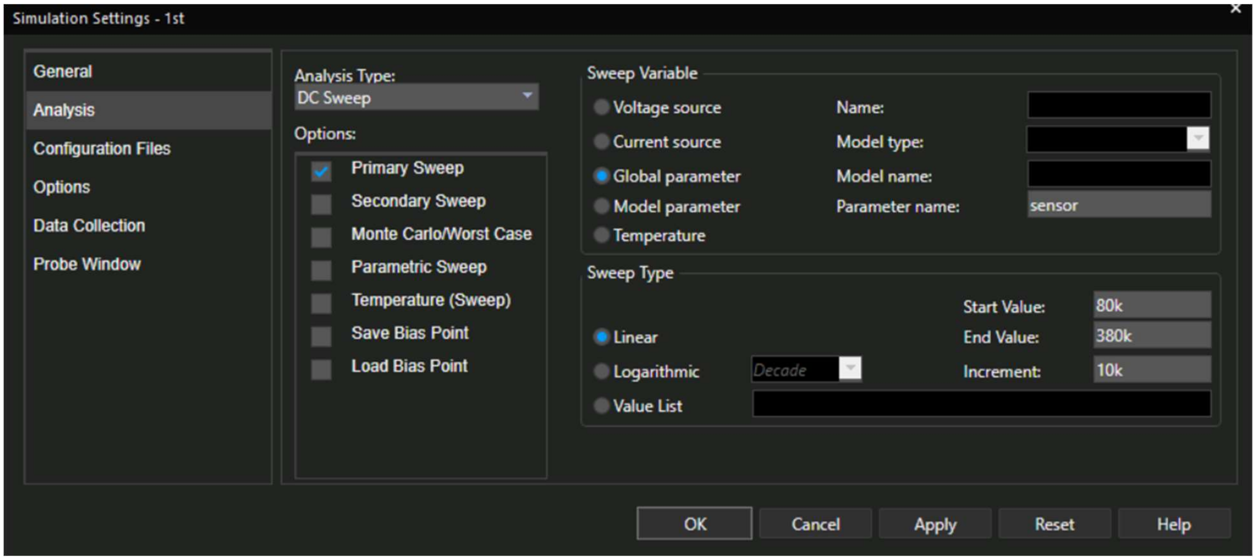
$$=> \boldsymbol{Vo_{max} = 3.95V}$$

$$\frac{Vcc - v^{-}}{R} + \frac{Vo - v^{-}}{Rsensor\_max} = 0 => \frac{5}{383k} + \frac{Vo - 5}{380k} = 0 => 383k * Vo = 15$$

$$=> \boldsymbol{Vo_{min} = 0.03V}$$

4.1.3.The simulation

For this part of the circuit we need a DC SWEEP Analyses to determine the voltages through simulation.



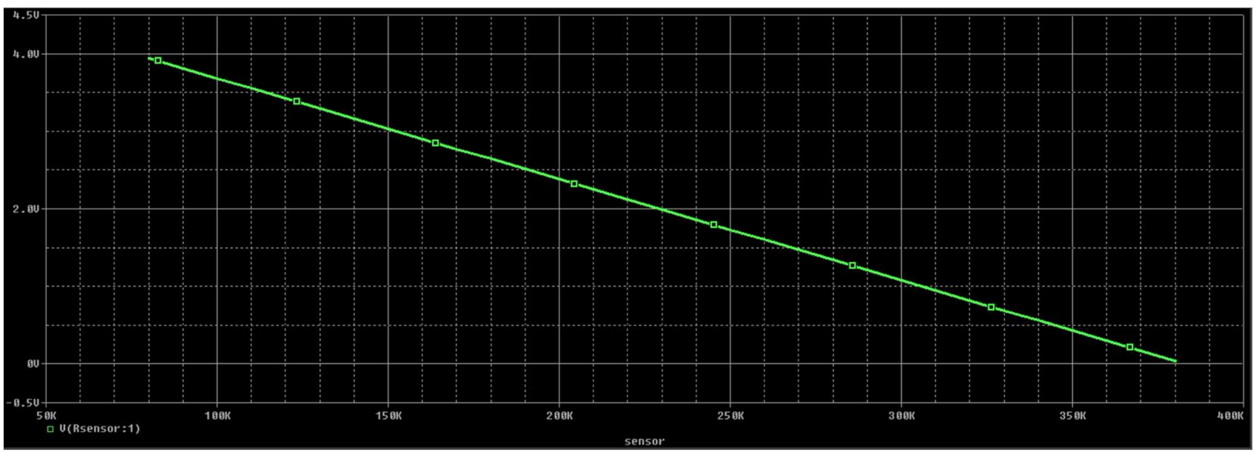
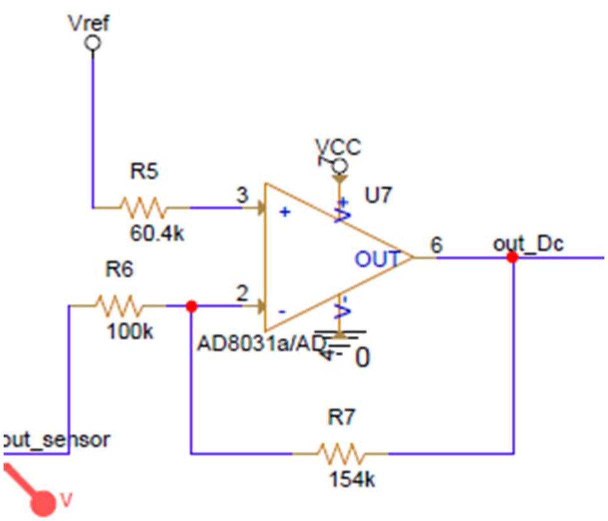
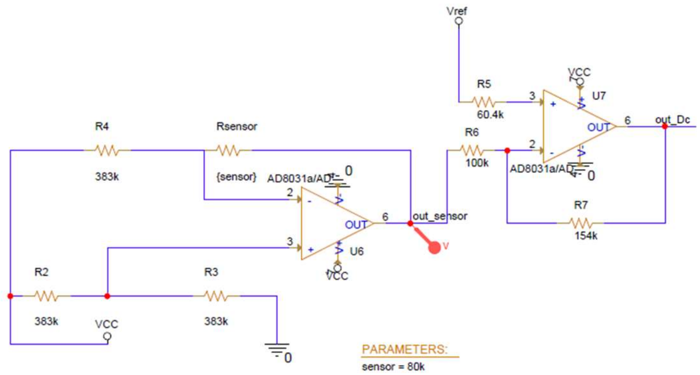


Figure 4.1 DC SWEEP for V_sensor

4.2 The voltage domain converter

4.1.2.The schematic





This circuit is used to increase the variation interval of the output voltage to [2V,Vcc-2V].I calculated the result by the difference between the minimum and the maximum voltage on the previous output(sensor) to determine the amplification by differentiating between 2V and 8V.I used the formulas from the inverting voltage domain converter. Finally I determined the output voltage.

4.2.2.The equations

V_out ϵ[2V,8V]

V_out_sensor ϵ[0.03V,3.95V]

$$V_{outsensor\_min} = V_{out\_max}$$

$$V_{outsensor\_max} = V_{out\_min}$$

$$v^+ = v^-$$

$$V_{out\_min} = -\frac{R7}{R6} * V_{outsensor\_max} + \left(1 + \frac{R7}{R6}\right) * V_{ref} \quad (1)$$

$$V_{out\_max} = -\frac{R7}{R6} * V_{outsensor\_min} + \left(1 + \frac{R7}{R6}\right) * V_{ref} \quad (2)$$

From (1) and (2) we get:

$$2 = -\frac{R7}{R6} * 3.95 + \left(1 + \frac{R7}{R6}\right) * V_{ref}$$

$$8 = -\frac{R7}{R6} * 0.03 + \left(1 + \frac{R7}{R6}\right) * V_{ref}$$

Now we determine R7/R6

$$\frac{R7}{R6} = \frac{V_{out\_max} - V_{out\_min}}{V_{outsensor\_max} - V_{outsensor\_min}} = \frac{6}{3.92} = 1.53k$$

From the E96 table we choose R7=154k and R6=100k

We find R5:

$$R5 = R7||R6 = 60.4K$$

We determine V_ref:

$$V_{ref} = \frac{V_{out\_min} + \frac{R7}{R6} * V_{outsensor\_max}}{1 + \frac{R7}{R6}} = \frac{2 + 1.53 * 3.95}{1 + 1.53} = 3.17V$$

We can verify if our values are good from the (1)and 2 equations

$$V_{out\_min} = -\frac{R7}{R6} * V_{outsensor\_max} + \left(1 + \frac{R7}{R6}\right) * V_{ref} = -1.53 * 3.95 + (1 + 1.53) * 3.17 = 1.97V = 2V$$

$$V_{out\_max} = -\frac{R7}{R6} * V_{outsensor\_min} + \left(1 + \frac{R7}{R6}\right) * V_{ref} = -1.53 * 0.03 + (1 + 1.53) * 3.17 = 7.97V = 8V$$

We made a Voltage Divide for V_ref to determine the resistances:

$$3.17 = \frac{R_{ref2}}{R_{ref2} + R_{ref1}} * 10$$

We determine R_ref2 and R_ref1 and we choose from the E96 table:
R_ref2=110k;R_ref1=237k

