UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

E344 Assignment 6

Willem Viljoen
22877169

The parts relevant to A6 is displayed *red* in the table of Contents.

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.

2 October 2021

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

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.

22877169 Studentenommer / *Student number*	Handtekening / *Signature*
W. Viljoen Voorletters en van / *Initials and surname*	2 October 2021 Datum / *Date*

Contents

List of Figures

List of Tables

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. Battery

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.

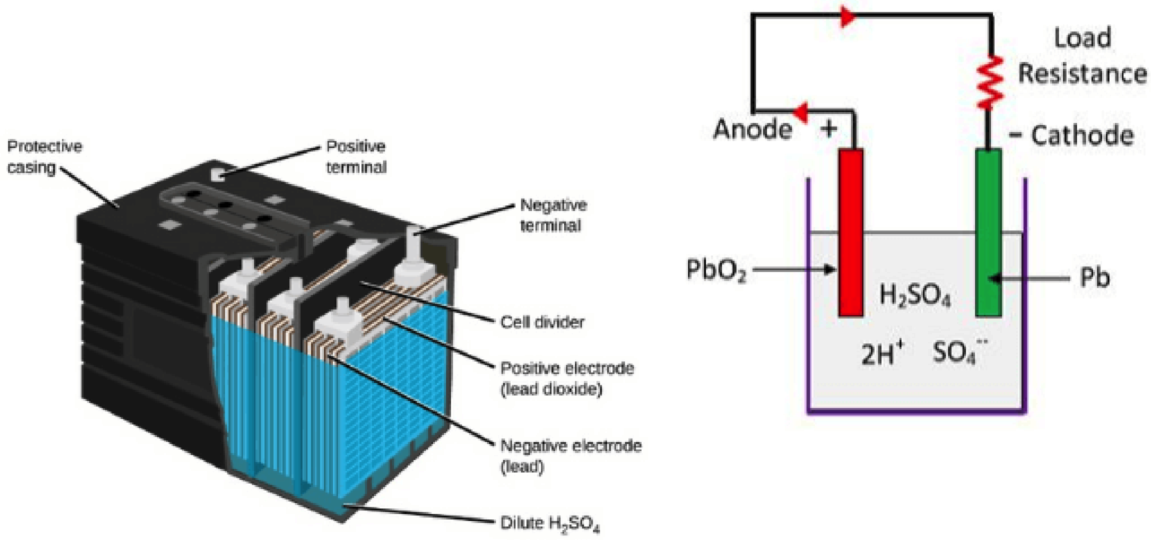


Figure 1.1: Picture and diagram of the inside of a lead-acid battery. [1]

The battery unit consists of a voltage of 6V and has 3 units. Each of the cells consists of a nominal voltage of 2V [6]. 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.

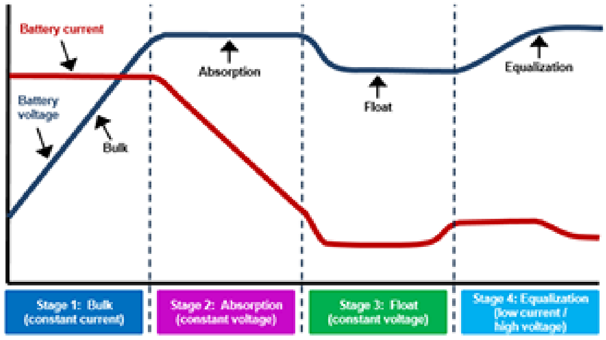


Figure 1.2: The charging stages of a battery. [2]

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 [6] 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 [6] of the battery you can witness the self-discharge characteristics graphically in Figure 1.4.

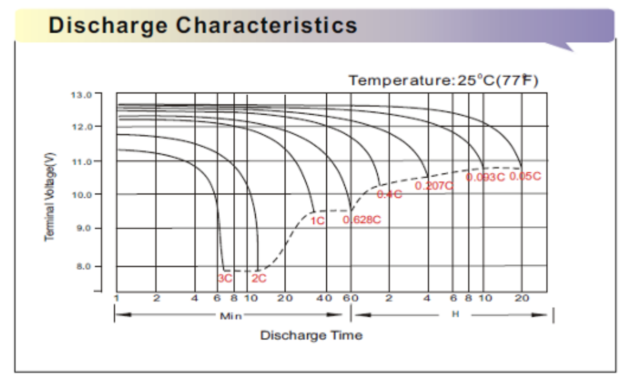


Figure 1.3: Battery datasheet extract 1.

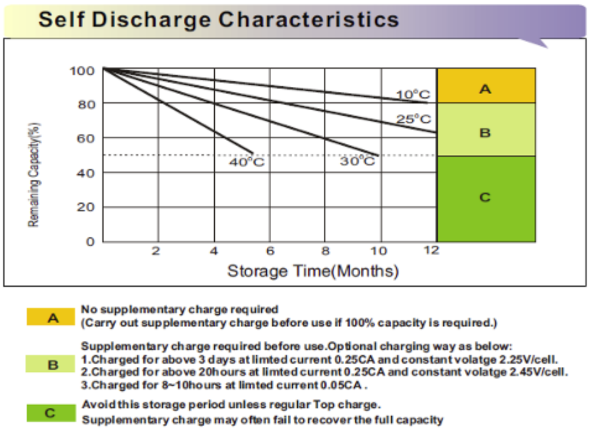


Figure 1.4: Battery datasheet extract 2.

1.2. Solar Module

Solar PV cell

Device that transforms the energy of light into electricity, and this is being done with the photovoltaic effect and it can be arranged in a specific way to form solar modules and arrays.

Structure

A PV cell is embodied of a pn-junction which is bordering the positive and negative doped semiconductor sectors and electrodes which controls the charge in the given regions and allows for the current to flow, anti-reflection coating and protective layers. A realistic and applicable example can be seen in Figure 1.5

Operation

Photons in sunlight can be soaked up, reflected or it can pass directly through a PV cell. When light is being absorbed, a solar module will be created by successfully connecting a P-type semiconductor and a N-type semiconductor with each other. Overabundance electrons in N-type will infuse the holes in the P-type (around the junction). This will carry on until equilibrium is achieved. A tiny region encircling the junction will have the opposite polarity to their doped regions. This will then create an electric field combating the flow of the current

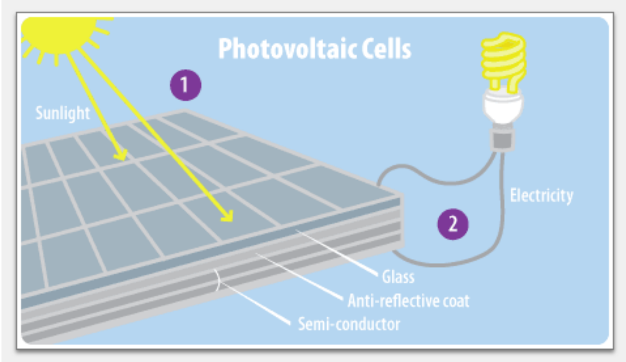


Figure 1.5: Simple solar panel model. [3]

(acting as a switch), this is called the depletions region. When photons from the sunlight hit the pn-junction it will energize the electrons and allow them to move cross the depletion region. The current will begin to flow.

