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E344 Assignment 4

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Report submitted in partial fulfilment of the requirements of the module Design (E) 344 for the degree Baccalaureus in Engineering in the Department of Electrical and Electronic Engineering at Stellenbosch University.

September 25, 2022

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Nomenclature

Acronyms and abbreviations

V Volts

A Ampère

PWM Pulse width modulation/modulated

DAC Digital to Analogue

Chapter 1

Literature survey

1.1. Operational amplifiers

For the design of the current sensor, an operational amplifier is used. The amplifier is necessary to amplify the signal that is measured through the ESP micro-controller. The operational amplifier is part of the current sensing of the right wheel of the system. With this in mind, certain configurations and other design choices are considered.
Some properties to consider with the operational amplifiers include the following: maximum allowable differential input voltage, maximum allowed common mode voltage, maximum allowable rail voltage, minimum allowable voltage between negative rail and input voltages and possible output voltages. The maximum allowable differential input voltage is the maximum voltage that can be applied to the inverting or non-inverting pins without causing damage to the characteristics of the op-amp. The maximum common mode voltage refers to the maximum input voltage for where the op-amp still functions properly. Since we are using a rail-to-rail op-amp, the input voltage can swing as high as the supply voltage but is limited to the value of the supply voltage.

Operational amplifiers: limitations and considerations

The MCP6462 is used for the build of the circuit.Its is a Dual operational amplifier with a supply voltage ranging from 1.8 to 5.5V. The range of allowable input voltages for this component is V_{SS} - 1V to V_{DD} + 1V. All other inputs and outputs are limited to V_{SS} - 0.3V to V_{DD} + 0.3V including the maximum allowable common mode voltage. The maximum allowable rail voltage is 5.5V for this component. These values are found from the Datasheet that can be found in the bibliography.

Operational amplifier configurations

The different configurations that can be used to amplify small signals include Low-pass , High-pass and Band-pass operational amplifiers. Low-pass operational amplifiers are used to filter out signals above a certain frequency, Band-pass operational amplifiers are used to filter out signals above and below certain frequencies and high-pass operational amplifiers are used to filter signal below a certain frequency. All three these configurations can be used with added amplification components to amplify and filter signals.

For the circuit designed in this Assignment, a Low-pass filter will be used seeing as all signals above 1kHz are to be filtered.

1.2. Current sensing

1.3. The interfacing and use of a Ultrasonic Range Sensor

An ultrasonic sensor is a sensor that uses sound waves to determine the time it takes for a sound wave to bounce of an object. The sound wave can then be used and analyzed to determine the distance the object is from the sensor. These waves are at a frequency that is outside the range of human hearing, hence why we call it an ultrasonic sensor. The sensor has a transmitter and a receiver function which it uses to send out and receive sound waves. Equation 1.1 is used to calculate the distance of the object to the sensor [5].

$$Distance(meters) = \frac{(time\ elapsed[seconds] \times 343[m/s])}{2}. \tag{1.1}$$

.

The specific sensor used for this circuit is the HC - SR04 ultrasonic sensor. When looking at the data sheet [1] of the sensor, important parameters are considered with the design of the circuit. These are in table 1.1.

Table 1.1: Electric Parameters of Ultrasonic Sensor

	Parameter	Value
Working Voltage	DC 5 V	
Working Current	15mA	
Working Frequency	40Hz	
Max Range	4m	
Min Range	2cm	

The sensor used for this circuit can be seen in figure 1.1. The sensor has two pins that are used as the transmitter and the receiver. The ”trigger” pin is used to transmit the signals and the ”Echo” pin then receives the signals that have bounced off of objects within a 4m range. This is why, when looking at equation 1.1, the ”time-elapsed” multiplied by the speed of sound in air, is divided by two. The sound travels to the object and then back again.

Figure 1.1: HC-SR04 Sensor [1]

.

The waves received by the echo pin are used to determine the distance. The longer the periods of the waves, the further the object and vice versa. The further away the object is from the sensor, the higher the output voltage of the circuit should be. This is also true for the opposite case. The trigger transmits 10μ waves every 60ms.

1.4. The conversion of PWM signals to Analogue values

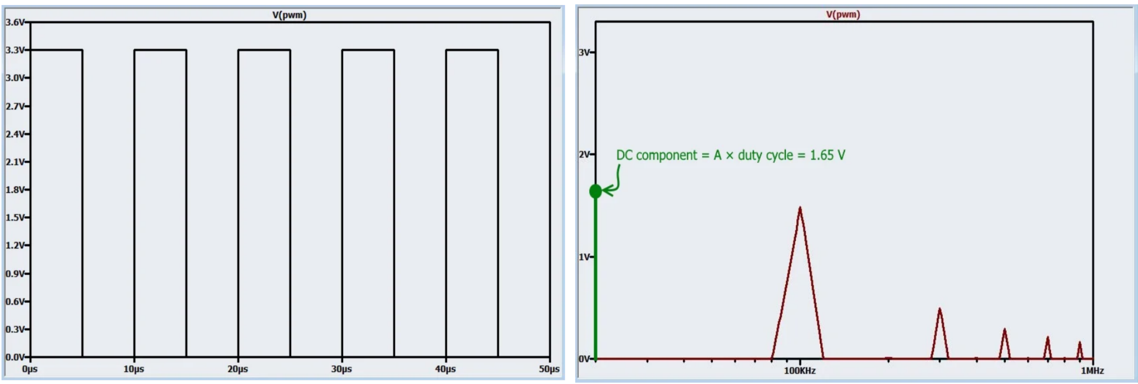
PWM signals are converted into DAC voltage for this part of the system. The pulses received from the sensor is put through a sallen-key low-pass filter to generate a DAC output.

Equation 1.2 in conjuction with hardware is used to vary the duty cycle of the PWM signal [2].

$$desired\ DAC\ voltage = A \times duty\ cycle. \tag{1.2}$$

.

When looking at Figure 1.2 1.2a and 1.2b it can be seen that a pulse signal contains a DC-component and spikes of the signals at different frequencies. The DC-component is the thing we are interested in, so we use a low-pass filter to filter out all the noise above a certain frequency. The sensor emits and receives pulses at 40kHZ frequencies. With this in mind, a frequency is chosen to ensure that the correct amount of noise is filtered out, this is often an incredibly low value. It can range from 1.5Hz to 10Hz depending on the frequency of the original signal [2].



(a) Pulse signal received

(b) FFT and DC-component of the same pulse

Figure 1.2:

Even though the change in the duty cycle of the signal changes the spectrum of the FFT, the first spike is still at a frequency that makes it possible to get the DC-value of the signal [2].

With all this in mind, the best option is a second order filter. The second order filter provides a more stable output with not a lot of noise. Which is exactly what is desired in the process of converting a PWM signal to a Analogue voltage. [2]

1.5. The conversion of Digital Values to Analogue Equivalents

For the Digital to Analogue conversion, a summing amplifier is used. Fig. 1.3 shows the configuration used for this design. To this design a voltage divider circuit is added to the positive input to configure the offset of the op-amp.

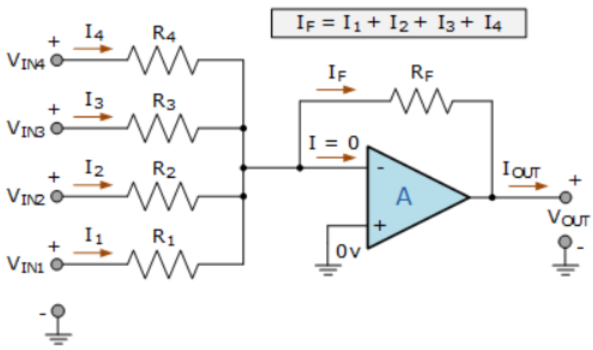


Figure 1.3: Summing Amplifier Schematic [3]

.

With this in mind, the following aspects pertaining to the design is taken into account. This includes the common-mode voltage in relation to the rail voltage of the op-amp, the output and input impedances of the circuit and the inverting or non-inverting configuration of the op-amp.

A input of 0000_2 should result in an output of more than 3V and an input of 1111_2 should result in an output of lower than 0.5V. Because of this it is assumed that the amplifier should be inverted, seeing as a low input results in a high output and vice versa. Because of this, an inverting summing amplifier is used. This configuration can be seen in fig. 1.3.

The common-mode voltage is the average voltage that is applied to the two inputs of the amplifier. [6]. The op-amp used for the circuit is a rail-to-rail op-amp, this means that the voltage supplied to the op-amp limits the value of the input voltages. The input voltage is limited to the supplied voltage , otherwise the op-amp can be damaged. For this circuit, the input values will be received as a high when the input is equal to 3.3V. Because of this, the supplied voltage can not be smaller than 3.3V, but should be bigger as to not affect the values of the DAC input by limiting them. This allows for more accurate input values seeing as the full range of voltages can be supplied.

The binary input for this circuit ranges from 0000_2 to 1111_2 that is converted to 0V to 3.3V. This is done by using weighted resistors. The negative feedback resistor R_f is used to bias the inverting op-amp at zero-potential. [3] For a 4-bit binary number, there are $2^4 = 16$ possible combinations for the A, B, C and D that can be seen in 1.3. These combinations range from 0000_2 to 1111_2 that corresponds to decimal values of 0 to 15. By making the weight of each input bit double the value of the previous resistor, the binary code ratio of 8-4-2-1 will respond to 2^3, 2^2, 2^1 and 2^0. This is used in combination with the feedback resistor and voltage divider circuit to produce the analogue output.

The input and output impedance of the circuit is an important aspect to consider. For the circuit we want a high input impedance and a low output impedance. This avoids loading affect and ensures that the current source delivers the maximum current it is supposed to. For the DAC input values, the resistors are chosen as high values to ensure a high impedance. This ensures that the voltage values from the DAC inputs are accurate.

1.6. Lead Acid Battery

A lead-acid battery is a rechargeable battery that uses lead and sulphuric acid reactions to function. The lead is submerged into the sulphuric acid to allow a controlled chemical reaction.This chemical reaction is what causes the battery to produce electricity. Then, this reaction is reversed to recharge the battery. [7]

The reactions are reversed when the battery is charged, and vice versa. This makes the battery able to be charged. The battery used has a maximum voltage of 7.2V and a maximum current of 1.2A.

Chapter 2

Detail design

2.1. Current sensor

The circuit is designed as an Active Low Pass filter with Amplification. When designing this circuit, certain resistor values are chosen and then used to design the rest of the circuit. The schematic below can be used as reference when describing the method that is followed.

