EE 316 - Electronic Design Project

Project:
Water Level Controller

Project Report
17 July 2020

Objective

Water tanks are used commonly to store water in use drinking water, irrigation agriculture. In these applications, the water is pumped into tanks via a motor and a pump. It is necessary to check the pump frequently to prevent water from flooding from the tank or running out of water. By adding a water level sensor into such tanks, we designed a circuit that processes data from the sensor and measures the instantaneous water level. In order to keep the water level between the specified levels, we created a module to drive the pump until the water level reached the desired level and, furthermore, we adjusted the speed of the pump in direct proportion to the difference in the water level. In addition, we have taken care to take into account the ease of production and cost while meeting the project requirements.

Group Members

Common efforts: Clock signal generation

Behiye Erdemir: Water level sensor, PWM generation

Esin Sanem İmamoğlu: Motor driver and, Protection circuit

Ömer Faruk Karadaş: DC water level signal, Water level controller and, Error amplifier

Contents

List of Figures

List of Tables

1. Background Information

1.1. Proper Electrode Materials and Geometries

There are different types of level sensors that can be divided into two classifications: point level measurement and continuous level measurement. Point level measurement indicates when a liquid is present at a certain point. Continuous level measurement indicates the continuous level of a liquid as it rises and falls. The point level sensors are capacitance, optical, vibrating. The continuous level measurement sensors are ultrasonic and radar. Within the scope of the project, important information is the water level according to a certain level. So, radar and ultrasonic sensors are unnecessary and expensive. Additionally, they can be affected by the vibration of the water. Cylindrical capacitors are low cost and have no moving part that is an advantage for the precise of the measurement. The capacitance expression for the cylindrical capacitor is;

$$C = 2\pi\varepsilon_0 \frac{\varepsilon_1 h_1 + \varepsilon_2 h_2}{ln(\frac{r_2}{r_1})}$$

The variable is this formula is the level of the water. The change in capacitance is due to the change in the dielectric value of the material. So, the change in water level causes the change in the capacitance.

1.2. PWM Driver Circuits for Inductive Loads and DC Motors

The speed of DC motors, that is used for toys, models, robots and other such electronics circuits, is controlled by regulating the voltage across its terminals. This regulation can be achieved by using Pulse Width Modulation (PWM). A series of On-Off pulses and varying the duty cycle control the motor speed. In addition, there are several solutions for generating PWM signals like using a comparator, NE555 timer. [1] We decided to use a comparator for generating PWM signal.

Comparators compare one analog voltage level, Vin, to another reference voltage level, V_{ref}, and generate an output signal based on this voltage comparison. [2] If V_{in} is greater than V_{ref} then the output voltage equals positive saturation voltage of the operational amplifier. Otherwise, the output will be equal negative saturation voltage.

1.3. Comparison of power efficiency in linear amplifiers and PWM drivers.

A Pulse width modulation (PWM) driver transmits a certain amount of voltage to the motor by turning the voltage between the transistors on and off at a very high frequency (typically **20 kHz** range). Unlike PWM, in a linear amplifier, transistors are always to some extent open. This allows the voltage to flow continuously to the transistors and motor instead of turning it on and off. Since some voltage is always flowing through the transistors, linear amplifiers suffer significant power loss and are usually in the range of **50%** or less. In contrast, PWM drives generally have **90**% efficiency or better. [3] According to the switching theory, the best switching condition occurs when the switching frequency is much higher than the dynamics of the motor. The motor should consider this incoming PWM signal to be DC voltage. Due to different references the frequency must be at least five times higher than the rotation speed of the motor. For example, if the motor rotates at **6000 rpm** (**100 rps**) the frequency must be higher than **5 * 100 Hz** = **500 Hz**. [4]

2. Design Overview

The water level in the tank should be measured and according to that measured value, water should be added automatically. As can be seen in **Figure 1:** Block Diagram of the Water Level Controller

, a cylindrical capacitor is placed on the tank for measuring the water level. The signal that occurs when the clock signal passes through the capacitor is delayed. This delayed signal is processed in block of "**DC Water Level Signal**", resulting in a DC signal proportional to the water level. On the other side, desired water level is adjusted by using potentiometer. On the

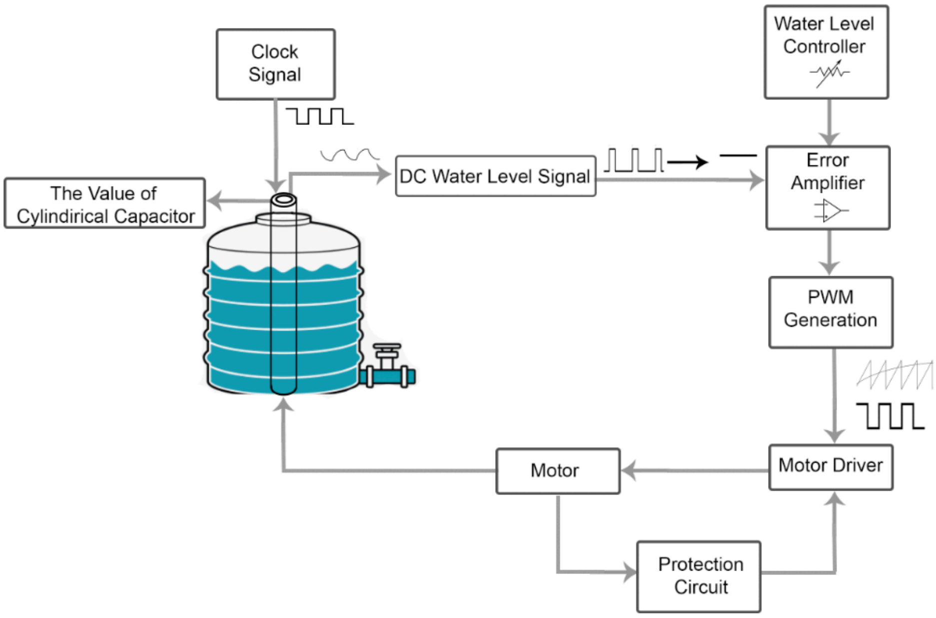


Figure 1: Block Diagram of the Water Level Controller

other side, the voltage level that is corresponding to the desired water level is adjusted in the block of "**Water Level Controller**" by using a potentiometer.

