E344 Assignment 4

Zaskia Van Zyl
22569650

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.

August 26, 2022

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Nomenclature

Variables and functions

V	Voltage
I	Current
A	Ampere
V_{ref}	Reference Voltage
f_o	roll off frequency

Acronyms and abbreviations

KVL	Kirchhoff's voltage law
ESP	Espressif Systems
Op amp	Operational Amplifier
VCVS	Voltage-controlled voltage-source
RC	Resistor-Capacitor
temp	Temperature
PWM	Pulse width modulation
DAC	Digital to Analogue converter
FFT	Fast Fourier transform

Chapter 1

Literature survey

1.1. Operational amplifiers

Operational amplifiers: limitations and considerations

Operational amplifiers have a few limitations. The supply voltage must range between $1.8V$ and $5.5V$. If the max supply voltage is exceeded the op amp will fail. The input voltage range is limited to V_{SS}-1V and V_{DD}+1V. The op amp is limited by rail-to-rail voltage a positive of 5.5V voltage and a negative is taken as a zero voltage from ground. Making use of rail-to-rail voltage gives us more control to work with. The op amp also has a maximum acceptable common mode voltage that provides limitations that need to be abide by. An operational amplifiers slew rate, the maximum rate of the output voltage over time, provides limits because to provide some stability at high frequencies it has internal frequency compensation.

that is due to the internal frequency compensation that is included in the op amp to provide stability at high frequencies. .

Operational amplifier configurations

Small signals can be amplifier by using a Low-, High- and a Band-pass operational amplifier. Each filter has there personal uses. Band-pass filter out signals outside the bandwidth that is being looked at, Low-pass filters out the signal above a certain frequency and the High-pass does the opposite only filtering out the signals below a certain frequency.

For this project we are working with signals above 1kHz therefor we need to use a Low-pass filter.

1.2. Current sensing

To be able to implement current sensing in a circuit it should be established what is needed.

Invasive sensing makes use of sense resistors as well as probes while non-invasive sensing does not

The difference between low-and high-side sensing is the placement of the resistor. Low-side sensing places the current sensing resistor between the grounds of the load and the power supply. High-side sensing places the shunt resistor between input of the load and the positive terminal of the power supply.

The advantage of low-side sensing is that is it much cheaper than than of high-side sensing.

1.3. Ultrasonic Range sensor

1.3.1. Converting PWM signals to analogue

PWM is changed to DAC voltage. DAC output is generate by the pulses that is used as an input into the Sallen-key filter. The duty cycle was varied by the application of the following equation.

$$DAC = (DutyCylcle) \times (A) \tag{1.1}$$

A pulse signal is received that has very prominent DC value as well as noise. The DC value is used by applying a low-pass filter that has the ability to filter out the noise that exceeds a certain frequency. To make sure that the best possible amount of noise is being filtered out the a value for the frequency is chosen. This value is usually very low to ensure the best results are achieved falling in between $1.5Hz$ and $10Hz$.

A second order Sallen-Key low pass filter is an active filter that was used because this filter has the ability to effectively rejects noise as well as apply a non-inverting gain. A VCVS design is created due to the use of 2 resistors and a non-inverting op-amp providing a Sallen-key filter with the ability the be cascaded due to the the high input impedance, stability and the low output impedance.

1.3.2. Fundamental operation of the range sensor

An ultrasonic sensor produces a "chirp" that is used to measure the distance of an object by measuring the amount of time that passes until the sound produced by the sensor has bounces off an object and been received by the sensor again.

$$x = \frac{t \times 343}{2} \tag{1.2}$$

Where t is rime in seconds, x is the distance and 343 represents the speed of sound at room temp.

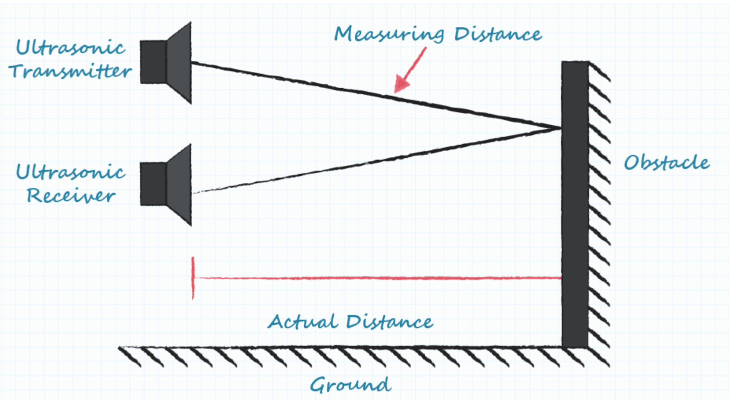


Figure 1.1: Movement of sound from and to the sensor. [?]

The sensor used in the physical build is the HC-SR04. This means that there are a few values that should be taken into account. The working sensor works at the following values $5V$, 15mA, 40Hz. The maximum range that the sensor works at is $4m$ and the smallest range the the filter can function at is $2cm$. The sensors accuracy can range to $3mm$.