The MCP6242 op-amp is used. it has a rail-to-rail voltage ranging from 1.8V to 5.5V. The common mode voltage and differential mode voltage can not exceed the rail voltages without damaging the op-amp. The maximum allowable output for the circuit is the maximum allowable input voltage to the ESP-microcontroller. The maximum allowable voltage is 5V. [8]. All this is kept in mind when designing the current sense circuit.

The gain is the first thing that is considered with the design of the circuit. The circuit is designed for a maximum current flow of 1.25A when the DC-motor is stalled and 250mA when the DC-motor is running freely. With this in mind, the maximum input voltage over the R_sense_V resistor is calculated as 12mV. This voltage is used as the input to the operational amplifier. The desired output voltage of the operational amplifier is specified 3.3V. The gain is then calculated with these values:

$$G = \frac{OutputVoltage}{InputVoltage} = \frac{3}{0.012} = 250. \tag{2.1}$$

.

For this circuit, the values for R_3 and R_2 are chosen. These values are chosen as 1500 Ω for R_3 and 33 kΩ for R_2.

For the design of the RC-filter, R_2 is chosen and used to calculate C_1. The cutt-off frequency is chosen as 10Hz, this allows for a settling time under 100ms. This allows for enough filtering of unwanted noise. R_2 is chosen as 1.5kΩ. The calculation can be seen in equation 2.2.

$$C_1 = \frac{1}{(2\pi)(R_2)(f_c)} = \frac{1}{(2\pi)(1500)(11)} = 9.645 \times 10^{-6}F. \tag{2.2}$$

.

The closest capacitor value of 10 μF is used.

For the design of the amplification, resistors R_3 and R_4 are determined. Resistor R_4 is chosen as 550kΩ and used to calculate R_3.

$$R_3 = \frac{R_4}{G-1} = \frac{550000}{250-1} = 2208.84\Omega. \tag{2.3}$$

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The closest available value of 2.2kΩ is chosen. All the resistors are big enough to ensure that the current does not exceed 150μA. The final circuit can be seen in Figure 2.1.

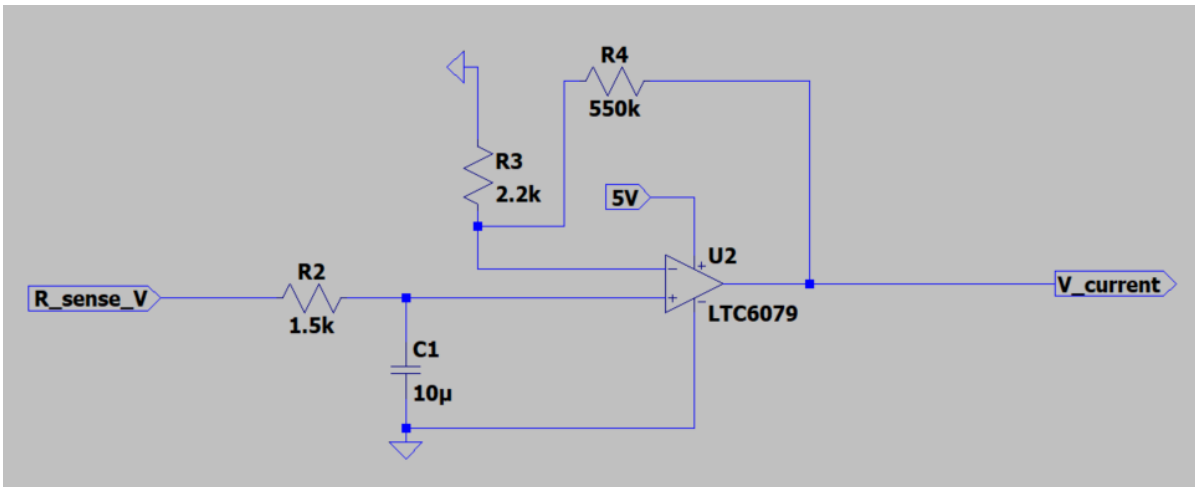

Figure 2.1: Active Low Pass Filter with Amplification Schematic

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2.2. Analogue Range Sensor

For the design of the ultrasonic sensor circuit, the following things are taken into account:

- The working voltage of the sensor is 5V.
- The working current is 15mA.
- The working frequency is 40Hz.
- The pulses that the sensor output are 40kHz pulses with more or less 5V amplitudes. The duty cycles of the pulses that are measured through the echo pin of the sensor are used to determine the distance of the object from the sensor.

A Sallen-Key filter is used in series with a Low-pass RC filter with added amplification. First the Sallen-key filter designed:

The op-amp used has limitations. The common-mode voltage is limited to the rail-to-rail voltage of the op-amp. If this is not adhered to, is could cause damage to the components.

The cut-off frequency is chosen as 1.5Hz. This allows for adequate filtering of the signals. For this filter, R_1 is equal to R_2 and C_1 is equal to C_2. These are the only components used, seeing as this is a unity gain low-pass filter. Equation 2.4 is used to calculate C:

$$f_c = \frac{1}{(2\pi)(\sqrt{R_1 R_2 C_1 C_2})}. \tag{2.4}$$

R_1 and R_2 are chosen as 12kΩ. $C_1 = C_2$ is calculated in the following manner:

$$C = \frac{\frac{1}{(f_c)(2\pi)}}{(\sqrt{R_1 R_2})} = \frac{\frac{1}{(1.5)(2\pi)}}{(\sqrt{(12 \times 10^3)(12 \times 10^3)})} = 8.842\mu F. \tag{2.5}$$

The closest value of 10μF is chosen.

A low-pass RC filter is used in conjunction to amplify and filter the output. This filter is also designed with a cut-off frequency of 1.5Hz. The output of the Sallen-key filter is measured and used to calculate the desired gain. To tune the gain of the circuit, a potentiometer is used as R_5.

For the RC-filter, R_3 is chosen as 22kΩ. Equation 2.6 is used to calculate C_3.

$$f_c = \frac{1}{(2\pi)(RC)} \tag{2.6}$$

$$C_3 = \frac{1}{(2\pi)(R_3)(f_c)} = 4.823\mu F \tag{2.7}$$

C_3 is chosen as 4.7μF.

The output of the Sallen-key filter is measured as 275.118mV at a maximum. This is the input to the RC filter. By following specifications, this value should be above 3V but should be less than 3.3V. Equation 2.8 is used to calculate what the gain more or less should be.

$$G = \frac{OutputVoltage}{InputVoltage} = \frac{3-0}{0.27512} = 10.9. \tag{2.8}$$

.

The gain is chosen to be 11. The ratio between R_4 and R_5 is used to get this gain with a potentiometer used in the place of R_5. Figure 2.2 represents the schematic for the entire ultrasonic sensor circuit built.

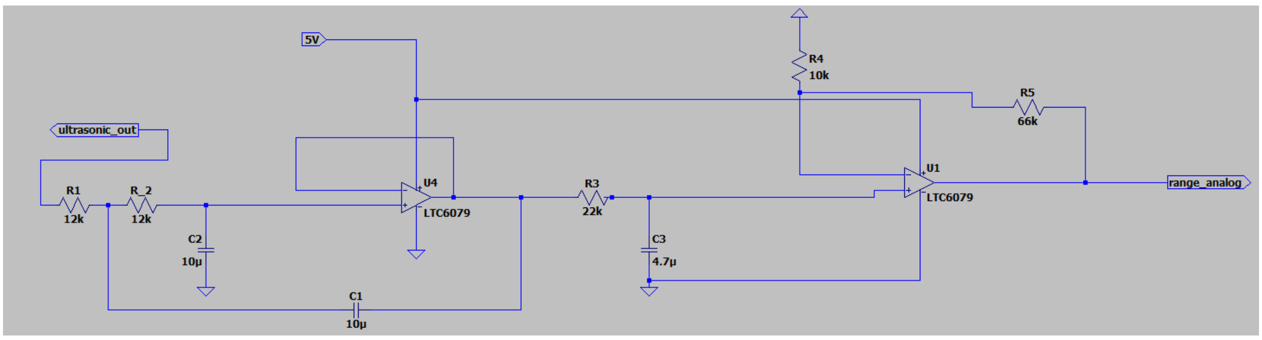

Figure 2.2: Ultrasonic Sensor Circuit Schematic

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All the resistors are chosen as high values to ensure that the current in the entire circuit does not surpass 750μF. These values can be seen in fig. 2.2.

2.3. Digital to Analogue Converter

The MCP6242 is used for the design of the circuit. The op-amp is a rail-to-rail voltage with supply voltage limits of 1.8V to 5.5V. Because it is a rail-to-rail op-amp the common-mode voltage can never exceed the supply voltage without harming the op-amp. This is also true for the maximum allowable output voltage. [9]

The expected DAC input voltages are 3.3V when high and 0V when the input is low. This is achieved by using a DIP Switch supplied with 3.3V. The output voltage of the circuit should be above 3V when the input is 1111_2 and below 0.5V when the input is 0000_2.

For the design of the circuit, a high input impedance and a low output impedance is favorable. This is to avoid any loading effect in the circuit and to allow the source to provide the maximum current possible. This is important for the accuracy of the output of the circuit and this is why the circuit is sensitive to the input impedance. This is avoided by using high resistor values as the input, it ensures high input impedance and low output impedance.

For the design of the input impedance, equation 2.9 is used. Values R_1 to R_4 is chosen and used to calculate R_f.

$$V_{out} = [(\frac{R_f}{R_1})V_{b3} + (\frac{R_f}{R_2})V_{b2} + (\frac{R_f}{R_3})V_{b1} + (\frac{R_f}{R_4})V_{b0}] \tag{2.9}$$

The reasoning behind the chosen input resistance values are discussed in the literature survey. The resistor values are documented in the table 2.1. These values are used to calculate R_f.

Input Resistor	Value Chosen
R_1	22kΩ
R_2	44kΩ
R_3	88kΩ
R_4	176kΩ

Table 2.1: Chosen input Resistor Values

V_{out} is chosen as 3.3V with the input assumed as 1111_2. The calculation for R_f can be seen in equation 2.10.

$$3.3 = (\frac{3}{20000})R_f + (\frac{3}{40000})R_f + (\frac{3}{80000})R_f + (\frac{3}{160000})R_f \tag{2.10}$$

$$3.3 = (\frac{9}{32000})R_f \tag{2.11}$$

$$R_f = 11733.3333\Omega \tag{2.12}$$

The op-amp has an offset that has to be compensated for. A voltage regulation circuit is used for this. Equation 2.14 is used to calculate the value of the resistors. R_6 is chosen as

33kΩ and used to calculate R_5.

$$V_{out} = \frac{R_6}{R_5 + R_6} V_{in} \tag{2.13}$$

$$R_5 = 17000\Omega \tag{2.14}$$

When the circuit is simulated, the values are changed to find the best output and potentiometers are used for R_f and R_5. The final values of the resistors are in table 2.2.