Efficiency of a polycrystalline PV module

When we convert solar energy (irradiance) to electrical energy there will be a little bit loss of energy. With regards to *Geotherm* [7], the module's cells consists of an efficiency of around 13-16 %.

Power characteristics of the solar PV module

With regards to the open circuit analysis the prospective difference was taken over the terminals when no current was drawn, thus leading to a maximum voltage over the terminals. Regarding a short circuit analysis, the terminals at the output are being connected, therefore there appears to be zero voltage over the terminals, leading to maximum currents being drawn. Polycrystalline silicon solar cells (in commercial modules) appear to commonly have open-circuit voltages of roughly 0,6V. Cells are being connected in series to supply and achieve a higher voltage and deliver more power. The solar module we use for our design has a V_{OC} of 21.6V and a I_{OC} of 0.34 A. We know that the maximum power point (MPP) is the highest output power that the device is able to deliver. Power can be displayed as $P = V \times I$. MPP can be achieved by the I-V curve 1.6. Drawing a graph of the product and including every voltage and its corresponding current is helpful. This will provide you with the supplied power since it's an active device. This highest value seen on this graph will be the value of the MPP. We know that there are 36 cells in the solar module and each of these cells individually has an open circuit voltage of 0.6V. The rated output power of the solar PV, Pmax is 5W. Readings were done on the solar module and can be viewed in Table 1.7.

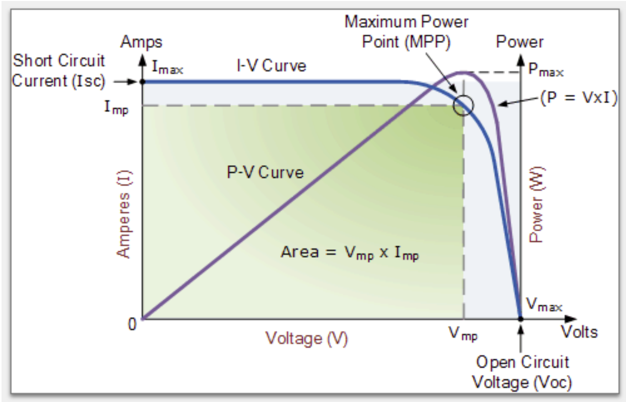


Figure 1.6: I-V curve. [4]

Tests	Isc	Voc
Dark (covered)	0 A	0 V
Indoors	495 mA	4.7 V
Ambient light	10.72 A	15.41 V
Oblique sunlight	139 A	20.46 V
Perpendicular sunlight	219 A	21.26 V

Figure 1.7: Readings done on solar module.

1.3. Fuse Protection

The average temperature in South Africa is 27°C in according to *weather-and-climate.com* [8], but tests done by *sustainable.org* [9] 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 [6]), 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

Chapter 2

System Design

For the model system I have developed, tested and reported a solar-powered light source. The power sources of this section are a 5W solar PV module and a 12 V (2 A) AC-DC power adapter. The design will be making provision for a battery backup while making use of a 6V lead acid battery. This acid battery will be able to recharge from the two power sources provided and mentioned. The displayed design will prevent the battery from charging too fast (keeping the charging V and I control in mind), and it will also prevent the battery from overcharging (by something called; overcharge protection). The design will successfully ensure that the battery will not be discharged past its suggested levels, undervoltage protection, and it will prevent high-current discharging (overcurrent protection). The circuit will be making use of a sensor because it wants to be able to measure the ambient light level. It also wants to turn on the LED load appropriately. The circuit will be making a variety of measurements available and this through a serial connection on a user interface on a PC, and this will allow control of the light source coming from the user interface. The conceptual design of the system is open for preview in Figure 2.1. The elements covered so far in the system design is:

– Battery and solar photovoltaic
– Voltage regulation
– Highside switch on supply side
– Overcurrent protection
– Undervoltage protection
– Current sense
– Lowside switch

The design of the elements mentioned above is shown in the content of the report and we can see the full circuit diagram of the system in Figure 2.2.

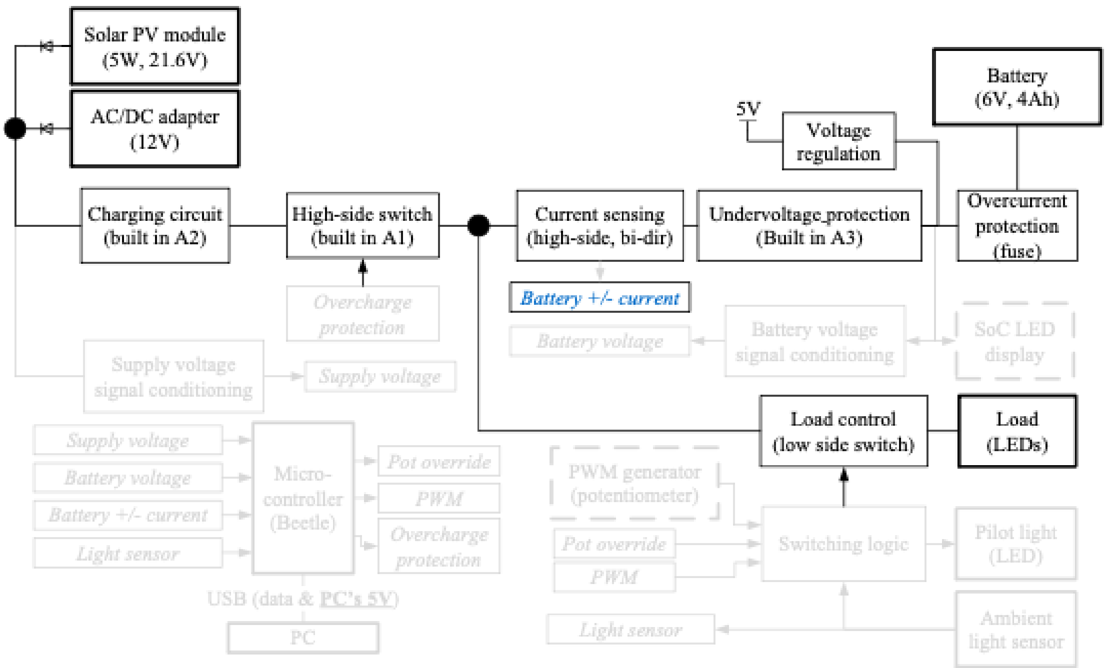


Figure 2.1: Flow diagram of the system model.

