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E344 Assignment 2

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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.

20 August 2021

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W. Viljoen Voorletters en van / *Initials and surname*	20 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. Charging Lead-Acid Batteries

Overview

Batteries are known as energy storage devices, and they act as power sources when their potential chemical energy is being converted to electrical energy this being achieved through an electrochemical process. In lead-acid batteries various electrodes are being submerged in an electrolyte, this is a mixture of water and acid and are used to store the energy. The battery we are using for the model will be a lead-acid battery. Figure 1.1 illustrates, with a picture and a diagram, what is taking place in the inside of the battery.

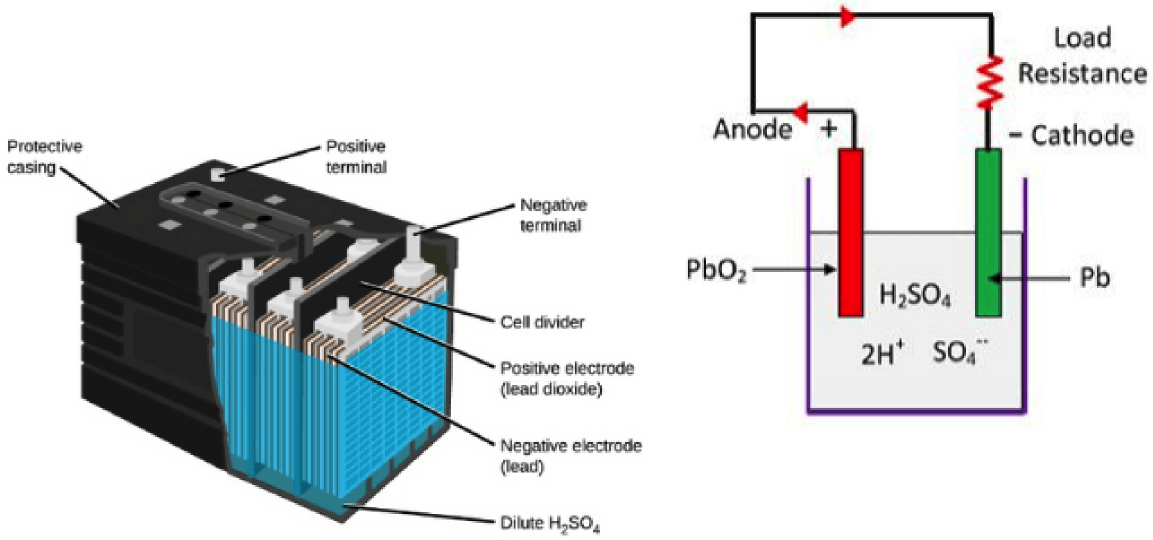

Figure 1.1: Picture and diagram of the inside of a lead-acid battery. [1]

The battery unit consists of a voltage of 6V and has 3 units. Each of the cells consists of a nominal voltage of 2V [3]. When fully charged, the battery possesses an open circuit voltage of 6.4V across the given terminals. It also consists of a rated power of 24Wh.
When the battery is being connected to a load, there will be a small instantaneous drop in the voltage. This drop is due to the internal resistance of the battery. The materials that are making up the battery is opposing the flow of the current. This resistance created, will cause the voltage to drop when current make its way through the battery when a load is connected.

Charging the battery

Power are being supplied to the battery and that charges it. The battery consists of different charging stages, shown graphically, in Figure 1.2. Terminal voltage are being adjusted so that the current will be constant, most of the charging phase occurs in this stage, charging to around 80 % of the battery's total capacity. Terminal voltage are being kept at a constant and this allows for final charging of the battery, as the current gradually decreases. Following that a very small terminal voltage will be applied to maintain the battery charging level. Finally, equalisation will occur. This is when the controlled overcharge is being performed rhythmically to increase the batteries longevity and by reversing negative chemical effects.