Resistor	Value Chosen
R_1	22kΩ
R_2	47kΩ
R_3	82kΩ
R_4	180kΩ
R_6	33kΩ
R_f	22kΩ Potentiometer
R_5	22kΩ Potentiometer

Table 2.2: Final Resistor values

The final circuit is shown in Fig. 2.3.

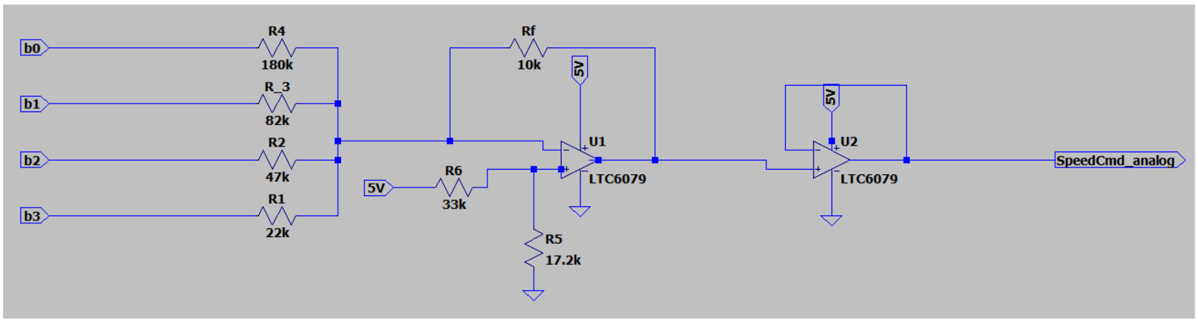

Figure 2.3: Digital to Analogue Converter Circuit

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2.4. 3.3V Voltage regulator

The LD33CV fixed voltage regulator is used to convert 5V to 3.3V. The 3.3V serves as the supply voltage to the Ultrasonic Sensor Circuit and the DIP-switch used for the DAC. Because the LD33CV is a fixed voltage regulator, the circuit only needs two extra capacitors to complete the final circuit. Fig. 2.4 is the schematic used to design and build the circuit. [10]

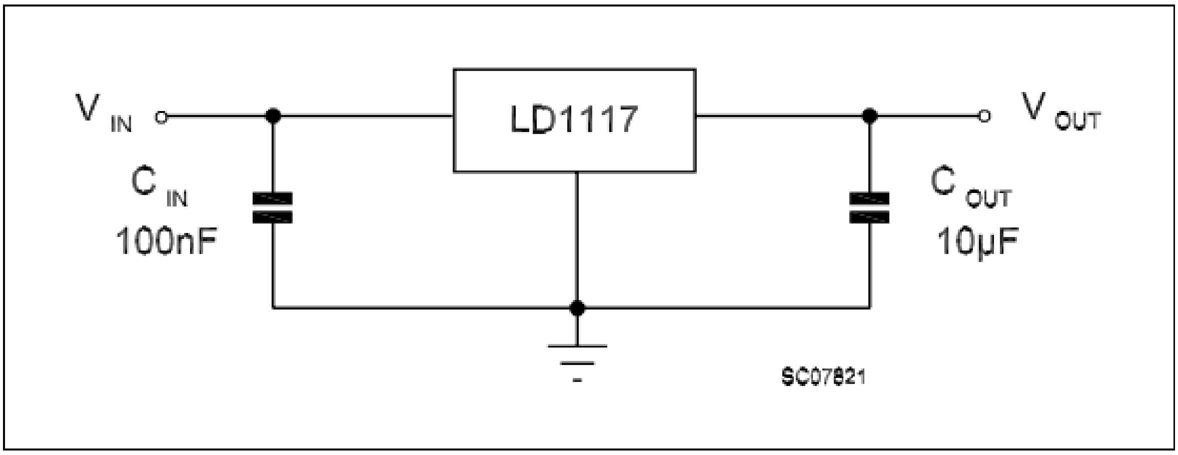

Figure 2.4: Digital to Analogue Converter Circuit

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2.5. 5V Voltage regulator

A 5V regulator is used to convert 7.2V to 5V. The 5V serves as a power supply for various components.

The component used is the LD1117 voltage regulator. The schematic used for the design can be seen in fig. 2.5 [4]. The component values on the schematic is used, but R_2 still needs to be calculated. Equation 2.15 is used to calculate R_2.

$$V_{out} = V_{ref}(1 + \frac{R_2}{R_1}) \tag{2.15}$$

$$R_2 = (\frac{5}{1.25} - 1)R_1 = 360\Omega \tag{2.16}$$

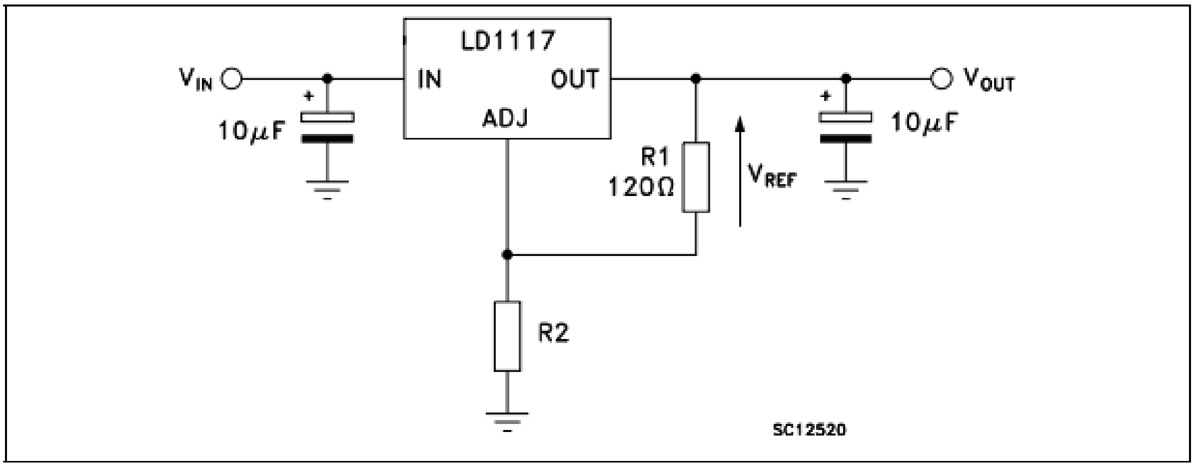

Figure 2.5: Digital to Analogue Converter Circuit [4]

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2.6. Motor Control Circuit and Driver

The motor control circuit is the first to be designed. An operational amplifier is used in conjunction with amplification and scaling to ensure the best output. The output of the DAC and and the Ultrasonic Range Sensor serves as the input of the motor control circuit.

The circuit is initially designed with a balanced bridge configuration in mind. Because of this, the ratio of the resistors are as follows:

$$\frac{R_A}{R_B} = \frac{R_C}{R_D} \tag{2.17}$$

V_{out} can then be calculated by using equation 2.18.

$$V_{out} = \frac{R_B}{R_A}(V_{RANGE} - V_{DAC}) \tag{2.18}$$

With these equations in mind, the following is considered: When the DAC input or the Ultrasonic Range Sensor input is equal to 3.3V, the output of the motor control circuit should be equal to 0V. When the DAC input is 3.3V and the Ultrasonic Range sensor input is equal to 0V, equation 2.18 changes to the following:

$$V_{out} = \frac{R_B}{R_A}(-V_{DAC}) \tag{2.19}$$

When the DAC input is 0V and the Ultrasonic Range sensor input is equal to 3.3V, equation 2.18 changes to the following:

$$V_{out} = \frac{R_B}{R_A}(V_{RANGE}) \tag{2.20}$$

The output of the circuit can range from 5V to 7.2V seeing as the op-amp used is a rail-to-rail op-amp. Because of this, the input needs to be amplified. The gain is calculated and then used to choose the resistor values.

$$Gain = \frac{7.2}{3.3 - 0.5} = 2.571 \tag{2.21}$$

With equations 2.19 and 2.20 in mind, the resistor values are chosen and documented in table 2.3. The final circuit can be seen in figure **??**.

Resistor	Value Chosen
R_A	10kΩ
R_B	27kΩ
R_C	10kΩ
R_D	27kΩ

Table 2.3: Final Resistor values

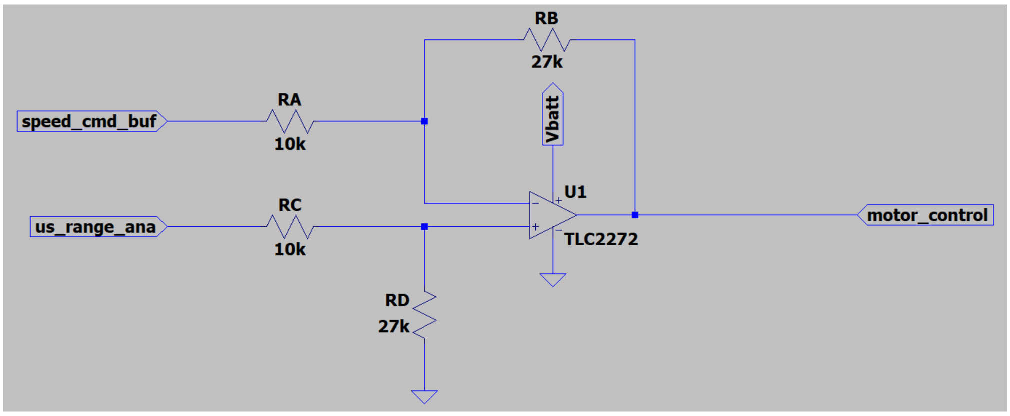

Figure 2.6: Final Motor Control Circuit

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A driver circuit is also necessary for the wheel to function. A TIP31C transistor is used to provide enough current to the DC-motor for it to function properly. For high speeds, a higher current is needed to drive the DC-motor. To ensure that this is possible, a Darlington pair is used. This is done but using a NPN 2N2222A transistor. This ensures that when the DC-motor needs more power to function, the Darlington pair will be able to provide it without damaging other circuitry components that have current limits. In conjunction with the two transistors, a diode is used to ground the the TIP31C resistor. This is to provide a voltage drop equal to that of the TIP31C transistor when the temperature of the transistor changes. The final driver circuit can be seen in figure 2.7 where the output of the motor control circuit is the input of the driver circuit.