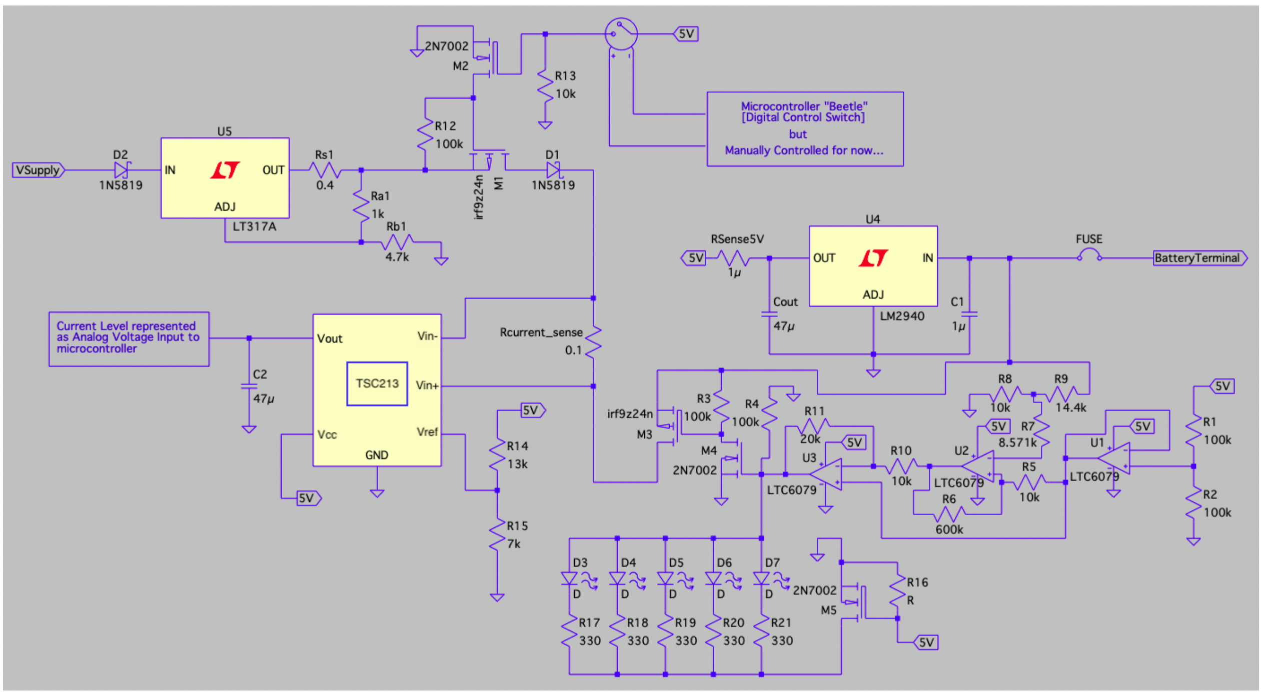


Figure 2.2: Circuit diagram of the system model.

Chapter 3

Detail Design

3.1. Voltage Regulation

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 [10] 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 [11] to the regulator and sealing the air gap with a given thermal gap pad [12].

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 [10]. When referring to the table in the datasheet [10] 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 [10] 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 [10] 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 [10]. 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 [10], 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 $R_s = 0.4\ \Omega$.

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 [13] 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 [14] 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 [14] 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.

3.2. 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 Figure4.5.

3.3. Overcurrent Protection

Assuming that a maximum temperature of 50°C will be reached, the following calculation can be made: According to *littlefuse.com* [5], Catalog Fuse Rating = $\frac{NormaloperatingCurrent}{0.75 \times PercentofRatingattemperature}$
.

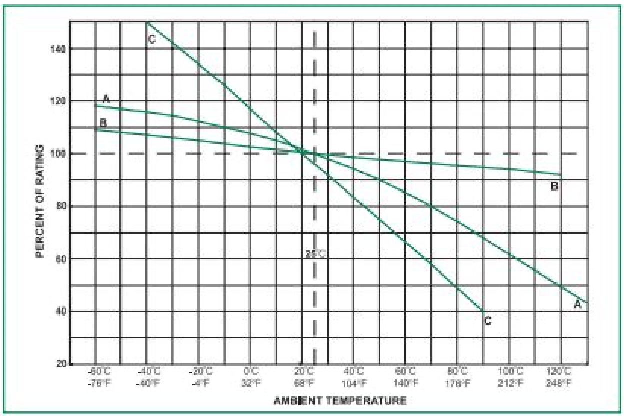


Figure 3.1: Following the graph of B for blade fuses: [5].

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.

3.4. Undervoltage Protection

Overview

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.

High-side Switch

As mentioned in the report before, a high-side switch was created for the charging circuit, refer to Figure 4.5. 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 3.2.

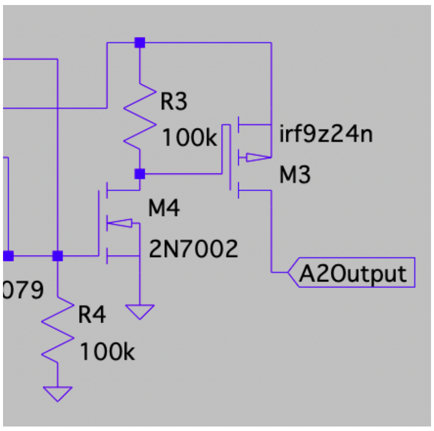


Figure 3.2: Circuit diagram of the system model.

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.

3.5. Current Sense

Bidirectional current sensor is connected over a resistor called Rsense. This resistor is placed in series between to battery and the load. It has a very small resistance such that its power dissipation can be neglected, and its tolerance is also very small so that the resistance value is accurate enough to give a more precise current reading through it. Then an op-amp is connected in parallel over the sense resistor with the inverting and non-inverting input terminals of the op-amp. The op-amp produces an amplified voltage signal of the potential difference over the resistor because of the high gain of the op-amp. This voltage signal is proportional to the voltage over the resistor and according to ohms low it is also directly proportional to the current through the resistor. Therefor output of the op-amp now follows the current flowing between the battery and the load and is scaled to represent the current level as an analog signal. We use the "TSC213" op-amp because it has a large enough gain to amplify to small voltage across Rsense. When the battery is charging 150 mA flows through Rsense which has a resistance of 0.1Ω and 450 mA will flow through Rsense in the opposite direction when the battery dis-charges to full-load. Because of the bidirectional current flow, a zero-reference voltage is required for the op-amp to determine the direction of the current in terms of its voltage output analog signal. a Reference voltage, V_{ref}, is designed for maximum swing while staying in range of the rail voltages of the op-amp. We determine this V_{ref} using the following equations provided by the datasheet op the TSC213 op-amp: "$\Delta V_{out} = \Delta V_{out(charge)} + \Delta V_{out(discharge)} = 3V$" and "$V_{ref} = \frac{5-3}{2} + \Delta V_{out(charge)} = 1.75V$". Furthermore two resistors is designed to apply voltage division to the 5V rail voltage, available for the circuit, to produce the V_{ref} voltage for the op-amp. Thus R1 and R2 is determined with a simple voltage division calculation and then scaled up to prevent unnecessary power dissipation in the resistors, to get the values of $R1 = 13k\Omega$ and $R2 = 7k\Omega$. Lastly the capacitor is placed at the output of the op-amp to filter out the signal, a 47μF capacitor is chosen, it's capacitance is high enough so that the signal is filtered good but not too high otherwise the output will become sluggish.