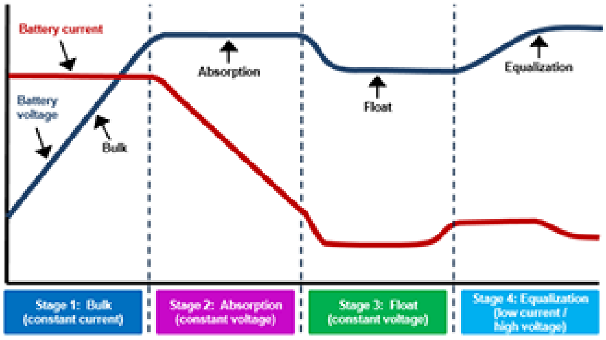

Figure 1.2: The charging stages of a battery. [2]

Discharging the battery

The battery consists of a rated capacity of 4Ah. The rating of these batteries is being measured at 25 °C and at a discharge rate of 1C. This indicates that, at a rated capacity of 4Ah, the battery will successfully provide 4A of current for approximately an hour. This will be achieved because the capacity will be influenced by the rate of the discharge and temperature. Generally, it's suggested to only use roughly 20 % of the battery's capacity to increase its longevity. Moving beyond this point can possibly damage the battery's ability to store energy. From the provided datasheet [3] of the battery, we are able to witness the discharge characteristics (graphically) in Figure 1.3.

The self-discharge ratio is less than 3 % per month at 25 °C. The ratio of the self-discharge expands as temperatures expands. Based on the ratio of the self-discharge, the battery will be able to be stored for a few months without having to recharge. Depth of discharge (DoD) or state of charge (SoC) will be monitored to avoid causing damage to the battery. As mentioned, from the datasheet [3] of the battery you can witness the self-discharge characteristics graphically in Figure 1.4.

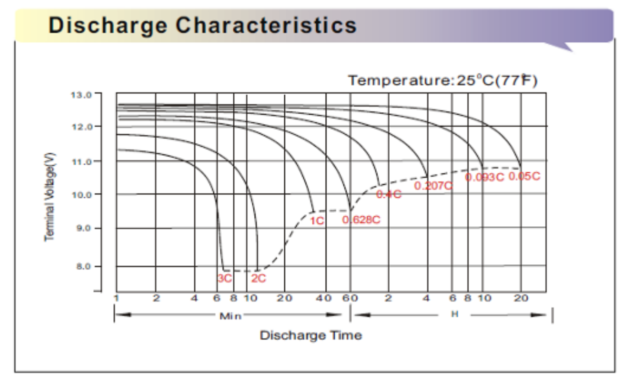

Figure 1.3: Battery datasheet extract 1.

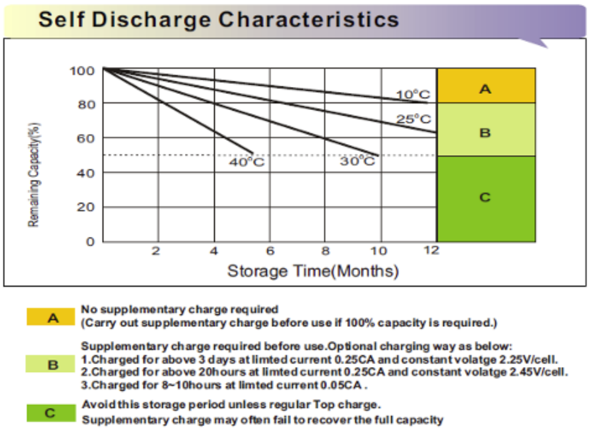

Figure 1.4: Battery datasheet extract 2.

1.2. Thermal Analysis and Heat Sinking

Type something here...

Chapter 2

Design

2.1. High Side Switch on Supply Side

The high side switch is used to switch the supply on or cut it off and is triggered with a control signal. This circuit is constructed with the use of 2 MOSFETs, resistors and a diode. The MOSFETs that we can use is the IRF9Z24NPBF PMOS and the 2N7000 NMOS. The Schottky diode is used to eliminate opposite voltage polarity, to insure no current flows into the supply source. With the use of the MOSFETs in the circuit we want to understand the requirements when they should allow or prevent current to flow. For the NMOS, the close switch state conditions are that the gate to source voltage, should be greater than the threshold voltage, which is 2.1V. For the PMOS to allow current to flow, the source to gate voltage, must be less than the threshold voltage, which is 2V. a Pull down resistor is required at the node which connects the control signal to the NMOS. Another resistor is added to scale down the switch on voltage of the PMOS which then allows current to flow through. When die control signal is set low, the NMOS wil by in the closed switch state to connect the supply to ground and no current will flow. The circuit is shown in Figure3.1.

