Stellenbosch

UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT

E344 Assignment 1

Marius Roos

22660003

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 6, 2022

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT | forward together sonke siya phambili saam vorentoe

Plagiaatverklaring / *Plagiarism Declaration*

1. Plagiaat is die oorneem en gebruik van die idees, materiaal en ander intellektuele eiendom van ander persone asof dit jou eie werk is.
   Plagiarism is the use of ideas, material and other intellectual property of another's work and to present is as my own.

2. Ek erken dat die pleeg van plagiaat 'n strafbare oortreding is aangesien dit 'n vorm van diefstal is.
   I agree that plagiarism is a punishable offence because it constitutes theft.

3. Ek verstaan ook dat direkte vertalings plagiaat is.
   I also understand that direct translations are plagiarism.

4. Dienooreenkomstig is alle aanhalings en bydraes vanuit enige bron (ingesluit die internet) volledig verwys (erken). Ek erken dat die woordelikse aanhaal van teks sonder aanhalingstekens (selfs al word die bron volledig erken) plagiaat is.
   Accordingly all quotations and contributions from any source whatsoever (including the internet) have been cited fully. I understand that the reproduction of text without quotation marks (even when the source is cited) is plagiarism

5. Ek verklaar dat die werk in hierdie skryfstuk vervat, behalwe waar anders aangedui, my eie oorspronklike werk is en dat ek dit nie vantevore in die geheel of gedeeltelik ingehandig het vir bepunting in hierdie module/werkstuk of 'n ander module/werkstuk nie.
   I declare that the work contained in this assignment, except where otherwise stated, is my original work and that I have not previously (in its entirety or in part) submitted it for grading in this module/assignment or another module/assignment.

22660003 Studentenommer / *Student number*	Handtekening / *Signature*
M Roos Voorletters en van / *Initials and surname*	August 6, 2022 Datum / *Date*

Contents

List of Figures

List of Tables

Nomenclature

Variables and functions

$p(x)$	Probability density function with respect to variable x.
$P(A)$	Probability of event A occurring.

Acronyms and abbreviations

Hz Hertz

Op-Amp Operational amplifier

dB Decibel

AC Alternating current

DC Direct current

BW Bandwidth

Chapter 1

Literature survey

When measuring the current going through a motor, a current sense is used. This is a small resistor in series with the motor. This resistor has a voltage over it which can be amplified and measured. Most current sensing circuits are composed of an amplifier and some sort of filtering circuitry. Operational amplifiers are the ideal choice for the amplification and will be examined in this document.

1.1. Operational amplifiers

Operational amplifiers: limitations and considerations

There are many advantages to using an operational amplifier. They are widely available in the form of integrated circuits. They have a broad range of uses and are a key component in many analog applications. Practical amplifiers have its own complications versus ideal op amps. Practical op Amps don't have infinite

Operational amplifier configurations

- Inverting amplifier. The inverting amplifier amplifies the inverse of the signal on the inverting input pin of the amplifier.
- Non-Inverting. The Non-inverting amplifier amplifies the signal on the non inverting pin of the amplifier.
- Voltage follower amplifier. Because the input impedance is high and the output impedance is low, the voltage follower makes a useful buffer. This mean changes to the input produce equivalent cahnges to the output.
- Voltage comparator. Voltage comparators compare the voltages on both input pins of the amplifier and derives the output to the supply rail of the higher input. Voltage comparators are also open loop because there is no feedback loop.
- Differential amplifier. Differential amplifiers amplifies the difference between the the inputs on the pins. This is also the configuration that is used in the design of the low side current sense.
- Summing amplifier. The summing amplifier outputs the sum of all the signals on its input pins with regards to weighted resistances

- Integrating amplifier. The integrating amplifier outputs an amplified signal of the integrated signal on its input pin.

The configuration used in the low side current sense is a differential amplifier, together with a lowpass filter.

1.2. Current sensing

There are two ways of current sensing that will be examined in this section. Low side and high side.

Low side current sense

Low side current sensing is when the load resistor (Rsense) is placed between the load and ground. This means that the voltage over it is really low and close to ground. This is better in terms of power usage however it does mean that the system ground and supply ground is different.

High side current sense

High side current sensing is when the current sensing resistor is placed between the load and the source. In this configuration the system is more susceptible to noise over the load. When the resistor is between the load and source, the voltage is also much higher which means the system uses more power.