Then, The DC signal that is the instantaneous voltage value, at the output of the 'DC Water Level Signal' block and the desired voltage value, at the output of the 'Water Level Controller' block become the inputs of the error amplifier. The error amplifier takes the difference between the instantaneous voltage value and the desired voltage value. We call this difference as error. What we want is that when the error value is high, the motor rotates and fills the water quickly. When generating the Pulse Width Modulation (PWM) signal by using a comparator required to drive the DC motor, the error value we refer to determines the duty cycle of this PWM signal. After the 'PWM Generation', with the signal we obtained, the process of driving the motor is carried out with the H-bridge in the 'Motor Driver'. Finally, a 'Protection Circuit' like a fuse or circuit breaker is used to prevent the motor from being overcurrent and as a result of damaging circuit equipment. All the while, schematic design, and simulations were done on LTSPICE simulation software [5].

3. Design Description

3.1. The Value of The Cylindrical Capacitor

The capacitance of a cylindrical capacitor that will be used in the project scope can be calculated by using the equation in below,

$$C = 2\pi\varepsilon_0 \frac{\varepsilon_1 h_1 + \varepsilon_2 h_2}{ln(\frac{r_2}{r_1})}$$

***Equation 1**: Where: C: Capacitance, r_1: inner radius, r_2: outer radius, ϵ_0: permittivity of space, ϵ_1: relative permittivity of the liquid, h_1: height of the liquid, ϵ_2: relative permittivity of the air (above* the liquid), h_1: height of the cylinder above liquid level. *permittivity of space, ϵ_1: relative permittivity of the liquid, h_1: height of the liquid, ϵ_2: relative permittivity of the air (above* the liquid), h_1: height of the cylinder above liquid level.

According to the formula, $2\pi\varepsilon_0$ and $ln(\frac{r_2}{r_1})$ are the constants and when the water level changes, only the variables h_1 and h_2 will change. So, the numerator part can be considered. Therefore, there needs a comparison between $\varepsilon_1 h_1$ and $\varepsilon_2 h_2$ to determine the effect of water level on capacitance change. ε_1 and ε_2 are previously known expressions for air and water. The relative permittivity of the air (ε_1) is **1.0006** and the relative permittivity of the water (ε_2) is **88**. So, $\varepsilon_1 h_1$ and $\varepsilon_2 h_2$ can be expressed as

$$88 * (h_1) + 1.0006 * (h_2) \quad \text{(Equation 2)}$$

Due to the large difference between ε_1 and ε_2, the change in capacitance can be clearly observed. 1 cm increase in water level means 1 cm decrease in air level due to the fixed length of the capacitor. For a mathematical expression, the equation can be expressed like that;

$$88 * (h_1 + 1) + 1.0006 * (h_2 - 1) \quad \text{(Equation 3)}$$
$$88 * h_1 + 88 + 1.0006 * h_2 - 1.0006 \quad \text{(Equation 4)}$$
$$88 * h_1 + 1.0006 * h_2 + 86.9994 \quad \text{(Equation 5)}$$

When comparing the second equation and the fifth equation, the difference calculated as **86.9994** and it is clearly can be seen that the fifth equation is greater than the second equation.

Consequently, the formula shows that, while the water level is increasing, the capacitance of the cylindrical capacitor also increases. Conversely, while the water level is decreasing, the capacitance of the cylindrical capacitor also decreases. In addition, due to the large difference between the relative permittivity of water and the relative permittivity of air, this change can be clearly seen as a result of measurements. In addition, the value of capacitance at certain points has given by the supervisor.

Cylindrical Capacitor Design Targets			
Description of design target	**Min**	**Max**	**Unit**
The water level at the capacitor	5	15	cm
The capacitance of the capacitor	130	270	pF

***Table 1**: Design target for Cylindrical Capacitor*

3.2. Clock Signal

To obtain an oscillator, we used **NE555** timer IC. It has 8 pins called ground, trigger, output, reset, control, threshold, discharge and VCC. **NE555** Timer has 3 modes as **a-stable, mono-stable, bi-stable** modes. In a-stable mode, there is no stable state, so it continuously switches between high and low which is used as a clock or square wave output. We used two resistors and a capacitor as shown in **Figure 2.** The Trigger and Threshold pins are connected to each other. A **10 nF** capacitor should be connected between reset and ground pins to ensure electrical noise does not affect internal voltage divider. In addition, Vcc is the positive supply and GND is ground.

There are some formulas that we used to find resistance and capacitor values.