2.2. Charging Regulator

Overview

We were informed to use the "LM317T" regulator supplied to us in the charging circuit, this is because it's versatile and can be of provision for both current and voltage requirements. The circuit that influenced the design we are using in this given project was established in the datasheet [4] of the "LM317". When reviewing the application notes of the provided datasheet, a charging circuit should be found. This extract consists of component values, however, we have to keep in mind that the values for this given project will be calculated below. Also the behavior of the regulator will change over time while it is in use, mainly due to thermal effects e.g. $T_{amb} and T_j$, these changes are eliminated by mounting the given heat sink [5] to the regulator and sealing the air gap with a given thermal gap pad [6].

Circuit Design

The charging voltage for the battery we are using in this project can successfully be estimated by examining the table labelled "Charging Method" in the provided datasheet [4]. When referring to the table in the datasheet [4] you will see that it states a fixed voltage of 2.4V per cell and that this must be used for the fixed voltage method. Consequently, the output voltage of the charging circuit will be 7.2V. This will be the output voltage for a low current draw, basically referring to when the battery is fully recharged. In this state, the voltage drops over the high-side switch and the diode are presumed to be 0.1V. With that stated, the output voltage of the regulator must be $V_o = 0.1 + 7.2 = 7.3$V. The resistors R_a and R_b visible in my circuit in the subsystem chapter for the charging regulator were calculated in the following manner:

The the datasheet [4] for the "LM317" provides the minimum output current needed for the voltage to be regulated is 3.5 to 5 mA. Thus the minimum current to safely choose is $I_{min} = 8.3$ mA. Then R_T is calculated to be $R_T = \frac{V_o}{I_{min}} = \frac{7.3}{8.3\times10^{-3}} = 880\Omega$. Applying the equation "$V_o = V_{ref} \times (1 + \frac{R_T - R_a}{R_a})$" provided in the datasheet [4] R_a was determined to be 152Ω. $R_T = R_a + R_b$, therefor $R_b = 728\Omega$. Finally to reduce the current drawn, the resistance of R_a and R_b are scaled up proportionally to give us $R_a = 1k\Omega$ and $R_b = 4.7k\Omega$.

We must now take in consideration the current limit and calculate R_s from there to complete the voltage regulation for the charging circuit.

Current Limit:

The charging current was selected lower than the maximum charging current of 0.3 $\frac{C}{s}$ and a rate of 0.1 $\frac{C}{s}$ were chosen as endorsed the datasheet [4]. R_s has notably been placed there to administer the battery's charging current. The more abundant the current is that flows through the regulator, the bigger and greater the voltage drop over the resistor R_s will be. Because the voltage regulators output is dependent on the given potential difference between that is visible between the output and adjust terminals, the expression for calculating R_s can be determined successfully. Making use of the formula that is needed for calculating R_s derived in Appendix B.1 of datasheet [4], it can be determined that $R_s = 0.5\Omega$. This given value was evaluated in an LTSpice simulation and was proved to be, approximately, the correct resistance, but some fine-tuning was required. The resistor value was tuned to $R_s = 0.4\ \Omega$.