More current sensing methods:

- Hall effect.
- Inductive.
- Magnetoresistive.

1.3. Interfacing with and using Analogue range sensor

Specifications of Ultrasonic sensor:

- Power Supply: +5V DC.
- Quiescent Current: ¡2mA.
- Working current: 15mA.
- Ranging Distance: 2-400 cm.
- Measuring Angle: 30º
- Trigger Input Pulse width: 10uS

The HC-SR04 Ultrasonic sensor emits a 40kHz sound wave and records how long it takes for the signal to return to it after bouncing off of any nearby objects. The way this works is when the trigger pin is set high, the sensor emits a short burst of sound at 40kHz. The echo pin is set high at the same time, when the sound bounces off of any nearby objects the wave travels back to the sensor. When the sensor records the returning sound wave the echo pin is set low again. This results in a PWM signal with a frequency determined by the micro-controller triggering the trigger pin. The duty cycle is determined by the distance of nearby objects to the sensor. Objects that are closer by will result in a smaller pulse width, since reflected sound wave will return the sensor quickly. Further away objects result in wider pulse widths because the reflected sound wave takes longer to return to the sensor.

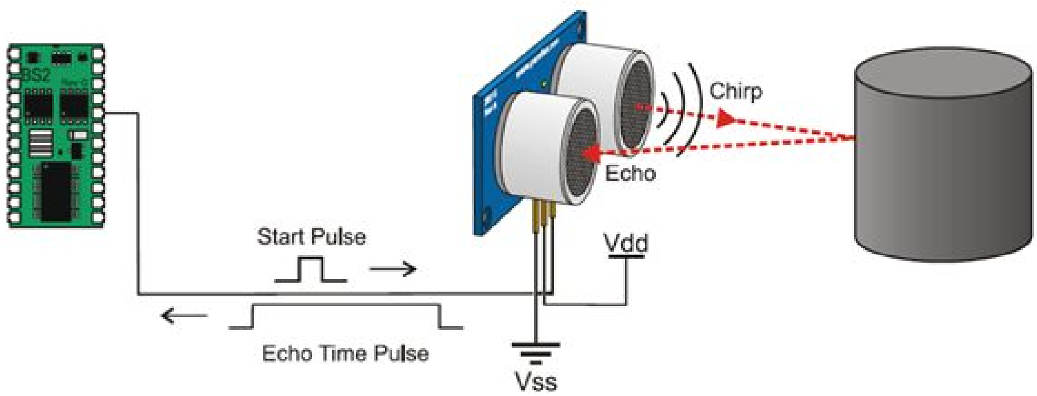


Figure 1.1: Ultrasonic sensor working.

1.4. Converting PWM signals to analogue

Converting a PWM signal to an analogue signal can be achieved by putting the signal through a low pass filter. A Passive RC Filter is usually all that is needed. However in this case we have a signal with a relatively low frequency with respect to its duty cycle. This means that the resulting in a very low mean voltage. Because of this it is necessary to amplify the filtered signal. A Sallen-key low pass filter is ideal for this. We also know that we will need quite large capacitors to be able to provide power when the PWM signal is low (This is most of the time). This will however not be enough having only an RC filter before amplification will still result in too much noise. To fix this a feedback capacitor can be placed in the feedback loop of the Op-amp. The feedback capacitor will take care of the ripple voltage. The basic