- $T_H = 0.693 \times (R_1 + R_2) \times C$
- $T_L = 0.693 \times R_2 \times C$
- $T = T_L + T_H$ (Period for a cycle)
- $f = \frac{1}{T}$

According to the formulas given above, obtained frequency is **148.8 kHz, R_1** is **30 kΩ, R_2** is **470 kΩ** and capacitor value is **0.01 nF**

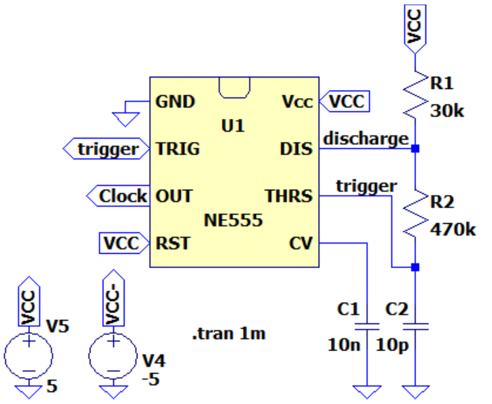


Figure 2: Schematic design of NE555 Timer in a-stable mode

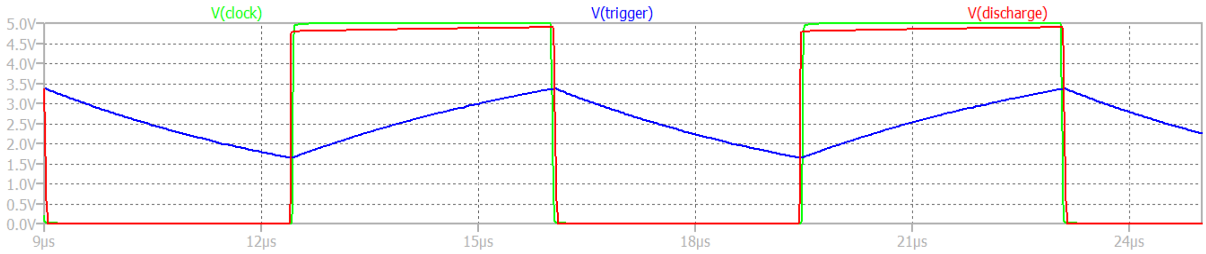


Figure 3: Simulation of output, discharge and trigger voltages.

Clock Signal Design Targets			
Description of design target	**Min**	**Max**	**Unit**
Clock Frequency	100	200	kHz
The capacitance of the capacitor	0.01	-	nF
Duty Cycle	51.55	-	%
Input Voltage	5	-	Volt

Table 2: Design target for clock signal

3.3. DC Water Level Signal

The DC water level signal module is a circuit that provides the instantaneous capacitance value of the water level sensor to the DC voltage. We followed these steps to obtain the DC water level signal.

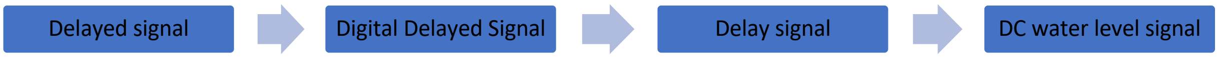


***Figure 5:** Workflow diagram to obtain DC water level signal*

As seen in **Figure 4**, **C_{sensor}** has been added to express the capacitance of the sensor. By adding a **1 kΩ** resistor to the clock signal, a delay signal is obtained which varies depending on the capacitance. The simulation of the circuit is shown in Figure 6.

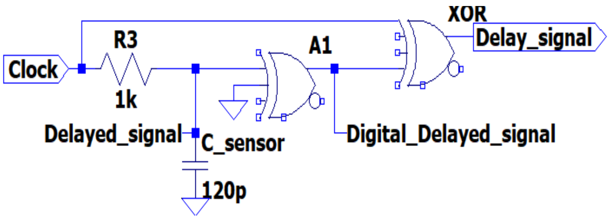


***Figure 4:** Schematic design for obtaining delay signal part*

After completing this step, a logic comparator circuit consisting of an XOR gate is used to digitalize the resulting signal. Depending on the input voltage change threshold value of the XOR Gate, a digitalized delay signal is obtained. This threshold value for **74HCT86** IC is **3.5** volts for high-to low-stage transition and **1.5** volts for low-to high-stage transition. You can see the digitized delayed signal that we obtained by this method in **Figure 6.**

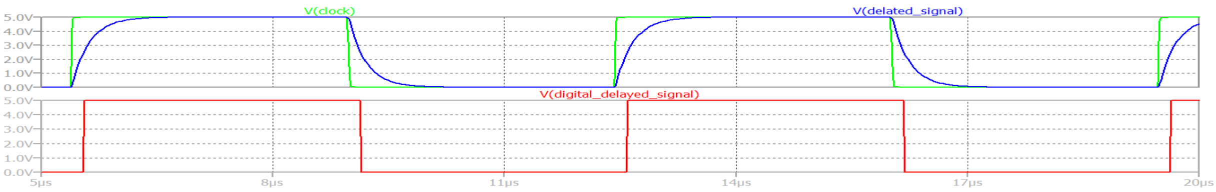


***Figure 6:** Simulation of Clock, digital delayed signal and Delay signal*

After completing this step, the delay between the two signals is obtained when the digitized delay signal and the clock signal are compared using an XOR gate. You can see the delay signal obtained in figure 7.

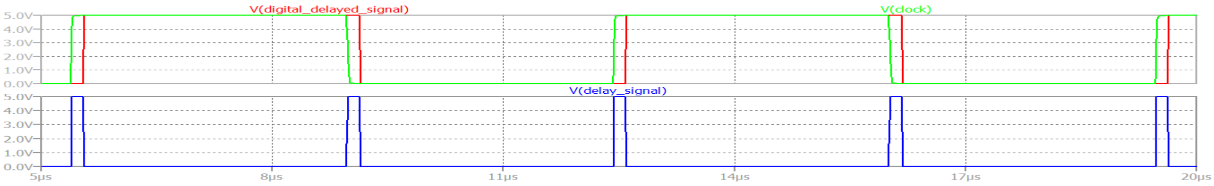


***Figure 7:** Simulation of Clock, Delayed and digital delayed signal.*

The water level signal is obtained by connecting a resistor and capacitor in the low pass filter (LPF) order to the delay signal obtained in the previous step. The cut-off frequency of the generated circuit must be small compared to the frequency of the delay signal. Required time to reach **99.99%** of the signal's saturation voltage is **5τ** ($\tau = RC$) (in our case, a R=**150Ω** and **C=1µF** delay time is **0.75ms**). You can see the circuit and simulation results in **Figure 8**.

