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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.

August 23, 2021

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Nomenclature

Variables and functions

$p(x)$	Probability density function with respect to variable x.
$P(A)$	Probability of event A occurring.
ε	The Bayes error.
ε_u	The Bhattacharyya bound.
B	The Bhattacharyya distance.
s	An HMM state. A subscript is used to refer to a particular state, e.g. s_i refers to the i^{th} state of an HMM.
$\mathbf{S}$	A set of HMM states.
$\mathbf{F}$	A set of frames.
$\mathbf{o}_f$	Observation (feature) vector associated with frame f.
$\gamma_s(\mathbf{o}_f)$	A posteriori probability of the observation vector $\mathbf{o}_f$ being generated by HMM state s.
μ	Statistical mean vector.
Σ	Statistical covariance matrix.
$L(\mathbf{S})$	Log likelihood of the set of HMM states $\mathbf{S}$ generating the training set observation vectors assigned to the states in that set.
$\mathcal{N}(\mathbf{x}\|\mu, \Sigma)$	Multivariate Gaussian PDF with mean μ and covariance matrix Σ.
a_{ij}	The probability of a transition from HMM state s_i to state s_j.
N	Total number of frames or number of tokens, depending on the context.
D	Number of deletion errors.
I	Number of insertion errors.
S	Number of substitution errors.

Acronyms and abbreviations

MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor

Chapter 1

Literature

1.1. Charging lead acid batteries

According to [?] lead acid batteries can be charged using four different techniques. Constant Voltage, constant current, tapaer current, two step constant voltage, however to obtain a maximum battery service life and capacity as well as long term acceptable recharging time and economy, a voltage-current limited design must be implemented. This is exactly what we intend to do. [?]

During constant voltgae charging the acceptable battery current decreases as the voltage and state of charge increases. The battery will be fully charged when the current stabilizes at a very low level after a efficient amount of time. [?]

The battery will go through four stages before it is charged completely. The maximum amount of current that is allowed to flow through the battery when it is depleted is 1A. When the battery is fully charged, it wil absorb a current of 10mA. [?]

1.2. Voltage regulation

A voltage regulator is electrical component that is placed in a circuit to regulates the output voltage of the component to one fixed voltage value. The LM317 is a very common voltage regulator and is also the regulator that will be used in the circuit. Voltage regulator have 3 pins Input, Output and a adjust pin. If the input voltage is large enough the regulation of voltage will start. The output voltage is fixed but can be any value between 1.2V and 37V. The output current is in excess of 1.5A. The difference between the output and adjust pin is always 1.25V. This relationship can be used to design the output voltage to any desired value that range between 1.2V and 37V. Voltage regulators can also be used to design a constant current at the output pin. Using the relationship of 1.25V as the $V_reference$ and placing a resistor between these to pins a desired ouput current can be designed. Combining a the constant voltage source with the constant current source, a efficient battery charger can be designed

1.3. Switching with MOSFETs

MOSFETs could be use as electronical switches instead of mechanical switches. A large enough positive gate voltage will be used to turn "ON" a circuit and a zero to turn the circuit

”OFF”. To turn ”ON” the MOSFET the gate voltage has to be large enough to put the MOSFET in the saturation region. I_D and V_{DS} will be larger than zero. To turn off the MOSFET the gate voltage has to be small enough to put the MOSFET in the cut-off region. I_D will equal zero and $V_{DS} = V_{cc}$.By using MOSFETs we can use low gate current to control high voltage circuits. [] MOSFETS are voltage controlled switches where BJTs are current control switches. MOSFET are more efficient switches for power supplies, this is why we will be using them [**?**].

These electronic switches can be placed in to main configurations. High side switch or low side switch. A high side switch has the load between the switch and ground. The load will receive a voltage when the MOSFET is in the saturation region.Usually a PMOS. A low-side switch has the load between the power source and the switch. The load will receive a voltage when the MOSFET is in the cut-off region.Usually a NMOS [**?**].