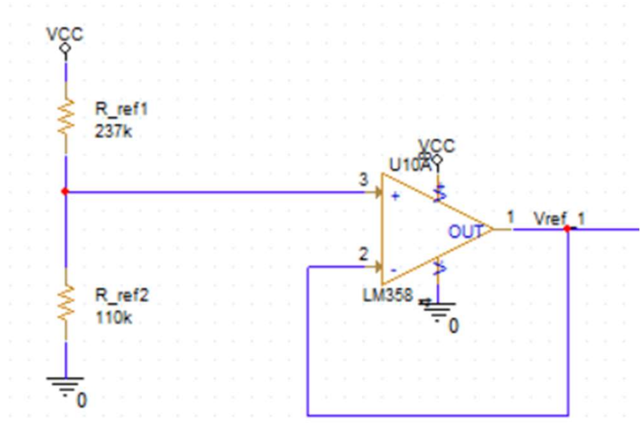


Figure 4.2.1 The Vref

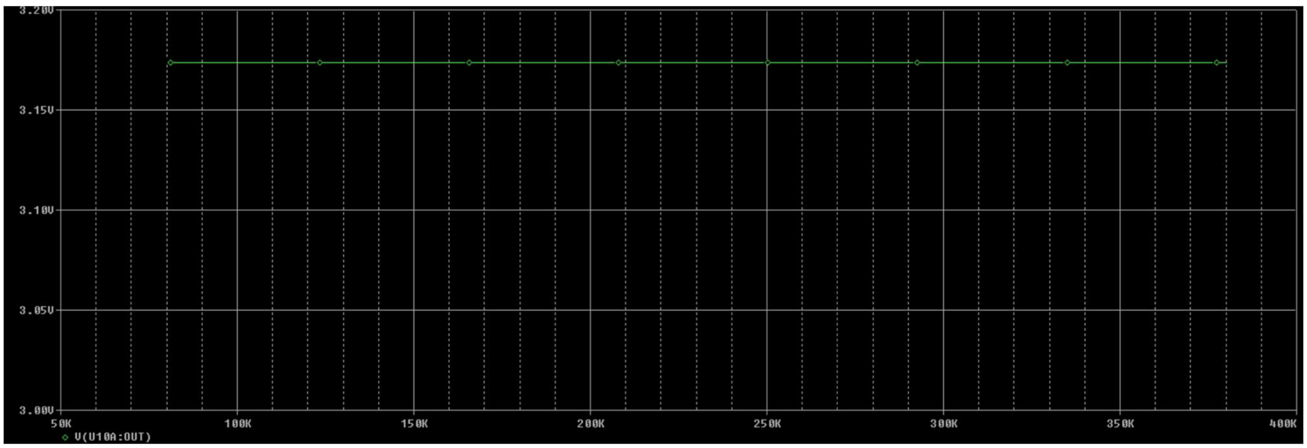
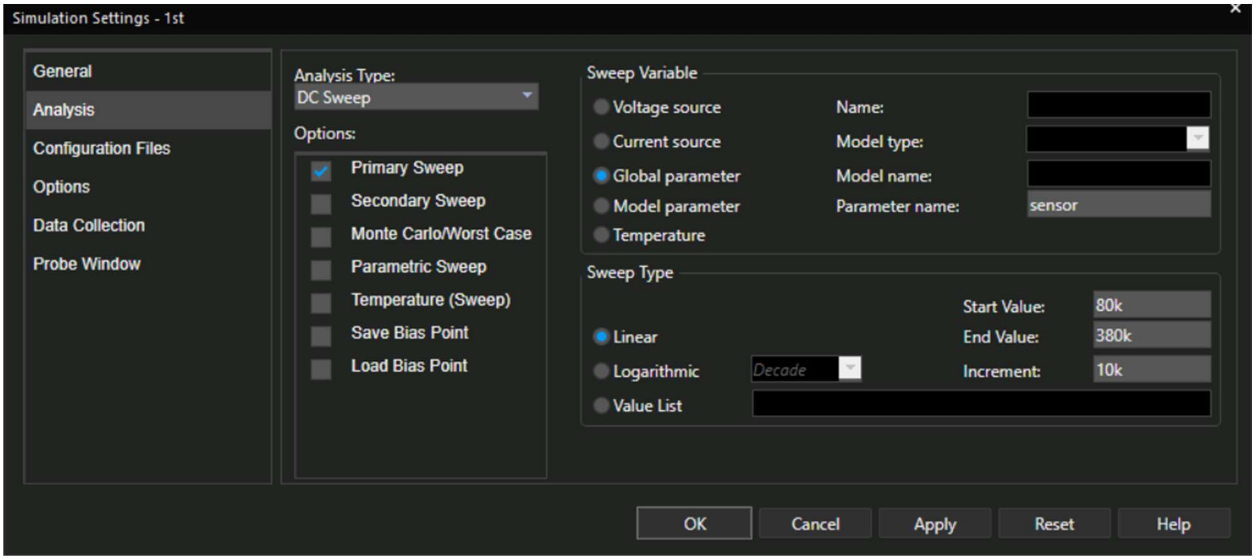
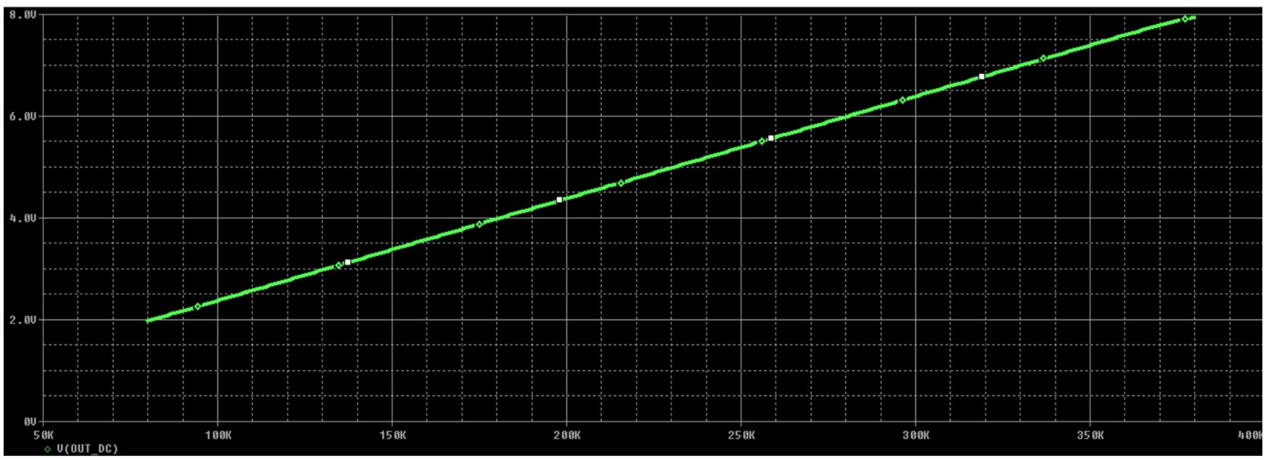


Figure 4.2.2 The DC Sweep for Vref

4.2.3.The simulation

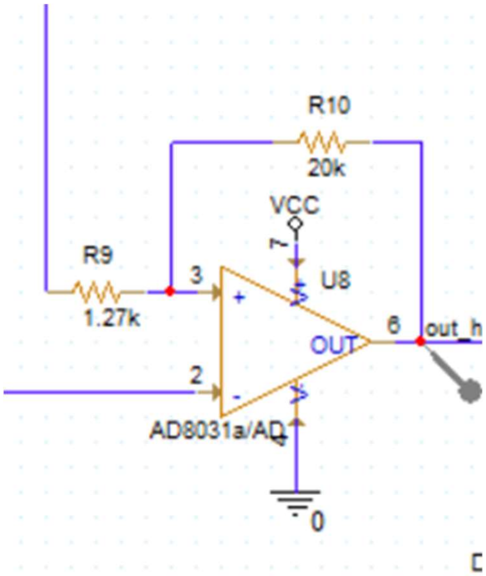
I have used the same simulation profile for this part and I obtained this graphic that goes from 8V to 2V that is in that interval [2V,Vcc-2V].





4.3.The hysteresis comparator:

4.3.1.The schematic



For this stage of the circuit,I have used an inverting hysteresis comparator to controll the irrigation pump.I considered the values for R9 and R10 to be from the E96 table.I determined the thresholds(Vth_high and Vth_low)and also the Vref _2 ,from the formulas that I know for hysteresis comparator.Finally I checked with the DC sweep analyses the new output voltage.