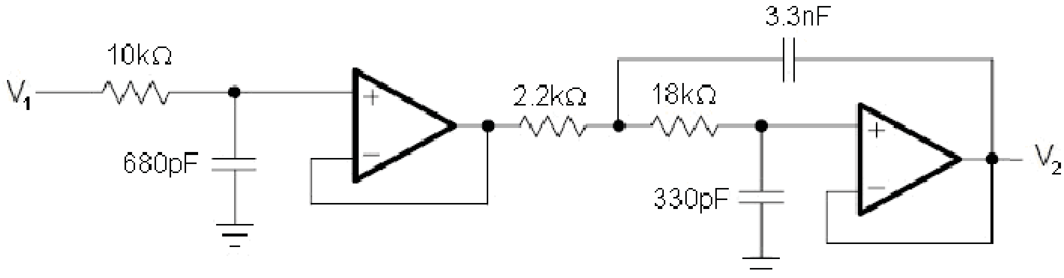


Figure 1.2: Basic Sallen key filter

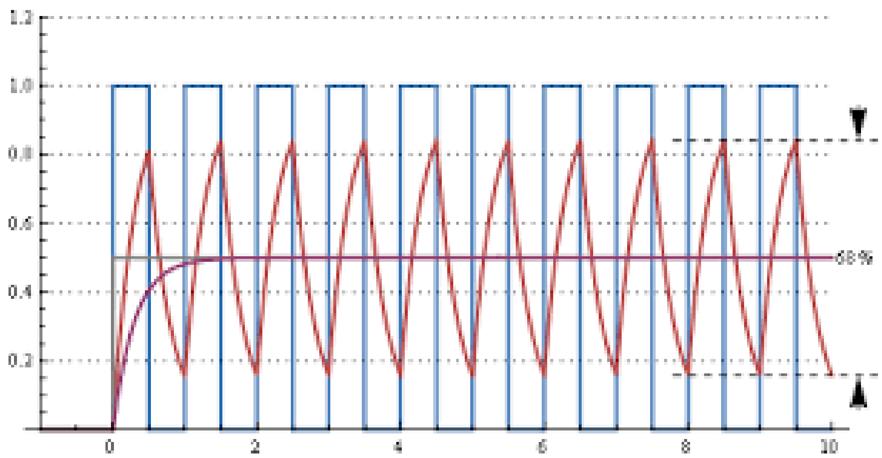


Figure 1.3: PWM signal converted to Analogue.

principal is that when the PWM signal is high, the capacitor charges up and when the PWM signal is low the capacitor dispels its stored energy to achieve a smoother signal.

1.5. Workings of analogue range sensor.

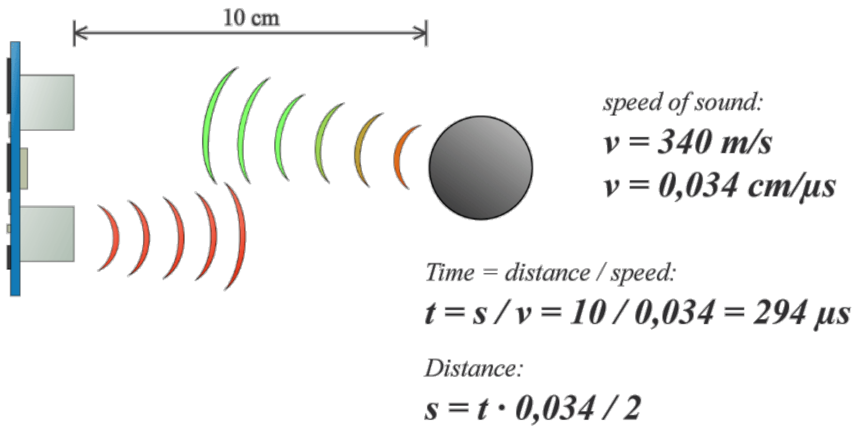


Figure 1.4: How an ultrasonic sensor works.

Chapter 2

Detail design

Before designing the system the maximum power through the load must be found. This can be done by stalling the motor (which is the load) to find the maximum current it can draw. When stalling the motor it is working at its hardest and therefore draws the most current. The motor draws around 150mA when running freely with only the wheel attached. When stalled it draws around 1A. figure(2.1) shows two circuit designs for a low side current sensor.

