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E344 Assignment 1

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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.

August 7, 2022

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Nomenclature

Variables and functions

Update this list to make it applicable to your project.

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

Acronyms and abbreviations

AC	Alternating Current
DC	Direct Current
Op-Amp	Operational Amplifier
BW	Bandwidth
R	Resistor
W	Watt
PS	Power Supply
dB	Decibel

Chapter 1

Literature survey

The purpose of this document is to present the reader with the basic principles low side current sensing. In order to do this, the most commonly used operational amplifiers are examined as well as the basics of current sensing. By observing the purpose and specifications of different configurations. The correct filter and operational amplifier configuration can be chosen in order to implement a low side current sensor.

1.1. Operational amplifiers

Operational amplifiers: limitations and considerations

Practical operational amplifiers have certain limitations when compared to ideal operational amplifiers. For example a differential amplifier amplifies the difference between the two input terminals. Therefor ideally if the two input terminals were the same then the output should be zero. In practice though this does not happen. There will be noise at the terminals which will make the inputs unequal and even if they were equal the operational amplifier would still have an output. When designing the correct configuration, the slew rate, bandwidth, input current and common mode rejection need to be considered. When observing the circuits frequency response, we design it to obtain the correct frequency response over a specific bandwidth. All practical operational amplifiers have a finite BW, this point where the gain begins to roll-over as the frequency increases is called the '3dB point'. It is shown in figure 1.1.

Operational amplifier configurations

Using different configurations of resistors and capacitors, many different types of operational amplifiers can be made. Some of the different types include inverting amplifiers, non-inverting amplifier, voltage follower, comparator, differential, summing and integrators. Operational amplifiers can have four different types of gain. Voltage gain, voltage in is amplified making voltage out larger in magnitude. Current gain, the current is amplified. Transconductance, voltage is made into current and finally trans resistance where current in and voltage out.