4.3.2.The equations

2V=0%;8V=100%

$$\frac{1}{100} * 6 = 0.06(6\ is\ the\ difference\ between[2V, Vcc - 2V])$$

$$0.06 * 100 + 2 = 8\ (Verified)$$

$$1\% = 0.06 + 2 => 10\% = 0.6 + 2 = 2.6V$$

$$40\% = 2.4 + 2 = \mathbf{4.4V} => \boldsymbol{Vth_L} \quad (1)$$

$$50\% = 3 + 2 = \mathbf{5V} => \boldsymbol{Vth_H} \quad (2)$$

$$60\% = 3.6 + 2 = 5.6V$$

[40%,50%]-the humidity level to maintain

[10%,60%]-the maximum humidity range

The system:

$$Vth_H = \frac{R9}{R10+R} * Vcc + \frac{R1}{R9+R1} * V_3\ ; \quad (3)$$

$$Vth_L = \frac{R9}{R10+R} * 0 + \frac{R10}{R9+R1} * V_3\ ; \quad (4)$$

I substitute everything in (3) and (4)

$$5V = \frac{R9}{R10+R} * 10V + \frac{R10}{R9+R1} * V_{ref\_2}$$

$$4.4V = \frac{R9}{R10+R} * 0 + \frac{R1}{R9+R1} * V_{ref\_2}$$

I reduce these 2 equations into:

$$0.6 = \frac{R9}{R10+R9} * 10V => \frac{R9}{R10+R9} = 0.06$$

R9=1.27k;R10=20k (From E96 table)

Now I determine Vref:

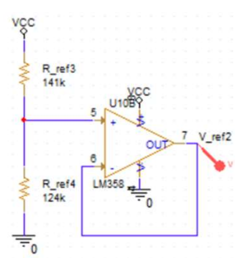
$$\frac{R10}{R10+R9} = \frac{20}{21.27} = 0.94$$

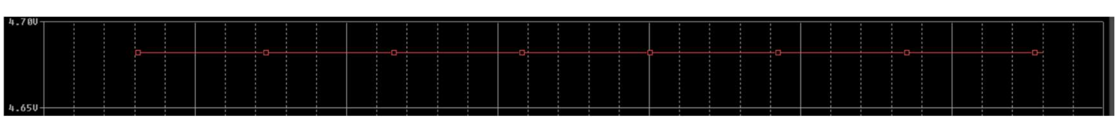
$$4.4 = 0.9 * V_{ref_2} => 0.94 * V_{ref_2} = 4.67 => V_{ref2} = 4.67V$$

We made a Voltage Divide for V_ref2 to determine the resistances:

$$4.67 = \frac{R_{ref4}}{R_{ref4} + R_{ref3}} * 10$$

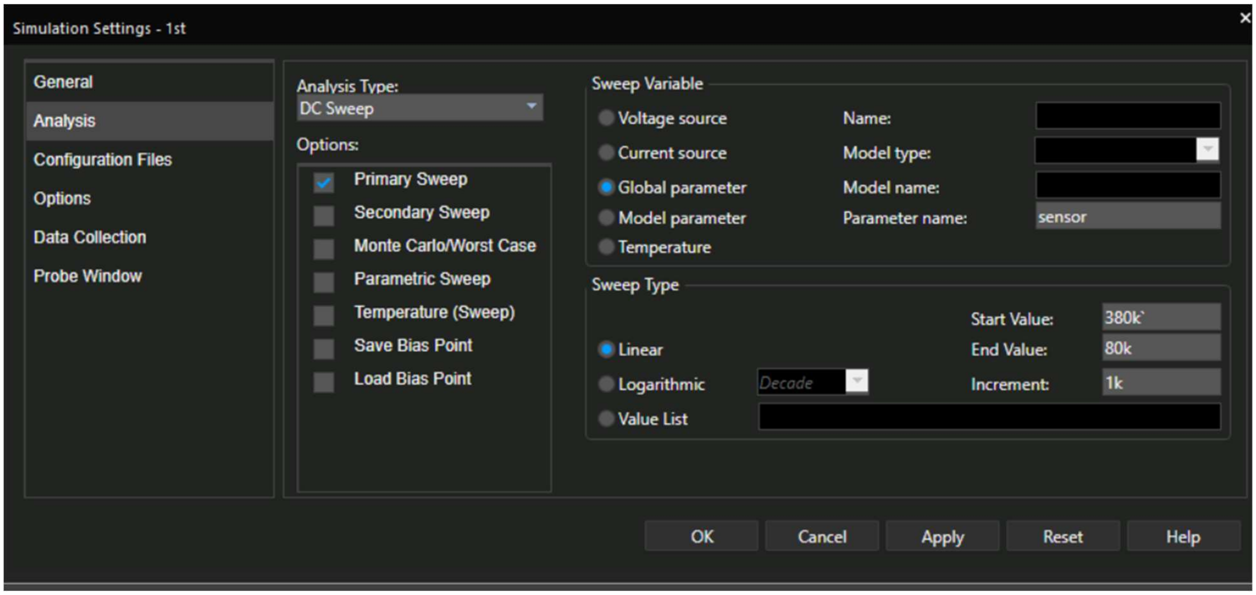
We determine R_ref2 and R_ref1 and we choose from the E96 table:
R_ref4=124k;R_ref3=141k

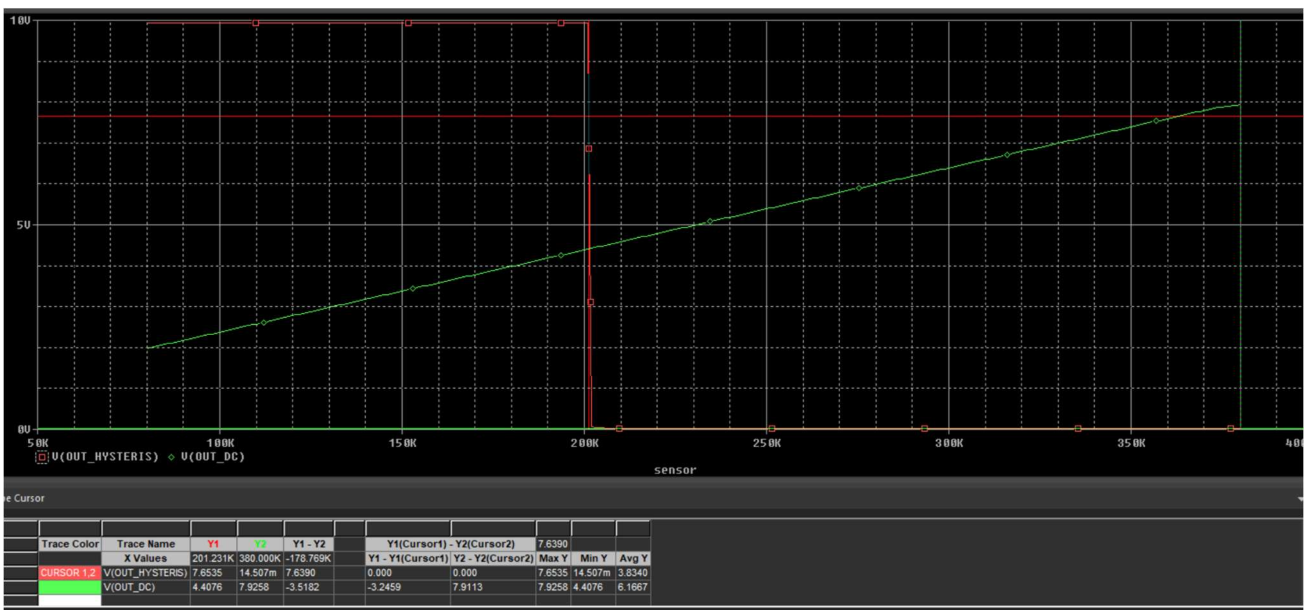




4.3.3.The simulation

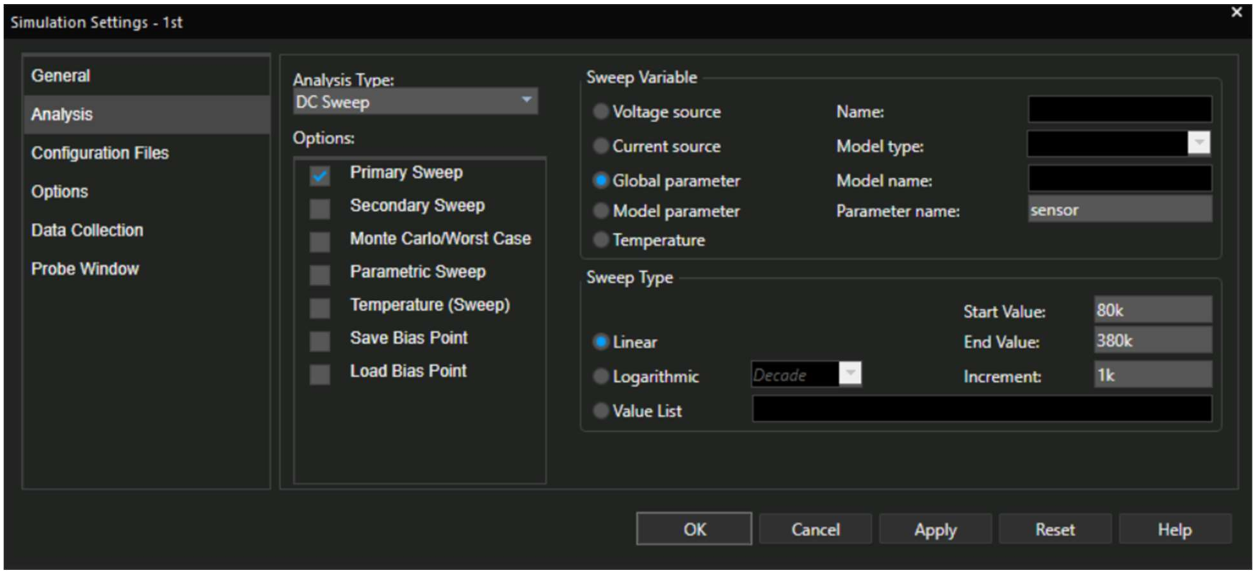
For the simulation profile to find the Vth_low on the graphic I decreased the increment from 100k to 1k.