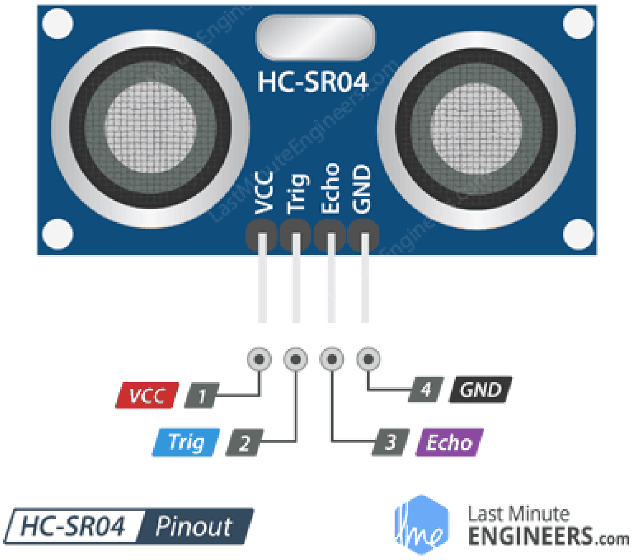


Figure 1.2: Ultrasonic sensor HC-SR04

[2] The sensor the 4 pins that can be used. The V_{cc} is the pin that is used to give power to the ultrasonic sensor. This is where the $5V$ input will be connected from the Arduino board. The Trig pin is where the sound pulse will be triggered from providing the ultrasonic sound chirps to be able to find the object in range when it is set as a high. The Echo pin will fall to a "low" when the sensor receives an echo after it bounced off of an object. The Echo pin will go high as soon as a sound "chirps" is transmitted and will go low if an echo is received. The GND is will be connect to the ground of the Arduino.

The sensor produces 8 pulses at 40KHz when the trigger pin has been set as high of $10\mu s$ and the Echo pin is set High. The only reason why 8 pulses it transmitted is to ensure that the sensor can correctly identify the echo of the signal and not just pic up other external ultrasonic sounds. When there is no pulse that is received after is bounced off an object in range the echo signal will go back to low after $38ms$. In the case that the 8 pulses are received back to echo pin will go back to low at the moment that the signal has been received. The echo pin will then generate a pulse that can have a pulse width anywhere between $150\mu s$ and $25ms$.

The distance can then be determined by the period of the signal that has been received by the echo pin. The larger the width of the wave the larger the distance from the sensor and the higher the voltage of the circuit. In the practical the trigger transmits every $60ms$ and produces a $10\mu s$ wave.

1.3.3. Converting digital values to analogue equivalents

A summing amplifier is used to convert the given digital signals to analogue signals. An inverting and non-inverting amplifier has a very big impact on the system. [4]

Inputs	0000	1111
Expected outputs	$>3V$	$<0.5V$

Table 1.1: Different results expected to at different inputs

When we take these results into consideration it can be seen that the best option is to make use of seeing as the high inputs produces lower input. [5]

The amplifier supplied by an average voltage. The average voltage is the common mode voltage to the op-amp. The input voltages of the operational amplifier is limited seeing as the rail-to-rail element of the op-amp limited to the supplied voltage. The operational amplifier can be damaged if the input voltage is not limited by the supplied voltage.

All the inputs produces an output that can range from $0V$ and $3.3V$. R_f is used as the feedback resistor that bias at a zero-potential the inverting operational amplifier.

A 4-bit binary number can produce number that range between $0 - 15$. A binary code $8 - 4 - 2 - 1$ will receive a result of 2^0, 2^1, 2^2 and 2^3.

1.4. Converting digital values to analogue equivalents

A summing amplifier is used to convert digital values to analogue values.

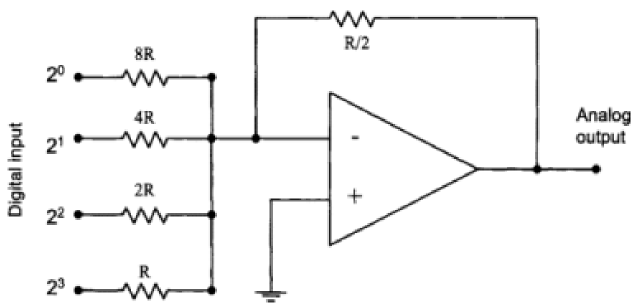
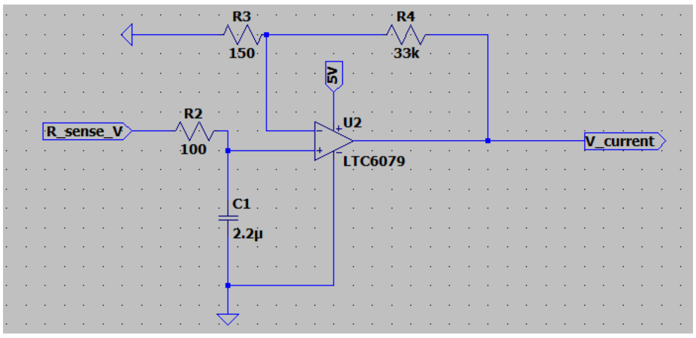


Figure 1.3: weighted summing amplifer [1]

Chapter 2

Detail design

2.1. Current sensor



(a)

Figure 2.1: Simulated circuit [4].

An active low pass filter is used to amplify the input to the op amp. This is used to filter out some of the unwanted noise in the system. The noise can be seen as a voltage source that is applied. To design our circuit we chose 2 resistor values and designed the other.

When designing the circuit one of the most important consideration were the maximum flow of current that could occur is in worst case. This is measured by stalling the motor when the current being drawn by the motor has stabilized. This is measured as 1.25A at stall and 0.1 at the stabilized state. R_{Sense_V} is calculated as

$$R_{SenseV} = I_{DC} \cdot R_{Sense}. \tag{2.1}$$

After calculating the R_{Sense_V} the gain can be calculated by.

$$G(Gain) = \frac{\Delta Output}{\Delta Input} = \frac{3 - 0.1}{0.0125} = 232. \tag{2.2}$$

The capacitor value can now be calculated by

$$C1 = \frac{1}{(2\pi)(R3)(f)} = \frac{1}{(2\pi)(100)(1000)} = 1.6 \times 10^{-6} F. \tag{2.3}$$

We chose our resistor values as 150Ω and 27000Ω and calculate R4.

$$R4 = \frac{R2}{G - 1} = \frac{33000}{232 - 1} = 143\Omega. \tag{2.4}$$

2.2. Analogue range sensor

The sensor needs the following to work properly. It needs a 5V input, 15mA current, 40Hz frequency and the pulse needs to bee close to 5V.

