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E344 Assignment 3

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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.

24 August 2021

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22877169 Studentenommer / *Student number*	Handtekening / *Signature*
W. Viljoen Voorletters en van / *Initials and surname*	24 August 2021 Datum / *Date*

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Nomenclature

Variables and functions

J	Joules
P	Power
W	Watt
V	Voltage/Volts
I	Current
A	Ampere
R	Resistance
Ω	Ohms
Q	Charge
C	Coulomb
t	time
$F.V$	Full Voltage
V_{OC}	Open circuit voltage
I_{SC}	Short circuit current
T_{amb}	Ambient Temperature
T_j	Junction Temperature
V_{sg}	Source to gate voltage
V_{gs}	Gate to source voltage
V_T	Threshold voltage
V_{Supp}	Supply voltage
V_{cc^+}	Positive voltage rail of an op-amp
V_{cc^-}	Negative voltage rail of an op-amp
V_{ref}	Reference voltage of an op-amp
V	Inverting input of an op-amp
V^+	Non-inverting input of an op-amp
R_s	Sense resistance

Acronyms and abbreviations

s.	seconds
e.g.	for example
LED	Light-Emitting Diode
mV	milli Volts
mA	milli Ampere
NMOS	Negative-channel Metal-Oxide Semiconductor
PMOS	Positive-channel Metal-Oxide Semiconductor
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
Temp	temperature
AC	Alternating current
DC	Direct current
op-amp	Operational Amplifier
LTspice	Circuit Simulation Software

Chapter 1

Literature

1.1. Fuse Protection

The average temperature in South Africa is 27°C in according to *weather-and-climate.com* [2], but tests done by *sustainable.org* [3] suggests that maximum temperatures of 40°C is reached during summertime Considering that the circuit will be mounted on a rooftop within a casing where components such as resistors and operational amplifiers also resides, it is viable to assume that temperatures of up to 50°C can be reached. The operating temperature of the battery also suggests that the circuit should be kept under 50°C. The RS-pro fuse is affected by ambient temperature, and this parameter should therefor be considered when choosing an applicable fuse. As seen in Table 1.1 (extract from datasheet [4]), the battery discharge rate should not exceed 1.85V/cell and approximately 1A when discharged over a 3 hour period (which is a fair maximum use time to assume for this system model). This should also be considered when choosing the fuse. Considering that the circuit will not exceed 400 mA of current under normal load conditions, a viable fuse can be chosen.

Table 1.1: Battery discharge current spesification.

6V 4Ah Lead-Acid Battery				
Variable:	$\frac{V}{cell}$	$\frac{F.V}{t}$	current	Temp
Value:	1.85	3h	0.899A	25^oC

1.2. Undervoltage Protection

The Undervoltage protection is placed between the system load, the charging supply and the fuse connected to the battery. The purpose of the undervoltage protection circuit is to prevent the battery from being discharged too deeply by the load. This will be done by using a system load switch to supply the battery power to the system or it will cut it off. For the design of the system load switch, a High-side Switch is used, switching between supply to system load or to cut-off the system load, from the battery. The high-side switch needs to be triggered by a sensitive voltage comparator circuit made up of op-amps. To conclude the operation, when the charging supply from the solar panel or power supply is online, it supplies to the system load and the battery to charge. When it is offline and the system load will now drain the battery, and the undervoltage battery protection circuit will then cut off the load from the battery. In short, the circuit will make use of operational amplifiers and a high side switch. Together, they will turn off current to the load if the battery voltage falls below 6 volt and resume the current once the voltage exceeds 6.2 V.

Chapter 2

Detail Design

2.1. Overcurrent Protection (Fuse)

Assuming that a maximum temperature of 50°C will be reached, the following calculation can be made: According to *littlefuse.com* [1], Catalog Fuse Rating = $\frac{NormaloperatingCurrent}{0.75 \times PercentofRatingattemperature}$.

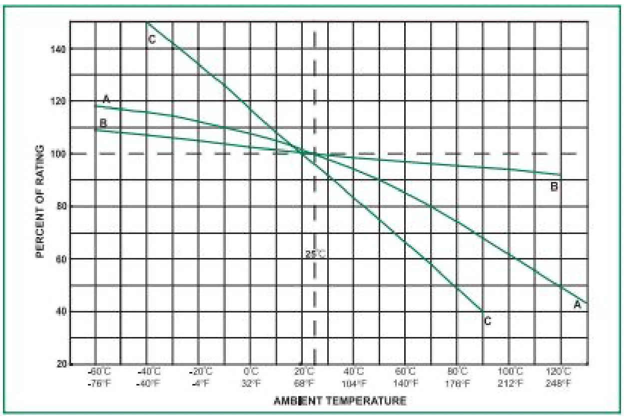

Figure 2.1: Following the graph of B for blade fuses: [1].