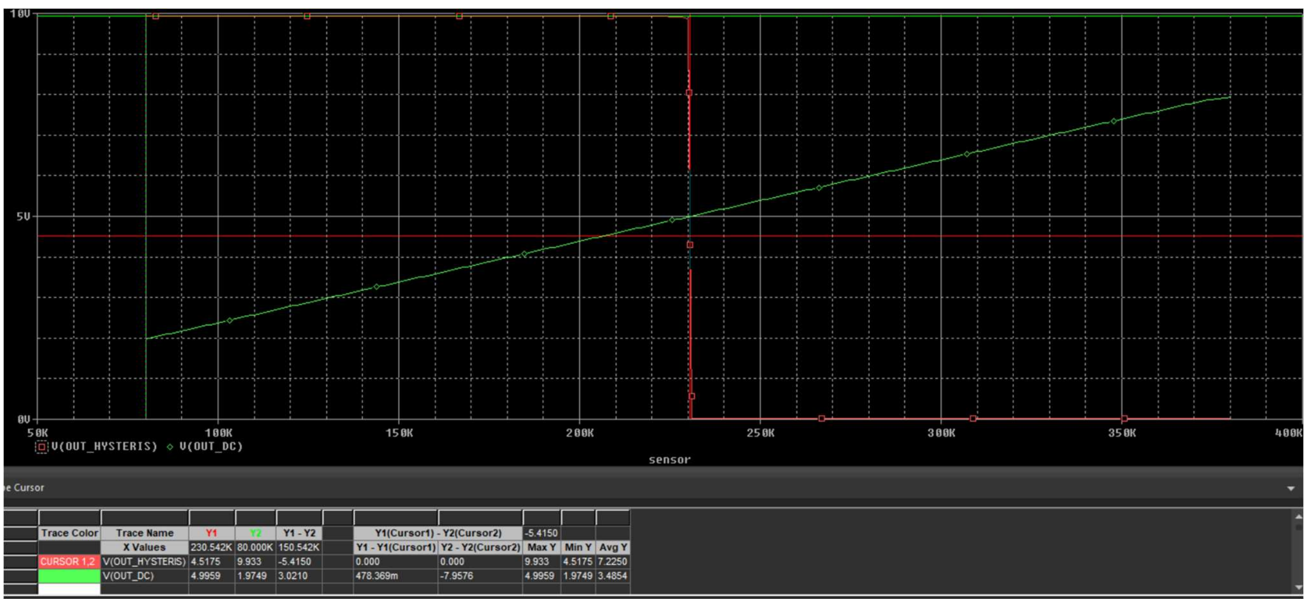




The actual Vth_L on the graphic is 4.40.

For the simulation to determine the Vth_h I reversed the start value and the end value but the increment is the same.





The actual Vth_h on the graphic is 4.99V.

4.4 The Relay and the LED

4.4.1.The LED

The pump status (on/off) is signaled by an RED LED. If the liquid level goes out of rangespecified the led lights up.

I considered two approaches for integrating the LED into the circuit. First, I explored the libraries and found the D1N5765 GaAsP Red LED Alternatively, I modeled the LED diode using PSpice Model Editor 4 to match my specific requirement for a red color. I then performed a DC Sweep analysis to verify whether the LED operates at the voltage indicated in the datasheet graph.

For the D1N5765 (GaAsP RED Led) this is the DC Sweep Analysis:

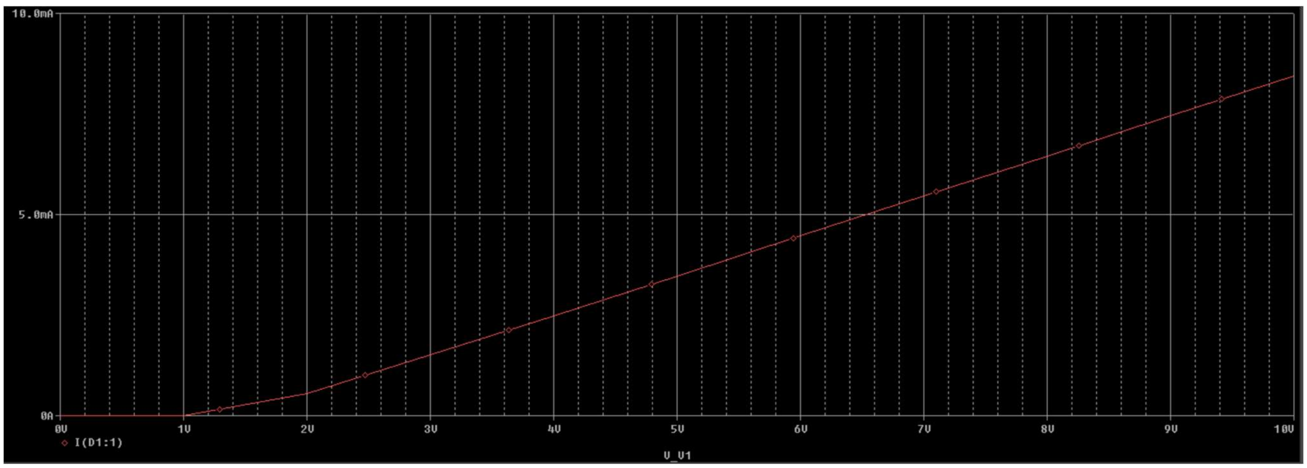


Figure 4.4

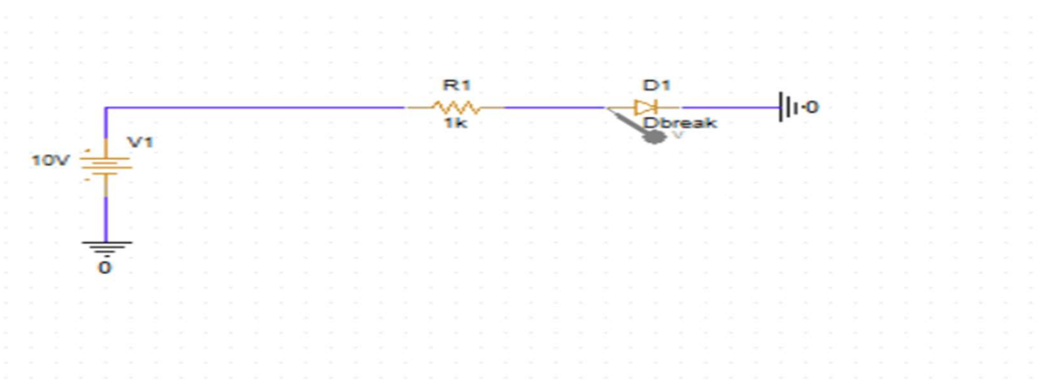


Figure 4.5 The Circuit for Red Led

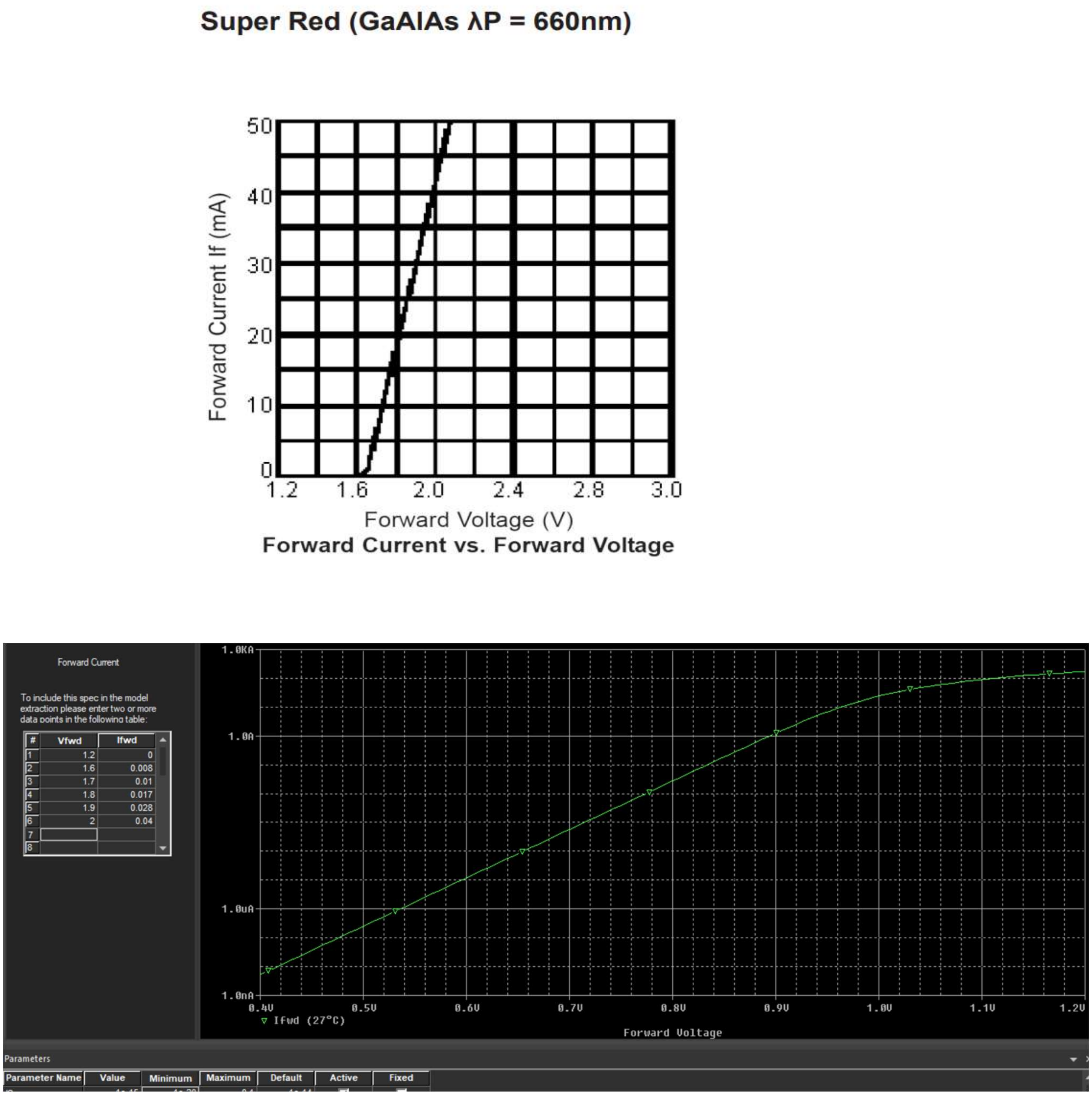


Figure 4.6 The graphic for the Red Led

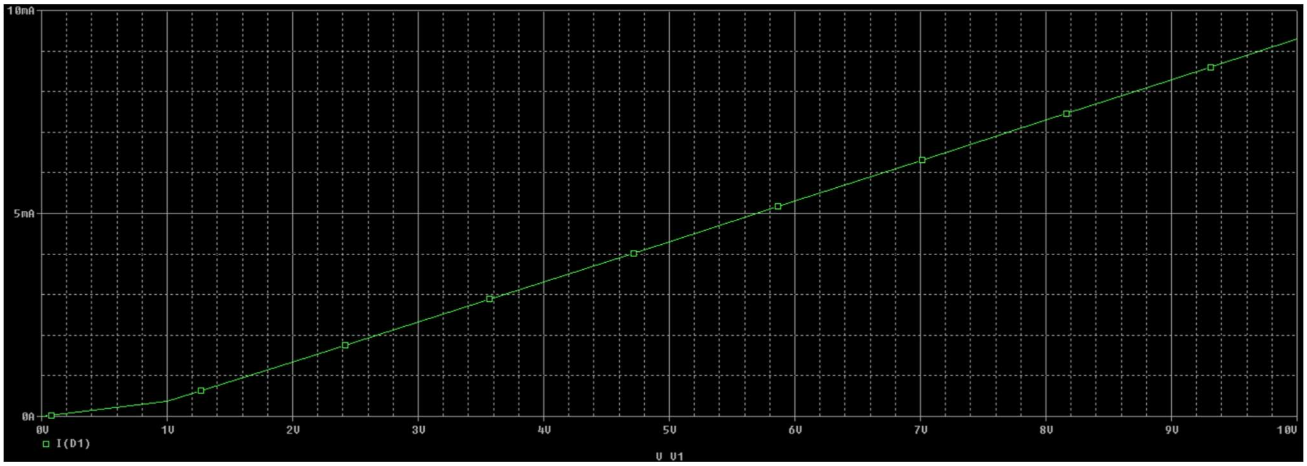


Figure 4.7 The DC Sweep Analysis for the LED

Figure 4.8 The LED and the Resistance

To determine the resistance I searched on the data sheet the V_led=1.9V and the current through the LED I_Led=28mA

$$R13 = \frac{V_{out} - V_{Led}}{I_{Led}} = \frac{10V - 1.90V}{28mA} = 289\Omega$$

From the E96 table I choose the value for R13 to be: 287 Ω

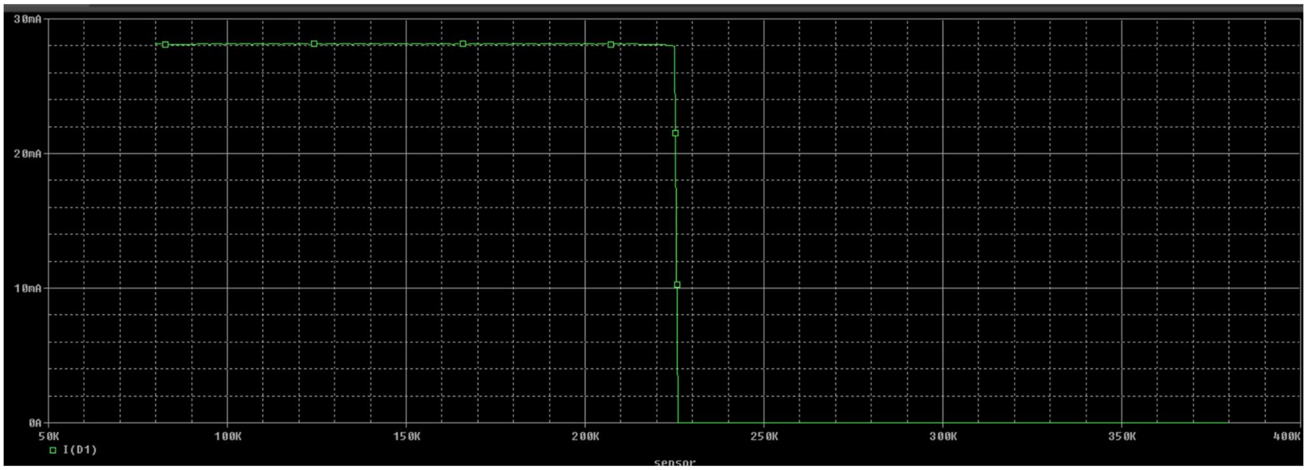


Figure 4.8 the current through LED

4.4.2.The Relay

For our circuit, to maintain a certain level of relative soil humidity in our specific range we need a pump controlled by an electromagnetic relay.The relay will be assembled using a resistor and a transistor.The values for the relay are from its datasheet.

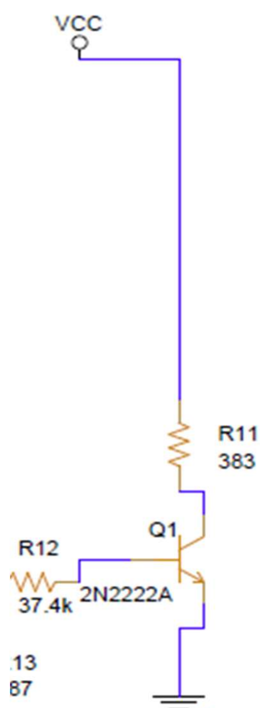


Figure 4.4 The Relay

From the datasheet for a 10V relay I took the current I_relay=25mA,the resistance R_11=383Ω and β =110,then I will calculate R12.

$$I_{relay} = I_{base} + \beta$$

$$I_{base} = \frac{I_{relay}}{\beta} = \frac{25mA}{110} = 0.22mA$$

$$V_{cc} = I_{relay} * R11 + V_{ce} \quad (1)$$

$$V_{in} = I_{base} * \mathrm{R12} + \mathrm{V_{be}} \quad (2)$$

If we solve the equation (1) we will get :

$$V_{ce} = V_{cc} - I_{relay} * R11$$

$$V_{ce} = 10V - 25mA * 383\Omega => V_{ce} = 1V(aprox)$$

If we solve the equation (2) we will get :

$$V_{in} = I_{base} * R12 + V_{be}$$

$$R12 = \frac{V_{in} - V_{be}}{I_{base}} = \frac{10 - 0.7}{0.25mA} = 37.2k\ \Omega$$

From the E96 table I took **R12=37.4kΩ** with tolerance 1%.

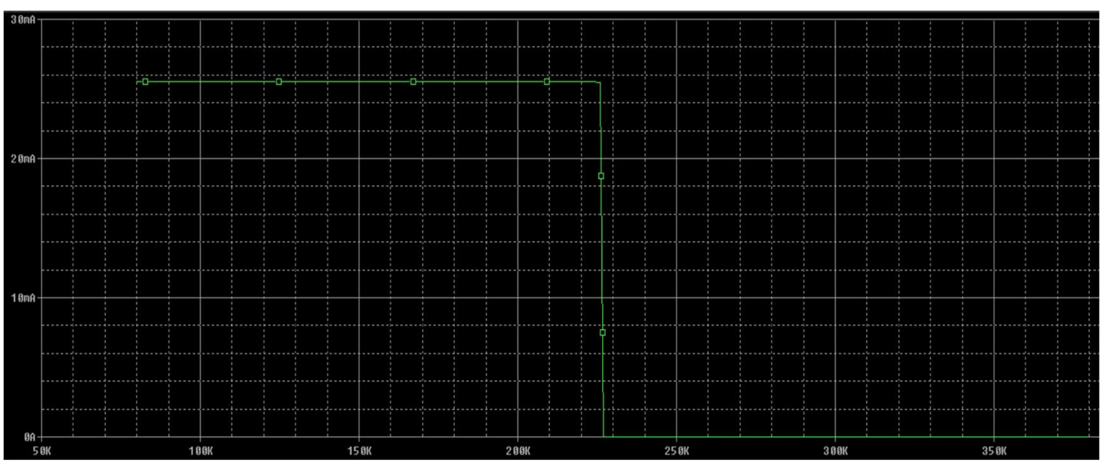
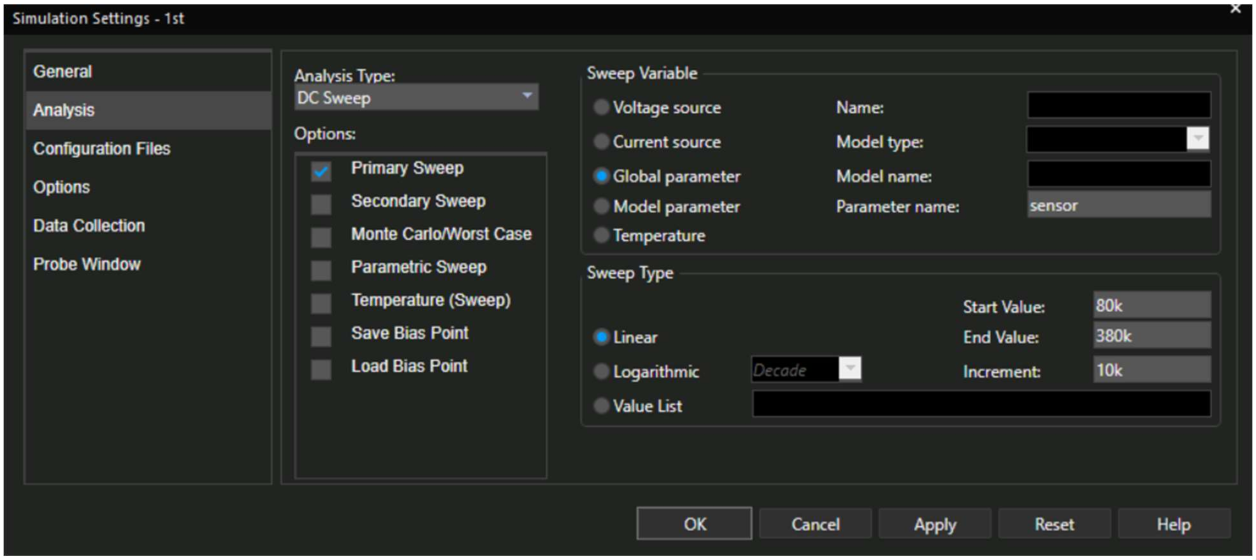