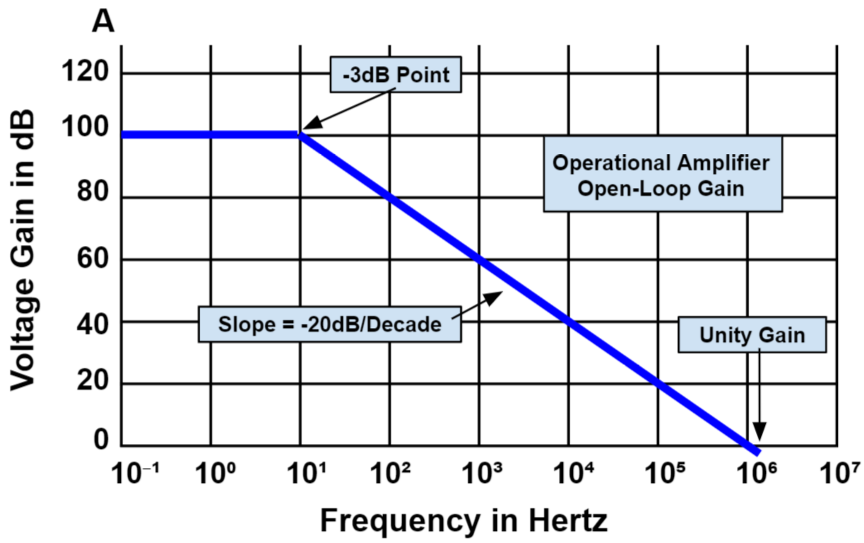

Figure 1.1: Frequency Response and Bandwidth

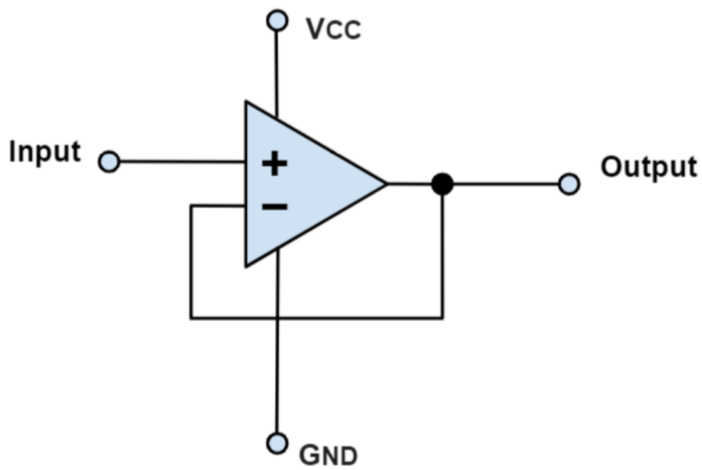

Figure 1.2: Voltage Follower

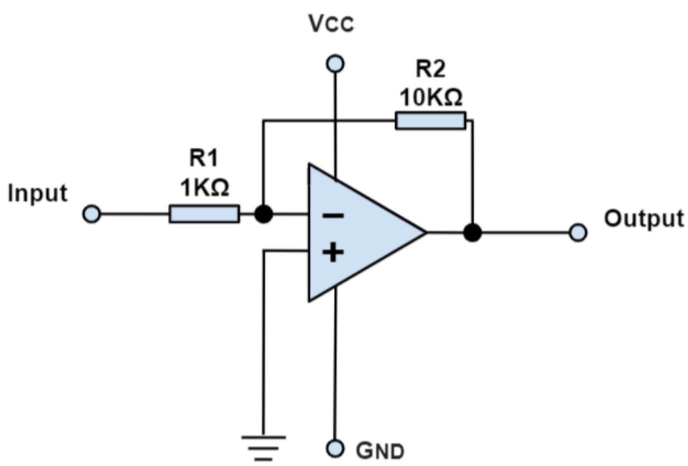

Figure 1.3: Inverting Amplifier

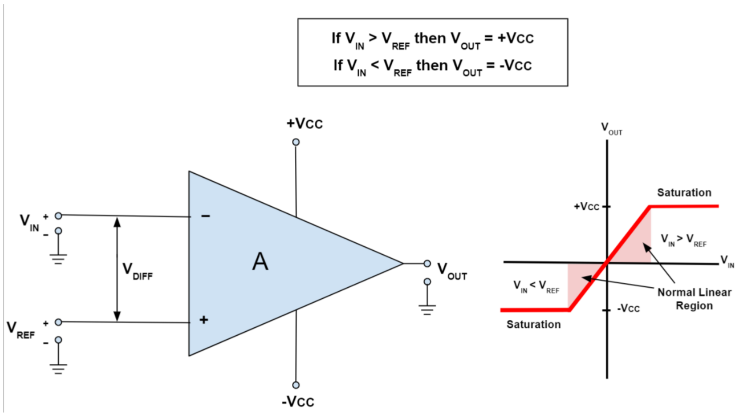

Figure 1.4: Voltage Comparator

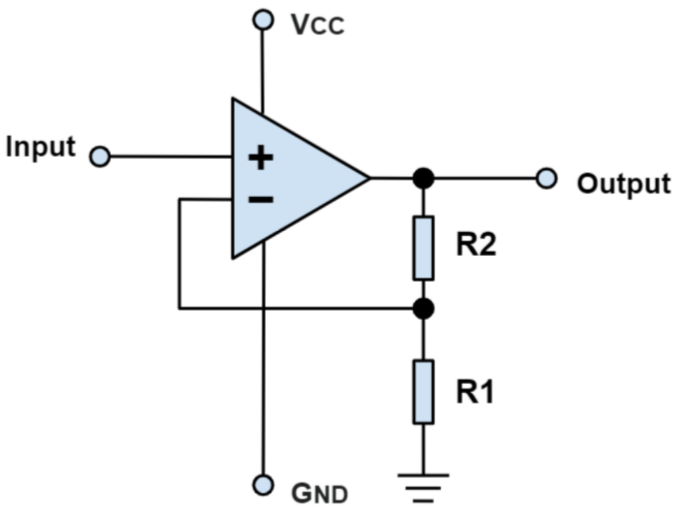

Figure 1.5: Non-Inverting Amplifier

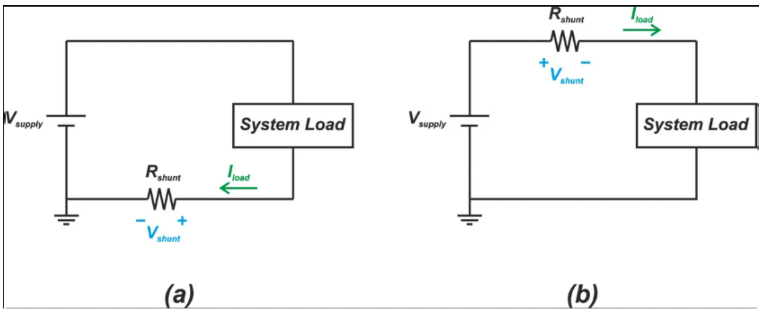

Figure 1.6: Lowside vs Highside

	Rogowski coil	Current Transformer	AMR	GMR	Hall effect	Fluxgate	Shunt
Current type	AC	AC	AC and DC	AC and DC	AC and DC	AC and DC	AC and DC
Current range	Medium	High	Medium	Medium	Medium	High	Low
Accuracy	Low	Medium	Medium	Medium	Medium	High	High
Temperature drift	High	Medium	Medium	Medium	Medium	Low	Low
Inherent isolation	Yes	Yes	Yes	Yes	Yes	Yes	No

Figure 1.7: Different Current Sensors

1.2. Current sensing

Low Side and High Side Current Sensing

Low side current sensing happens when the sensing resistor is placed below the load. The voltage seen at the current sensing circuit is near ground and therefor uses less power and is safer. This does however make the system ground and supply ground different. The configuration can be shown in Figure 1.6. A high side current sensor configuration is achieved by placing the sensing resistor between the power supply and load. The system then only has one ground however the sensing circuit is more susceptible to fluctuations over the load.

AC Current Sensing and DC Current Sensing

Certain current sensors and methods of measuring current can only measure AC or DC currents. Different methods are shown in figure 1.7. This needs to be considered when designing for the collision detection.

Power requirements

It is important to not use too much power when designing the current sensor. By using a low-side current sensor. The dissipated power in the shunt resistor will be less. By using less power, the DC motor will be able to perform better and the vehicle will last longer.