Although MOSFETs make great swithes, the gate voltage might not be enough to control the voltage over V_{DS}. If this is the case the maximum gate voltage will not be enough to put the switch into the saturation region. We thus use a second MOSFET at the gate of the first to regulate the voltage. This MOSFET is known as a driver. [**?**]

Chapter 2

Design

2.1. Overview

The objective is to design a circuit that will safely charge a battery to a 100% without damaging the batterys service life, capacity or recharge time. The components that will be used is a IRF9Z24NPBF (PMOS),2N7000(NMOS),LM317(voltage regulator),TO-220 Heat sink and two 1N5819(Schottky diode) . The battery charging circuit has design requirements. The voltage delivered to the battery must be high enough to allow full charge of the capacity and low enough as to not damage the battery. The circuit must deliver 2.4V to each cell. There are 3 cells and therefore a voltage of 7.2V(minimum of 6V) must be regulated over the battery therminal. The allowable save current can be found on the Battery(RS - 4Ah) datasheet[4] as 400mA. The battery charging circuit should be able to dissconnect from the battery terminal and therefore a high side switch must be build. This high side switch will also consist of a driver MOSFET. A design requirement is that if the minimum voltage(6V) is regulated the IRF9Z24NPBF has to be in ON (in saturation). For this to be true the IRF9Z24NPBF has receive a minimum gate voltage of 4V. The LM317 will receive 12V as input. This is in the operational range of the voltage regulator.

2.2. High-side switch

As mentioned above the high side switch will consist of two mosfets. The IRF9Z24NPBF must be in saturation when the minimum of 6V is supplied to it. For this to be true the gate volage has to be 4V. We design for 5V for extreme cases. R2 is in parallel with V_{on} and will have the same voltage drop. by making R1 and R2 large we can ignore V_{DS1}. By choosing $R2 = 50k\Omega$ and $R1 = 10k\Omega$ we can use voltage division to to calculate that:

$$V_{BE_{ON}} = V_{out_{min}}(\frac{R2}{R2 + R1}) = 5V \tag{2.1}$$

and when $V_{out} = 7.2$:

$$V_{BE_{ON}} = V_{out_{min}}(\frac{R2}{R2 + R1}) = 6V \tag{2.2}$$

By choosing these resistor values I_D(if not there) will not exceed 0.12mA($V_{out} = 7.2V$):

$$I_D = \frac{V_{out_{min}}}{R1 + R2} = 0.12mA \tag{2.3}$$

The power dissipation is :

$$P_{R1+R2} = I_D^2(R1 + R2) = (0.12m)^2(60k) = 0.864mW \tag{2.4}$$

This is a good choice as this will limit the power dissipation of R1,R2 and the 2N7000(NMOS). A Schottky diode will be place between the IRF9Z24NPBF (PMOS) and the battery terminal as to keep the battery charging when the supply node goes low.

2.3. Charging regulator

2.3.1. Voltage regulation

The voltage output requirement is to deliver the voltage terminal 7.2 (2.4V per cell). We use R3 and R4 to design the LM317 to deliver the required voltage.Using [?] we see $R3 = 470$ This is a good choice as the current through this resistor will be:

$$I_{470\Omega} = \frac{V_{ref}}{R3} = \frac{1.25}{470} = 2.66m\text{ohm} \tag{2.5}$$

The power dissipation is thus:

$$P_{R3} = I_{470\Omega}^2 R3 = (2.66m)^2 * 470 = 3.33mW \tag{2.6}$$

This means minimum power loss.

To calculate R4 we use the equation:

$$V_{out} = V_{REF}(1 + \frac{R4}{R3}) \tag{2.7}$$

this equation leads to:

$$R4 = R3\frac{V_{out}}{V_{REF} - 1} = 2237.2\Omega \tag{2.8}$$

We will be using $R4 = 2.2k\Omega$ as found in the labs.

This total power dissipation of R3 and R4 is thus:

$$I_{R3+R4} = \frac{V_{out}}{R3 + R4} = \frac{7.2}{2200 + 470} = 2.697mA \tag{2.9}$$

and thus:

$$P_{R3+R4} = I_{470+2200\Omega}^2(R3 + R4) = (2.66m)^2 * 470 = 19.42mW \tag{2.10}$$

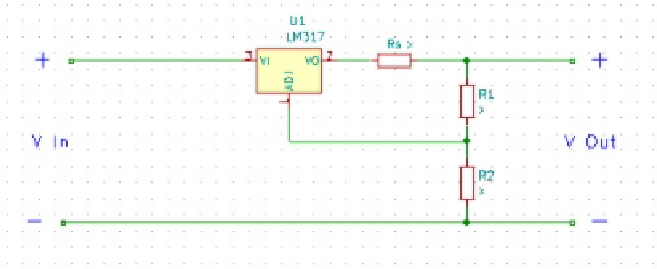


Figure 2.1: Battery charger [?, ?].