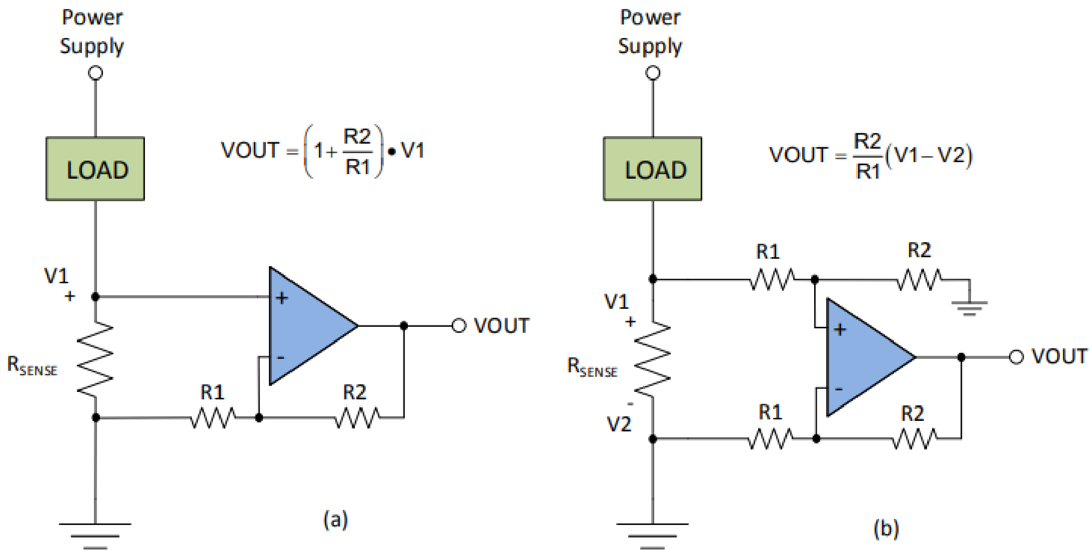


Figure 2.1: Low side current sensors

Figure 2.1(a) on the left, achieves current sensing with two external gain setting resistors. It uses fewer components than the one on the right but, for circuits with high ground currents it can be less accurate. Figure 2.1(b) Is a difference amplifier that senses the voltage drop directly over the sense resistor. This system is more accurate because the voltage drop from the resistor to the pcb is removed.

$$Rsense = \frac{Vsensemax}{Iloadmax} \tag{2.1}$$

$$Gain = \frac{VOmax}{Vsensemax} \tag{2.2}$$

With Rsense = 10 mΩ and Iloadmax = 1A we can find Vsensemax to be 10mV and the gain 300 since the maximum output voltage shold be 3V.

$$Vout = \frac{R2}{R1}(V1 - V2) \tag{2.3}$$

R1 is chosen as 300Ω and R2 is chosen as 100kΩ. These are chosen so that the circuit uses less than 150uA

Next the filter capacitors must be calculated.

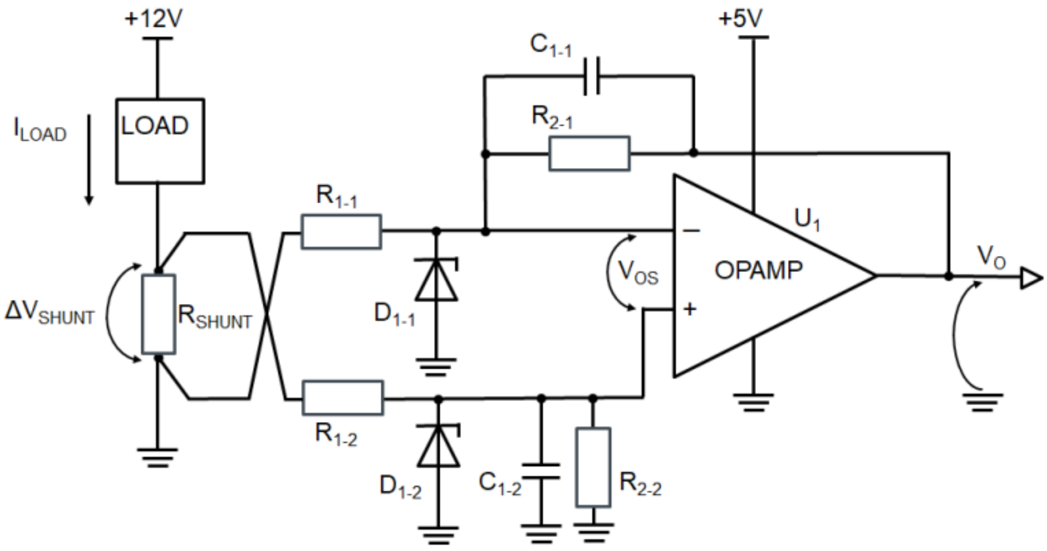


Figure 2.2: Lowpass filter incorporated with circuit.

$$C1 = \frac{1}{(2pi)(Fsense)(10)(R2)} \tag{2.4}$$

With the frequency of the sense resistor chosen as 10Hz the capacitor values can be calculated. initial calculations showed that capacitors of 5nF must be used but after tweaking the circuit in LtSpice it was found that 50 nF works better.