Chapter 3

Results

3.1. High Side Switch

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

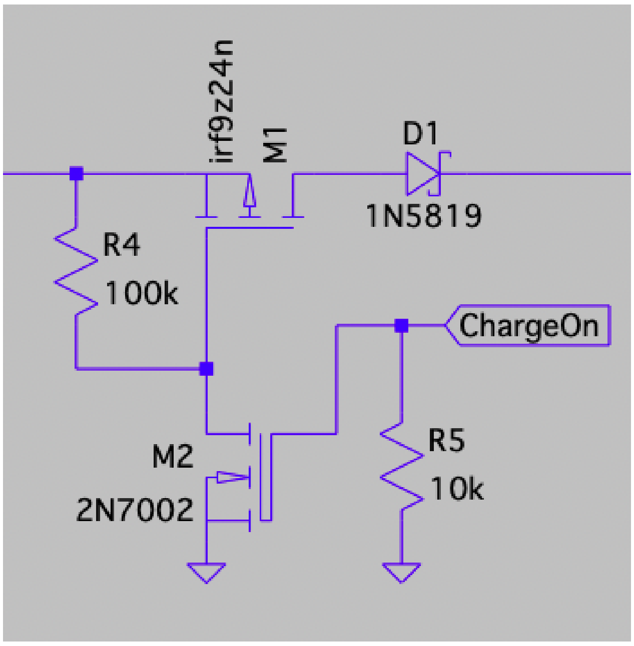

Figure 3.1: High-side Switch on supply side.

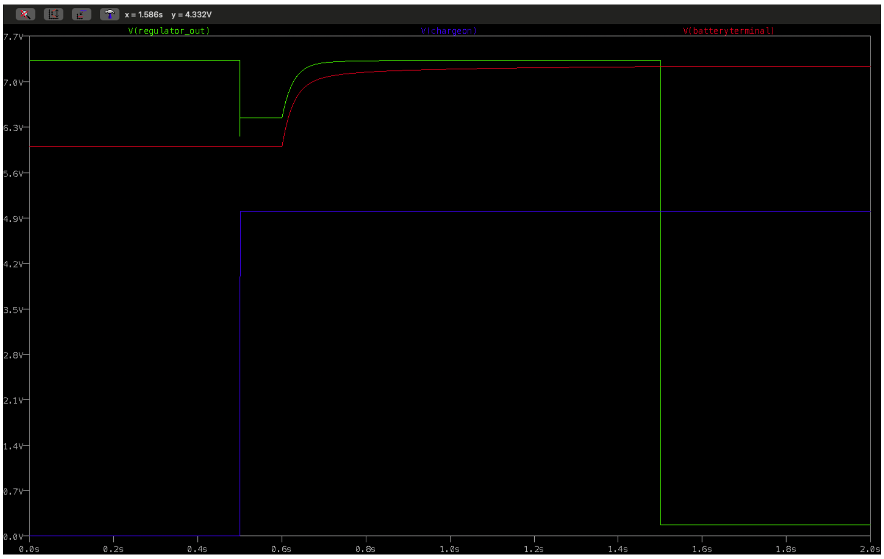

Figure 3.2: High-side Switch Simulation.

3.2. Charging Regulator

The circuit I built and measured is shown Figure3.3, the measurements confirmed the results seen in the simulation shown by Figure3.4.

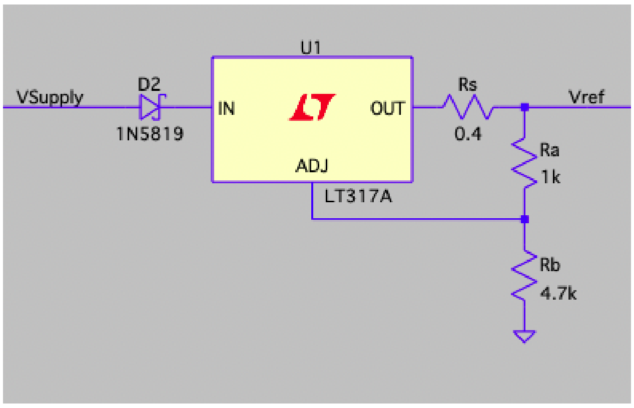

Figure 3.3: Charging Regulator.