1.3. Converting PWM to Analog

What is PWM

Pulse width modulation is a way to control analog devices using with a digital output. PWM can be used by the MCU to control a variable speed motor. PWM simulates an analogue signal by applying power in pulses. Typically the base frequency is fixed This is done by changing its duty cycle. Figure 1.8 shows an example of different PWM signals with varying duty cycles. As the duty cycle increase so will the average value and as it decreases so will the average value. PWM can be converted to an analogue signal using a simple RC low-pass filter or a Sallen-Key filter. The duty cylce determines the magnitude of the filters output. Figure 1.9 shows the spectrum and desired bandwidth of the pulses. A simple RC or active filter can be used to get the desired bandwidth.

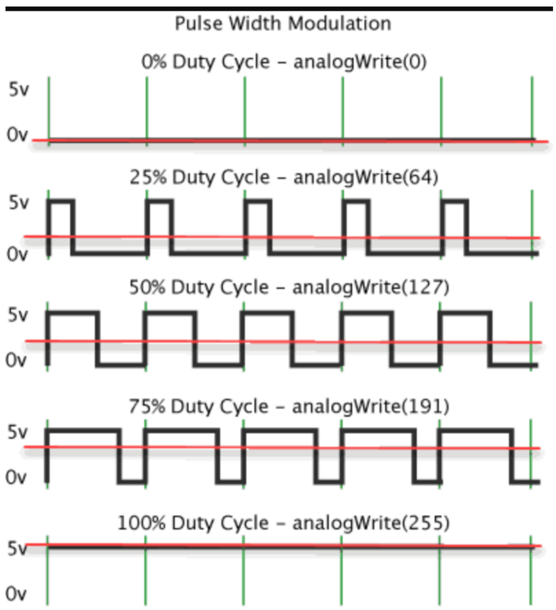

Figure 1.8: Duty Cycle of PWM signals

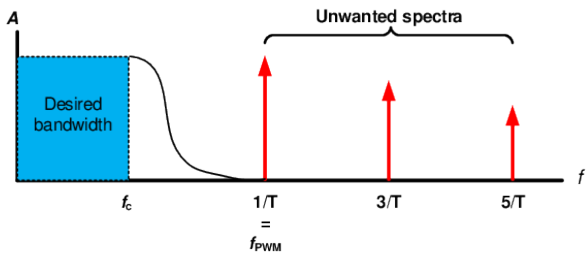

Figure 1.9: Spectra needed to be filtered

1.4. Fundamental operation of the range sensor

There are many ways of detecting the presence of an object. Certain proximity sensors are used for different tasks. Some are suited to detecting ferrous metals, all metals or objects/people. There are magnetic, capacitive, ultrasonic and more. Ultrasonic sensors are useful for detecting objects up to several meters. The way that objects are detected is based on an ultrasonic pulse being emitted from a sensor transmitter at a specific frequency when the trigger is set. This wave is then reflected off the object and received. The amount of time taking from transmitting a pulse signal to the signal being received is called the time of flight. The time of flight is used to measure how far away the object is from the sensor. By powering the sensor and filtering the pulses. An analog signal can be generated with different values based on how close the object is. This value can be read by a microprocessor to detect the object. The reason for the a change in value is due to the pwm. Figure 1.10 shows a diagram of an ultrasonic sensor.

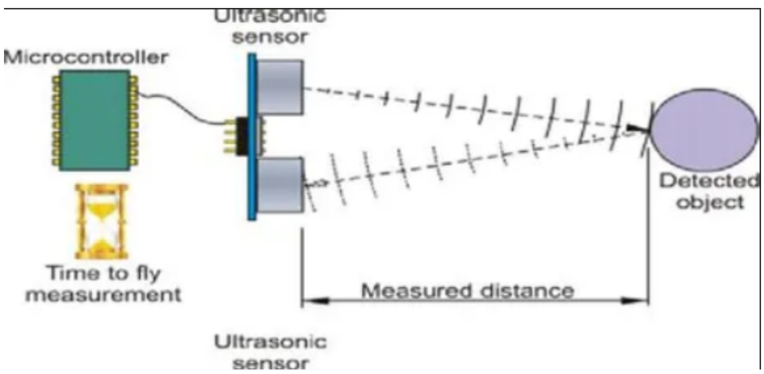

Figure 1.10: Current sensor detection

1.5. Interfacing with an Ultrasonic Range Sensor

The HC-SR04 ultrasonic sensor emits a sound wave at a specific frequency. The waves then bounce off the object and the sensor receives them. The received signal is a PWM signal. This must then be converted to an analog signal, the signal is converted by using a filter. This filter can be a simple RC filter or an active filter. The capacitors discharge causing the pulse signal to smooth out to an analog one. Depending on the width of the pulse the mean voltage of the analog signal changes. When the signal is received the echo pin is sent low. This received signal will correspond to the distance the object is. Closer objects have smaller analog voltage signal and the magnitude increases as the object gets further away.

