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E344 Assignment 3

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Design (E) 344 for the degree Baccalaureus in Engineering in the Department of Electrical
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Contents

List of Figures

List of Tables

Nomenclature

Variables and functions

Acronyms and abbreviations

MOSFET	Metal Oxide Semiconductor Field Effect Transistors
OC	Open Circuit
LED	light-emitting diode
Op Amp	Operational Amplifier

Chapter 1

Fuse

1.1. Literature

A fuse is an electrical device that is use for saftety purposes in order to protect against overcurrent. It consists of a metal wire or strip that conducts current, but melts when too much current flows through it, thus disconnecting the circuit and stopping current from flowing between the two points where the fuse was connected. Fuses are rated according to a maximum continuous current that the fuse can conduct without melting. The fuse also has a maximum voltage rating, which needs to be greater than what would become open circuit (OC) voltage, otherwise an arc may occur. Fuse ratings change according to the operational temperature of the enclosure or area in which the fuse is situated. The fuse is then re-rated according to a re-rating curve of rated current vs ambient temperature as seen in figure B.1. The time it will take for a fuse to blow is determined by it's time-current characteristics as shown in figure B.2. Thus, the higher the ambient temperature the lower the fuses's rated current and the lower the required time to blow.

1.2. Design

The load which our battery will have to power will consist of 5 ultra-bright light-emitting diodes (LEDs), which will draw 100mA in total. We will also allow for 50mA of headroom in order to power some other things in our circuit like the 5V voltage regulator. The maximum current that will enter our battery is during charging which is designed as $400mA$ and is thus the maximum current our fuse should be able to continuously handle. Fuses should only be operated at around 75% of their rated value [2]. Our fuse will typically operate in an enclosure which will be in direct sunlight, thus we need to take temperature rerating into account. Assuming an ambient temperature of 45°C, our fuse has a temperature rerating factor of around 97% [1]. The recommended fuse size can thus be calculated as:

$$Ideal\ Fuse\ Rating = \frac{Nominal\ Operating\ Current}{Temp\ Rerating\ Factor \times 0.75} = \frac{400mA}{0.97 \times 0.75} = 0.55A$$

The next available fuse size should therefore be chosen, thus we will pick a 1A fuse. If something happens and there is a short circuit and the battery discharges 10A or more through the load the fuse will break in 0.01s as seen in figure B.2, thus protecting the circuit from damage.

Chapter 2

Undervoltage battery protection

2.1. Overview

The circuit consists of two main parts, undervoltage protection section and the voltage regulator. As seen in figure 2.1 the circuit receives an input from the node ”A2 Output”, which is the charging voltage as designed in A2. The voltage regulator used is the LM2940 5V voltage regulator which takes input from the battery and provides a constant 5V output. Three operational amplifiers (Op Amps) together with a high-side switch are used to implement the undervoltage protection circuit. The main Op Amp implements a schmitt trigger comparator with hysteresis. The output from the last Op Amp is either a 5V or 0V signal and is used to turn the PMOS MOSFET on or off to allow the battery to discharge or stop discharging.

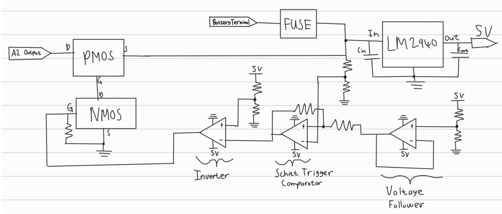


Figure 2.1: Conceptual Block Diagram Of Circuit

2.2. 5V rail

Our circuit needs a constant 5V output to power various elements such as the Op Amps. In order to achieve this a constant 5V regulator was implemented. The regulator chosen was the LM2940 regulator rather than the LM7805 because the LM2940 voltage regulator has a lower minimum input (6V) and a lower minimum voltage dropout (0.5V) [3]. The LM7805 regulator has a minimum dropout voltage of 2V [4] and thus it will not be able to provide constant voltage regulation across the whole battery voltage range. The maximum output current of the LM2940 regulator is 1A [3].

2.3. High-side switch

In order to design a high-side switch that uses logic level voltages (0-5V or 0-3.3V) we need to make use of a complementary pair of PMOS and NMOS MOSFETs. Pullup resistor R3 is added to keep to p-channel MOSFET off in unkown floating voltage states and to provide a large enough voltage drop over V_{gs} in order to fully turn the PMOS on when required.. Similarly a pulldown resistor R4 is added to the gate of the n-channel MOSFET to keep it off in unknown states. Resistor R3 in figure 2.2 is also used to limit the amount of current that flows through the n-channel MOSFET. If the voltage output from the Schmitt Trigger (at node V NMOSGate) is at a high of 5V the n-channel MOSFET will be turned on, thus pulling the gate of the p-channel MOSFET to ground and turning it on. According to the 2N7000 n-channel MOSFET datasheet [5] the maximum current that can flow through the drain-source channel is 200mA, thus the minimum resistor value for R3 can be calculated as:

$$R3_{min} = \frac{7.8V}{200mA} = 39\Omega$$

This value was designed for extremities and would most likely not work in the physical circuit as it is a very small resistor and it is the minimum resistance value that R3 can be, I chose a value of $100k\Omega$ as a design choice.