3.6. Low-side Switch

The given design requires a low-side load control that will help it to manage the current flow to 5 displayed indistinguishable bright LEDs. The low-side load control will be embodied out of a NMOS which will act as a switch to the LEDs and when it receives a control signal of 0V and 5V it will be able to turn on and off. Every one of the LEDs will be drawing 20mA of current, with a battery voltage of V_{bat}=7.2V, this will then lead to total current drawn by the load of 100mA. To be able to successfully meet this present requirement, each LED will need to consist of a current limiting resistor that is connected in series and needs to be designed to limit the current to meet the desired amount for the LED. The mentioned 5 ultra-bright LEDs will be drawing 20mA(each) which we will call, I_{LED}. The LEDs have voltage aimed forward of 3.2V which we will label V_F and the value of the current limiting resistor, R_{lim}, will be calculated by making use of the equation: "$R_{lim} = \frac{V_{bat}-V_F}{I_{LED}}$", and as a result we will get $R_{lim} = 200\Omega$. For the NMOS that preforms the switching we will need a pull down resistor of $10k\Omega$ to get to correct V_{gs} voltage from the 5V rail voltage available to us. See Figure4.11.

3.7. Supply Voltage Signal Conditioning

In this provided section of the circuit we desire to make use of the input of the system which are the solar panel or AC adapter to be able to receive an analogue signal. If completed, we can send it to the Beetle MCU's ADC peripheral to further the process of further use. Firstly, we need to make sure we regulate the voltage to a level at which the ADC peripheral can positively handle it. Most of the known MCU's makes use of 5V as the power supply and therefore, we intentionally designed the output of the provided circuit to stay below the above mentioned value. We achieve this by making use of a simple voltage divider in the circuit. The formula: "$V_{out} = (\frac{R1}{R2} + R2) \times V_{in}$" is used to determine the resistor values, with $V_{out} = 5V$ and $V_{in} = 22V$. From the above mentioned, the ratio of R1 : R2 is 5 : 17. I then went ahead and chose my resistor values as $R1 = 100k\Omega$ and $R2 = 27k\Omega$ because these values were easily achievable. It's also important to know that the signal is receptive to noise and therefore, it's important to address it. To resolve the provided issue we went ahead and added a simple RC filter. This filter is specially designed to suppress noise up to 1kHz. A resistor value of $1.5k\Omega$ was then chosen, from there the capacitor value was calculated with the following formula: "$f_{cut-off} = \frac{1}{2\times\pi\times R\times C}$". The capacitor value was proved to be $C = 106.1nF$. a Final value of $100nF$ was chosen because it doesn't affect the desired cut-off frequency and is easy accessible.

3.8. Battery Voltage Signal Conditioning

This given section of the circuit successfully achieves the same target as the supply voltage section, only this time with the battery voltage. Identical restrictions apply with regards to the respect to the ADC maximum voltage. In this given circuit we want to place our focus on the battery voltage and convert the 5.7V - 7.5V to a signal that ranges from 0V - 5V. To achieve this we will make use of an op-amp to initiate a comparison with the constant reference voltage to the battery voltage and then achieve an output in which the signal is increasing with the same correlation as the battery voltage. The first we did was regulated the battery voltage in half because taking into consideration that the rail voltages of the op-amp are to be 5V and we can't exceed that. Two identical resistors are used of to do this each with values of $10k\Omega$. Following this, the reference voltage was generated by regulating the 5V source. The desired design is based around the voltage of the battery and when it's at 5.7V, following the regulation it will be 2.85V. Therefore, the reference voltage will be chosen as 2.85V this is done to use the 5.7V as the new "0V". As the voltage increases to 7.5V we want the output to reach a maximum of 5V (in order to not exceed rail voltages). The formula: "$V_{out} = (\frac{R4}{R3} + R3) \times V_{in}$" was used to obtain the resistor values, with $V_{out} = 2.85V$ and $V_{in} = 5V$. From this the ratio of R4 : R3 is 2.85 : 2.15. I therefore chose my resistor values as $R4 = 57k\Omega$ and $R3 = 43k\Omega$, because these resistor values were easily accessible. A buffer will be used to ensure that the feedback voltage doesn't affect the constant reference voltage. Following this, these values will be placed in comparison and the output will be amplified using the op-amp. The resistor ratio was calculated making use of the formula: "$V_{out} = \frac{R_f}{R1} \times$ (V_2 - V_1)", using the reference voltage and the maximum battery voltage as $V_1 = 2.85V$ and $V_2 = 3.75V$. R1 was chosen with the value of $10k\Omega$. A value of $55k\Omega$ for R_f was finally achieved. After simulating the value in LTSpice to ensure that the output increases (with the same ratio as the battery input voltage) a more suitable value of $82k\Omega$ was established to be chosen.

Chapter 4

Subsystem and Results

4.1. Voltage Regulation

Charging Regulator:

The circuit I built and measured is shown Figure4.1, the measurements confirmed the results seen in the simulation shown by Figure4.2.

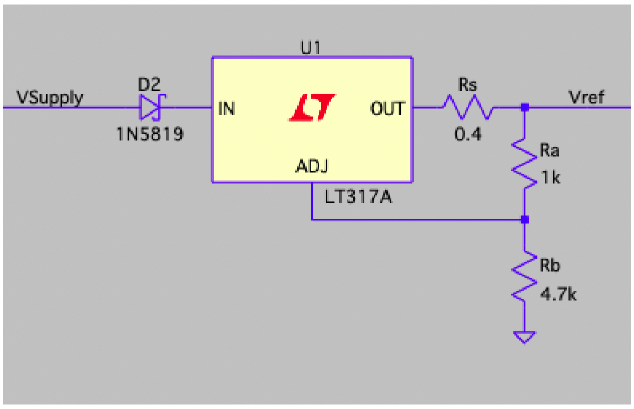


Figure 4.1: Charging Regulator.