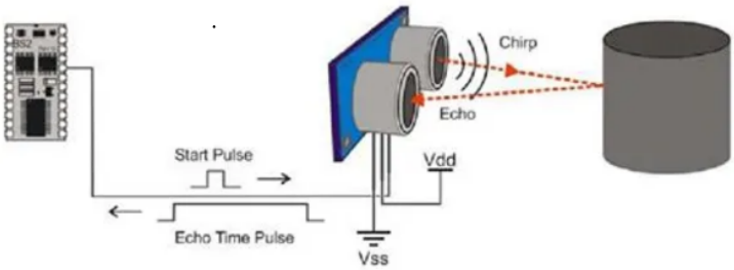

Figure 1.11: Current sensor detection

Chapter 2

Detail design

The maximum stall current was found to be 1.01 A. This was found by powering the motor and attaching the wheel. By stopping the wheel and observing the current used by the motor when the wheel was not able to move, the maximum current was observed. This was done quickly as stalling the motor for long will destroy the motor. The measurement and setup can be seen in figure 2.1. When the motor was running with no force stopping it, it used about 150mA. However the motor will have to move the entire vehicle and therefor will consume about 200-300mA.

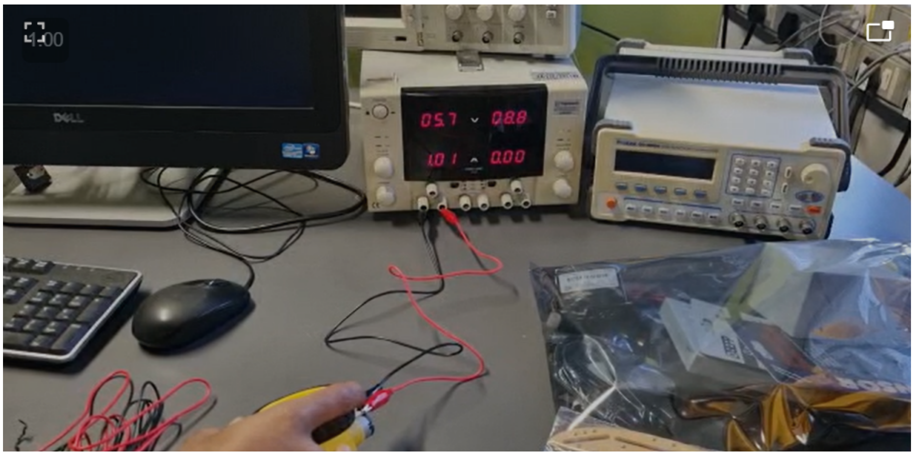

Figure 2.1: Stalling Test

Figure 2.2 was taken from Texas instruments. These were the main implementations of a low side current sensor. 2.2a is simpler to build and implement a filter on but is less stable than 2.2b. Due to disturbances on the sensing resistor 2.2b was chosen. If the motor/load affects the current sensor, the effects will be nullified by the extra resistors in 2.2b. The value of R1 was chosen as 250 Ohm. The gain was chosen 300 in order to get a voltage output of over 3Vs. The rest of the resistor values were worked out using the equation in figure 2.2. These values were tweaked in LTSpice in order to get the best output. The max voltage the ESP can read is 3.3V therefor the circuit was designed to be in this range. This can be seen in 2.4

The frequency response was chosen to be around 20 Hz. The following equation was used in order to work out the correct values for the circuit. This was then changed on LTSpice to get a better smoother curve. By smoothing out the graph shown in figure 2.4, the slew rate increased. A value in the middle was chosen. Figure 2.3 is the final design of the circuit. The resistor values were chosen to use less than 150 uA.