The cut-off frequency is picked in this case it is 1.5Hz. The value of R1 and R2 is the same as well as the value of C1 and C2. Resistor are chosen as 12kΩ and the Capacitor are calculated to be a value of $8.842\mu F$.

A value of 10 μF is used because it is the value that comes closest.

A low-pass RC filter is used with a cutt-off freqeuncy of 1.5Hz. R3 is picked to be 22kΩ and then the capacitor is calculated as 4.82 μF. This gives us a gain of 10.9 if the outut is devided by the input voltage. The circuit never goes past 750μF.

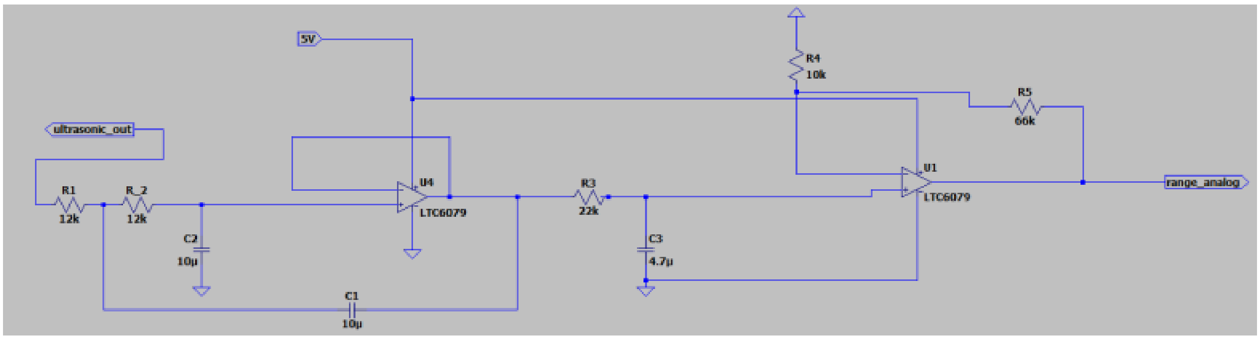


Figure 2.2: Analogue range sensor circuit

2.3. Digital to Analogue converter

A digital to analogue converter is designed to convert the digital input signals that is received to analogue output signals. The DAC is very sensitive to when it comes to input impedance and the circuit has to be protected against it. [4]

The operational amplifier that is used implements rail-to-rail that means that is supply voltage will always be limited to 5.5V and have a minimum of 1.8V. This makes it possible for the common-mode voltage to become bigger than the supply voltage while illuminating the possibility that the operational amplifier will be harmed.

A potentiometers is implementer in order to apply further turning to achieve the wanted results.

The source has an output impedance that could if it is not considered have a very big impact on the system.

The input voltages can range between 3.3V and 0V. This is made possible when the DIP-switch is implemented making it easier to apply inputs. 0.5V should be the maximum voltage for an input of 1111 and 3V should be the minimum voltage for a input of 0000.

$$V_{out} = \frac{R_f \times V_{b3}}{R_1} + \frac{R_f \times V_{b2}}{R_2} + \frac{R_f \times V_{b1}}{R_3} + \frac{R_f \times V_{b0}}{R_4} \tag{2.5}$$

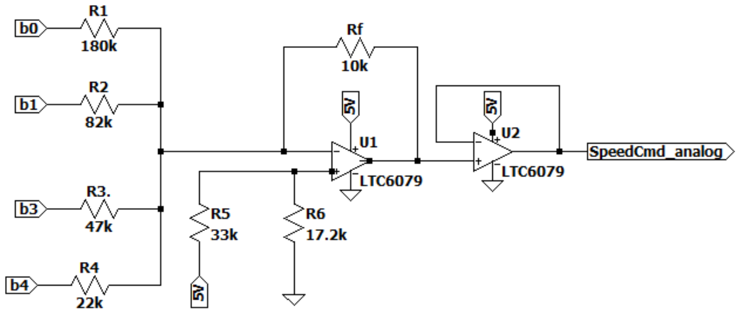


Figure 2.3: DAC simulated circuit

Resistor values used	
$R1$	$22k\Omega$
$R2$	$47k\Omega$
$R3.$	$82k\Omega$
$R4$	$82k\Omega$
$R5$	$17.2k\Omega$
$R6$	$33k\Omega$
R_f	$10k\Omega$

Table 2.1: Different results expected to at different inputs

The resistor values are chosen for $R1$, $R2$, $R3$ and $R4$.
For the input of 1111 a V_{out} is picked to be $3.3V$. R_f is calculated:

$$R_f = 11733.33\Omega \tag{2.6}$$

To be able to achieve the best output the values are tuned in the simulation but also in the build by implementing a potentiometers. R_f and R_5.

2.4. Voltage Regulator

A 6V DC battery will supply the system with nominal 7.2V. Seeing as the systems needs a 3.3V and a 5V input voltage regulators are used to be able to supply the correct amount voltage to the circuitry.

2.4.1. 5V Voltage Regulator

A voltage regulator is needed to convert the battery voltage to 5V. The regulator used for this is, is the LD1117 Voltage Regulator. The structure of the circuit can be seen in figure xx. When looking at the schematic, the only component value still needed is R_2. The steps to find this value, can be found in the datasheet of the component. [2] LD1117 is used because it has a very low dropout voltage. It supply's 800mA from 1.1V dropout and 100mA form 1V dropout voltage. This means that it will be able to deliver the needed current even if it is at its minimum dropout voltage.