Figure 2.2: LM317 Temperature Characteristics

This is significantly small and should cause any problems.

This means minimum power loss.

2.3.2. Current limit

The current limit requirement is 400mA. This requirement should not influence any of the values that are chosen in section (2.3.1) that designs for the voltage regulation requirements. The resistor Rs has to be significantly small as to not cause a large voltage drop across it. A low R_S value will also have no effect on the voltage regulation mathematic as it will be so small that it will be neglegable. A value of 0.3Ω is choosen as this value is sificiantly small and the output current requirement is met with this resistor.

Designing a resistor this small is problematic. there arent resistors this small and the voltmeter struggles to measures such low resistor values. The oscilloscope was thus used to measure 1.2Ω resistors in parallel until the desired value was achieved. In this design a 0.1 ohm resistor and 4 1,2Ω resistors are placed in parallel.

2.3.3. Thermal analysis

The heat sink improves the power dissipation of the LM317. The heat sink is attached to the voltage regulator with thermal paste in between as to not allow air between the two components. The heat sink allows the LM317 to not overheat. This is required for the circuit because when the LM317 heats up its physical characteristics change and no design choices was made for these changes. therefore we try to avoid this problem by improving the heat/power dissipation through the heat sink.

2.4. Circuit diagram

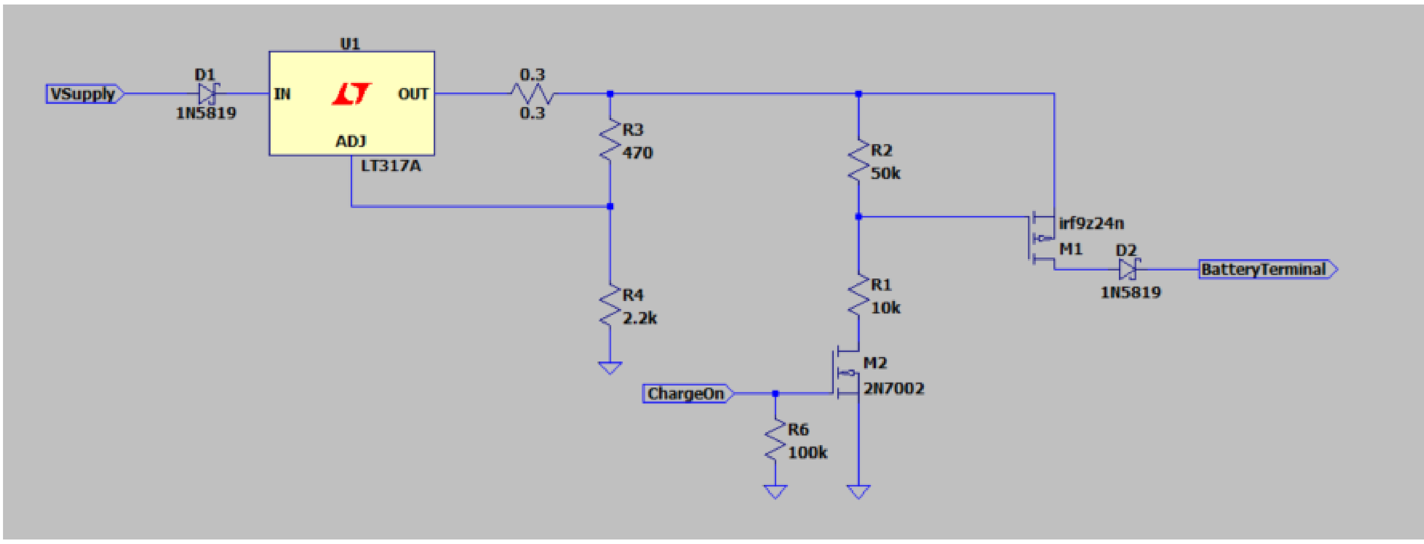


Figure 2.3: Battery charging circuit design

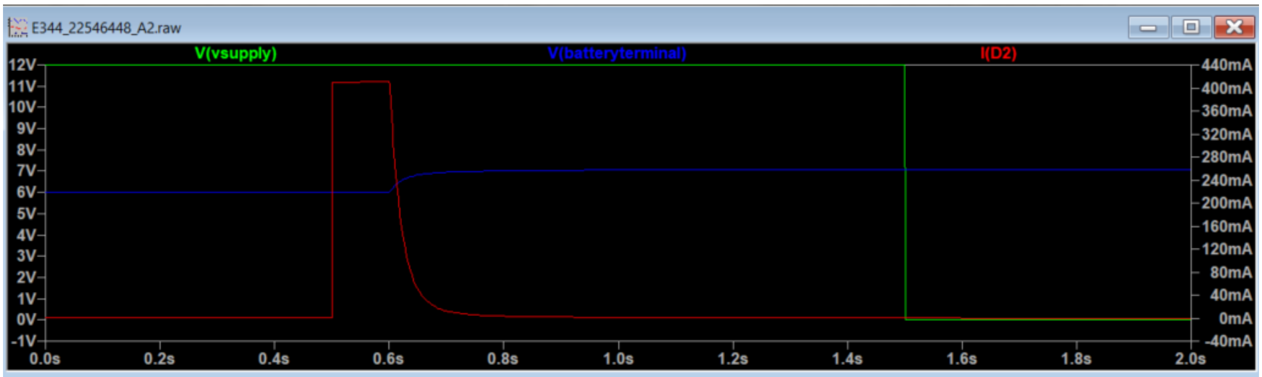
Chapter 3

Results

3.1. Simulation results