$$\frac{1}{2pi*fsense*10*R2}$$

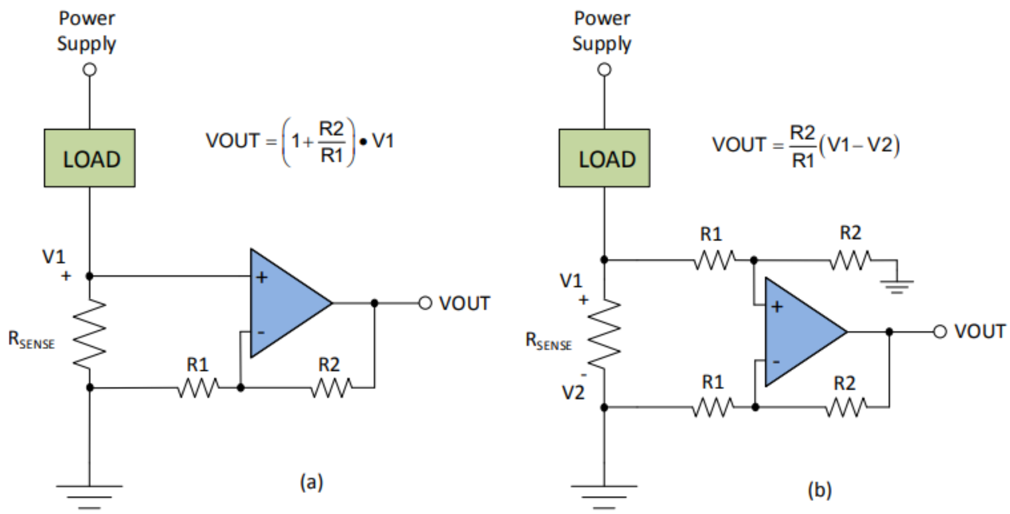

Figure 2.2: Simulation

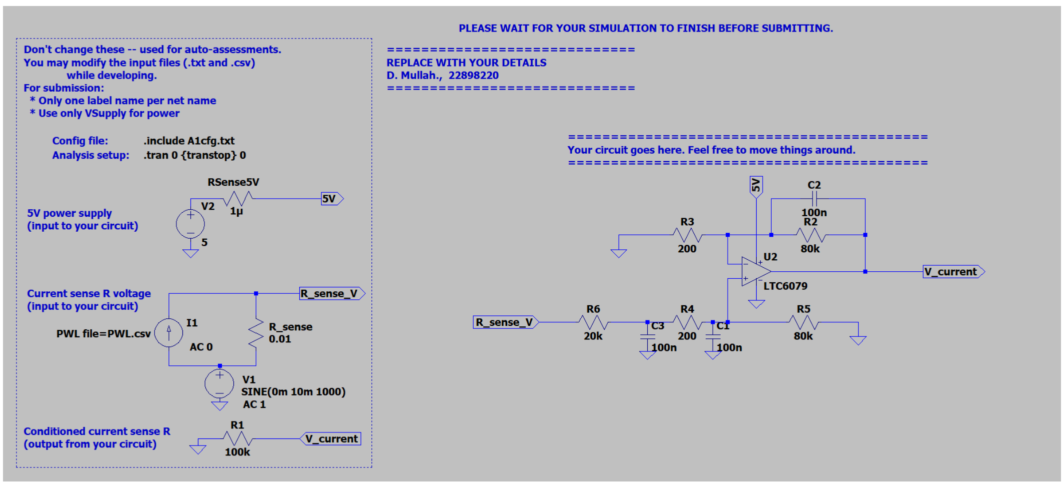

Figure 2.3: Final Design

2.1. Design of PWM to Analog Converter

The filter was initially designed for a frequency of 8Hz. The reason being is that the PWM signal has a frequency of 16Hz and the design must be half of the PWM signal. The circuit consisted of two op amps. The first one was set up as an active filter. The second op amp was used to control the gain. Figure 2.4 shows the final implementation of the circuit.

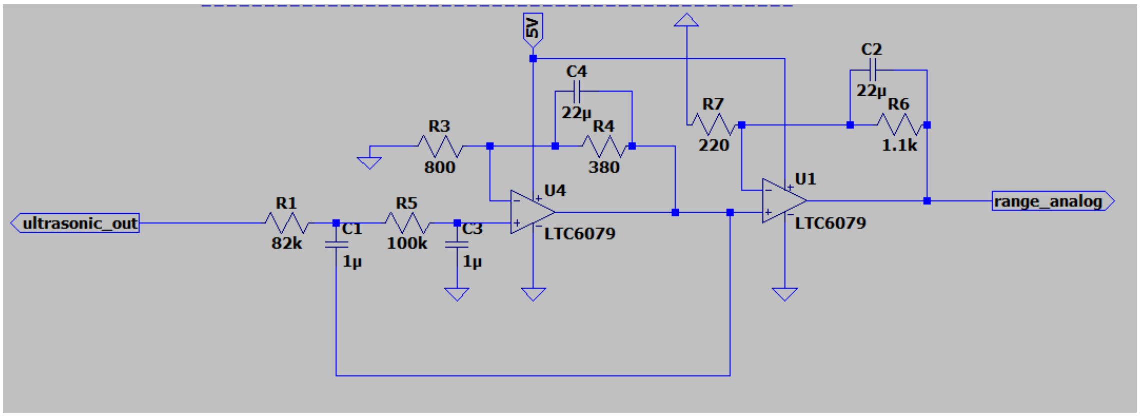

Figure 2.4: circuit diagram of ultrasonic sensing circuit

The following equations show the gain of the each op amp. They were both set up with the same gain equation.

$$Gain = 1 + \frac{R2}{R1}$$

Design of the frequency.

$$f = \frac{1}{2*pi*R*C}$$

The values of the capacitors needed to be increased as the circuits initial response was too fast. Increasing the capacitors for the RC filter was selected to be 1u as this value gave a really smooth output with little noise. The resistor values were just chosen to provide a gain which made the output greater than 3V but less than 3.3V. The Op amps have a gain of around 5 when powered by 5V. The 22u F capacitors were chosen to smooth out the response. It filters the ripple. The final signal can be seen in the results.

Chapter 3

Results

3.1. Current sensor

The simulated result of low side current sensing circuit is shown in figure 3.1. The slew rate and smoothness of the output both meet the requirements. The measured stalling test is shown in figure 2.1 above. The outcome of the stalling test was within the expected range.