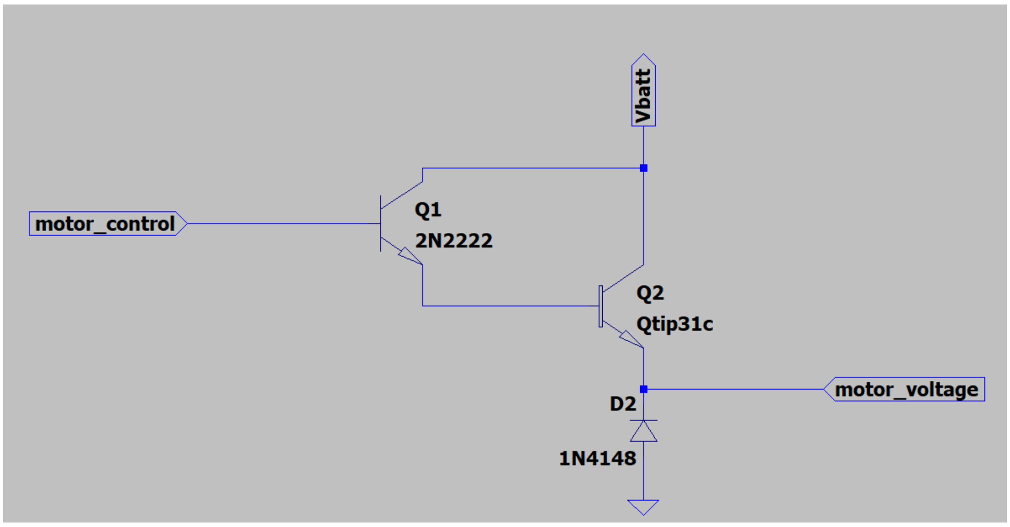

Figure 2.7: Driver Circuit

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2.7. System Design

The system design so far can be be seen in fig. 2.8.

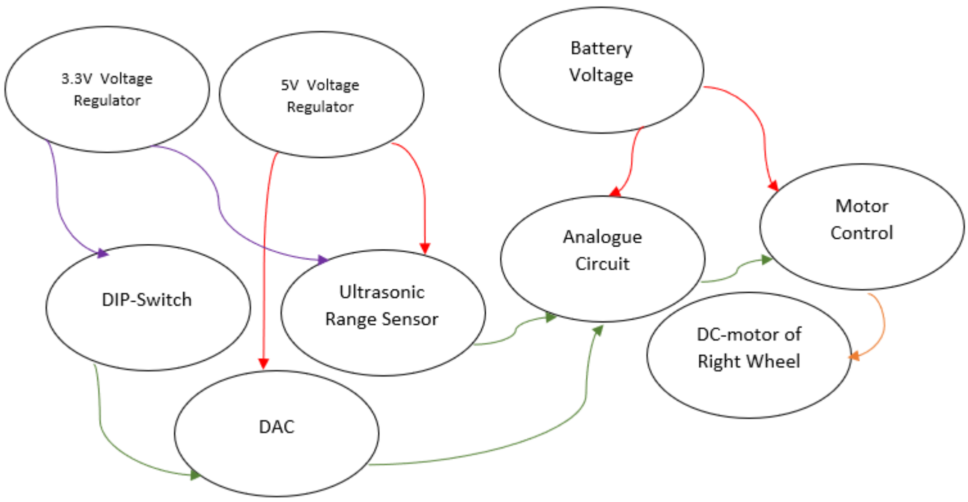

Figure 2.8: System Design Diagram

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Table 2.4 documents the meaning of different arrows.

Arrow Color	Meaning
Red Arrow	The red arrows represents the supply voltage to the different circuits. The battery voltage serves as the supply to the Analogue Circuit and Motor Control. The 5V output from the regulator serves as the supply to the ultrasonic sensor en the DAC.
Green Arrow	These arrows represents the link between different circuitry. The output of some circuits serves as the input of other circuits.
Purple Arrow	The 3.3V output of the voltage regulator serves as the input to the DIP-Switch and the Ultrasonic sensor op-amp.
Orange Arrow	The output of the Motor Control Signal and Driver serves as the input to the DC-motor of the right wheel of the car.

Table 2.4: System Design Diagram Arrow Meaning

2.8. Range Sensor and PWM Control

A Range sensor and PWM control is used to drive the DC motor of the right wheel. The ESP-microcontoller provides the trigger for the range sensor with the echo being fed back into a separate input pin into the ESP. The distance the object is from the sensor is calculated through software. The following snippets of code is used in the calculation:

```
pinMode(echoPin, INPUT);
duration = pulseIn(echoPin, HIGH);
```

Figure 2.9: Range Sensor Code Snippets

.

PWM is used to drive the DC motor. The duty cycle is calculated with the following equation 2.22 in mind:

$$PWM - control = a * speed - instruction - b * proximity \tag{2.22}$$

The proximity is calculated using the maximum range of the sensor minus the distance the objects is from the sensor.

2.9. Current Sensing

The current sensing for the left wheel is very similar to that of the current sensing of the right side. The initial design can be seen in 2.1. Similar values are used to these, with some tweaking to fit the circuit for the wheel. The switching frequency is 1kHz. The final values chosen can be seen in table 2.5. These values are to ensure enough filtering and ample gain to have a correct output voltage. The circuit schematic can be seen in fig. 2.10.

Resistor	Value Chosen
R_1	1kΩ
R_2	440Ω
R_3	590kΩ

Table 2.5: Final Resistor values

2.10. Low-side Switch

A low-side switch is used to control the current flow through the motor. The MOSFET used is chosen to have a VGS-voltage lower than 3.3V so that it can function from an output from the ESP-microcontroller. The MOSFET should be able to carry a current of at least 1.5A to be able to drive the motor. A pull-down resistor and diode is used to ground the MOSFET from the gate. With all this in mind, the FQD13N06L MOSFET is chosen.

The final circuit can be seen in 2.10.

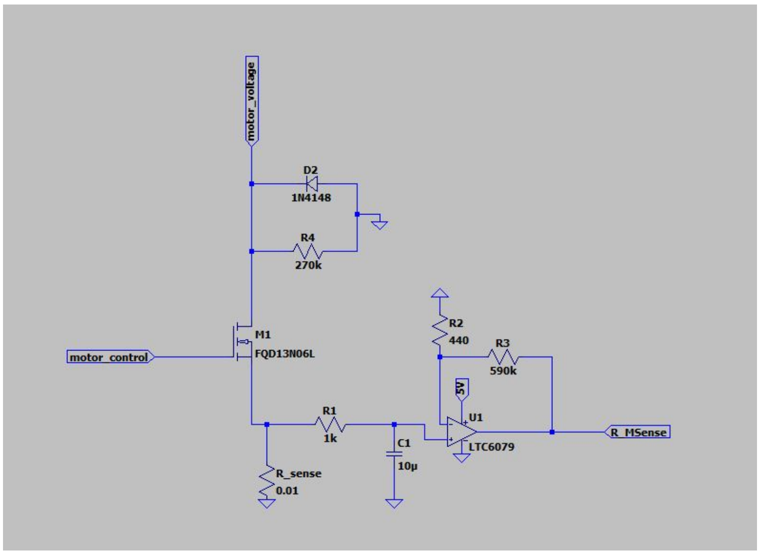

Figure 2.10: Range Sensor Code Snippets

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2.11. Undervoltage Protection

The lead-acid battery used has a maximum current of 1.2A even though the system is designed for a maximum current of 500mA. Because of this a high side switch is used to limit the current flow from the battery when the battery voltage is too high. A Schmitt trigger is used to control the switch.

The final design can be seen in fig. 2.11.

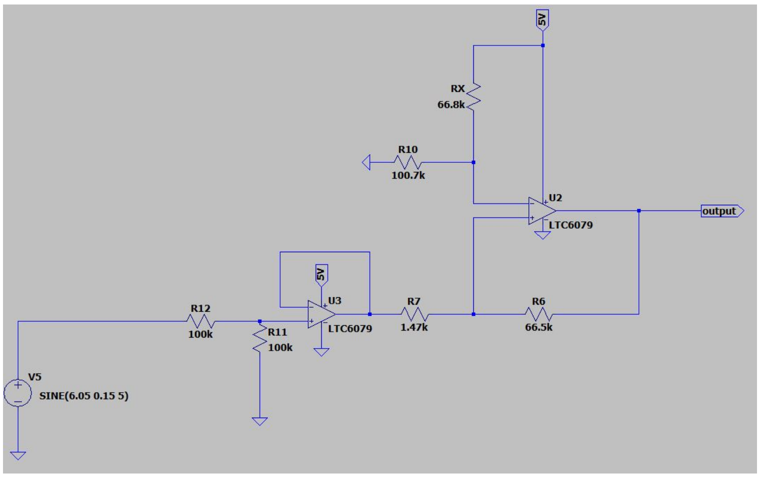

Figure 2.11: Charger Schematic

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2.12. Battery Charger

The charger for the lead-acid battery consists of a high side switch and a voltage regulator. The high-side switch insures that the battery does not overcharge when it is full.

When designing the switch, there are a number of things that need to be taken into account. The switch consists of two MOSFETS, a PMOS and a NMOS. The PMOS functions as the switch itself while the NMOS allows for the PMOS to turn on when its threshold voltage is greater than its source-to-gate voltage. The high side switch design can be seen on fig. 2.12. For the threshold voltage to be greater than the source-to-gate voltage , resistor R_3 is used. Current can only flow through the resistor when the NMOS is turned on. To ensure that the PMOS does not waste power when it is switched on fully, resistor R_3 is chosen as a large value. The value is chosen as 60kΩ to keep current flow at a optimal level. When the NMOS is switch off, the charge at the gate could damage the MOSFET. To prevent this, resistor R_5 of 10kΩ is added.

A voltage regulator is also part of the charger. The voltage regulator regulates the input voltage from the adapter so a voltage that the battery can use to charge. The regulator used is the LT317A voltage regulator. The 250Ω R_2 is gotten from the datasheet. After this, R_4 is calculated. Equation 2.23 is used to calculate the value of R_4.

$$R_4 = \frac{R_1(V_{batt} - V_{ref})}{V_{ref}} = 1.15k\Omega \tag{2.23}$$

R_1 is inserted to maintain a voltage of 1.25V between the output and the adjustment pin. This is necessary for when the battery has a depleted voltage of 6V. The value for R_1 is 0.5Ω.