The circuit works as intended. The regulated voltage at the battery terminal is 6V at first. This is why we designed IRF9Z24NPBF to be on and its voltage $V_{BE_{on}} = 5V$ at 6V output. At six second the voltage increases from 6 to 7.2V at the exaxt same time the current spikes to 400mA for about half a second. This is due to the chargeon node that increased from 0V to 5V. At this point the Battery is being charged at a optimal voltage and current. The circuit therefore meets all the design requirements. The current drops down to 0A again after no more than a second. When the supply voltage drops to zero the battery therminal keeps on charging, and the voltage delivered to the battery remains 7.2V. This is due to the 1N5819 Schottky diode.

Figure 3.1: The Ltpice results for the designed charging circuit.



3.2. Measured results

Convince the reader that your circuit performed as expected using measured results. Same principle as for the simulation results, but now with measurements (e.g. oscilloscope plots).

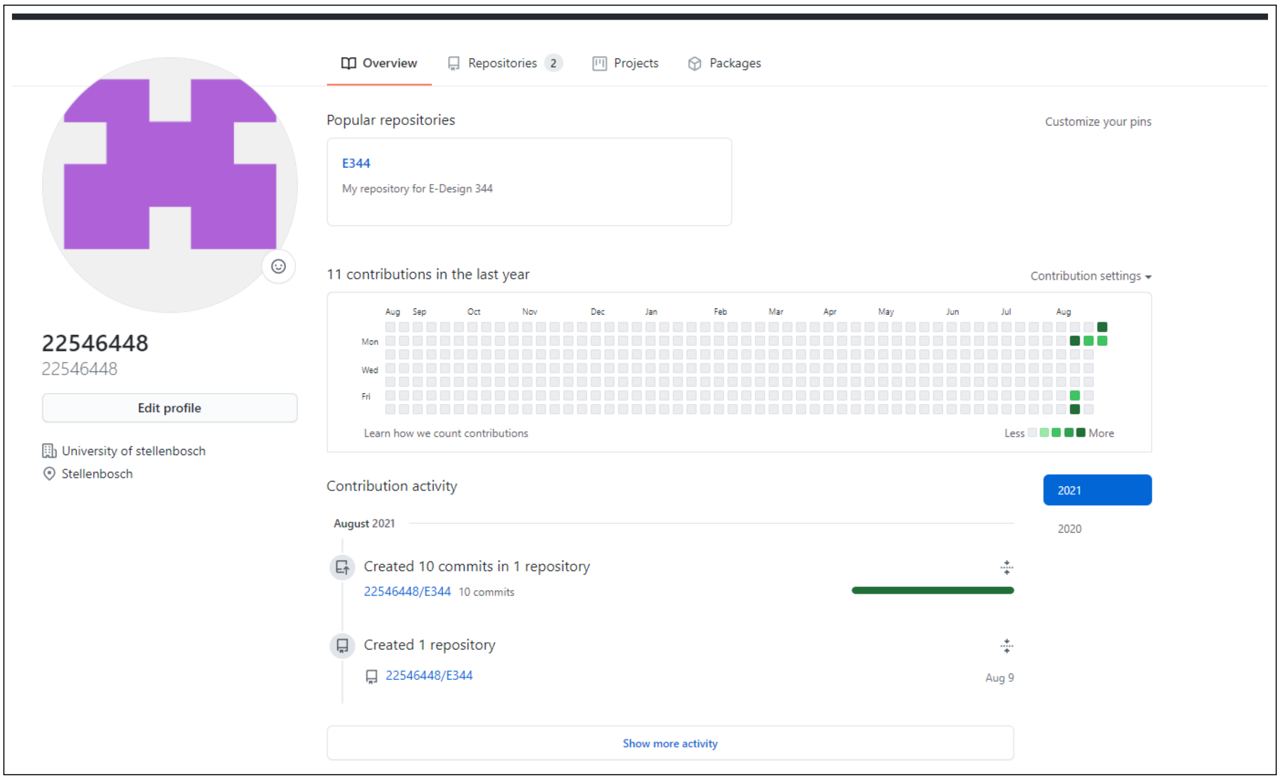
In reality these values differ slightly from the simulated values on let spice, but the key ideas and design ideas stay intact. The output voltage of the LM317 is slightly lower than the intended value. This report designed for 7.2V but in reality the physical circuit delivered a 7.1V ouput voltage when no load attached to the battery terminal. The maximum output current is also a bit larger than intended for. This report designed for a 400mA maximum output current but in reality the physical circuit vlaue was 430mA. These minor changes in circuit value should not harm the battery in any way as these values are well in the range of save design. The difference in outpot voltage and current could be do to the 0.3Ω resistor as it was extremely difficult to design this it. It could also be due to any of the other resistors tolerance range.