Figure 4.4.2 The I_relay graphic

5.Analyzes for the circuit

5.1 DC Sweep for the V_sensor



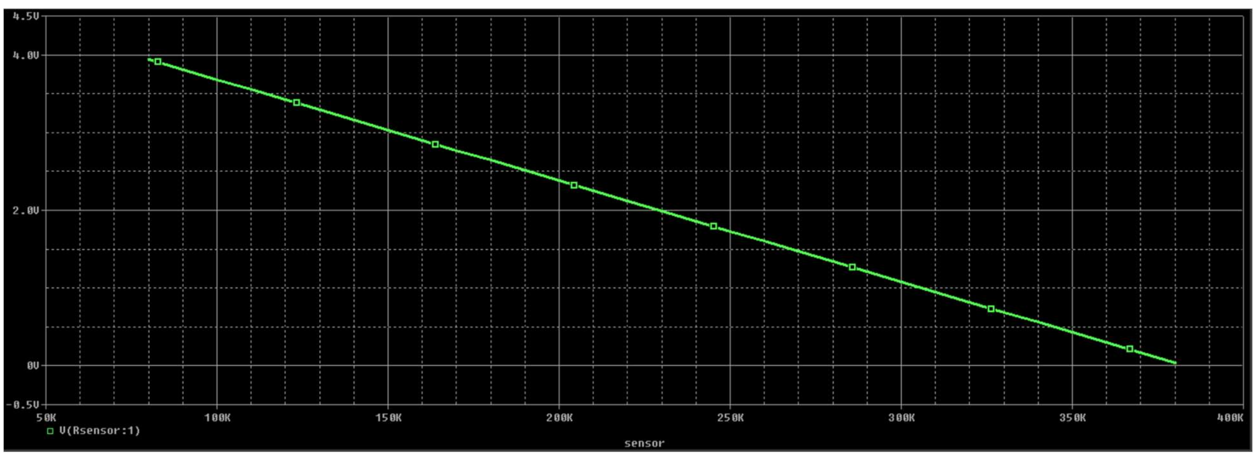
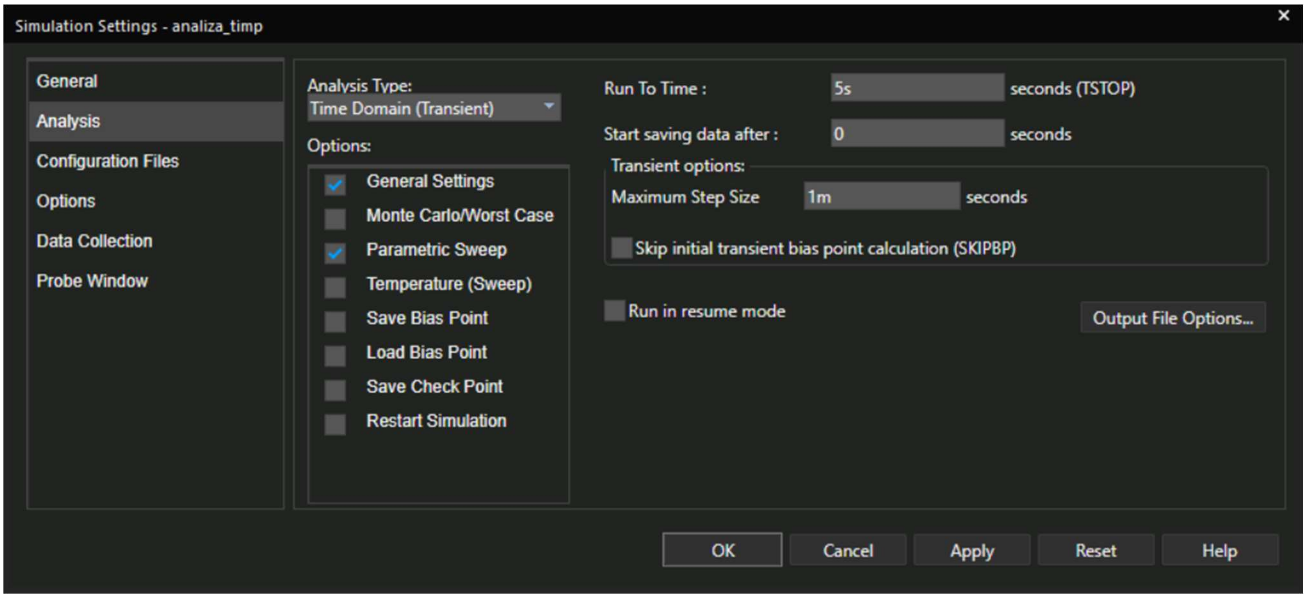


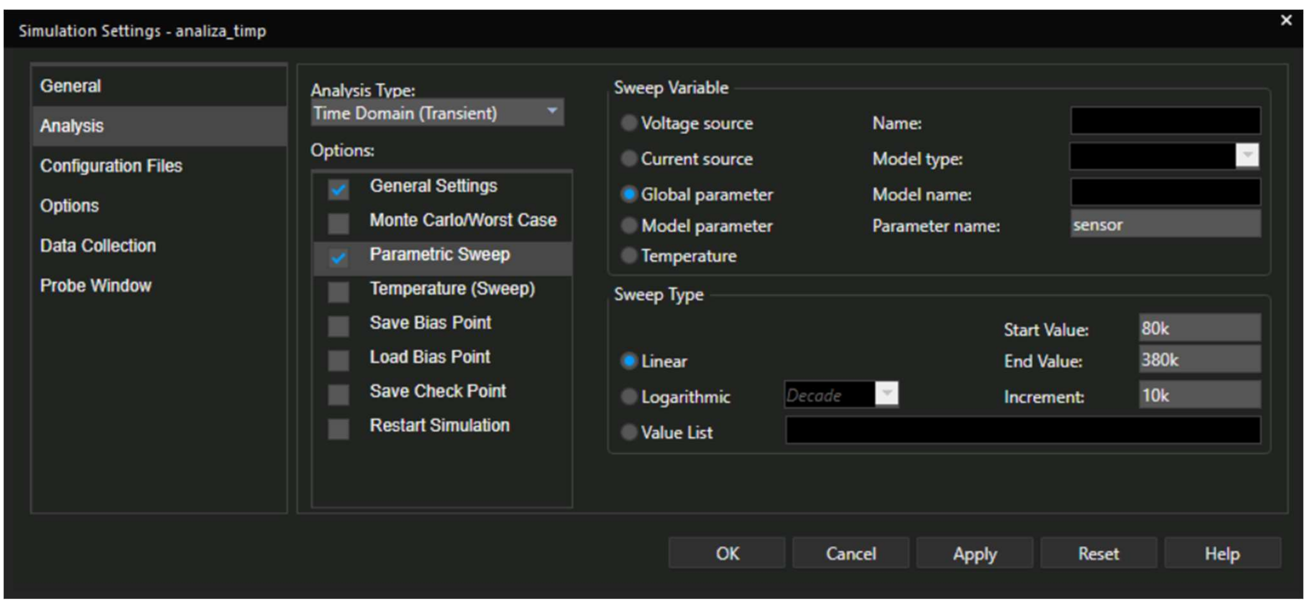
Figure 5.1.1 DC SWEEP

We can observe that using a DC Sweep analysis for the sensor parameter between the values of the resistance(80k and 380k),our voltage is varying between[0.03V;3.95V]

5.2 Transient analysis for the V_sensor

I have used a Parametric Sweep in Time Domain(transient) for the sensor parameter for the values 80k and 380k.