Equation 2.7 is used to determine the value of R_2.

$$V_{out} = V_{ref} + \frac{(R_2)(V_{ref})}{R_1} \tag{2.7}$$

$$R_2 = (\frac{5}{1.25} - 1)R_1 = 360\Omega \tag{2.8}$$

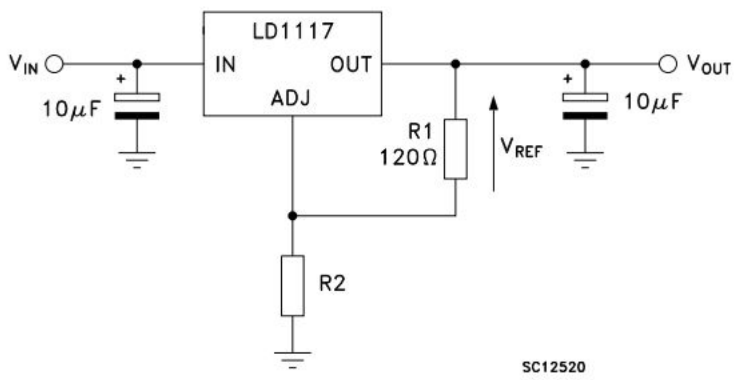


Figure 2.4: 5V Regulator Schematic [2]

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2.4.2. 3.3V Voltage Regulator

Various different components in the system use a supply voltage of 3.3V. The LD33CV voltage Regulator is used to provide this. Seeing as the LD33CV is a fixed voltage regulator, the circuit only consists of the regulator component and two capacitors. One with a value of 100nF and another with a value of 10μ. The schematic seen in figure 2.5 is used as reference when designing and building the circuit. 5V serves as the input voltage. [3]

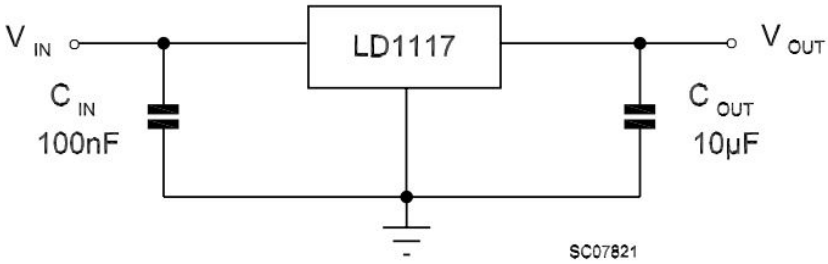

Figure 2.5: 3.3V Voltage Regulator Schematic [3]

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2.4.3. Design of System

Figure 2.6 is a diagram of the system design so far.

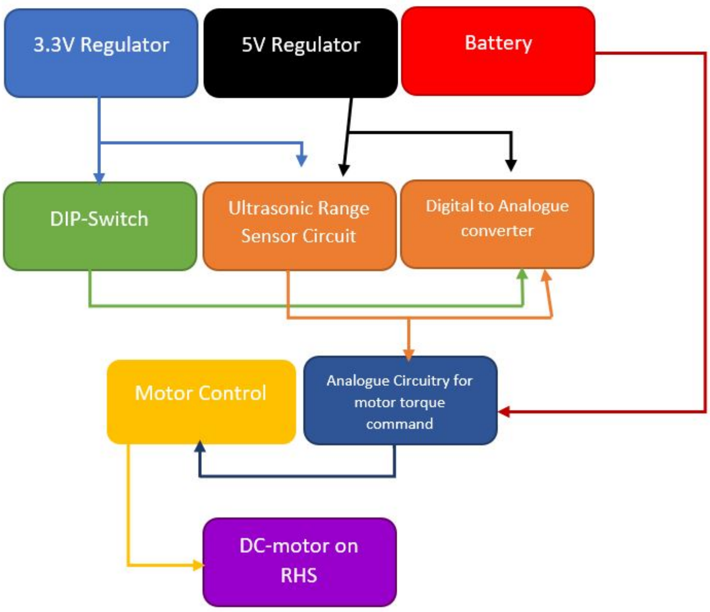

Figure 2.6: System Design Diagram

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2.5. Motor control

A op-amp is used to determine the difference between the torque command signal and the output of the range sensor. The given MCP6242 can't supply the needed voltage this means that the TLC2272 op-amp must be used.

The resistor values are chosen with the assumption that unity gain and a balanced bridge is implemented.

$$\frac{R_A}{R_B} = \frac{R_C}{R_D} \tag{2.9}$$

$$V_{out} = \frac{R_B}{R_A}(V_{RANGE} - V_{DAC}) \tag{2.10}$$

2.10 The output of the motor control circuit should be 0V if the Ultrasonic range senor or the DAC is equal to 3.3V. In the case that the ultrasonic sensor input is 0V and the DAC is 3.3V the V_{range} is equal to zero. In the that the ultra sonic sensor is 3.3V and the DAC input is 0V the V_{DAC} term would just be equal to zero.

$$Gain = \frac{R_A}{R_B} = \frac{7.2}{3.3 - 0.5} = 2.571 \tag{2.11}$$

The rail-to-rail op-amp limits the circuit output to range from 5V to 7.2V creating the need to amplify the input.