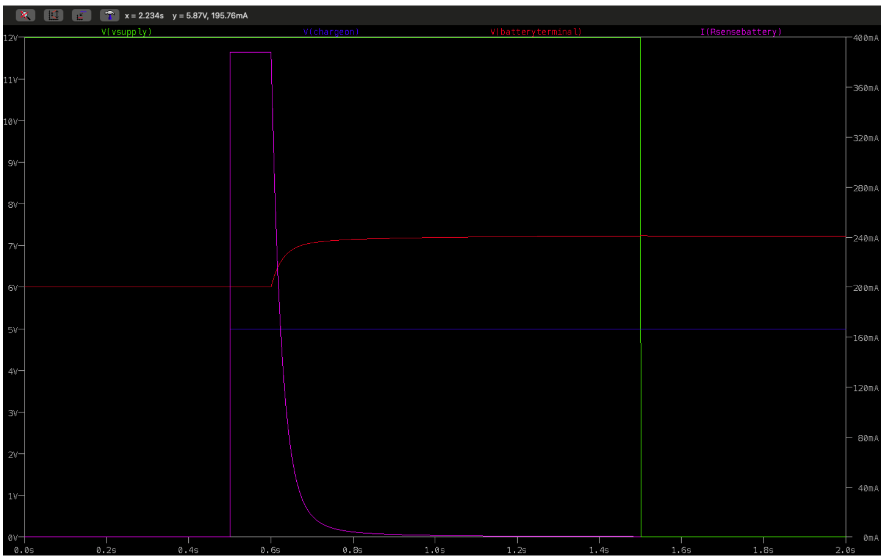


Figure 4.2: Charging Regulator Simulation.

5V-rail Regulator:

The circuit I built and measured is shown Figure4.3, the measurements confirmed the results seen in the simulation shown by Figure4.4.

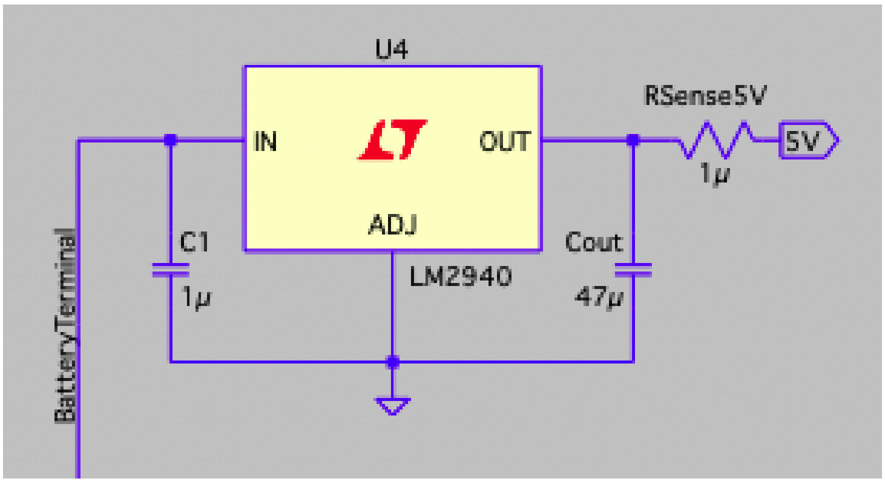


Figure 4.3: 5V rail voltage regulator.

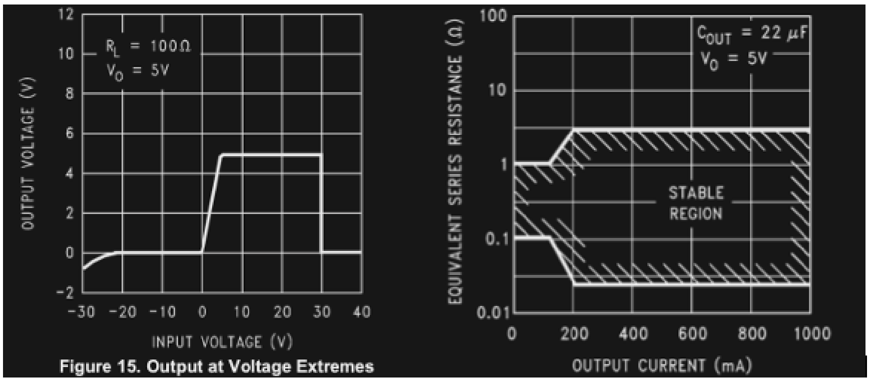


Figure 4.4: 5V rail voltage regulator Simulation.

4.2. High Side Switch on Supply Side

The circuit I built and measured is shown Figure4.5, the measurements confirmed the results seen in the simulation shown by Figure4.6.

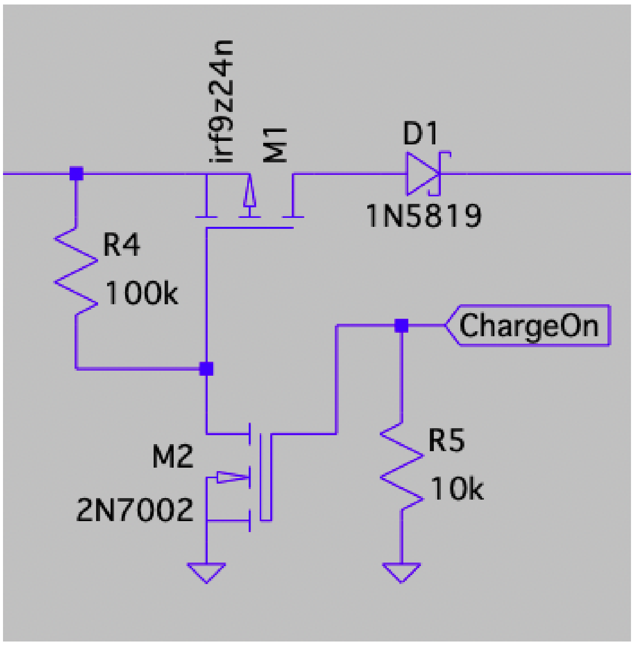


Figure 4.5: High-side Switch on supply side.

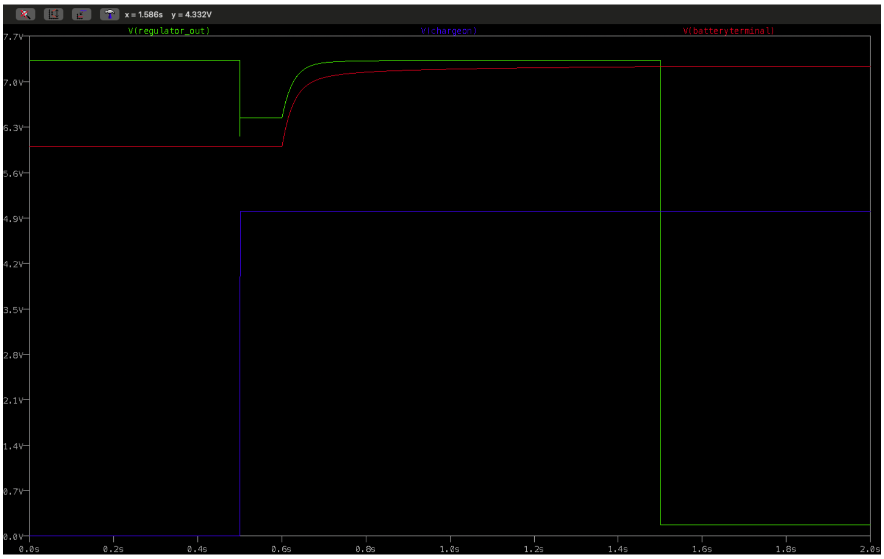


Figure 4.6: High-side Switch Simulation.