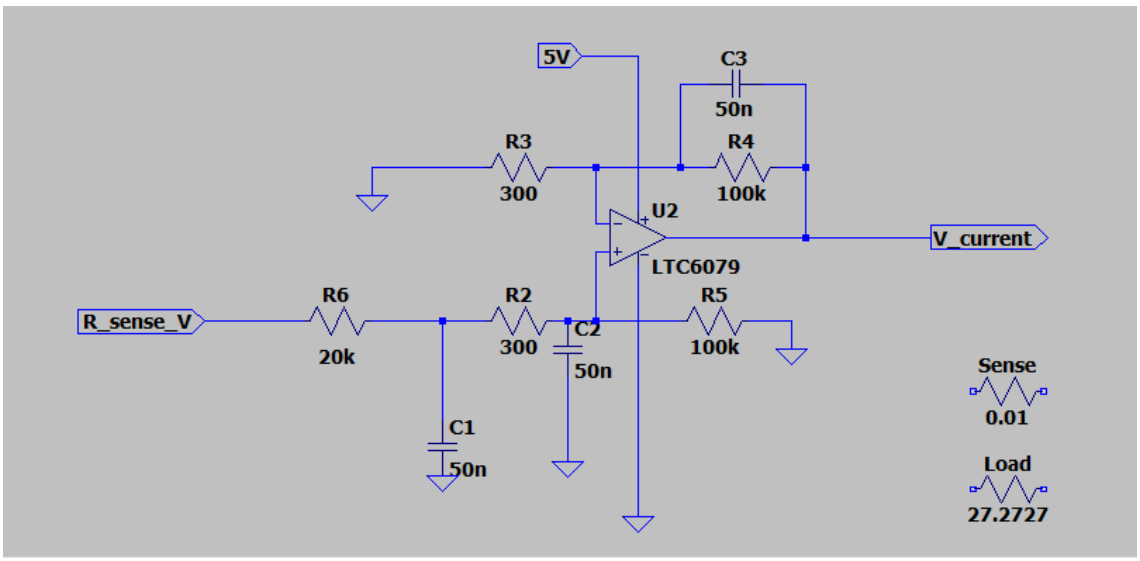


Figure 2.3: Final design.

Design of the PWM to analogue converter: To start, the filter needed to be designed for a certain cutoff frequency. This frequency was chosen to be 7Hz Since the PWM signal has a frequency of 16Hz.

$$Fcutoff = \frac{1}{(2pi)(RC)} \tag{2.5}$$

The required cutoff frequency ended up being much lower than 7Hz. The final values for R and C was worked out to be 680nF 120kΩ

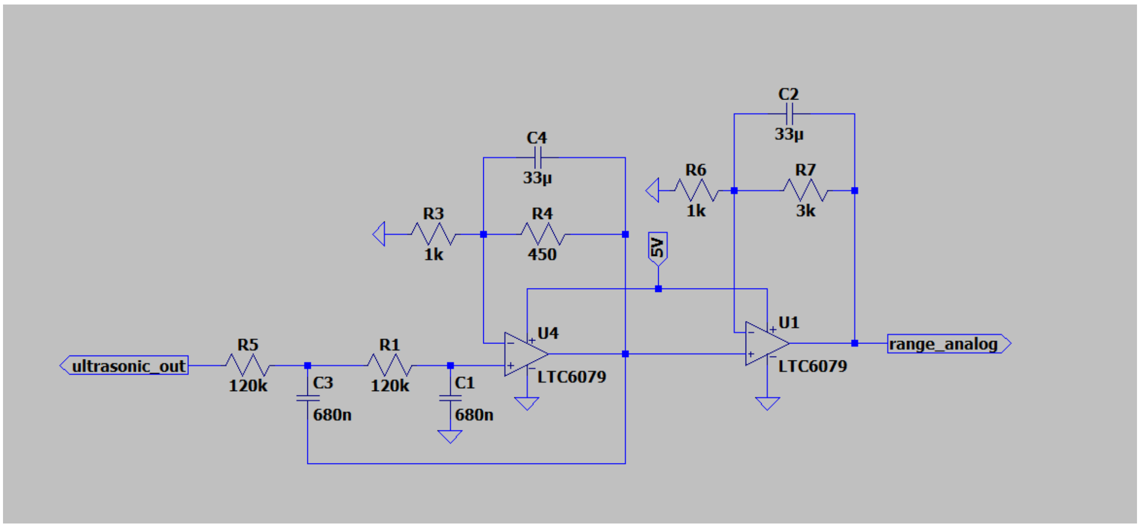


Figure 2.4: Final design.