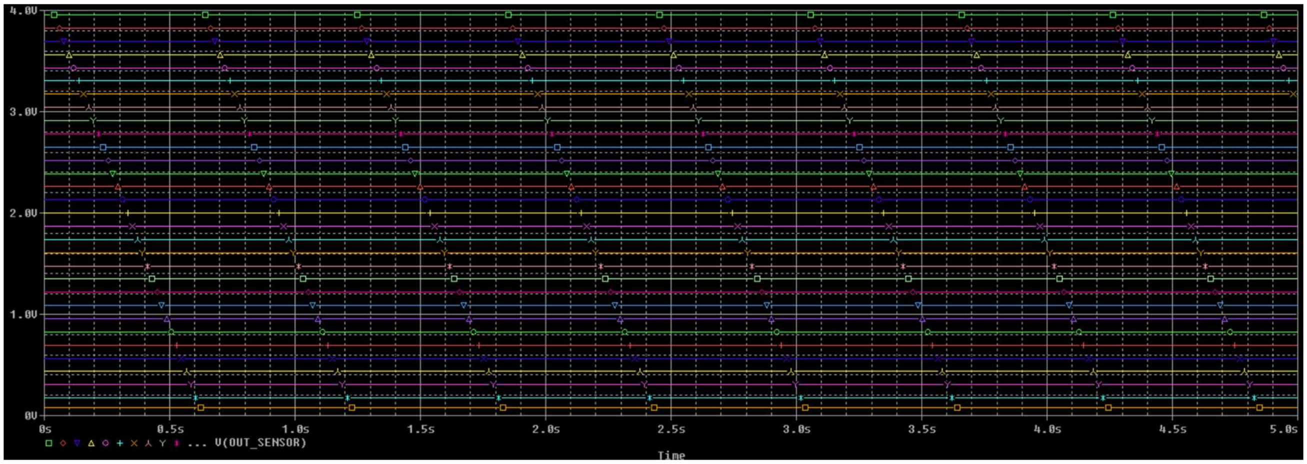
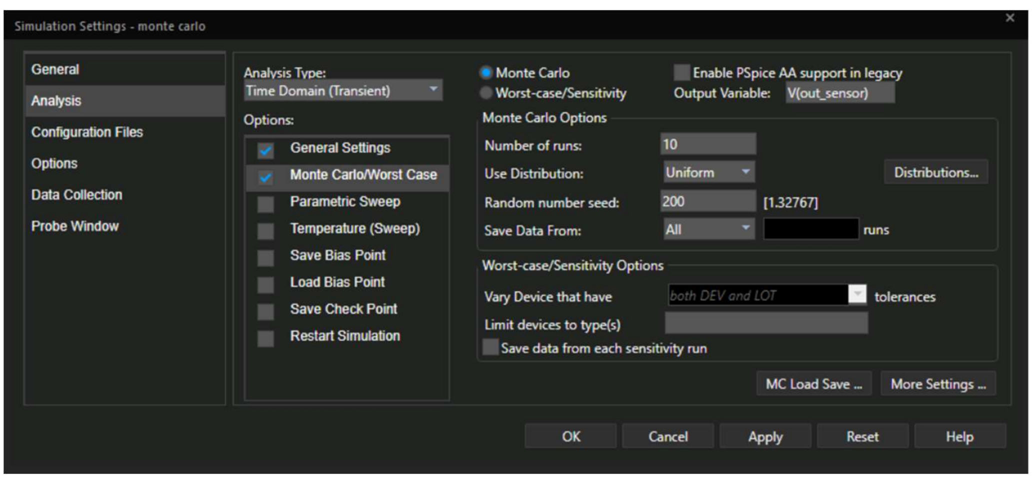


Figure 5.2.1 Transient domain graphic

The sensor voltage in time is between 0.03V and 3.95V for my values.

5.3 Monte Carlo analysis for the V(out_sensor) and V(out_dc)

Monte-Carlo analysis is a way of statistical analysis for asee how the circuit behaves, after amplification at variations of component values according to the tolerance range.We show the maximum voltage at the output of the circuit after amplification.



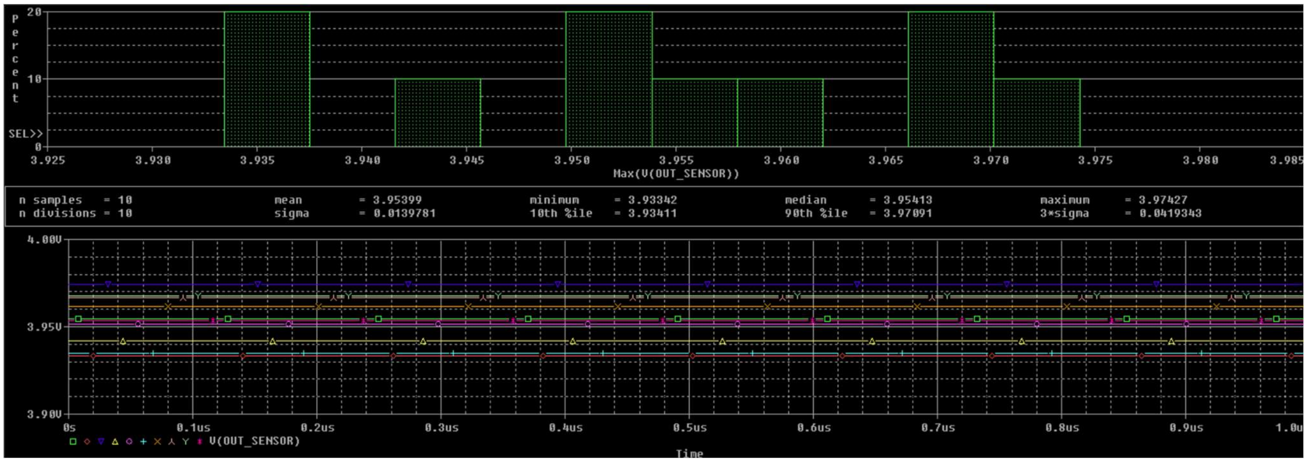


Figure 5.3.1 The monte carlo analysis for V(out_sensor)

This analysis in figure 5.3.1 shows us the variations of tolerance range because we have the maximum output voltage for the sensor 3.95V and here it is 3.97V

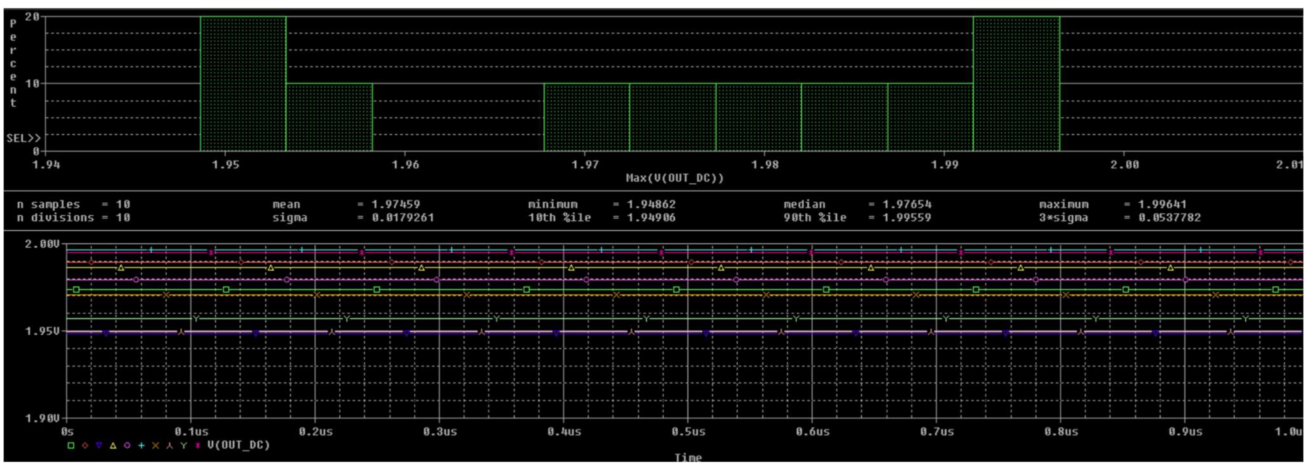
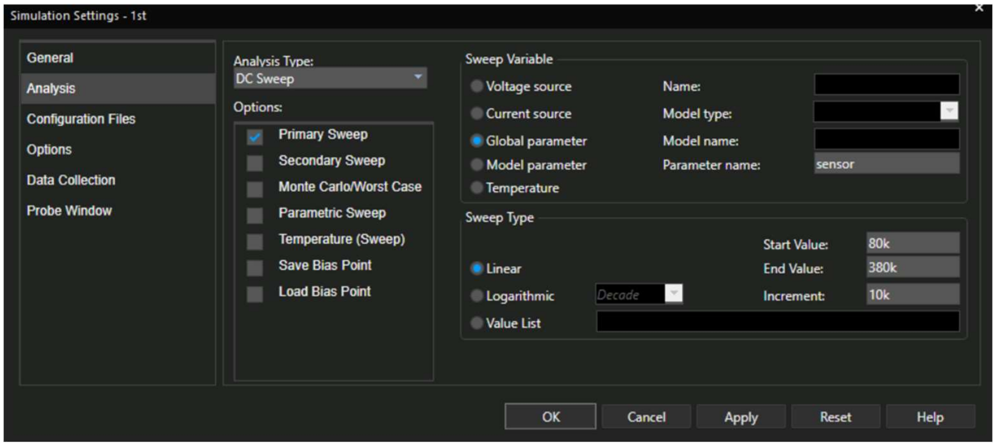


Figure 5.3.1 The monte carlo analysis for V(out_dc)