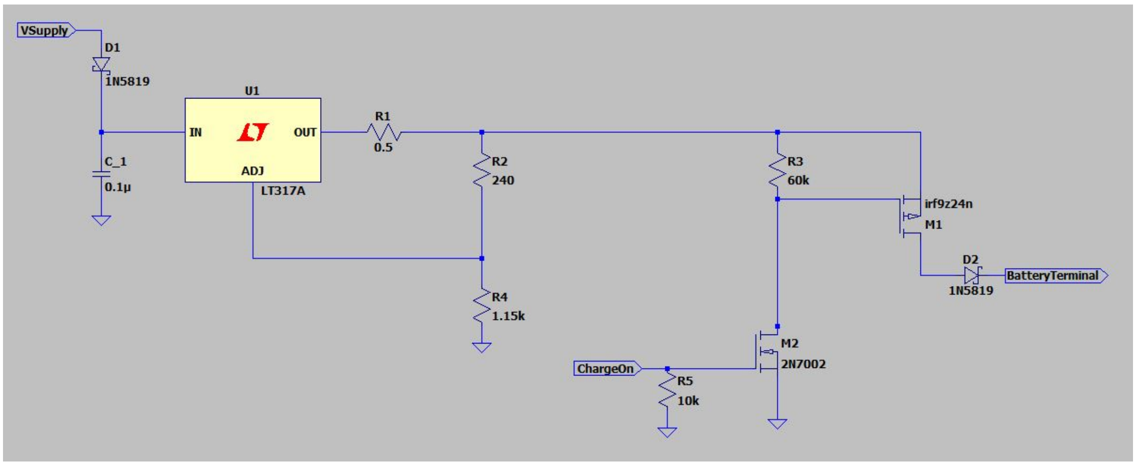

Figure 2.12: Charger Schematic

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Chapter 3

Results

3.1. 5V Regulator

The following resistors are used in the building of the regulator. They can be seen in table 3.1.

Resistor	Value Chosen
R_1	330Ω
R_2	120Ω

Table 3.1: Final Resistor values

The measured output can be seen in fig. 3.1.

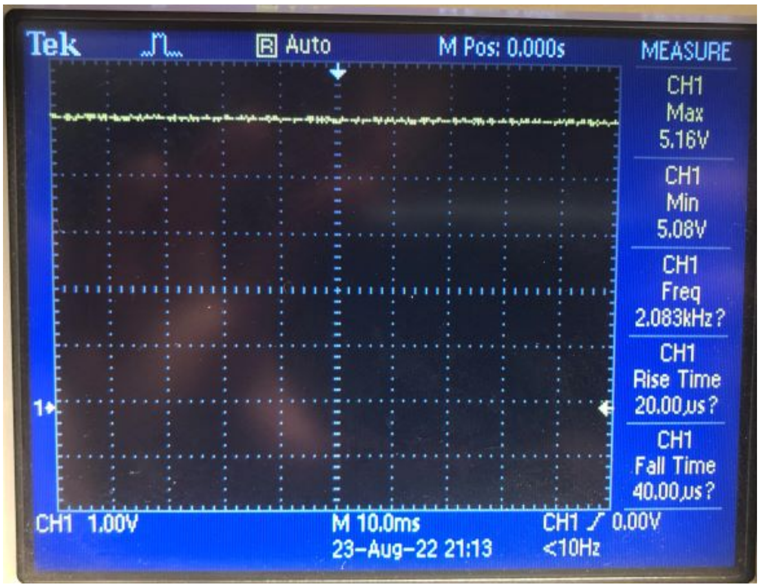

Figure 3.1: Measured Output of 5V Regulator

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3.2. Current sensor

The measurements of the simulated circuit and built circuit are shown in the figures below. The results of the built and simulated circuits are the very close.

- When look at Figure 3.2a and Figure 3.2e it can be seen that the values are very similar. The peak value of the simulation is around 3.15V. Even thought the values differ, they are very close. This could be due to the tolerances of the resistors and capacitor that is used when building the circuit. Even though the value isn't exactly as expected, it is still acceptable.

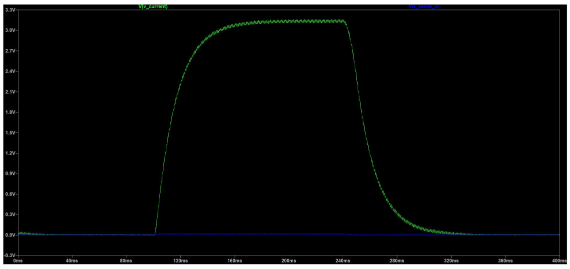
- Figure 3.2d represents the values measured when the motor is stalled. As can be seen on the figure, the output voltage is equal to 3.60V. This is higher than what was designed for, but still greater that 3V. This could be also be due to the tolerances of the resistors and capacitor that is used when building the circuit.

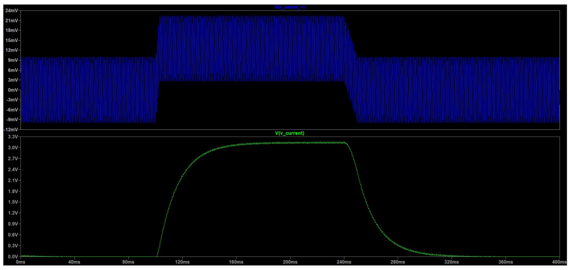
- Figure 3.2f represents the output voltage when a load is added to the motor. As can be seen under cursor 2 on the figure, the output voltage is equal to 1.84V. This is expected seeing as there is a load added.

- In each of the tests, the step output reach 90 percent of the maximum output in less than 100ms. This can specifically be seen on Figure 3.2d when the motor is stalled. In the figure, the maximum is reached within 100ms before 90 percent of the maximum is reached.

The noise levels of the simulated circuit can be seen on fig. 3.2b. The noise on the output is measured at 53.2mV with the noise on the input measured at 19.7mV. The current through the circuit is documented in fig. 3.2c with the maximum current measured at 80µA.

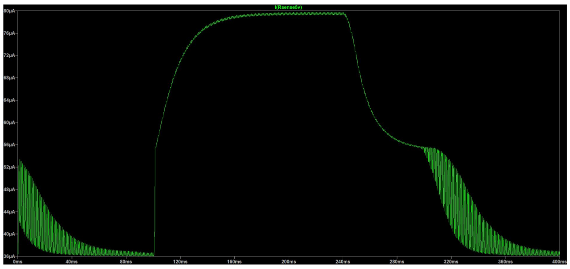
The step input vs. output response can be seen in Figure 3.2e. The noise levels of the output versus the input can be seen in all the figures representing the measured output of the built circuit.



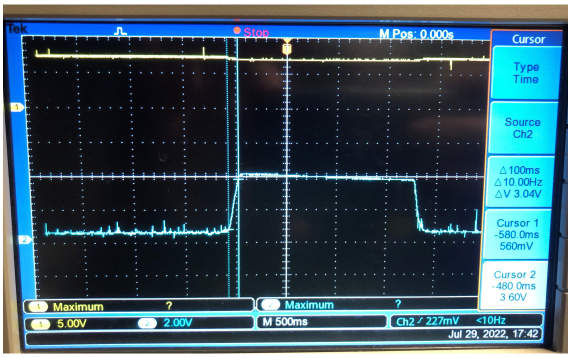


(a) Output of Simulated Current sense circuit

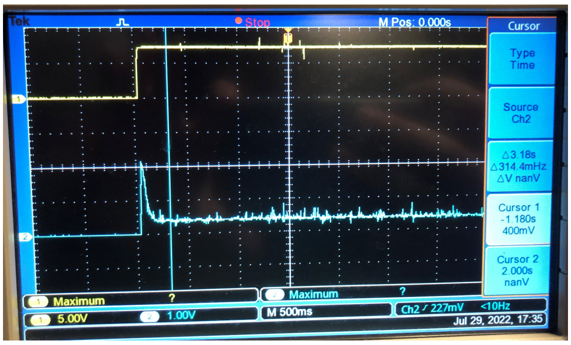
(b) Noise level Input vs. Output



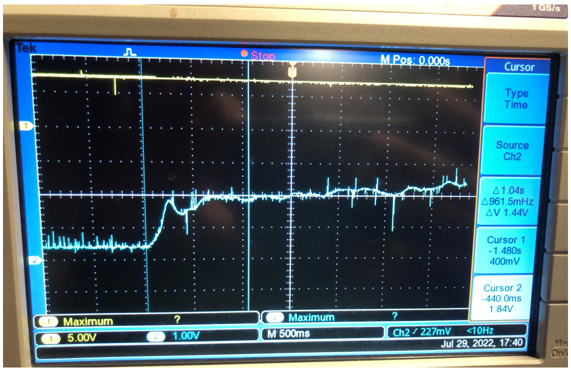
(c) Current measured through simulated circuit



(d) Measured output on oscilloscope when motor is stalled



(e) Output of circuit when motor runs normally



(f) Output of circuit when load is added to motor

Figure 3.2:

The results of the voltage measured by multimeter are seen in the table below.

Table 3.2: Measured Voltages

	Measured output voltage with different inputs
Motor running freely	400mV
Motor being stalled	3.60V
Motor under slight load	1.84V

3.3. Range Sensor Circuit

After the design of the Ultrasonic Sensor Circuit, the circuit was simulated and then built. Figure 3.3 represents the circuit built on LT-Spice. This circuit is used to simulate the output of the final circuit.

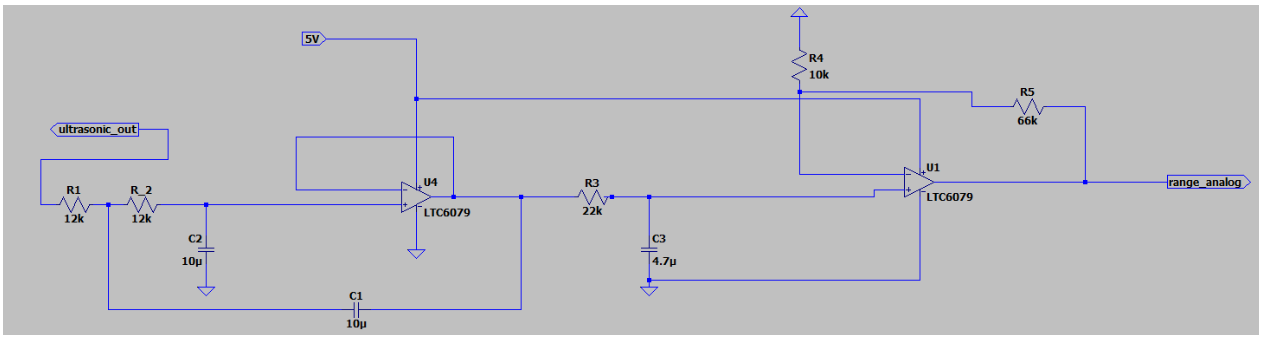


Figure 3.3: Ultrasonic Sensor Circuit Schematic

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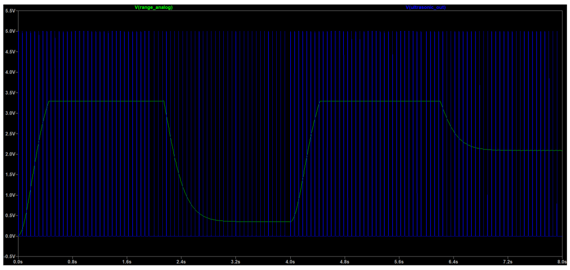
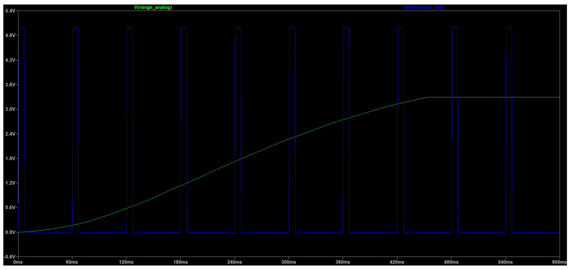
Figure 3.4 represents the output step response of the simulated circuit. In Fig. 3.4a the response output of the circuit over different distances can be observed. Different voltage outputs can also be seen at different distances.