The gain of the filter needed to be 5.8. This is because the individual gains of the two op-amps are as following:

$$Gain = 1 + \frac{Rfeedback}{Rnegative} \tag{2.6}$$

This leaves us with:

$$Gain = (1 + \frac{450}{1000}) * (1 + \frac{3000}{1000}) \tag{2.7}$$

Which equals 5.8.

The feedback capacitors were changed to best filter out the Ripple voltage. It was found that 33uF worked best and reduced the noise to below 70mV.

Chapter 3

Results

The result of the circuit is satisfactory, the noise is filtered out and the signal gets within within the desired margins in less than 100ms.

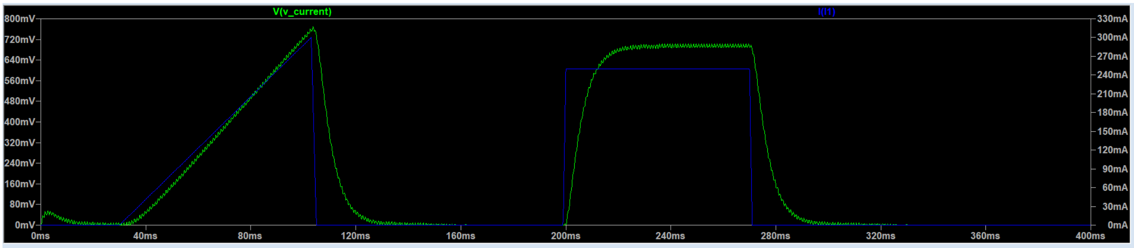


Figure 3.1: Response to ramp and step input.

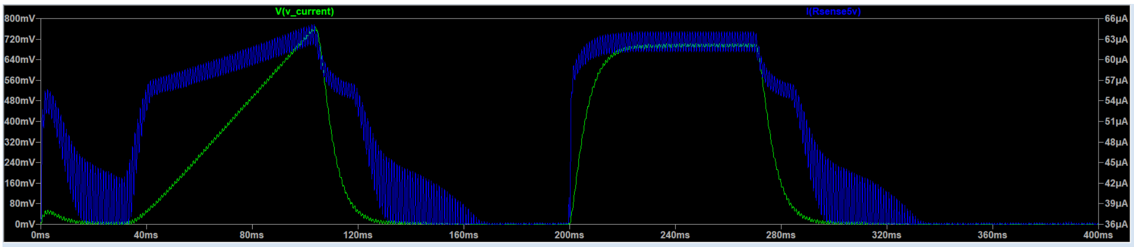
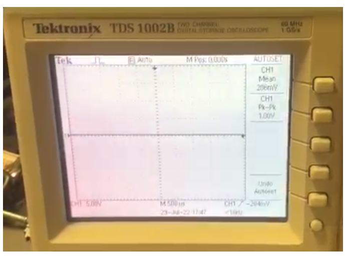
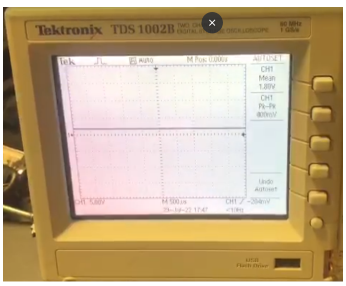


Figure 3.2: Circuit current draw.

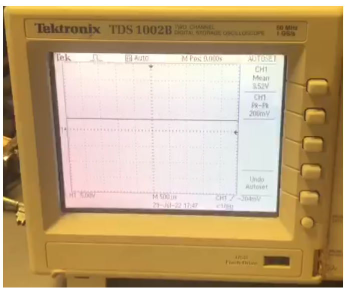
3.1. Current sensor



(a) Voltage output at freerun.



(b) Voltage output at slight load.



(c) Voltage output at stall.

Figure 3.3: Current sense circuit output at different loads.

3.2. PWM to analogue

The circuit performs as expected and meets all requirements.