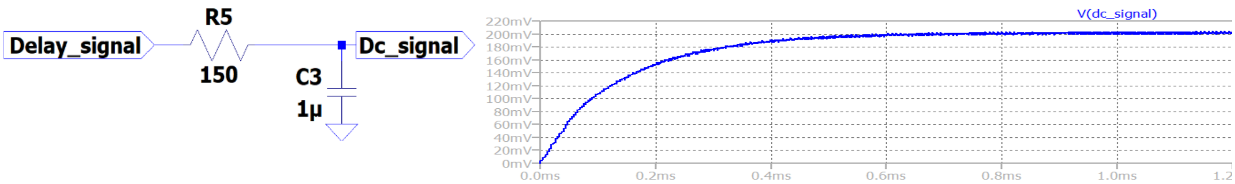


***Figure 8**: a) Schematic design of passive LPF for obtaining DC signal from delay signal. b) Simulation results of LPF*

DC Water Level Signal Design Parameters			
Description of design parameter	**Min**	**Max**	**Unit**
Clock Frequency	150	-	kHz
Clock Duty Cycle	50	-	%
Sensor capacitance(C_sensor)	120	250	pF
Output voltage (Dc_signal)	129.7	268.7	mV
Saturation time (delay)	0.75	-	ms

***Table 3**: Design target for The DC water level signal*

3.4. Error Amplifier

The error amplifier module is an amplifier that takes the difference of the desired and current water level DC voltage and then gains it for PWM generation. To obtain difference between desired water level and current water level, we chose to build a difference amplifier. With this circuit as seen in **Figure 9**, we were be able to achieve amplified DC error signal. While determining design specifications of difference amplifier, we consider applicability of circuit and proper output signal for PWM generation.

According to the information provided to us by our supervisor, the sensor has **250pF** capacitance at its maximum water level (**15 cm**) and **120pF** capacitance at its minimum level (**5 cm**). We obtained DC water level signals corresponding to these capacitance values at approximately **130 mV** and **270 mV** respectively. Based on these calculations, in the maximum case (when the desired level is **15 cm** and the current is **5 cm**) the difference signal becomes **140 mV**. The calculated maximum difference signal is because PWM is quite small to produce. We chose the gain of the difference amplifier with the maximum difference signal to be equal to the maximum value of the triangle wave we obtained in **section 3.6.** Considering these specifications, the amplifier gain is approximately **22**, calculated from **3.2V / 140mV** also $\boldsymbol{R_6}, \boldsymbol{R_{16}}$are equal **1 kΩ** , and $\boldsymbol{R_{14}}, \boldsymbol{R_{15}}$ are equal to **22kΩ** due to equation 7.

- $V_{Error} = \left(\frac{R_{16}+R_{14}}{R_6+R_{15}}\right)\frac{R_{15}}{R_{16}} V_{pot} - \frac{R_{14}}{R_{16}} DC_{signal}$ [6]
- For $R_{16} = R_6$ and $R_{14} = R_{15}$, $V_{Error} = \frac{R_{14}}{R_{16}}\left(V_{pot} - DC_{signal}\right)$ [7]

When the circuit is simulated in accordance with the calculated values, the error signal obtained in the maximum case ($\mathbf{V_{pot}}$= **271.1 mV** and $\mathbf{DC_{signal}}$ = **129.7 mV**) is as in **Figure 10**

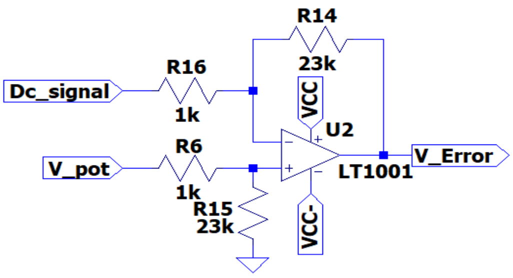


***Figure 10:** Schematic design of Error amplifier*

Error Amplifier Signal Design Parameters			
Description of design parameter	**Min**	**Max**	**Unit**
Non-inverting input voltage (V_pot)	130.7	271.1	mV
Inverting input voltage (Dc_signal)	129.7	268.7	mV
Output voltage (V_Error)	0	3.2	V
Positive supply voltage	5		V
Negative supply voltage	-5		V

***Table 4**: Design targets for the error amplifier*

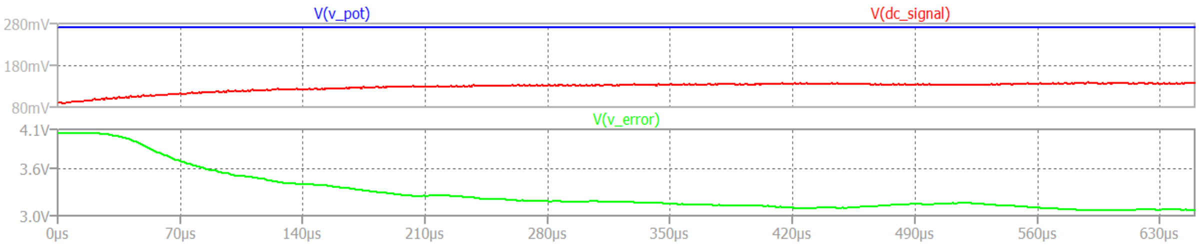


***Figure 9:** Simulation of the error amplifier in the case of maximum water level difference where the desired water level is 15 cm and the current 5 cm*

3.5. Water Level Controller

In the simplest terms, the water level control module is a potentiometer that provides output voltage between the specified two voltages values. In more detail, it is a circuit giving output voltage in the range of **130mV** and **270mV DC** voltage values corresponding to **5 cm** and **15 cm** water level. This circuit is created by adding extra resistance to both sides of a standard potentiometer. You can see the circuit schematic design in **Figure 11**.