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

Table 2.2: Final Resistor values

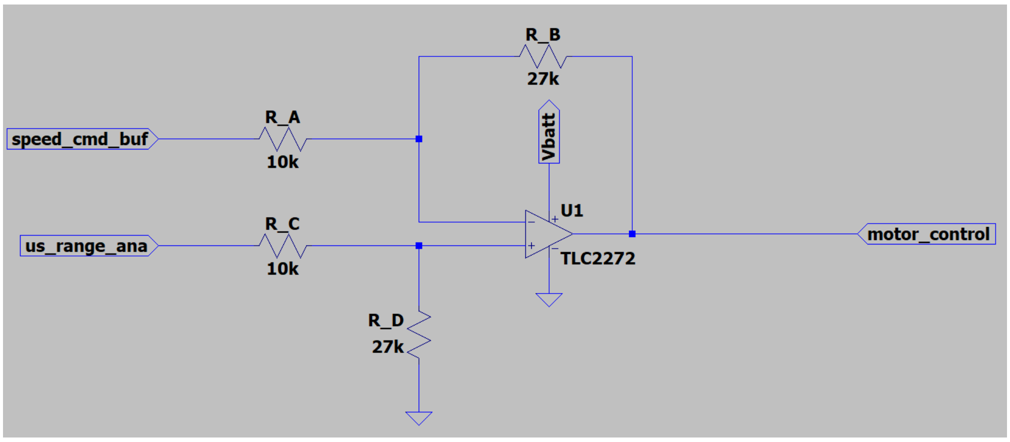

Figure 2.7: Motor Control Circuit

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To ensure that the wheel can function a driver circuit needs to implemented. This is done to by implementing the TIP31C to provide current to the DC-motor. A Darlington pair in included to ensure make it possible for the Dc-motor to get high current for higher speeds. The Darlington pair is implemented by using a NPN2N2222A transistor. The Darlington pair will make it possible for the motor the get more current without damaging the rest of the circuit seeing as the other components have current limits. To provide a voltage drop, that is the same as the voltage drop that occurs in the TIP31C if the temperature changes, a LED and 2 transistor are used to ground the TIP. The driver uses the output of the motor control circuit a input. This can be seen figure 2.8

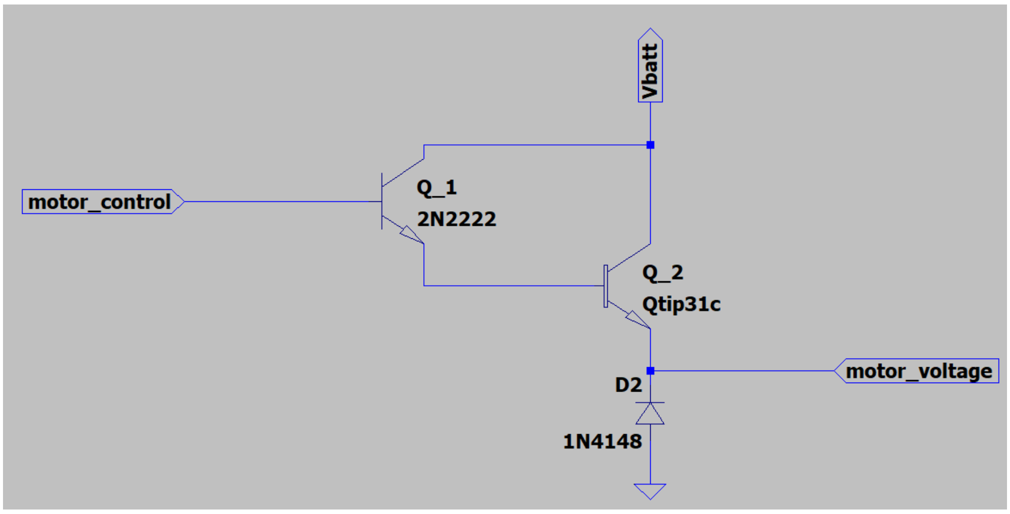

Figure 2.8: Driver Circuit

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Chapter 3

Results

3.1. 5V Regulator

Resistors R_1 and R_2 are chosen as 360Ω and 120Ω respectively. With this in mind, the circuit is built. The results can be seen in figure 3.1.

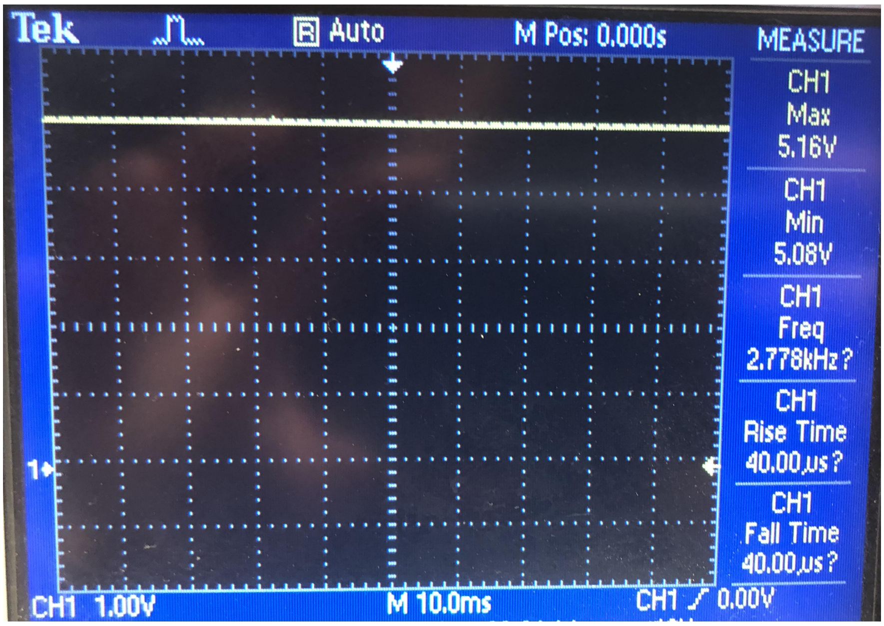

Figure 3.1: Output of 5V Regulator

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3.2. Current Sensor

3.2.1. Simulated results

The noise in the 70mv peak-peak range that is allowed.