4.3. Undervoltage Protection

The circuit I built and measured is shown Figure4.7, the measurements confirmed the results seen in the simulation shown by Figure4.8.

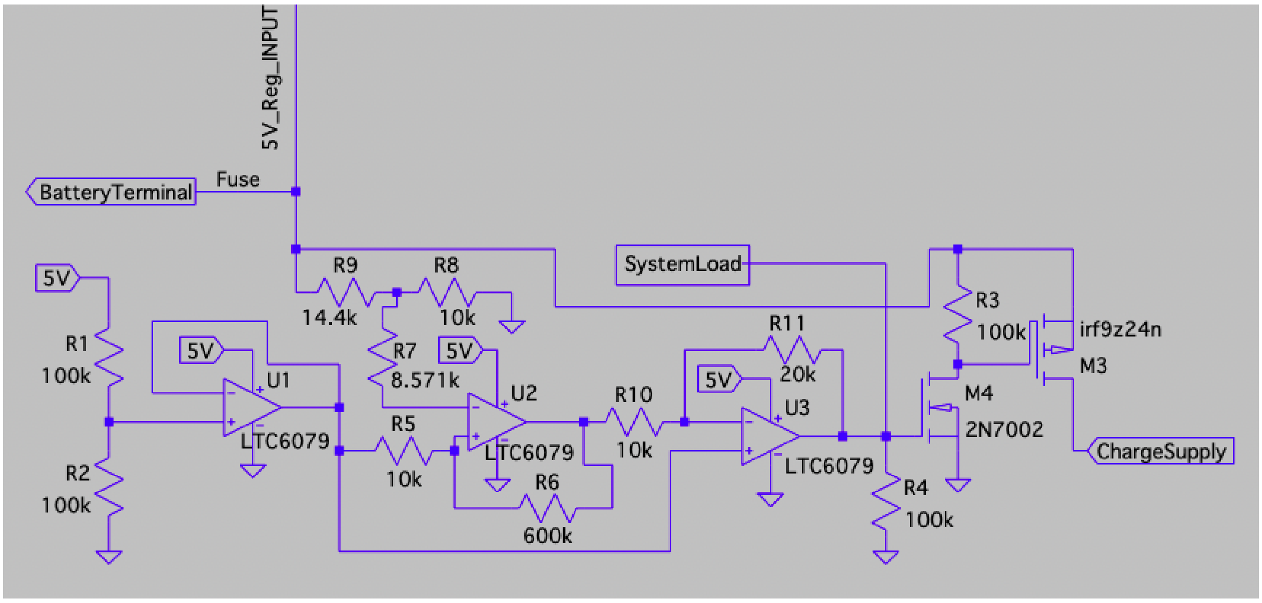


Figure 4.7: Under-voltage Protection circuit.

Figure 4.8: Under-voltage Protection circuit Simulation.

4.4. Current Sense

The circuit I built and measured is shown Figure4.9, the measurements confirmed the results seen in the simulation shown by Figure4.10.

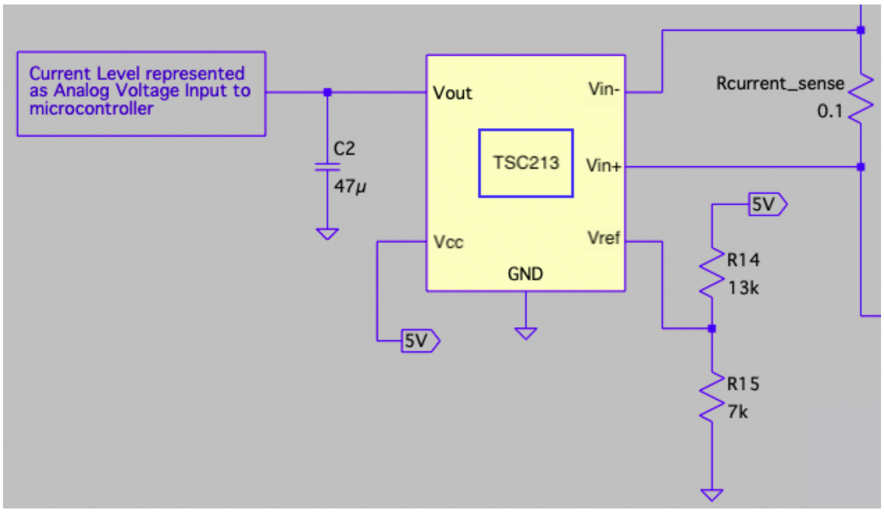


Figure 4.9: Current sense circuit.

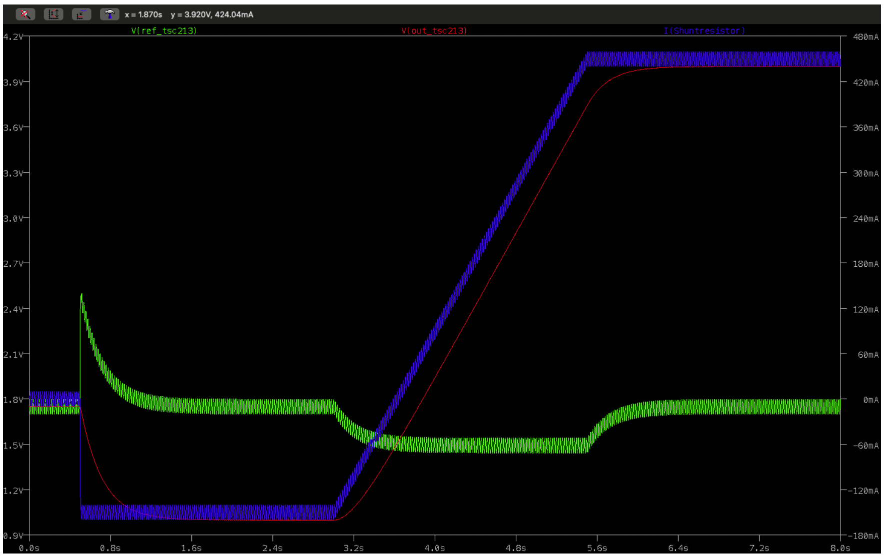


Figure 4.10: Current sense circuit Simulation.

4.5. Low-side Switch

The circuit I built and measured is shown Figure4.11, the measurements confirmed the results seen in the simulation shown by Figure4.12.