In figure 3.4b the response time of the circuit can be seen. It is measured as 449ms, which is within the required rise time. The noise of the Analogue Output can be seen in figure 3.4c. The noise is very low so it can be assumed that it is within the 70 mV Pk−pk requirement .

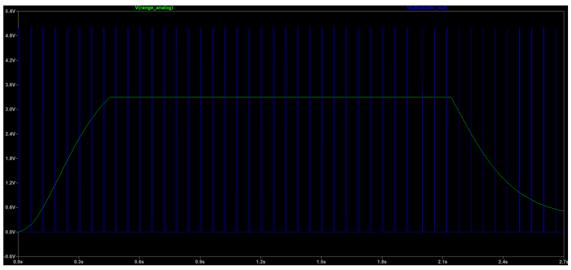
The current measurement can be seen in Figure 3.4d. The value measured at a maximum distance is 218µA. This is within the 750µA requirement that is the specified.



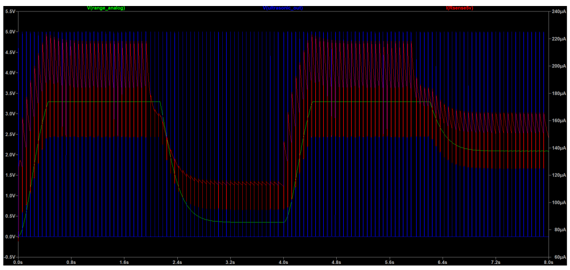
(a) Output of circuit at full range of distances



(b) Step Input vs. Response Output



(c) Noise Level on Analogue Output



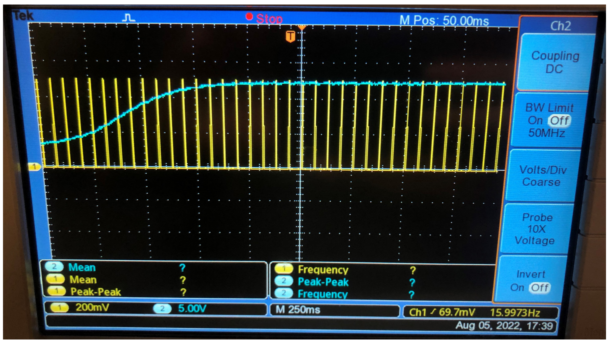
(d) Current Measurement Output of circuit

Figure 3.4: Figures of Simulated Outputs of Ultrasonic Sensor Circuit

After simulation, the circuit is built and the outputs are documented again. This can be seen in the figures below. The noise on the output response is very little, this can be seen on Figure 3.5a. This is very similar to the simulated circuit.

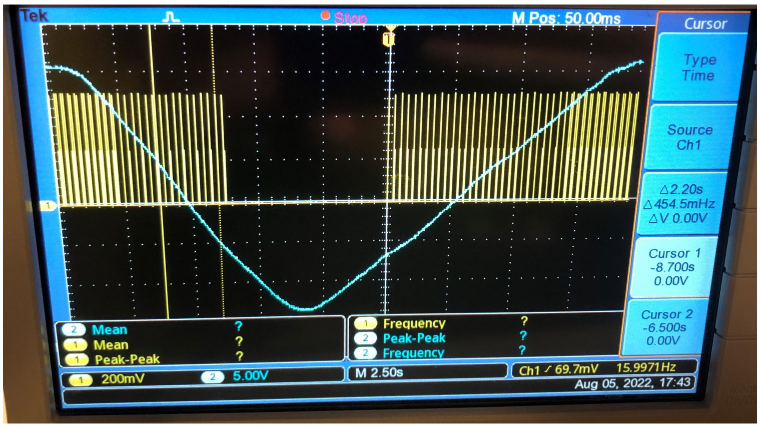
Figure 3.5b shows the response of the circuit to a step input. The response time of 880ms that is measured can be seen on this figure. This is more than the simulated results but still adheres to the requirements.

The output response at different ranges can be seen on Figure 3.5c. On the figure it can be seen that as the object gets closer to the sensor, the voltage decreases and then increases again as the object is moved further away. The response is as expected and very smooth.



(a) Noise Level in vs. Out

(b) Step Input vs. Response Output of Circuit



(c) Output Response of circuit at different ranges

Figure 3.5: Measured output of circuit on oscilloscope

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3.4. Digital to Analogue Converter Circuit

For the DAC circuit, a summing inverting amplifier is used in combination with a voltage regulator to compensate for the offset of the amplifier.

After the design of the DAC circuit, the circuit is simulated and then built. Figure 3.6 represents the circuit built.

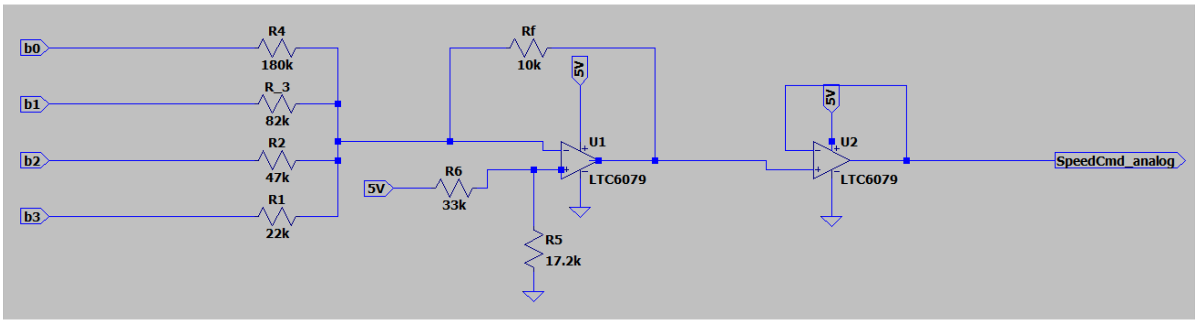

Figure 3.6: Digital to Analogue Converter Circuit

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Fig. 3.7 represents the output of the circuit with inputs ranging from 0000_2 to 1111_2.

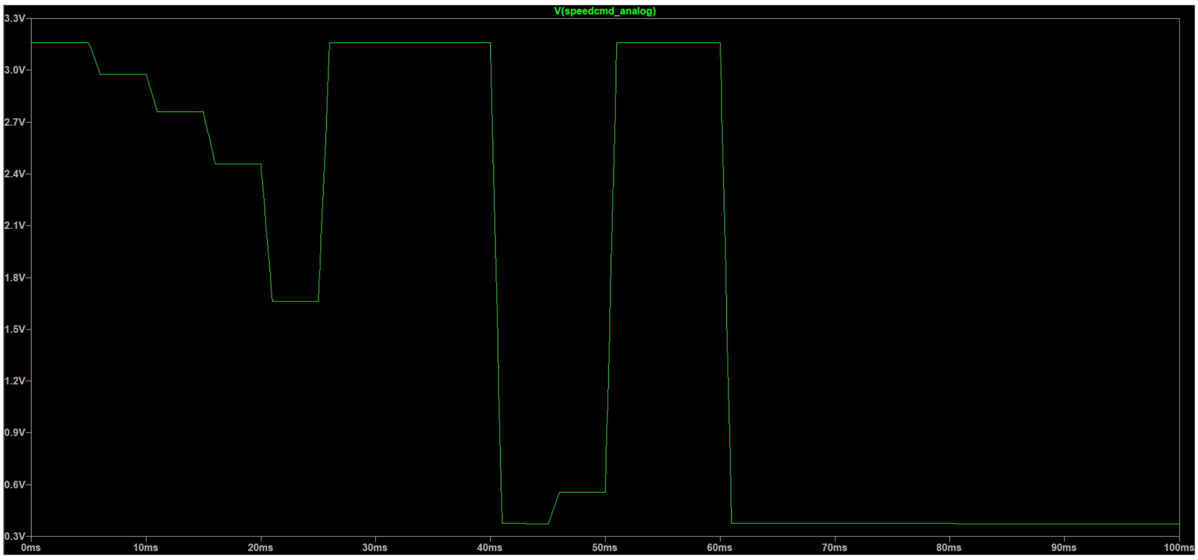

Figure 3.7: Output of a range of Inputs

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The current through the entire circuit is also measured. The maximum is measured at 355.99882µA with the minimum at 193.98644µA, which is acceptable. The total current output can be seen in Fig. 3.8.

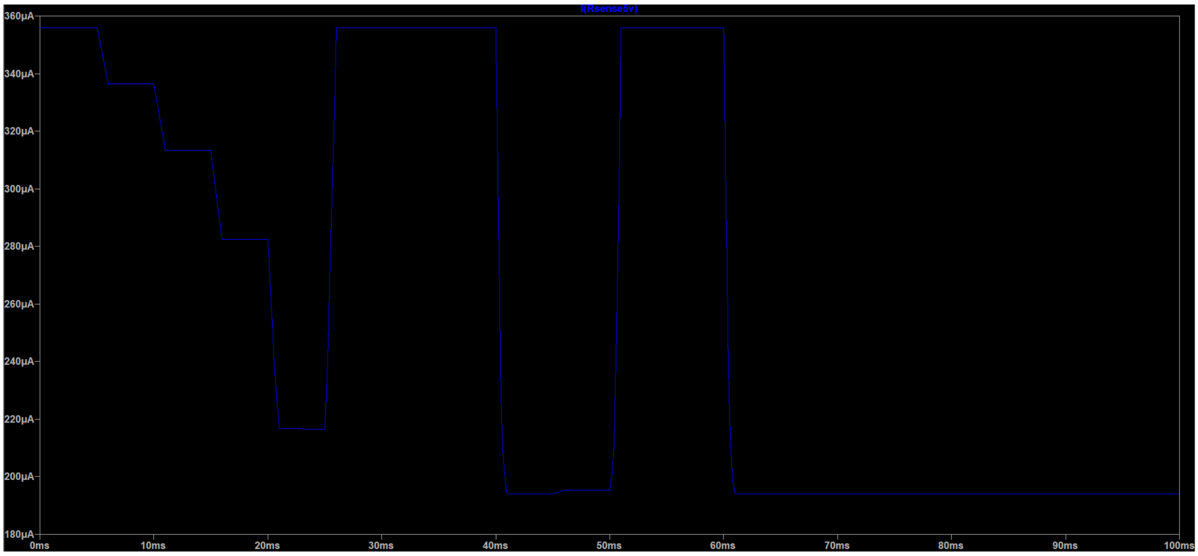


Figure 3.8: Current trough the entire DAC circuit

.