As shown in equation (8) and (9), the output voltage equation based on input voltage and resistors is obtained by applying node analysis.

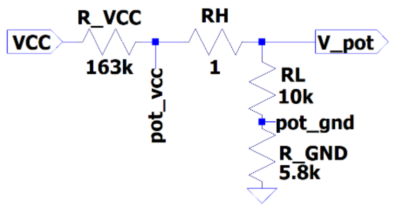
$$\frac{VCC-V_{pot}}{R_{VCC}+R_H} = \frac{V_{pot}}{R_L+R_{GND}} + \frac{V_{pot}}{Rload} \quad \text{(Equation 8)}$$

$$V_{pot} = \frac{VCC}{R_{VCC}+R_H} \div \left(\frac{1}{R_L+R_{GND}} + \frac{1}{Rload} + \frac{1}{R_{VCC}+R_H}\right) \quad \text{(Equation 9)}$$

As shown in below, the limit conditions of the circuit were determined by considering the specified points and using a **10 kΩ** potentiometers.

- **At VCC = 5V,** $\boldsymbol{R_H = 0\ \Omega}$ **and** $\boldsymbol{R_L = 10\ k\Omega}$**, V**$_{\mathbf{pot}}$ **= 140 mV,** $\boldsymbol{R_{Load} = 22.5\ k\Omega}$
- **At VCC = 5V,** $\boldsymbol{R_H = 10\ k\Omega}$ **and** $\boldsymbol{R_L = 0\ \Omega}$**, V**$_{\mathbf{pot}}$ **= 270 mV,** $\boldsymbol{R_{Load} = 22.5\ k\Omega}$

When the equation (9) is solved according to the given conditions, resistance value of R_{VCC} and R_{GND} are obtained. These resistance values as follows, $\boldsymbol{R_{VCC} = 163\ k\Omega}$, $\mathbf{R_{GND} = 5.8\ k\Omega}$. When the circuit is simulated in accordance with the calculated values, the resulting output voltage is in the range of **130.7 mV 271.3 mV**.



Water level controller design parameters			
Description of circuit parameters	**Min**	**Max**	**Unit**
Supply Voltage (VCC)	5	-	V
Output Voltage (V_pot)	130	270	mV
Potentiometer Resistance	10		kΩ

Table 5: *Design target for water level controller*

Figure 11: *VCC is power supply (5V),* R_{VCC} *is resistor on the VCC side,* R_{GND} *is resistor on the ground side,* R_H *is VCC side of potentiometer,* R_L *is ground side of potentiometer, and* R_{load} *is equivalent resistor on the amplifier side*

3.6. Generating PWM Signal

A Schmitt Trigger, which will be used as a comparator, has two different threshold voltage levels that can be observed on transfer characteristics. Therefore, the noise on the input signal can't affect the output. So, it is advantageous using Schmitt Trigger to generate a clear PWM signal.

As can be seen from in **Figure 12** that is provided to us by our supervisor for comparator module, two signals are needed. One of them is the triangular wave and the other is the reference voltage. In addition, noise is given as an input for simulation. It was observed in the simulation is given in **Figure 13** that the noise did not affect the output.

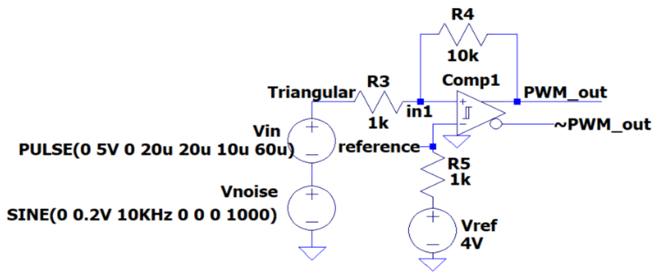


Figure 12: *The schematic for the comparator module provided by our supervisor*

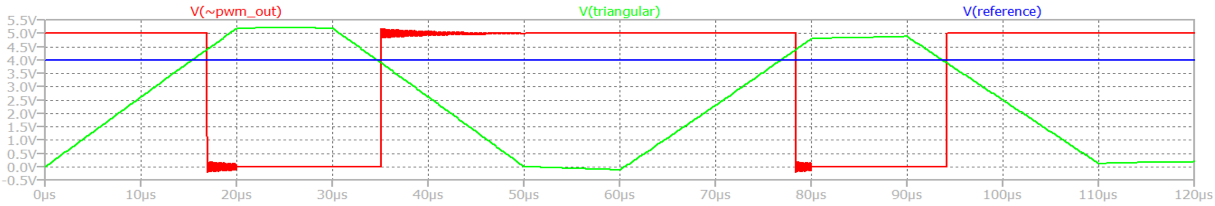


Figure 14: Simulation result of the schematic for comparator module provided by our supervisor

For this project, as given in **Figure 14**, we use an operational amplifier to generate a triangular wave in frequency **27 kHz** for the first input of the comparator. [6] For the use of the MOSFET driver in the 'Motor Driver' block, we have determined the frequency of the signal in the 20kHz range suitable for the driver. [4] After that, the triangular wave is used as an input of the emitter follower. According to the research, the emitter follower is used in many circuits where a circuit such as an oscillator does not need to be loaded but provides a lower impedance to the output. [7]