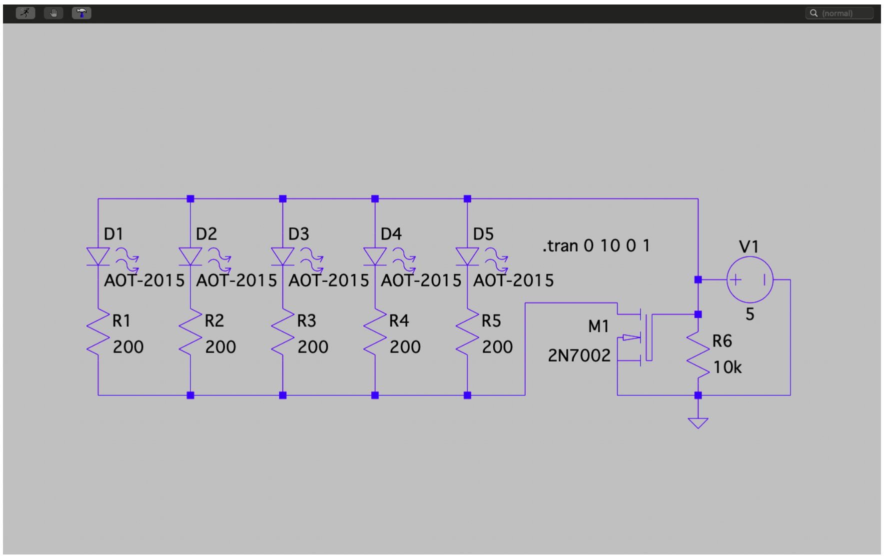


Figure 4.11: Low-side Switch and LED load circuit.

Figure 4.12: Low-side Switch and LED load circuit Simulation.

4.6. Supply Voltage and Battery Voltage Signal Conditioning

The circuit I built and measured is shown Figure4.13, the measurements confirmed the results seen in the simulation shown by Figure4.14.

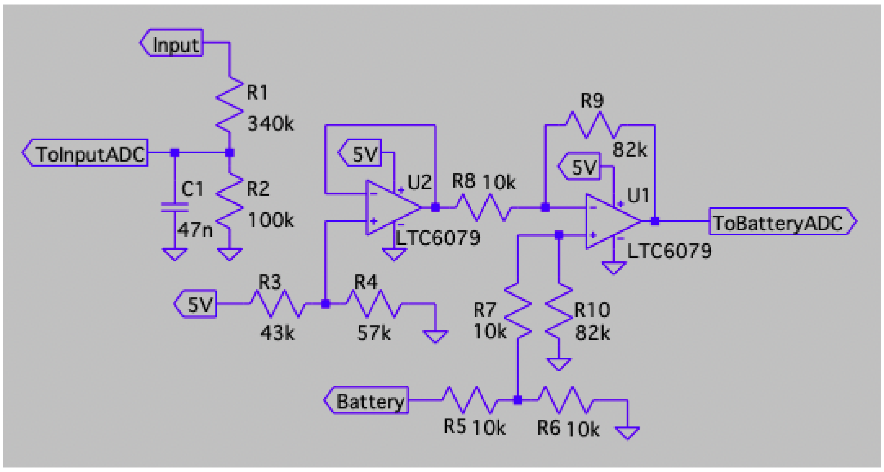


Figure 4.13: Current sense circuit.

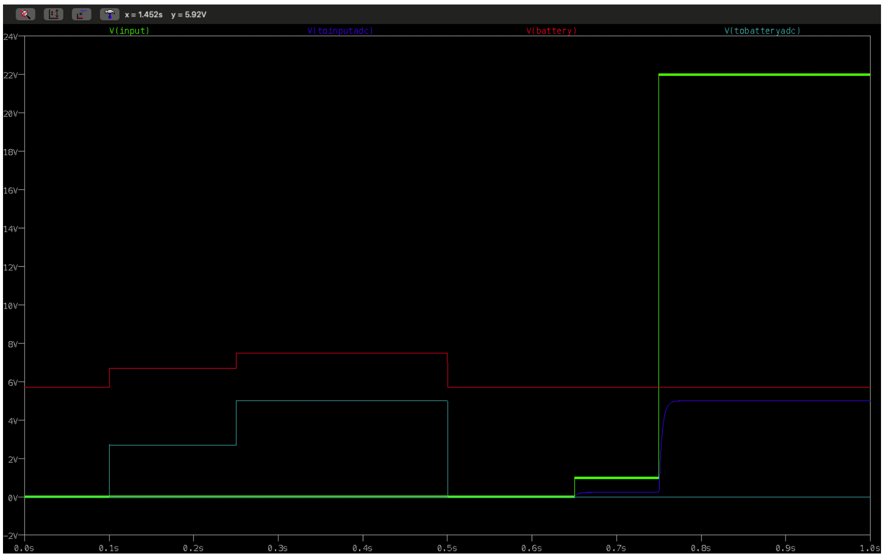


Figure 4.14: Current sense circuit Simulation.

Chapter 5

System Practical Model

Type something about PracCirc here...

See Figure 2.2 that shows my full circuit diagram from which the model is built.

Figure 5.1 shows my circuit built of the model.

Figure 5.2 shows close up my student card and barcode 061.

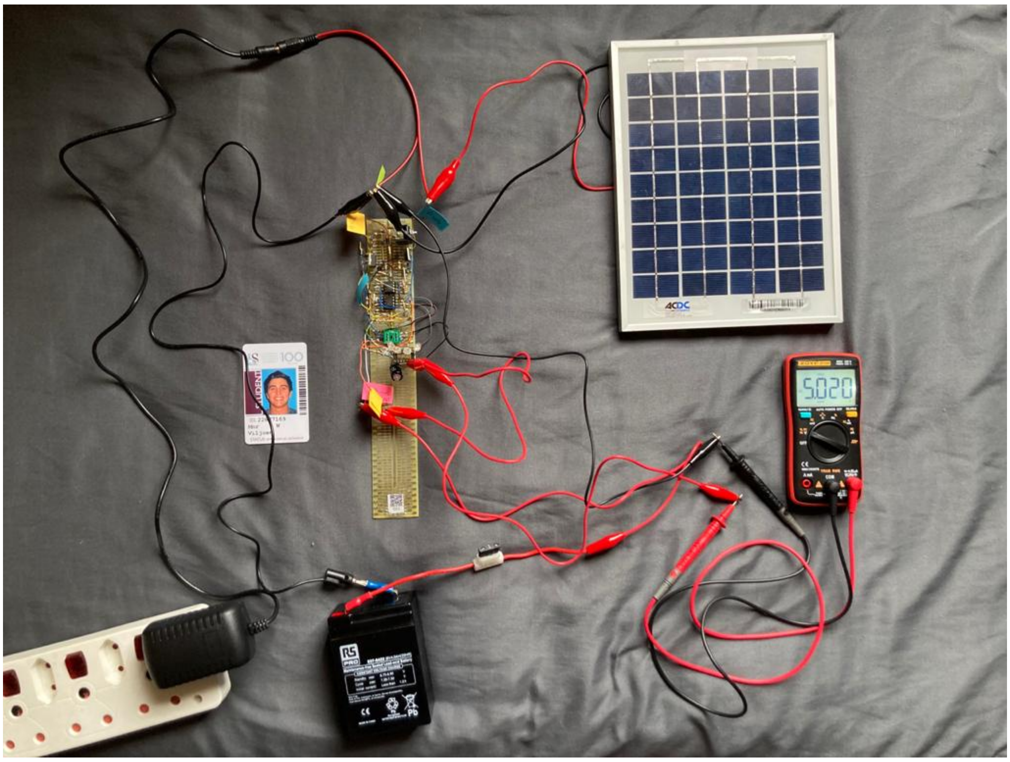


Figure 5.1: Practical model built of the circuit.