5.4 DC Sweep after the differential amplifier(voltage domain converter)



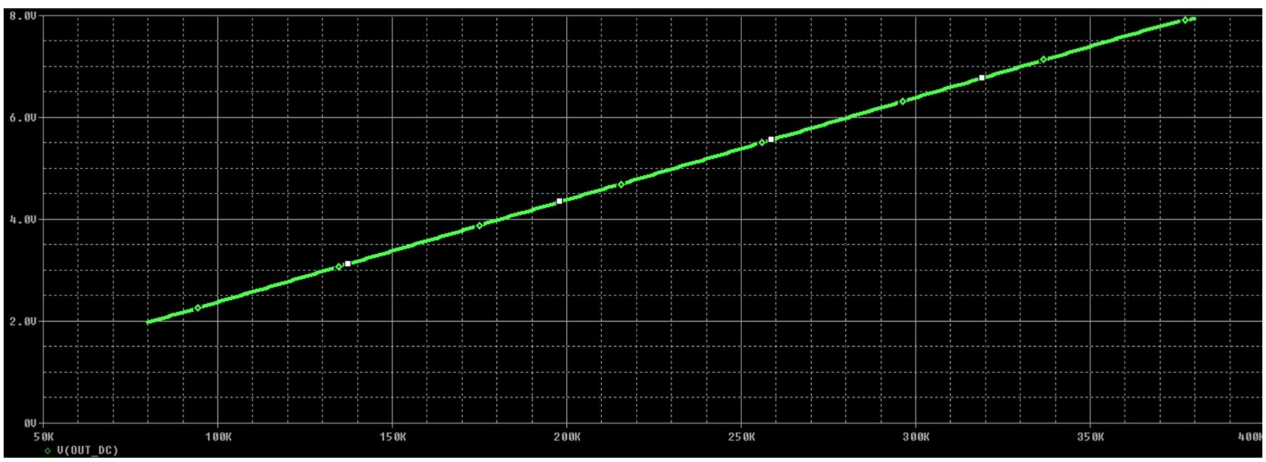


Figure 5.4.1 The graphic after differential amplifier

Our voltage range extended from 2V to 8V,so the circuit works properly.

5.4 DC Sweep of the voltage after Hysteresis comparator

We use this analysis to see the thresholds(high and low).To see the Vth_low we first put the 80k resistor and for the Vth_high we first put the 380k in the simulation.

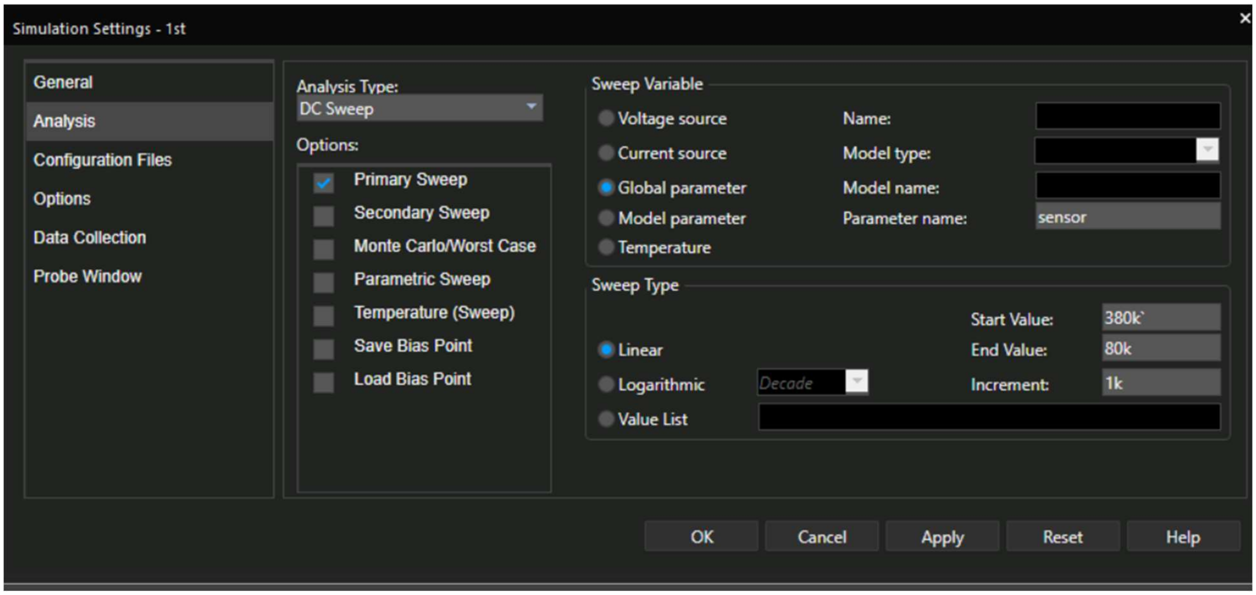


Figure 5.4.1 The simulation profile for Vth_low

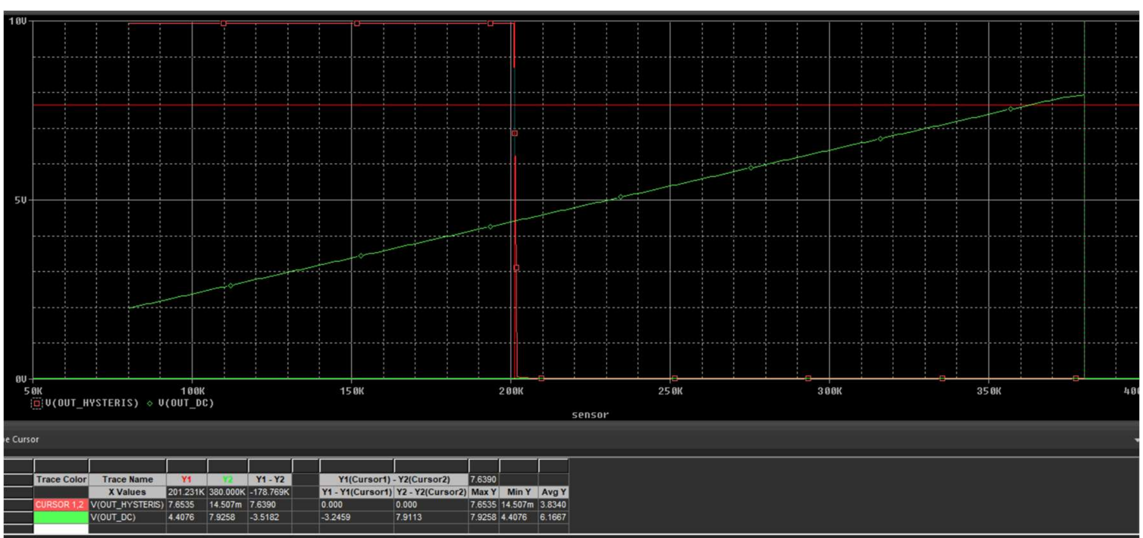


Figure 5.4.2 The simulation for Vth_low

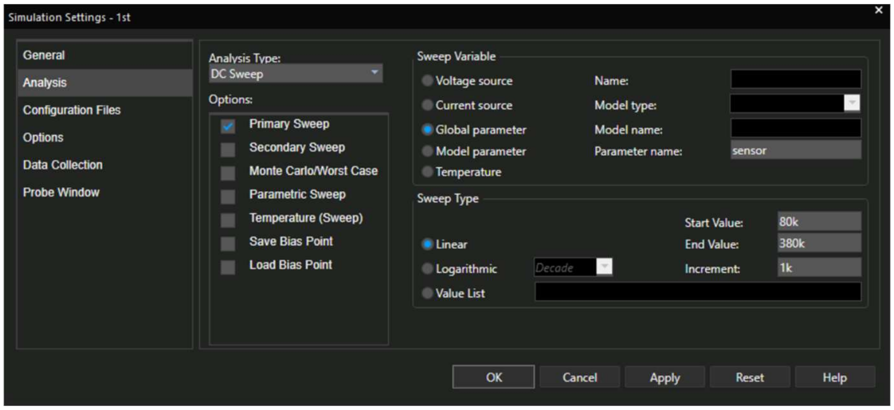


Figure 5.4.3 The simulation profile for Vth_high

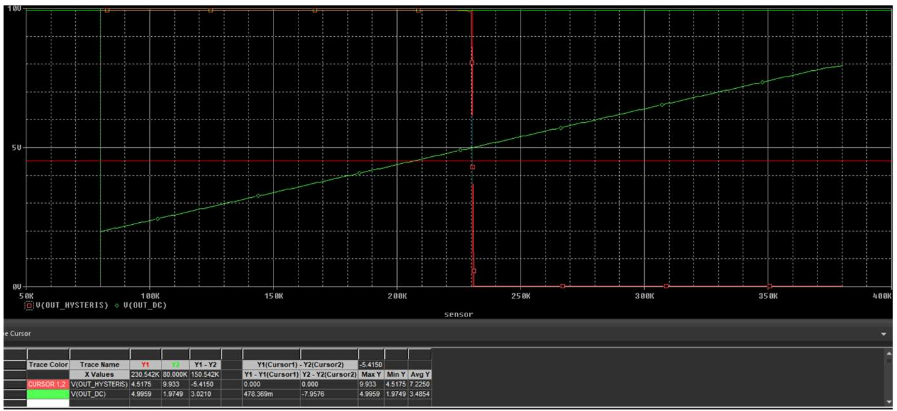


Figure 5.4.4 The simulation for Vth_high

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