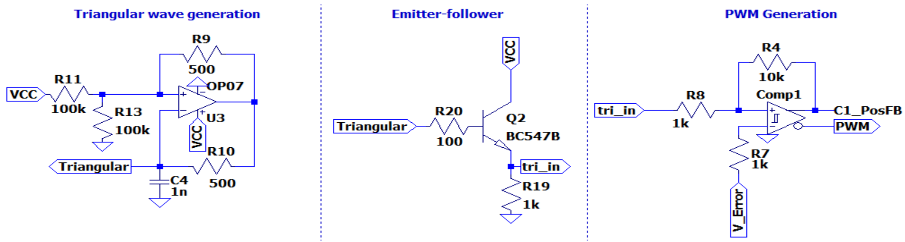


Figure 13: Designed circuit schematic for comparator module

On the other hand, the reference voltage that is the comparator's second input is the output of the error amplifier in this project. Finally, the output of the comparator is taken from the ~Out (Not Out). Because, the requirement of the project is while the error voltage is high voltage level, then the duty cycle will be high. The result of the simulation can be observed in **Figure 15.**

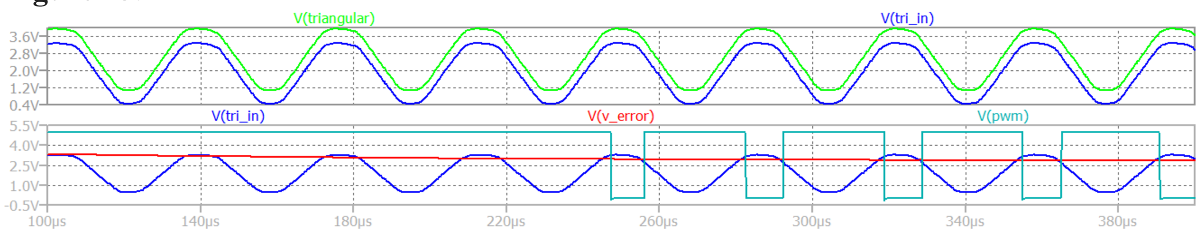


Figure 15: Simulation of the designed circuit for comparator module

The Circuit of The Triangular Wave Design Targets			
Description of design target	**Min**	**Max**	**Unit**
Input Voltage	5	-	V
Output Voltage	1.4	3.9	V
Frequency of the Output	27.4	-	kHz
Output Duty Cycle	50	-	%
V_{rms} value of the Output	2.9	-	V_{rms}

Table 6: Design targets The Circuit of The Triangular Wave Design Targets

Emitter Follower Design Targets			
Description of design target	**Min**	**Max**	**Unit**
Input Voltage	1.4	3.9	V
Output Voltage	0.4	3.2	V
Frequency of the Output	27.4	-	kHz
V_{rms} value of the Output	2.0	-	V_{rms}

Table 7: Design targets for the Emitter Follower

Circuit of the PWM Generation Design Targets			
Description of design target	**Min**	**Max**	**Unit**
Input Voltage	1.4	3.9	V
Output Voltage	0	5	V
Reference Voltage	0	3.6	V
Frequency of the Output	27.4	-	kHz
Duty Cycle	0	100	%
Duty Cycle of the Output	0	66.6	%

Table 8: Design targets for the Circuit of the PWM Generation

3.7. Motor Driver

In Half Bridge Circuit, there are two inputs which switch to control output voltage. Each switch operates alternately for each clock cycle. [8] When Half bridge DC Motor head is connected to the voltage source, motor starts rotating in one direction. Therefore, to control the driving of the DC Motor, Half Bridge is used as shown in the **Figure 16** above. In this circuit; 2 AND Gates, 2 MOSFETs, 1 comparator and 2 buffers are used. Specifically, in the implementation of motor pump, we used L298N gate.

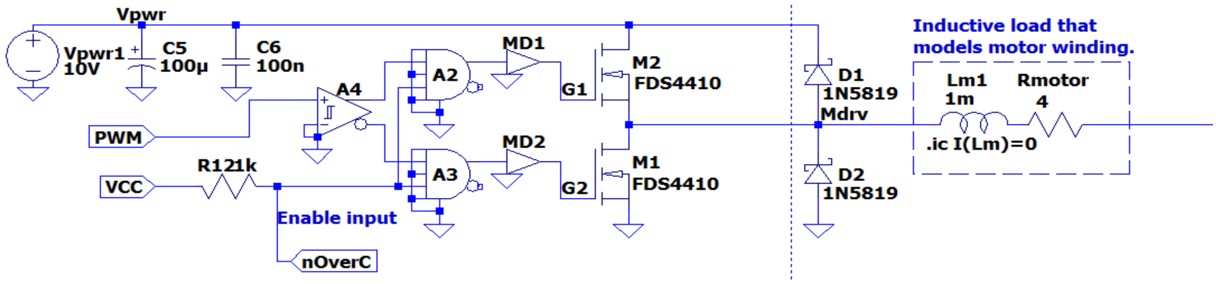


Figure 17: Schematic design of Motor Driver and Protection Circuit [9]