3.2.2. Measured results

As can be seen in the above figures **??** the simulated and measured results correlate very closely with slight differences that can be due to noise in the system. The response time of the circuit can be seen to be more than good enough if relying on the expected results. The response time is around 900ms. It is very apparent that the closer the object get to the sensor the bigger the voltage gets.

Figures/simres.png

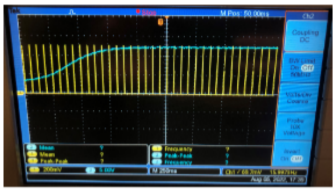
Figure 3.2: Simulated results

Load	Value
Full load	3.8VΩ
No load	230mVΩ
Slight load	3.8VΩ

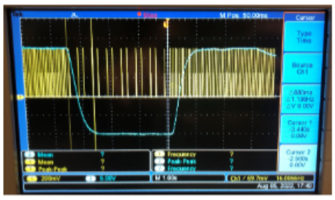
Table 3.1: outputs for different load inputs

In the above table 3.1 can be seen that all the obtained values fall within the given specifications.

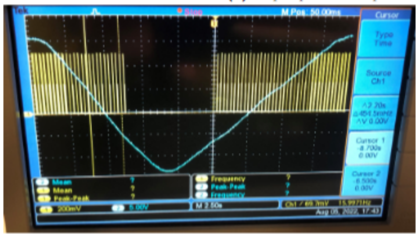
Simulated voltages are almost double that of the no-load output voltages seeing as the simulated values worked with 200mA and not 100mA that was used in the circuit itself.



(a) Noise Level in vs. Out



(b) Step Input vs. Response Output of Circuit



(c) Output Response of circuit at different ranges

Figure 3.3: DAC simulated circuit

3.3. Analogue Range Sensor

3.4. Digital to analogue converter

3.4.1. Simulated results

To be able to compensate for the offset of the amplifier an inverting summing amplifier is used with a voltage regulator. This circuit can be seen in Figure ??

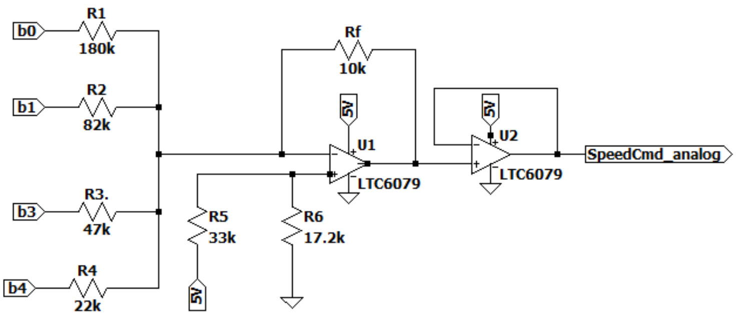


Figure 3.4: DAC simulated circuit

The current has a range between 356μA and 194μA. The voltage output can be seen to fluctuate depending on the input that is given.

3.4.2. Measured results

As expected the different voltage inputs will deliver different outputs.

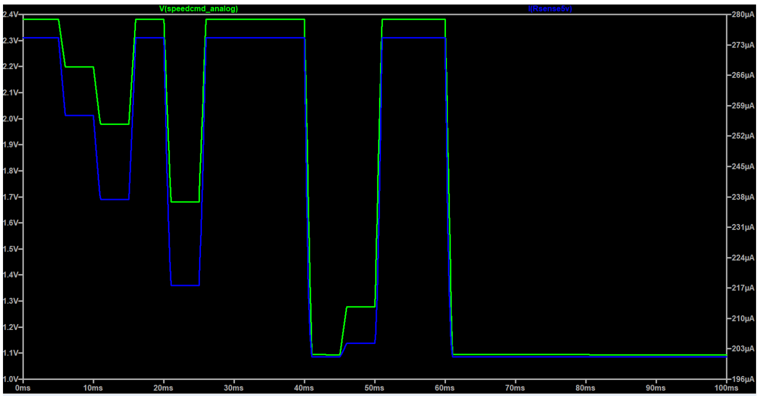


Figure 3.5: Output with different voltage inputs

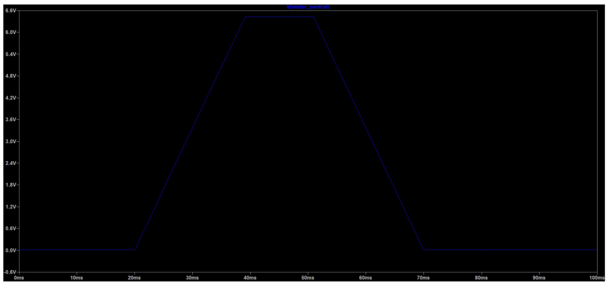
Inputs	0000	0001	1111	1110
Multiple row	$3.25V$	$3.00V$	$0.24V$ $1.74V$	

Table 3.2: Different results measured at different inputs

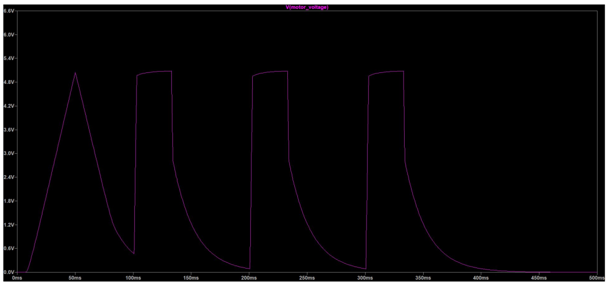
3.5. Motor Control

The motor control circuit is simulated and then built, the results can be seen in the figures and table below.