Considering a normal operating current of 400 mA at 50°C (Worst case scenario) : $\frac{0.4}{0.75 \times 0.96} =$ 0.6 A . a Fuse of 0.6A is needed, considering that a fuse smaller than this will blow with normal operation. Also a rate of approximately 1A is determined in the literature fuse section from the battery specifications. The fuse size must therefor be in the range of 0.6A to 1A to protect the battery and the system without blowing under normal operation.
Therefor I have chosen to use the RS-pro 1A Fuse.

2.2. Undervoltage Protection

5V-rail Regulator

When working with a 5V it's important to remember that there are two voltage regulators still available. We will be taking the "LM7805" and, "LM2940" linear voltage regulators into consideration. When we examine table 6.5 in the datasheet [5] provided for the "LM2940" it's visible that the dropout voltage consists of a maximum of 1V, while consisting of a representative dropout voltage of 0.5V. When referring to the datasheet [6] for the "LM7805" it will be visible that the typical dropout voltage for the "LM7805" regulator will be 2V. The contributing voltage for the 5V regulator will be the given battery charging grant, and therefore the supply voltage will be near 5V. To make sure that the product of the voltage regulator does not fall below 5V, we will choose the regulator with the lowest dropout voltage. With that being said, the "LM2940" is chosen. The only design that was required for the circuit of the voltage regulator is given by the datasheet [6] of the "LM7805" regulator, which is two shunt capacitors to filter out ripple, one on the input side and one on the output side of the regulator.

High-side Switch

As mentioned in the report before, a high-side switch was created for the charging circuit, refer to Figure **??**. This design will be making use of two resistors in the middle of the grant and the drain of the NMOS. The two resistors will react as voltage divider to guarantee that the V_{sg}, of the PMOS, does not surpass the 20V maximum that was being specified in the provided datasheet. But, in this application, we will be switching the supply after the regulation or from the battery, and the results will be that the V_{supp} voltage will be remarkably lower than 20V and I will not need the R4 resistor. I also do not need the pull-down resistor, R5, at the entrance of the NMOS. Furthermore, we will not be making use of the diode D1. The final circuit design of the high-side switch can be viewed in Figure 2.2.

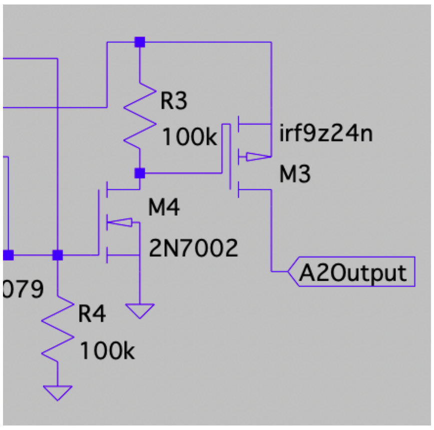

Figure 2.2: Circuit diagram of the system model.

Switch Trigger:

Voltage monitoring with hysteresis

If we are making use of a "MCP6241" op-amp consisting of a 5V upper and 0V lower rail when comparing the two voltages in the order of 6V, then the common mode voltage (in the order of 6 V) will exceed the maximum of $V_{DD}+0.3 = 5.3V$ which is specified in the datasheet provided for the "MCP6241". Regarding this we need to lower our input voltage including the reference. We will be scaling down our voltage signal with R8 and R9 the undervoltage protection circuit. We will need to compare our 1/2 signal to the reference voltage in order of the 3V. Because we want to turn off the load when the voltage drops below 6V and then turn it back on, but only when the voltage exceeds 6.2V, keeping in mind that a simple comparator will not be successful nor work. We will be designing a Schmitt Trigger that will provide the desired hysteresis effect.

Schmitt trigger circuit design

In the provided under-voltage protection circuit resistors, R5 and R6, will be in control of the above-mentioned hysteresis effect. Substantially, they are acting as a voltage divider, between the given reference voltage and V_o of the second op-amp, this then creating a new reference that is depending on the output of the 1st op-amp. The relationship is described by the equation "$V_{ref2} = V_{ref1} + \frac{R_5}{R_5+R_6} \times (V_o - V_{ref1})$".
We have to satisfy two conditions for the dead-band to work. $V_{ref2} = 3.1V$ if $V_o = 5V$ and $V_{ref2} = 3V$ if $V_o = 0V$. Therefor we design resistor values R1, R2, R5, R6 so that it meets the two conditions. To conclude, the circuit design starts with a op-amp circuit to buffer a reference signal then we put in the op-amp acting as the Schmitt trigger, and lastly we add a third op-amp to invert to output to the correct control signal.