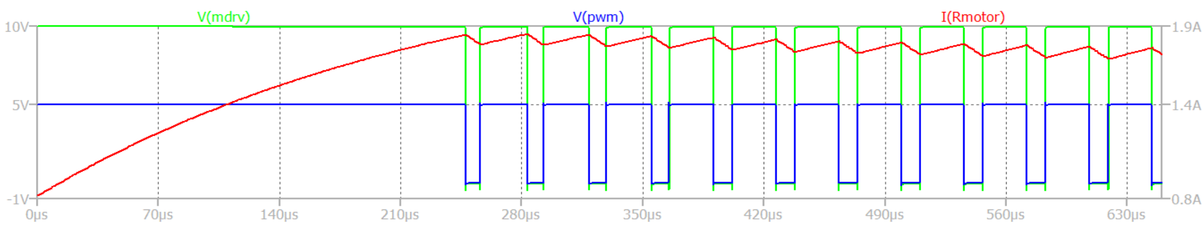


Figure 16: Simulation of Motor Driver Circuit

Motor Driver Design Targets			
Description of design target	**Min**	**Max**	**Unit**
Supply Voltage (Vcc)	5		V
PWM Signal Voltage (V_{pwm})	0	5	V
Duty Cycle of PWM Signal	0	66	%
Enable Input Voltage	0	5	V
Vpwr1	10	-	V
Output Voltage (V_{mdrv})	0	10	V
Duty Cycle of Output	0	66	%
Frequency of Output	27.4	-	kHz

Table 9: Design targets for the Motor Driver

3.8. Protection Circuit

The aim of the circuit is protecting overcurrent. R17 and R18 are used to adjust **200 mV** between the resistances as can be seen from **Figure 18**. Voltage of R_{cs} should be **204 mV**. By using Ohm's Law;

$$\mathbf{204mV = I * 0.1\Omega}$$
$$\mathbf{I = 2.040\ A}$$

Therefore, the current on the R_{cs} is **2.040 A**. The case $\mathbf{V_{Rcs}} < \mathbf{204mV}$ has non-inverting characteristic. In this case, transistor is close which is connected to the enable input so the motor driver. Therefore, it decides whether the motor should drive or not.

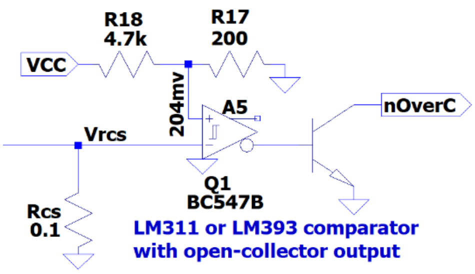


Figure 18: Schematic of the Protection Circuit [9]

Protection Circuit Design Targets			
Description of design target	**Min**	**Max**	**Unit**
Supply Voltage (V_{cc})	5	-	V
Output Voltage (nOverC)	0	5	V
Voltage of R_{cs} (V_{rcs})	80	200	mV
Reference Voltage	204	-	mV
Current Threshold	2.04	-	mA

Table 10: Design targets for the Protection Circuit

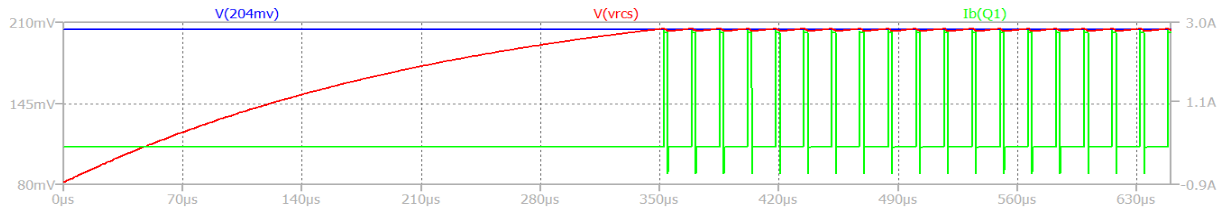


Figure 19: Simulation of the protection circuit

4. Conclusion

Water tanks are used commonly to store water in use drinking water and irrigation agriculture. It is necessary to check the pump frequently to prevent flooding from the tank or running out of water. By the motivation of this deficit and requirement, the project with closed-loop control was carried out.

Briefly, the capacitance of a capacitor, creates a delay in reference to the oscillation signal, was allowed to determine the water level for different capacitance values. The difference between the instantaneous water level determined in this way and the water level set by the user was enabled the generation of the PWM signal, which determines the motor speed required to bring the water level to the set level. After all, a circuit breaker circuit was considered to protect components from overcurrent conditions that may occur.

Due to the Covide19 pandemic and quarantine period, it was not possible to test our design in the laboratory. However, the schematic design was simulated on LTspice Simulation Software and the results were as targeted in the ideal conditions. If our circuit design could be tested with laboratory equipment, errors that could have occurred due to the nature of the electronic components would actually be detected. In this case, the design would be rearranged to achieve the desired results to eliminate errors.

Due to Covid19, the production phase of the designed water level control module could not be exceeded. However, we have completed the PCB design of the Circuit to move the designed circuit one step further from the simulation and added the 3D design of the circuit to see the closest to the real of the circuit. In this way, we can better visualize the stages that await us during the production phase. Layout design, PCB design and 3D design of the water level control module are given in **Appendix 1**.

5. Component List

Component description	Part Number	Manufacturer	Supplier
NE555	NE555P	Texas Instruments	Mouser Electronics
LM741	LM741CN/NOPB	Texas Instruments	Mouser Electronics
74HCT86 (XOR GATE)	MC74HCT86ADG	ON Semiconductor	Mouser Electronics
BC547B (BJT)	BC547B	ON Semiconductor	Mouser Electronics
LM393(Comparator)	LM393BIDR	Texas Instruments	Mouser Electronics
L298N	L298N	STMicroelectronics	Mouser Electronics

Table 11: *List of critical hardware components and their sources.*

References

[1] electronics-tutorials, "Pulse Width Modulation used for motor control," [Online]. Available: https://www.electronics-tutorials.ws/blog/pulse-width-modulation.html. [Accessed 17 May 2020].