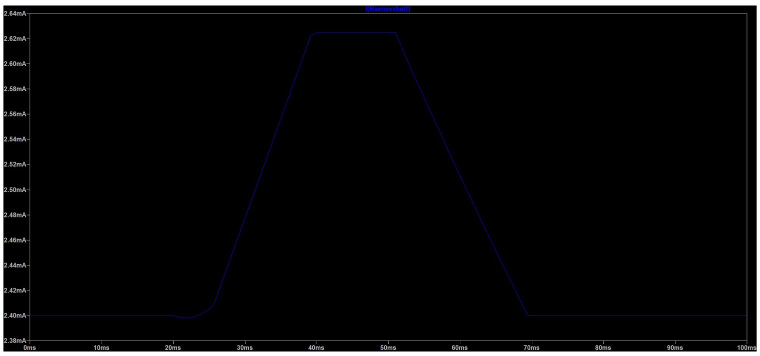
The results of the simulated circuit can be seen in figure xx



(a) Motor Control Voltage Output



(b) Voltage Output of Motor Control and Driver



(c) Current measured through the Battery Voltage Supply

Figure 3.6: Output of simulated Motor Control and Driver Circuit

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measured results of current through entire circuit can be seen in table below.

The maximum output voltage is never more than 5.8V due to the implemented darlinton

Volateges	Input 0011 (fast)	Input 0001 (slow)
Object is close	0	0
Object is far away 4.24	3.35	
No object infront of sensor 5.3	3.36	

Table 3.3: Voltage Outputs of Motor Control Circuit

pair.