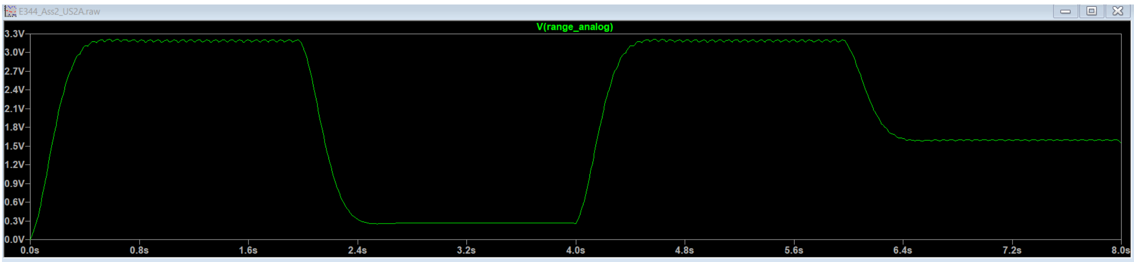
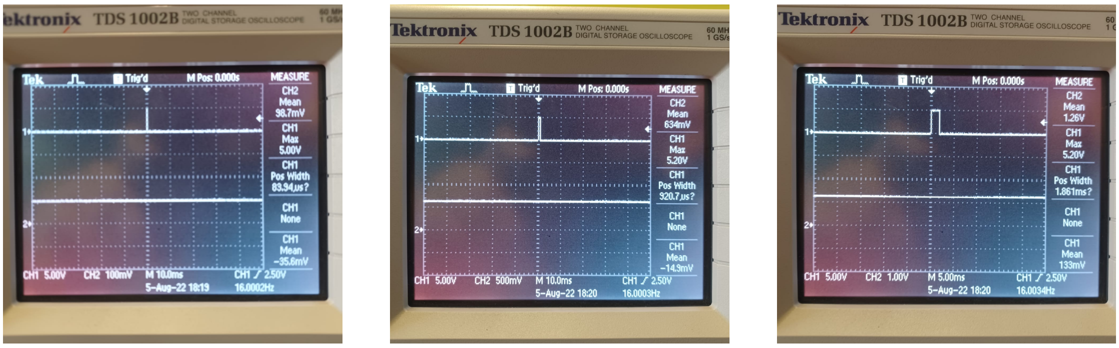
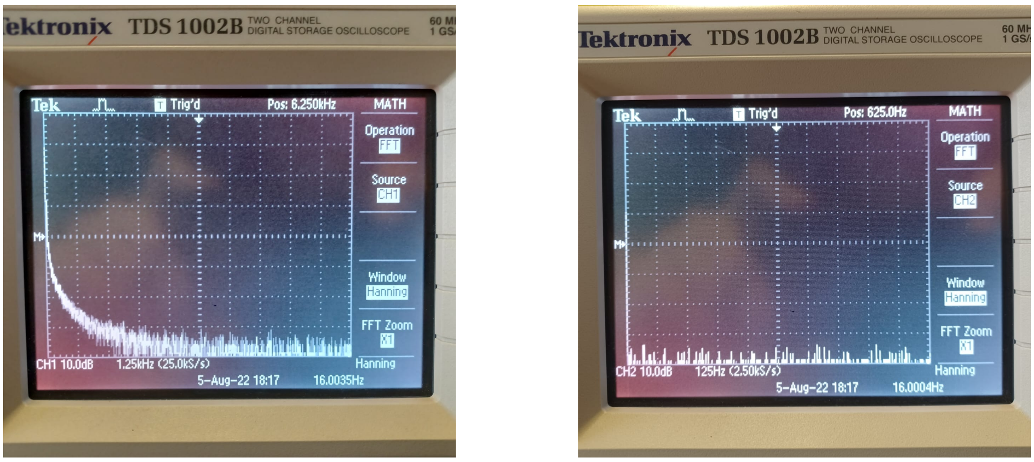


Figure 3.4: Spice simulation.



(a) 1 cm. **(b)** 15 cm. **(c)** 30 cm.

Figure 3.5: Circuit input and output wit obstacle at different distances.



(a) Input noise. **(b)** Output noise.

Figure 3.6: Fourier transform of noise in vs noise out.

Chapter 4

Physical implementation

Figure 4.1: Circuit and student card.

=====================Legend========================

Green= Sense resistor.

Blue= Input(This is where the motor is connected in series)

Red= VDD

Brown= Output.

===

Figure 4.2: PWM circuit and student card.

======================Legend========================

Green= Ground.

Blue= VDD = 3.3V

Red= Feedback capacitors

Pink= RC Capacitors

===

Bibliography

Appendix A

Social contract

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
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, ...Marius Roos.................................... 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	Student number: 22660003
Signature: MJ Booysen (Digitally signed by MJ Booysen Date: 2022.07.02 13:22:09 +02'00')	Signature:
Date: 1 July 2022	Date: 24/07/2022

1

Appendix B

GitHub Activity Heatmap