Chapter 3

Results

3.1. Undervoltage Protection

The circuit I built and measured is shown Figure3.1, the measurements confirmed the results seen in the simulation shown by Figure3.2.

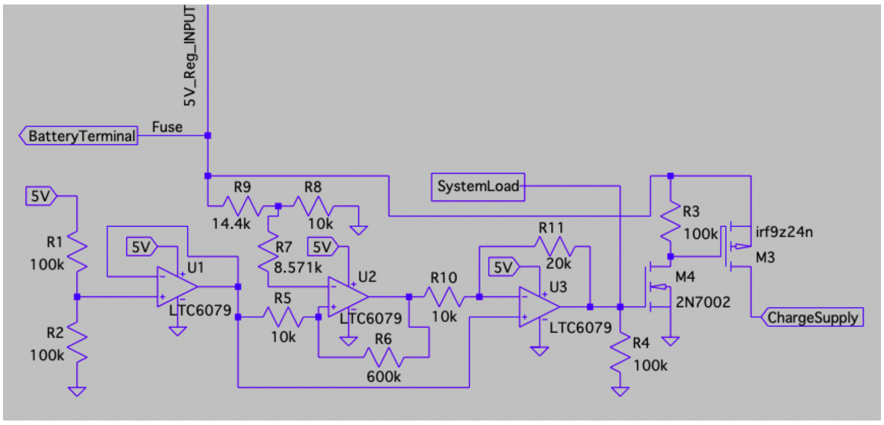

Figure 3.1: Under-voltage Protection circuit.

Figure 3.2: Under-voltage Protection circuit Simulation.

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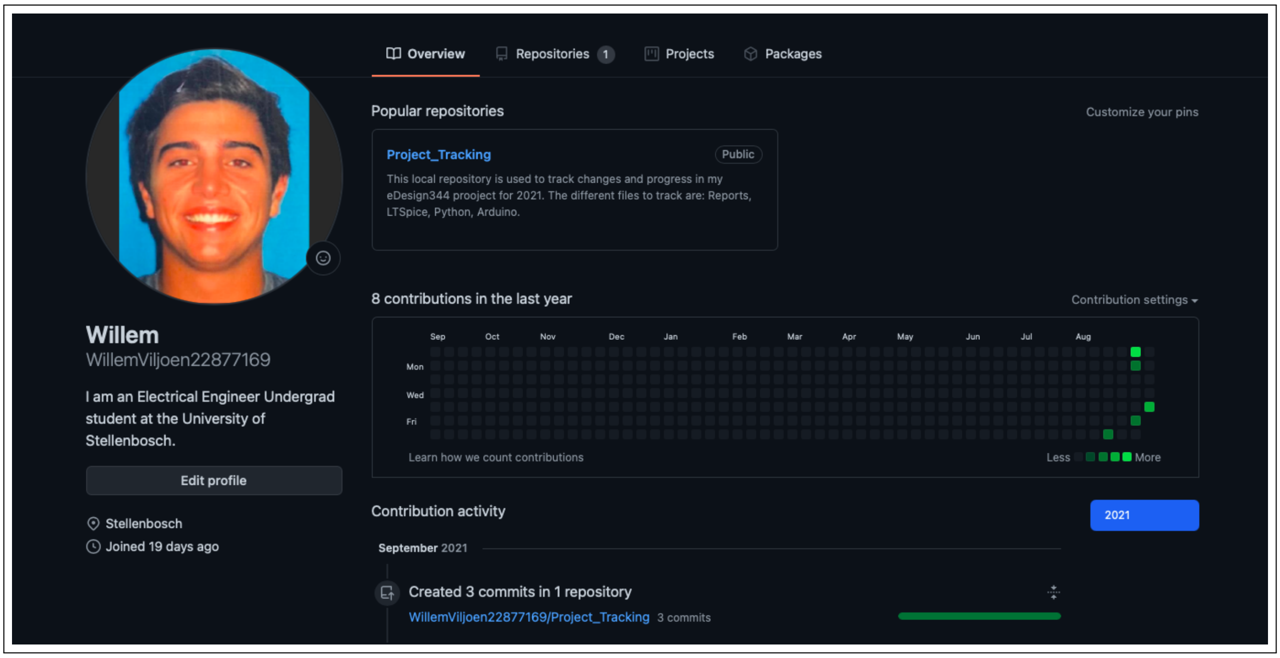
Appendix A

GitHub Activity Heatmap



Appendix B

Social contract

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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, ...Willem Viljoen...................... 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: 2021.08.04 22:12:45 +02'00'

Date: 4 Aug 2021

Student number: ....22877169................

Signature: ....

Date: ....16 Aug 2021..........................

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