But except for the minor value changes in output voltage and output current. The circuit works as intended. And goal was achieved. The battery will be charged savely when attached to the battery terminal of this circuit.

Appendix A

GitHub Activity Heatmap

Take a screenshot of your github version control activity heatmap and insert here.



Appendix B

Images

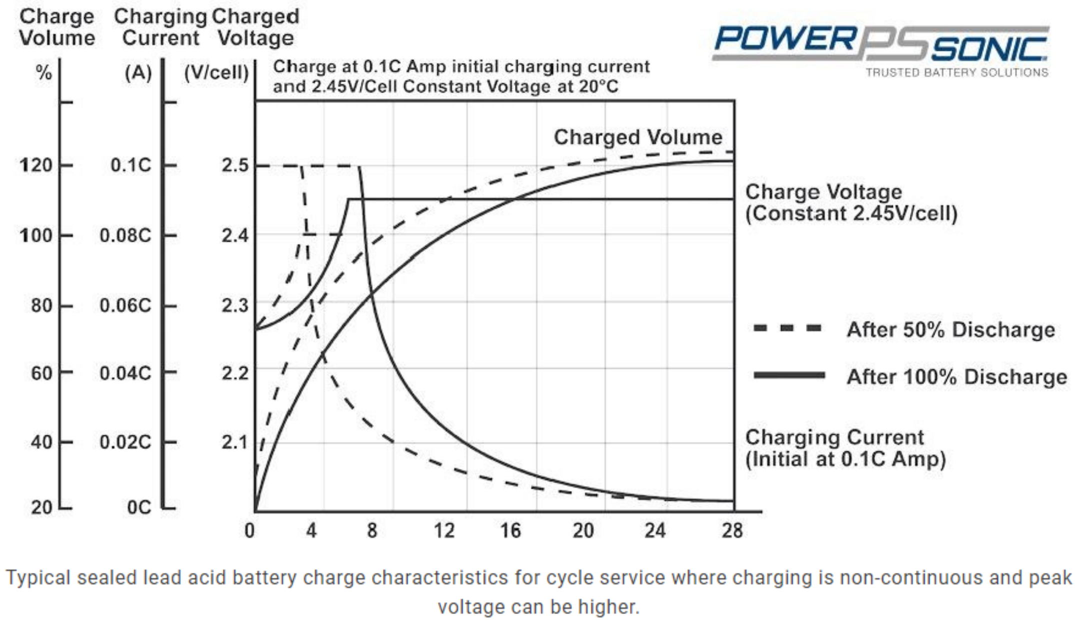


Figure B.1: Charging characteristics of a Lead Acid Battery [?]

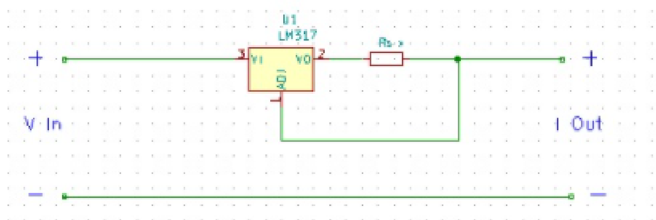


Figure B.2: Current Regulator [?, ?].