[2] electronics-tutorials, "Op-amp Comparator and Comparator circuit," [Online]. Available: https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html. [Accessed 17 May 2020].

[3] D. Collins, "When do you need a linear amplifier versus a PWM drive?," WTWH Media LLC, 29 November 2018. [Online]. Available: https://www.motioncontroltips.com/when-do-you-need-a-linear-amplifier-versus-a-pwm-drive/. [Accessed 2020 March 28].

[4] S. Spännare, "Some power PWM drivers for DC electric motors," January 2002. [Online]. Available: https://www.picotech.com/library/application-note/some-power-pwm-drivers-for-electric-dc-motors. [Accessed 1 04 2020].

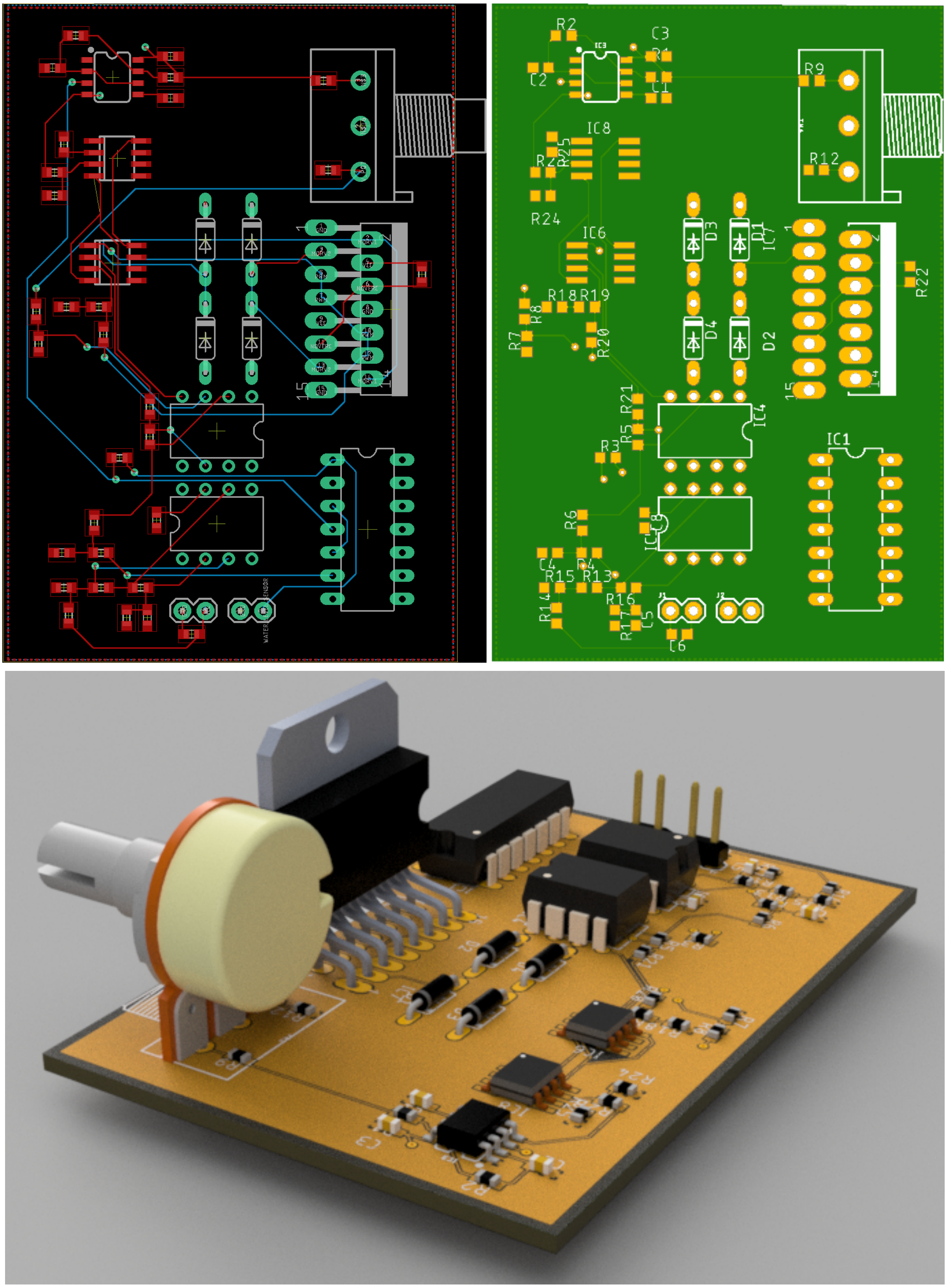
[5] B. Ozdemirel, "An archive of LTspice schematic files that contain circuit examples for projects.," [Online]. Available: https://cms.iyte.edu.tr/course/view.php?id=576. [Accessed 03 05 2020].

[6] M. Sadaghdar, "Making an Electric Toothbrush (Speed Control of a DC Motor)," 19 September 2013. [Online]. Available: http://www.electroboom.com/?p=359. [Accessed 10 04 2020].

[7] electronics-notes, "Transistor Emitter Follower Circuit: Common Collector Amplifier," [Online]. Available: https://www.electronics-notes.com/articles/analogue_circuits/transistor/transistor-common-collector-emitter-follower.php. [Accessed 17 May 2020].

[8] B. Bell, "Half-bridge topology finds applications in high density power converters," 05 08 2006. [Online]. Available: https://www.eetimes.com/half-bridge-topology-finds-applications-in-high-density-power-converters/.

Appendix 1



Appendix 1*: a) Top left image is layout design of water level control module, Top right image is PCB design of water level control module, and Bottom image is 3D design of water level control module.*