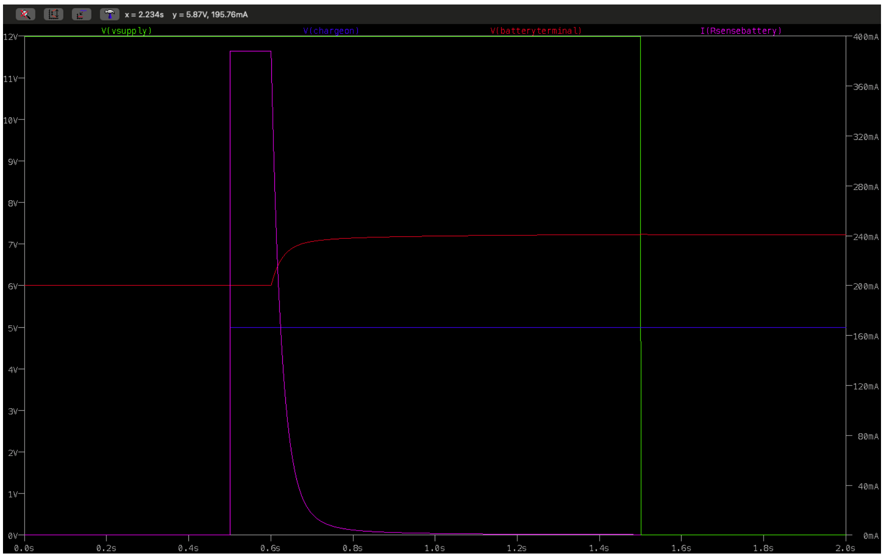

Figure 3.4: Charging Regulator Simulation.

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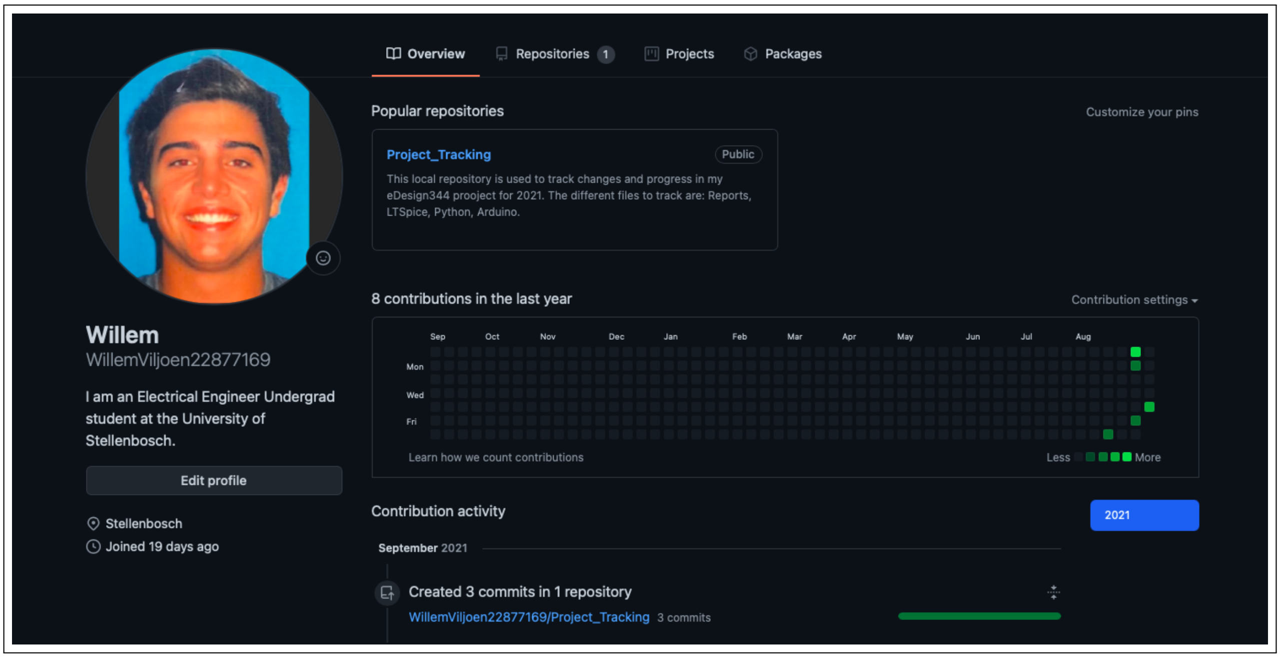
[6] RS PRO, “Datasheet non-silicone thermal gap pad,” 2009. [Online]. Available: https://learn.sun.ac.za/pluginfile.php/2909377/mod_resource/content/1/Non-Silicone_Thermal_Gap_Pad.pdf

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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