The circuit is built from the schematic used for simulation. The output of the circuit is measured and documented in table 3.5. The different input bits are implemented using a DIP Switch, with 3.3 V set as high.

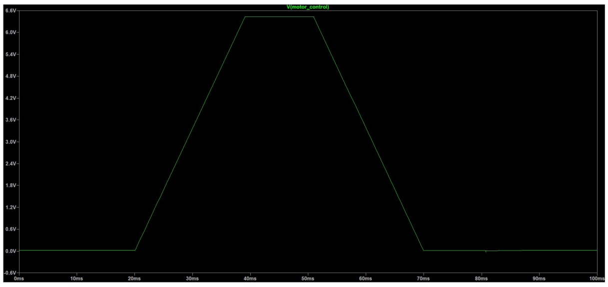
Binary Input Values	Analogue Output Voltage
0000	3.16 V
0001	1.66 V
1110	1.91 V
1111	0.39 V

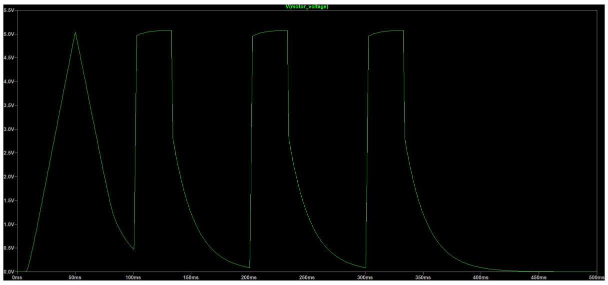
Table 3.3: Measured Analogue Outputs

3.5. Motor Control

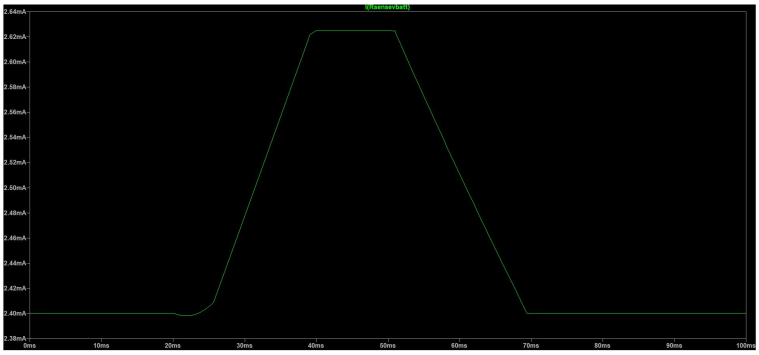
The results of the Motor Control and Driver Circuit is documented in the figures and tables below.

Fig. 3.9 represent the various outputs of the motor control circuit. The voltage output of the circuit can be seen in fig. 3.9b. The output voltage ranges from 88.5mV to 5.03V which is well within the requirements. The motor control results can be seen in fig. 3.9a, the output voltages ranges from 0 to 6.4V. The current flow through the circuit can be seen in fig. 3.9c, the current is low enough so it would not damage any components used in the final build.





(a) Motor Control Results **(b)** Voltage Output of Motor Control and Driver



(c) Current through the Battery Supply

Figure 3.9: Measured output of simulated Motor Control Circuit

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The current used from the battery is also documented, this can be seen in fig. 3.10. The maximum current is measured at 2.62mA which is small enough to not damage any circuitry components.

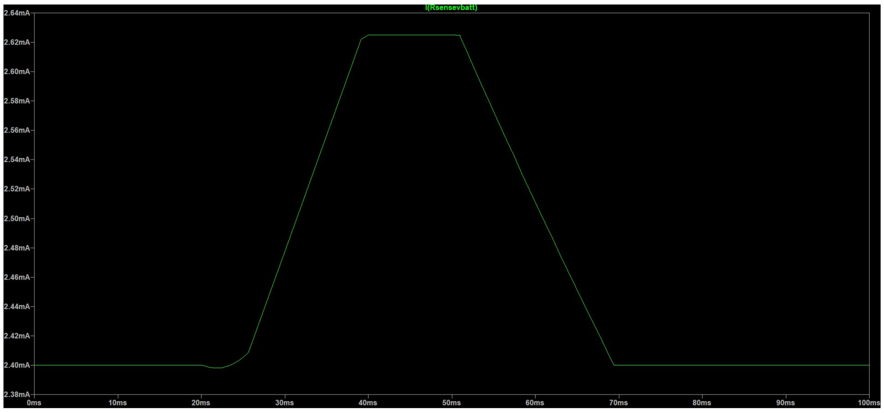

Figure 3.10: Current used from the 7.2V Battery

.

The measured output of the final circuit is documented in table 3.4. The output voltage is measured at different speeds with a object at various distances from the ultrasonic sensor.

3.6. Left side wheel control

The left-side wheel circuit is implemented. The simulated results of the current sense can be seen in fig. 3.11. When the object is far away, the output voltage is 3.25V and when the

	Fast (0011 input)	Slow (0001 input)
Object Near	0.00V	0.02V
Objects Far	5.32V	3.42V
No object	5.41V	3.42V

Table 3.4: Measured Output of Motor Control

object is under 1m away, the voltage is 1.85V until standstill when the object is within range.

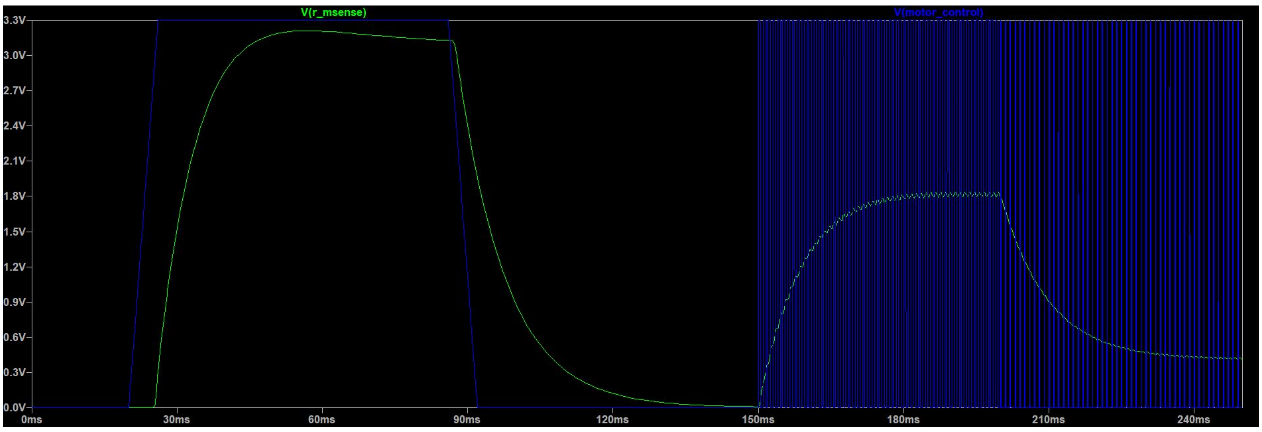

Figure 3.11: Results of simulated circuit

.

The measured output is very similar to the simulated values. The output voltage of the current sense circuit is documented in table ??

Binary Input Values	Analogue Output Voltage
fast	3.29 V
slow	1.66 V
stand still	0.53 V

Table 3.5: Measured Analogue Outputs

3.7. Undervoltage Protection

The simulated output can be seen in figure ??. It can be seen on the figure that the signal switches to a high when the input voltage is equal to 6.15V and switches to a low when the input voltage is equal to 5.92V.

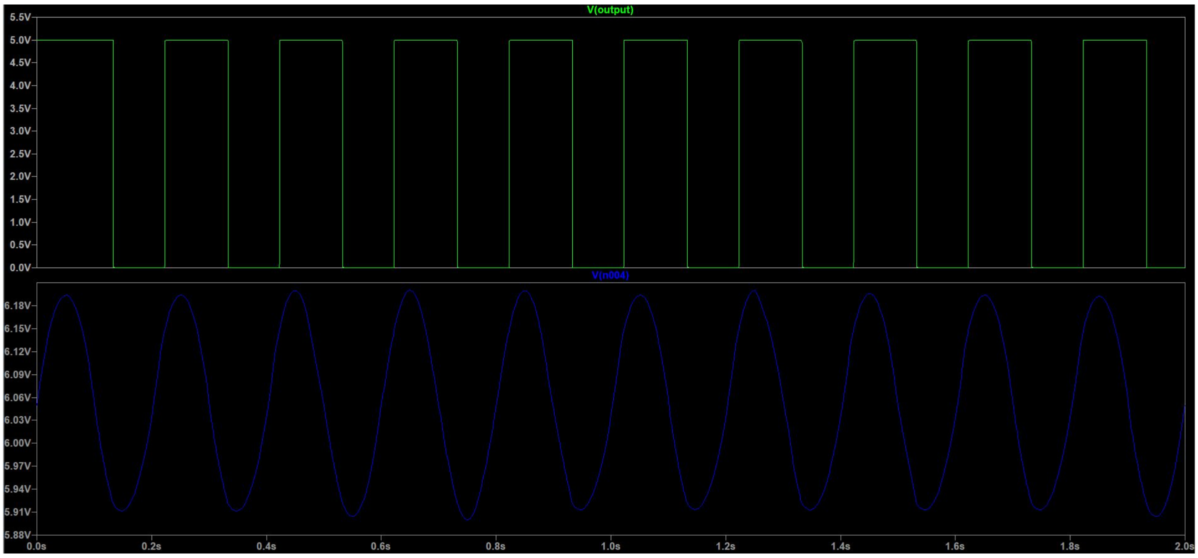

Figure 3.12: Simulated output of Undervoltage Protection Circuit

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The circuit is then built and the output is measured. These values can be seen in fig. 3.13.