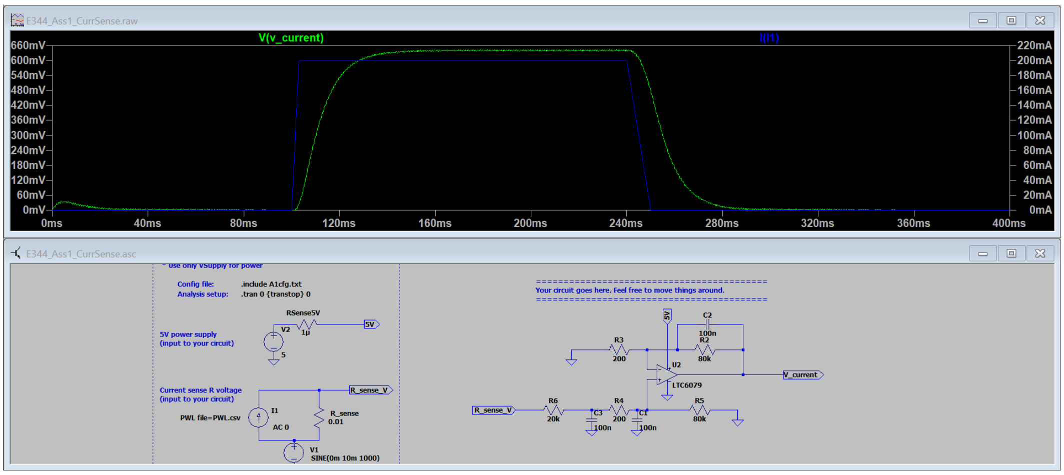

Figure 3.1: Circuit and Output

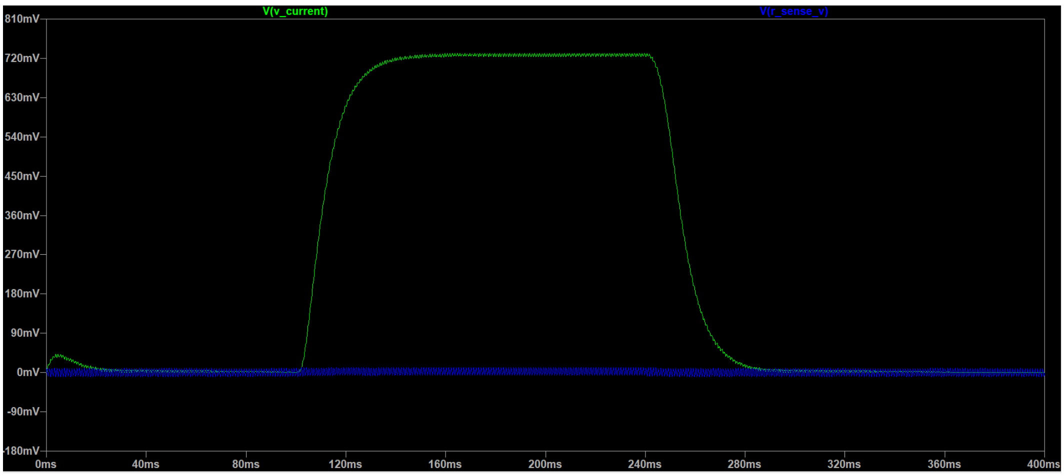

Figure 3.2: Input Vs Output

3.2. Current sensor Physical Measurements

The circuit performed well during regular running and when the wheel was stalled. However when the supply current was set to zero the circuit had a voltage output of 0.35V which is above the requirement. This is due to incorrect biasing with the resistor values. The solution would be to add a voltage clipping circuit at the input or recalculate the resistor values. The solution was not implemented due to time and the circuit did respond correctly to all the other specifications.

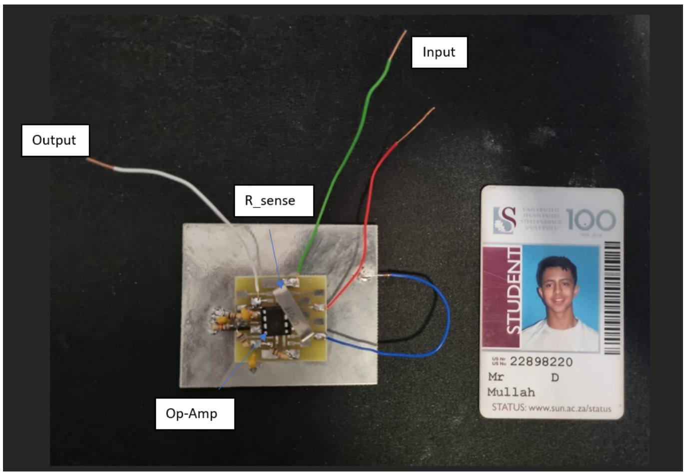

Figure 3.3: physical circuit

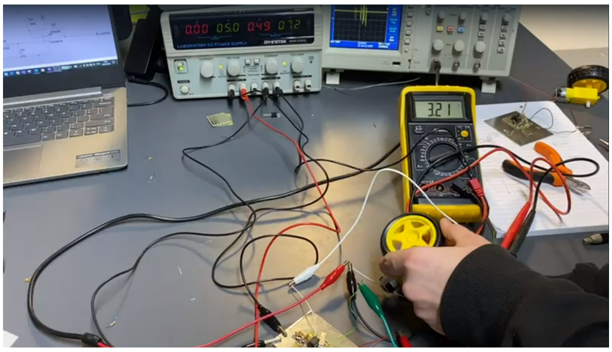

Figure 3.4: stalling test

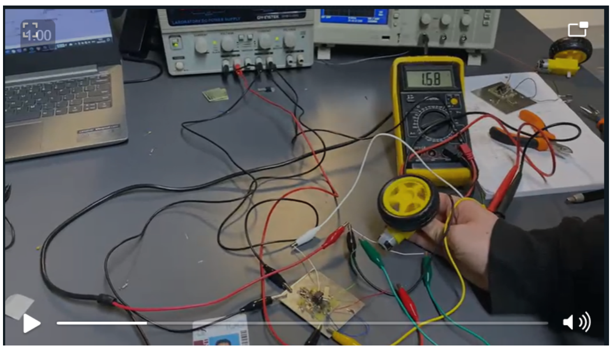

Figure 3.5: running test

3.3. Ultrasonic Sensor Physical Measurements

The circuit performed well and met all the requirements.The output is never above 3.3V and the voltage measured at 1m is 3.18V.