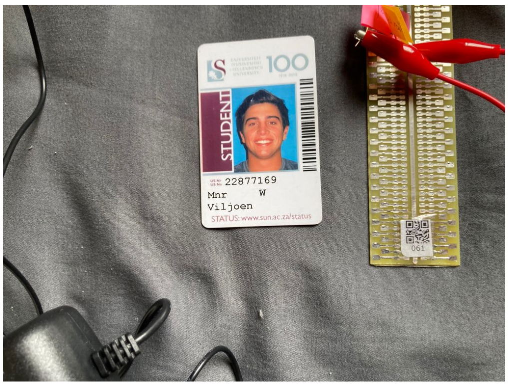


Figure 5.2: Studentcard and barcode close up.

Bibliography

[1] Electrical4U, "Working of lead acid battery," 2020. [Online]. Available: https://www.electrical4u.com/working-of-lead-acid-battery-lead-acid-secondary-storage-battery/

[2] ChargeTek, "Battery charger basics," 2015. [Online]. Available: https://chargetek.com/basic-information.html

[3] Global Climate Change, "Solar enery," 2017. [Online]. Available: https://archive.epa.gov/climatechange/kids/solutions/technologies/solar.html

[4] Alternitavie Energy Tutorials, "Solar cell i-v characteristic," 2010. [Online]. Available: https://www.alternative-energy-tutorials.com/photovoltaics/solar-cell-i-v-characteristic.html

[5] LF, "Littelfuse fuses," 2000. [Online]. Available: https://www.littelfuse.com

[6] RS PRO, "6v 4ah lead-acid battery datasheet," 2009. [Online]. Available: https://docs.rs-online.com/ce41/0900766b81580e4e.pdf

[7] Geotherm, "Polycrystalline silicon solar cells," 2021. [Online]. Available: https://geothermhvac.com/mono-vs-poly-better/

[8] Unknown, "Sa weather and climate information," 2020. [Online]. Available: https://weather-and-climate.com

[9] Marc Bailey, "Global weather analysis," 2007. [Online]. Available: https://sustainable.org

[10] STM, "1.2 v to 37 v adjustable voltage regulators datasheet," NaN. [Online]. Available: https://learn.sun.ac.za/pluginfile.php/2893561/mod_resource/content/0/LM317T.pdf

[11] AAVID THERMALLOY, "To-220 heat sinks datasheet," NaN. [Online]. Available: https://learn.sun.ac.za/pluginfile.php/2893566/mod_resource/content/0/TO-220%20Heat%20Sinks.pdf

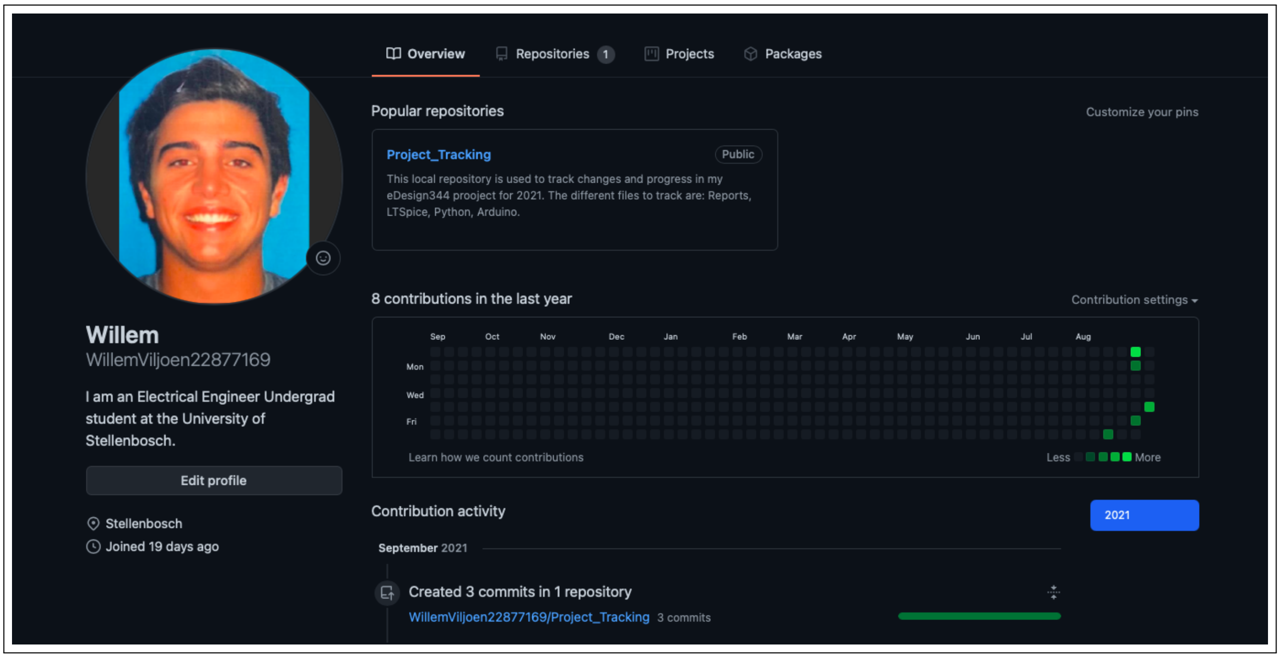
[12] RS PRO, "Datasheet non-silicone thermal gap pad," 2009. [Online]. Available: https://learn.sun.ac.za/pluginfile.php/2909377/mod_resource/content/1/Non-Silicone_Thermal_Gap_Pad.pdf

[13] Texas Instruments, "Lm regulators datasheet," NaN. [Online]. Available: https://learn.sun.ac.za/pluginfile.php/2876545/mod_resource/content/0/LM2940.pdf

[14] ——, "μa7800 series positive-voltage regulators," 2003. [Online]. Available: https://learn.sun.ac.za/pluginfile.php/2893559/mod_resource/content/0/LM7805.pdf

Appendix A

GitHub Activity Heatmap



Appendix B

Social contract

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
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, ...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..........................

1