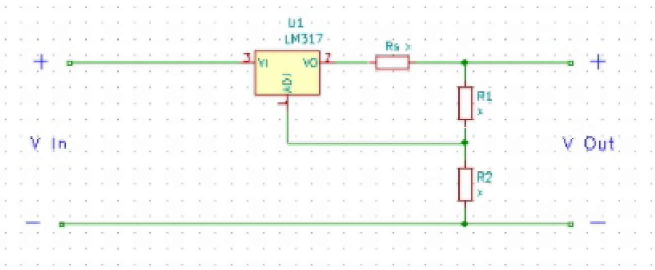


Figure B.3: Battery charger [?, ?].

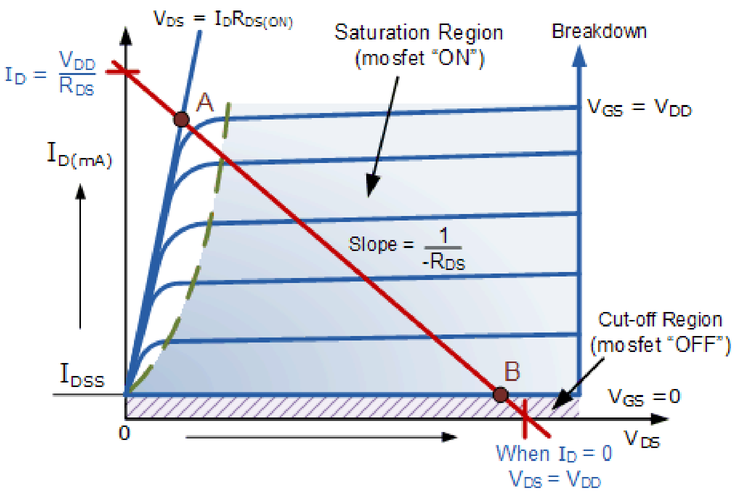


Figure B.4: MOSFET characteristic curve [?, ?].

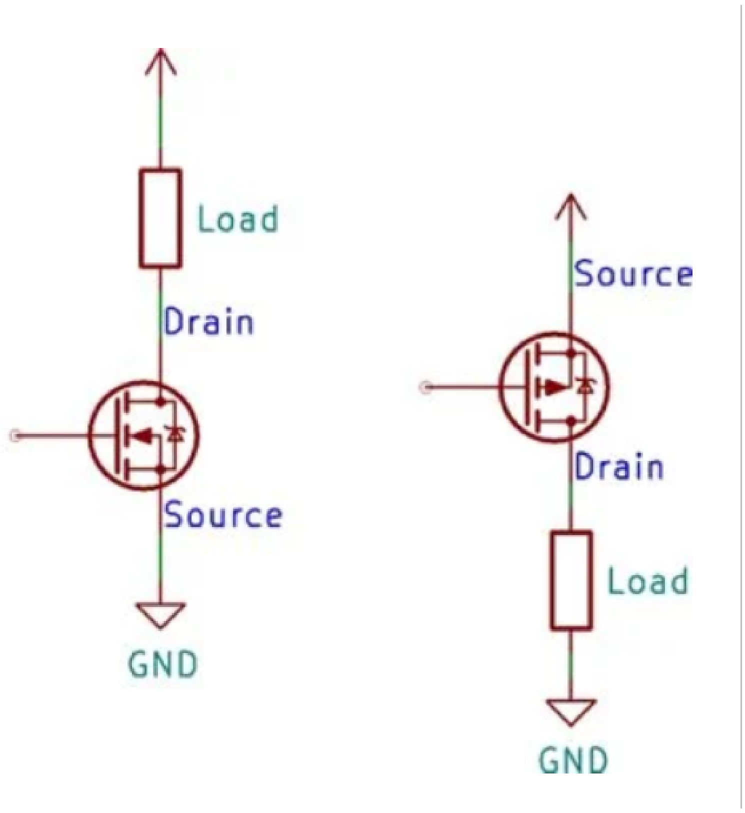


Figure B.5: A low-side switch and a high-side switch [?].

Appendix C

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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, MC van der Berg .... 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: 22546448

Signature: Michiel Christiaan van der Berg Digitally signed by Michiel Christiaan van der Berg Date: 2021.08.16 00:26:10 +02'00'

Date: 15 Augustus 2021

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