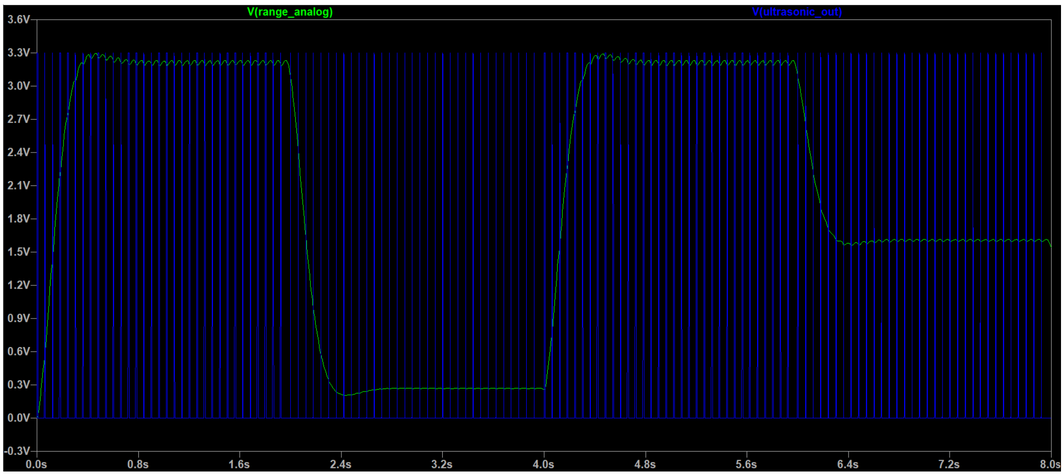

Figure 3.6: Output of ultrasonic sensor

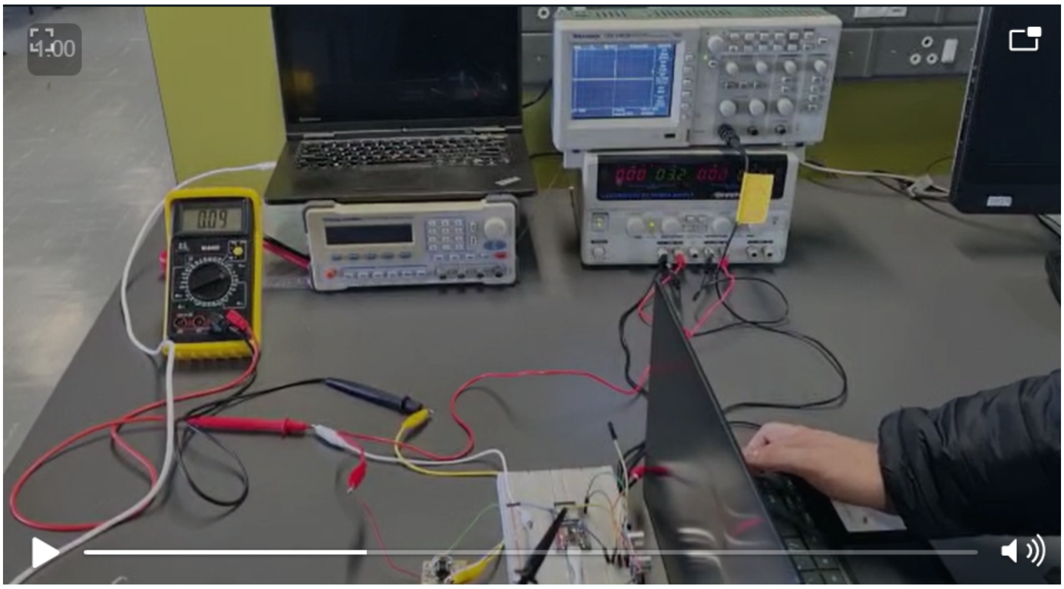

Figure 3.7: Voltage level at 5cm

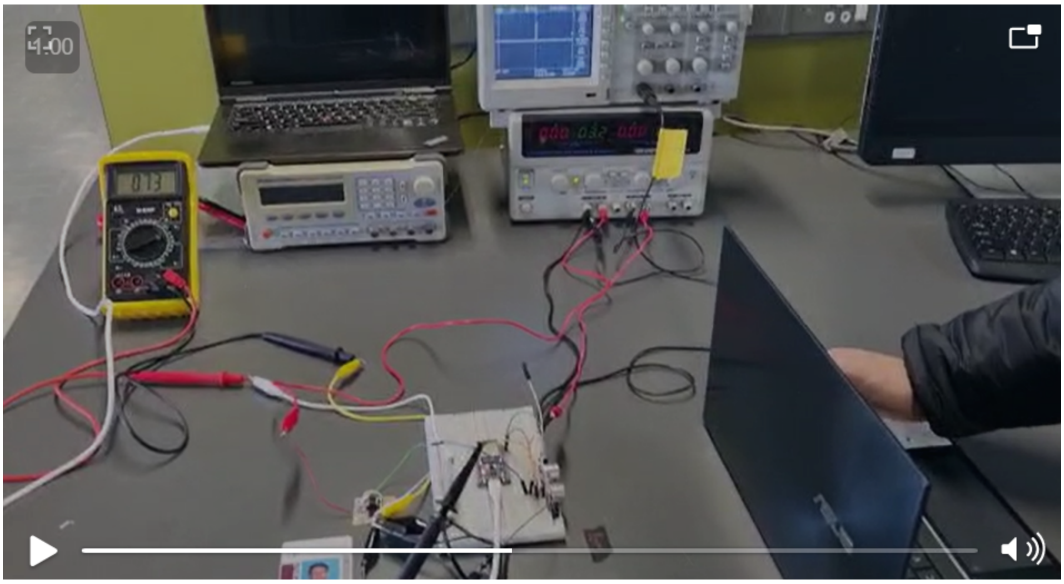

Figure 3.8: Voltage level at 10cm

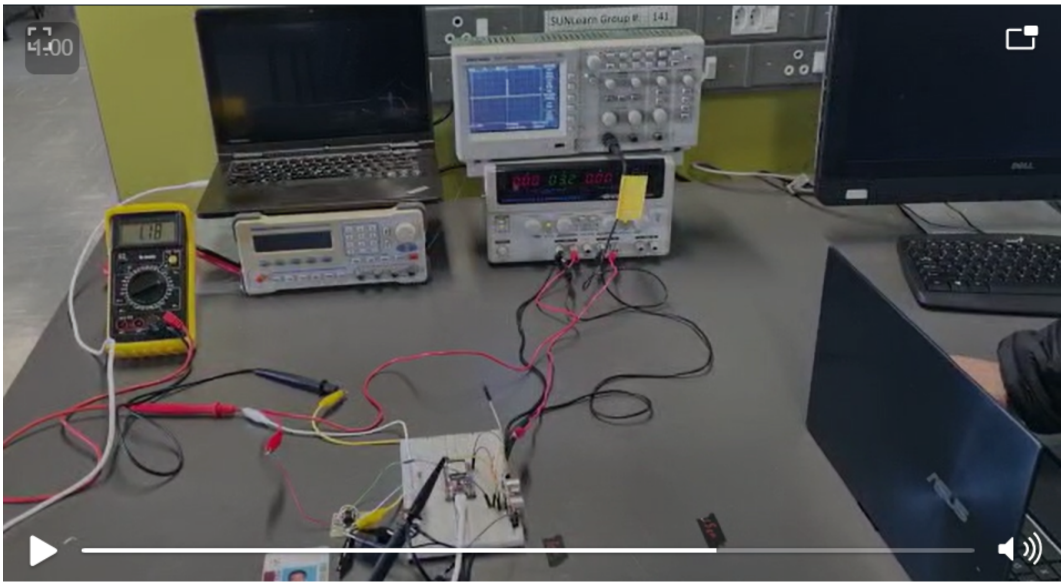

Figure 3.9: Voltage level at 30cm

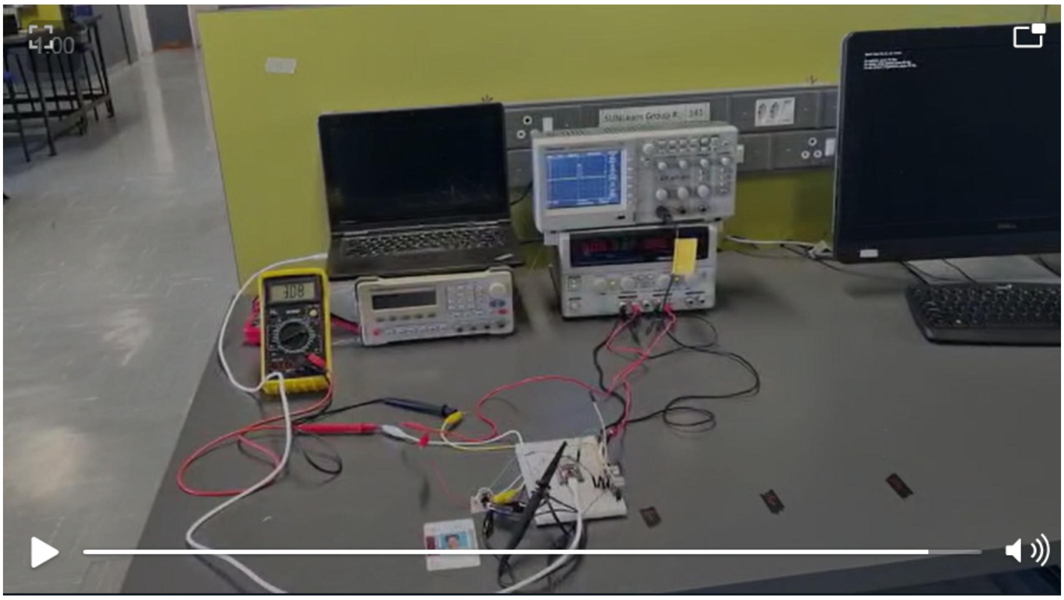

Figure 3.10: Voltage level at 1m

Bibliography

Appendix A

Social contract

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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, Daanyaal Mullah 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: 22898220

Signature: DMullah

Date: 31 July 2022

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Appendix B

GitHub Activity Heatmap