Chapter 4

Physical implementation

Figure 4.1: Picture of circuit and Student card

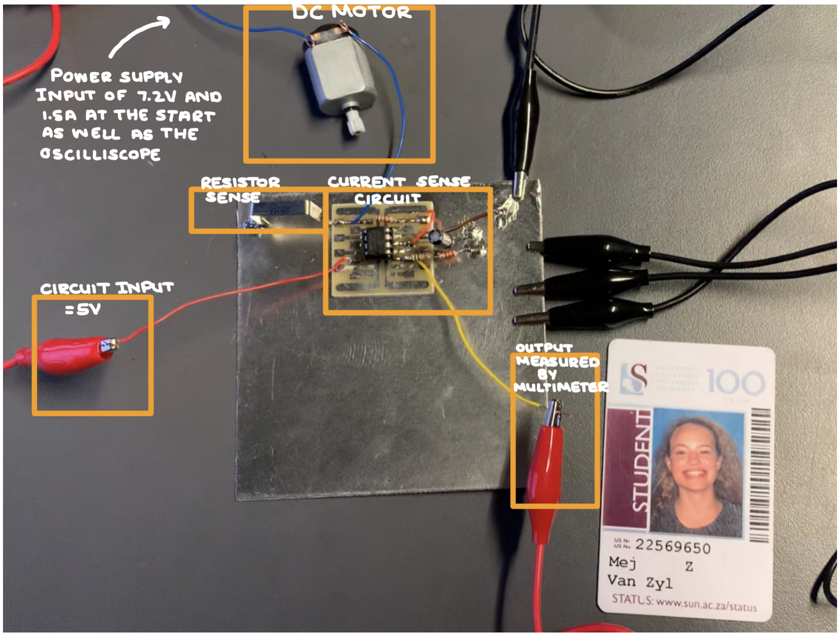

Figure 4.2: Picture of circuit and set-up in the labs

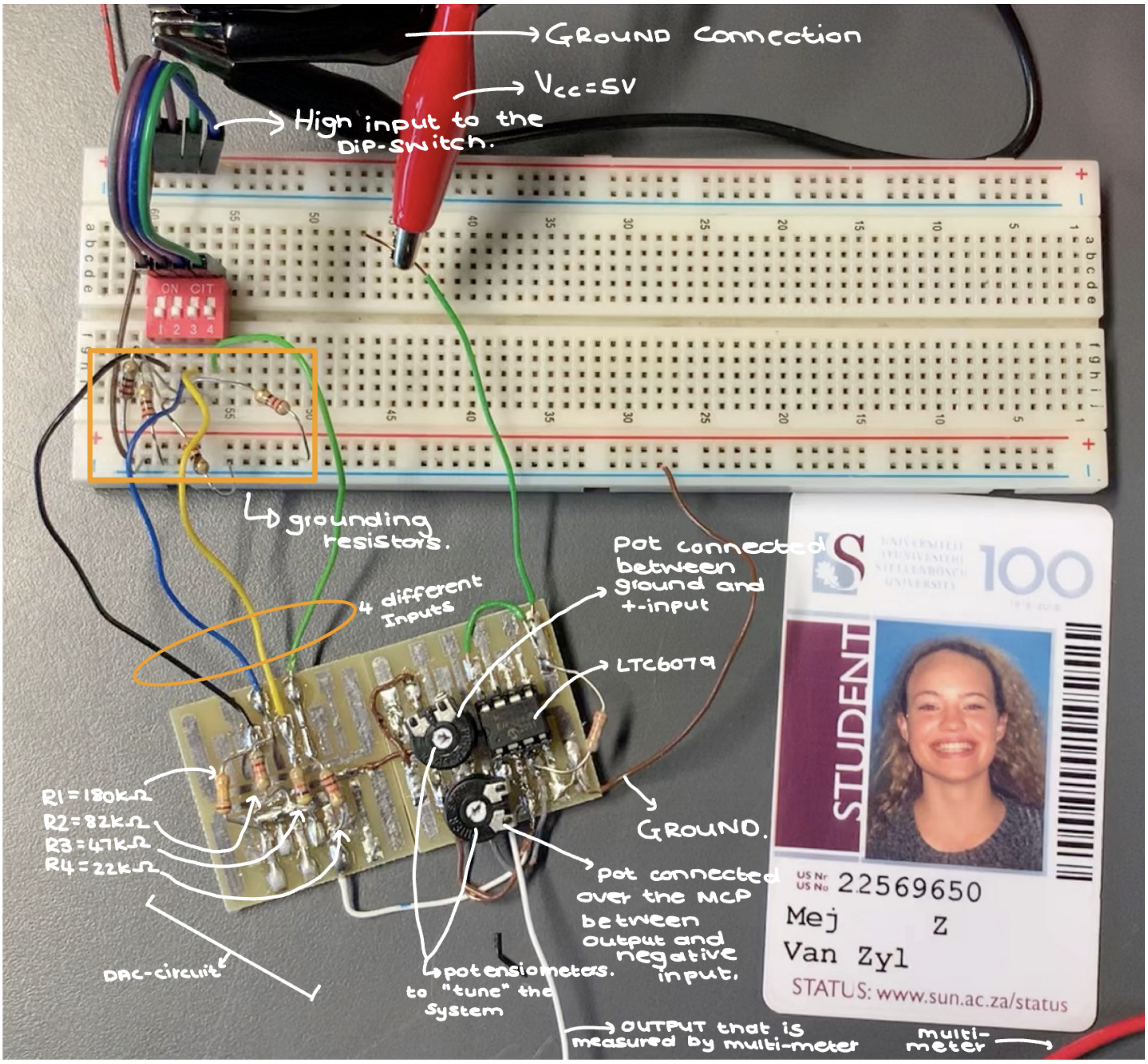

Figure 4.3: Student card and DAC Circuit

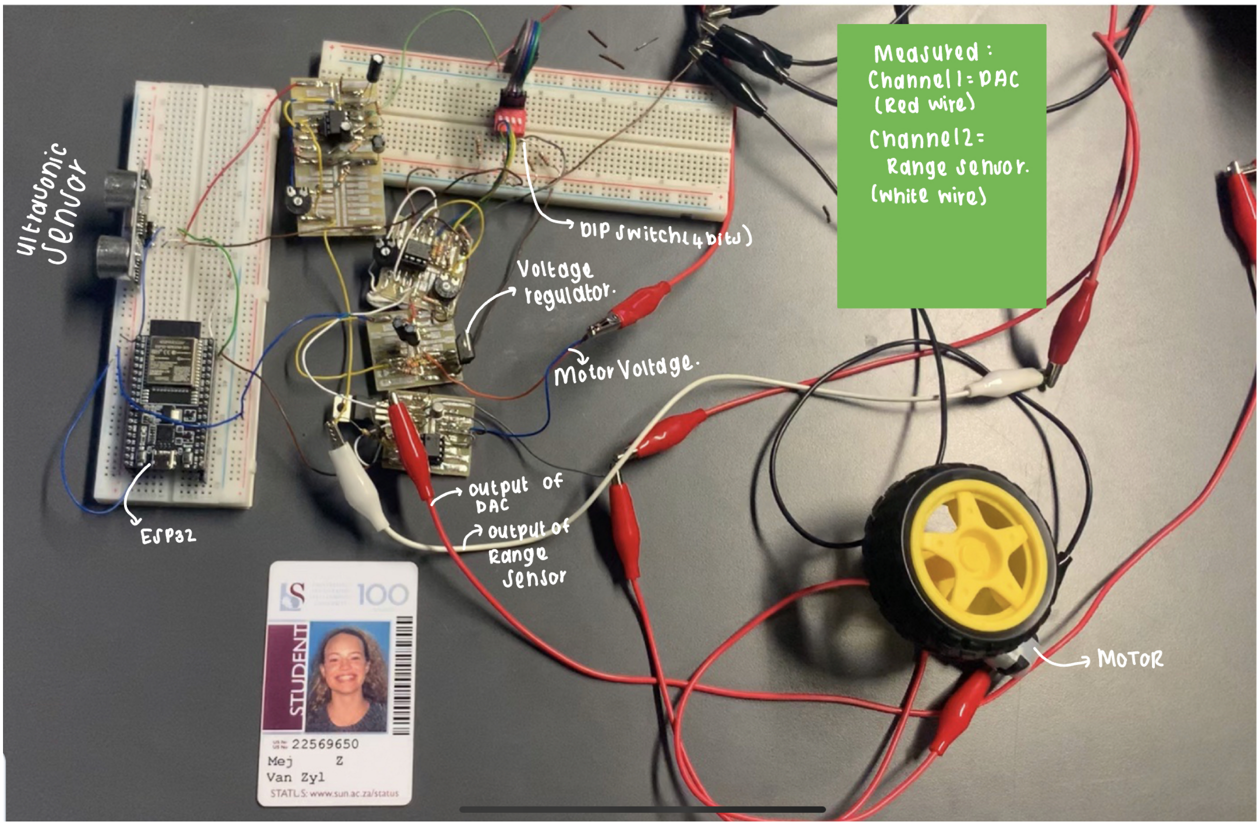

Figure 4.4: A4 circuit

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Appendix A

Social contract

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jou kennisvennoot • your knowledge partner

E-design 344 Social Contract

2021

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 the Teaching Assistant (Kurt Coetzer) spent countless hours to prepare for E344 to ensure that you get your money's worth and 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 tests and 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, ...Zaskia Van Zyl... 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 Booysen

Signature: ...... Digitally signed by MJ BOOYSEN Date: 2021.07.29 16:46:05 +02'00'

Date: 29 July 2021

Student number: 22569650

Signature: ......

Date: 22/07/2022

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Appendix B

GitHub Activity Heatmap