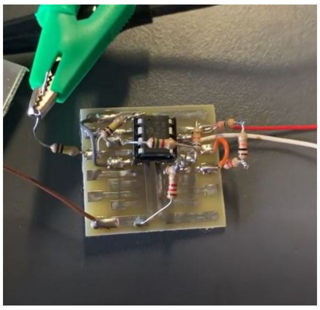

Figure 3.13: Built Undervoltage Protection Circuit

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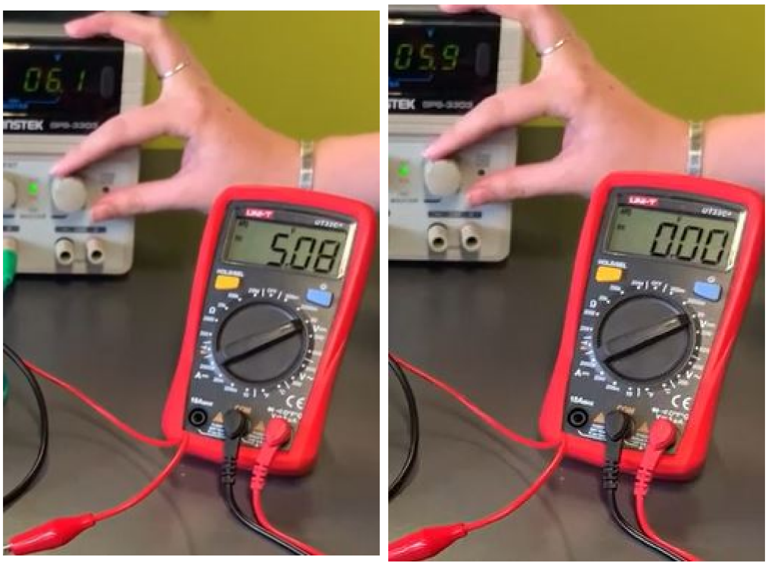
A varying input of 5.7V to 6.5V is supplied to the input of the circuit. The respective high and low outputs can be seen in figures 3.17a and 3.17b.



(a) Voltage output above 6.1V **(b)** Voltage output under 6.1V

Figure 3.14: Voltage Output of Undervoltage Protection Circuit

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3.8. Lead-acid Battery Charger Circuit

The circuit is first simulated, the simulated result can be seen in fig. 3.17. The stabilised output voltage of the circuit is measured at 7.16V.

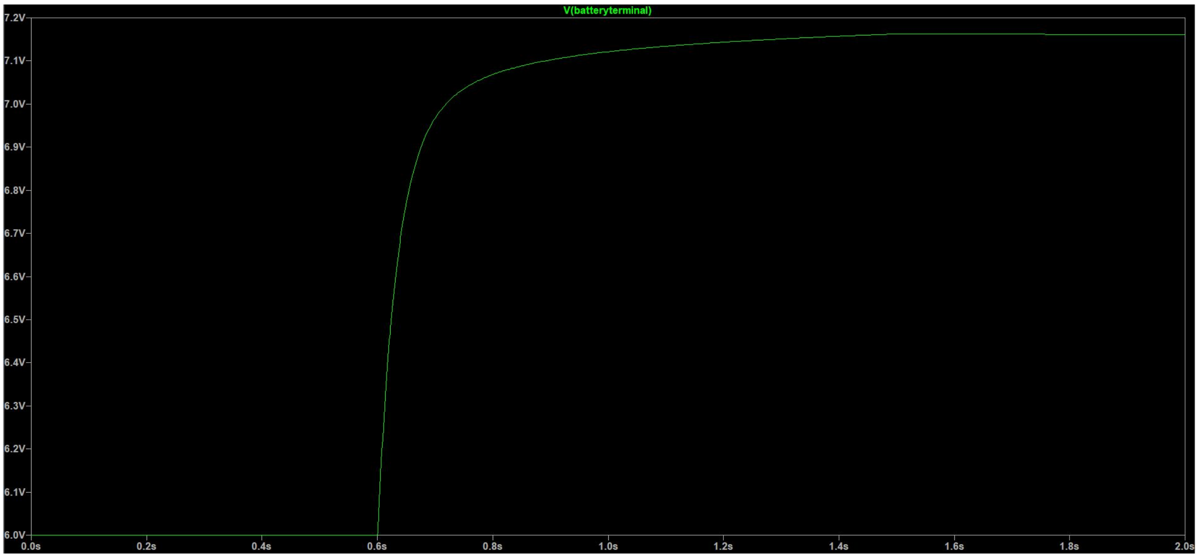

Figure 3.15: Simulated output of Charger Circuit

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The circuit is then built. For the testing of the circuit, the enable-input of the circuit is set to a high by providing 3.3V to it. The final circuit can be seen in fig. 3.16.

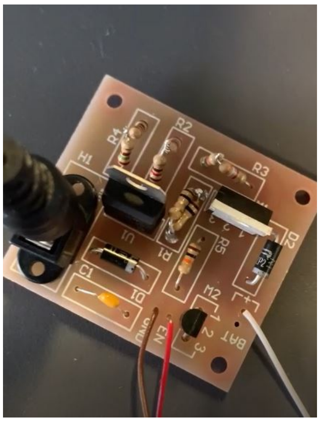

Figure 3.16: Built Charger Circuit for the Lead-acid Battery

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The measured output can be seen in figures xx and xx respectively. A 1kHz resistor is connected between output of the charger and ground so that current can flow and the output can be measured effectively. A 50Ω is then added over output and ground and measured again.

(a) Output with 1kΩ resistor connected

(b) Output with 50kΩ resistor added

Figure 3.17: Voltage Output of Charger Circuit

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Chapter 4

Physical implementation

In Figure 4.1 a photo of the built circuit can be seen. Different components are labeled.

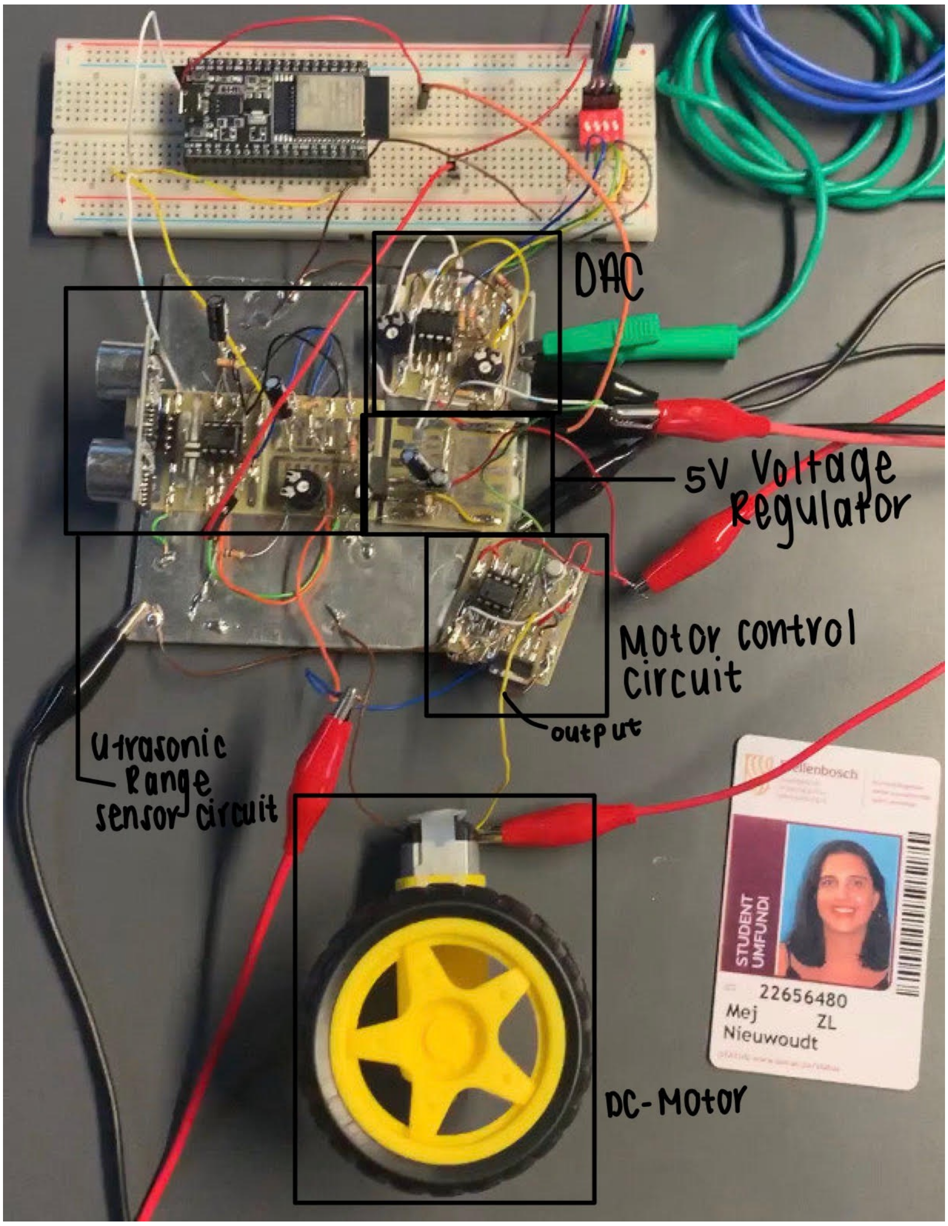

Figure 4.1: Photo of circuit

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Appendix A

Social contract

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jou kennisvennoot • your knowledge partner

E-design 344 Social Contract

2022

The purpose of this document is to establish commitment between the student and the organisers of E344. Beyond the commitment made here, it is not binding.

In the months preceeding the term, the lecturer (Thinus Booysen) and a few paid helpers (Rita van der Walt, Keegan Hull, and Michael Ritchie) spent countless hours to prepare for E344 to ensure that you get your money's worth, that you are enabled to learn from the module, and demonstrate and be assessed on your skills. We commit to prepare the assignments, to set the assessments fairly, to be reasonably available, and to provide feedback and support as best and fast we can. We will work hard to give you the best opportunity to learn from and pass analogue electronic design E344.

I, Zoë Nieuwoudt .... have registered for E344 of my own volition with the intention to learn of and be assessed on the principals of analogue electronic design. Despite the potential publication online of supplementary videos on specific topics, I acknowledge that I am expected to attend the scheduled lectures to make the most of these appointments and learning opportunities. Moreover, I realise I am expected to spend the additional requisite number of hours on E344 as specified in the yearbook.

I acknowledge that E344 is an important part of my journey to becoming a professional engineer, and that my conduct should be reflective thereof. This includes doing and submitting my own work, working hard, starting on time, and assimilating as much information as possible. It also includes showing respect towards the University's equipment, staff, and their time.

Prof. MJ (Thinus) Booysen

Signature: MJ Booysen Digitally signed by MJ Booysen Date: 2022.07.02 13:22:09 +02'00'

Date: 1 July 2022

Student number: 22656480

Signature:

Date: 22/07/2022

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Appendix B

GitHub Activity Heatmap