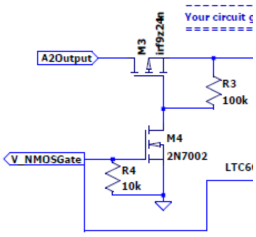


Figure 2.2: Circuit Diagram of High-Side Switch Portion

2.4. Voltage monitoring with hysteresis design

We will make use of three Op Amps in order to design our voltage monitoring circuit. The main Op Amp (U2 in figure 2.3) will be designed as a inverting comparator with hysteresis. Our undervoltage protection circuit needs to allow the battery to discharge when the battery voltage is above 6.2V and not allow it to discharge when the voltage falls below 6V. Hence, we have two threshold switching points, giving a hysteresis deadband of 0.2V. However, because of the common mode input range of -0.3V to 5.3V and the max differential voltage of 5V [6], we need to scale the input voltage and the reference voltage to appropriate levels. We use voltage dividing resistors R1 and R2 to divide the input voltage from the battery by 2. These resistors need to be large to limit the current through them, so they were arbitrarily chosen as $100k\Omega$. The input voltage will now vary from 3V to 3.1V and we need to switch at around 3.05V, thus we can use our 5V supply and two voltage dividing resistors R11 and R12 to provide a reference voltage of 3.05V. These two resistors can be calculated as follows (where V_H is the high threshold switching voltage):

*Please refer to figure 2.3 for a visual reference to the mentioned resistors.

$$\frac{R_{11}}{R_{12}} = \frac{V_{cc}}{V_{cc} - V_H} = 1.5789$$

$$\text{pick } R_{12} = 10k\Omega$$

$$\therefore R_{11} = 15.79k\Omega$$

Resistors R9 and R10 provide the positive feedback needed for hysteresis and are calculated as follows:

$$\frac{R_9}{R_{12}} = 30 \qquad \therefore R_9 = 30 \times R_{12} = 300k\Omega$$

$$V_H = V_{ref}(1 + \frac{R_{10}}{R_9}) \qquad \therefore R_{10} = 5k\Omega$$

A voltage follower Op Amp was implemented to ensure that the reference voltage would not change due to the hysteresis. The comparator with hysteresis was implemented as an inverting comparator, thus to ensure the required output we implemented another comparator with a reference voltage of 2.5V, which simply inverts the signal from 0V to 5V and vice versa.
All the calculated values were slightly adjusted and the closes real resistor values were picked for the physical building of the circuit

2.5. Circuit diagram

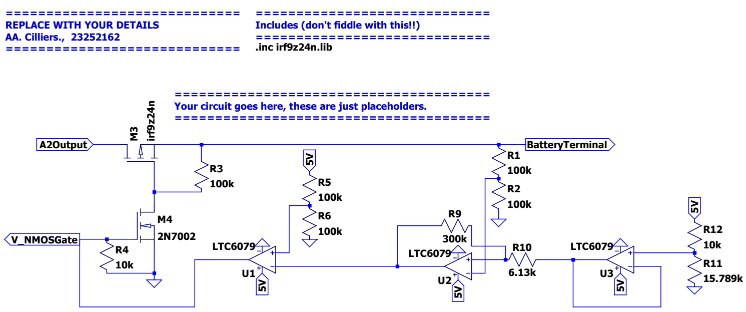


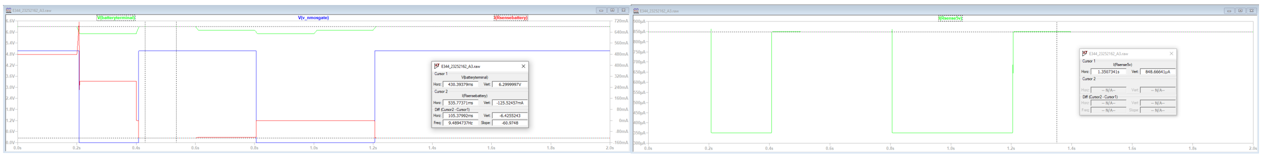
Figure 2.3: Full Circuit Diagram of Undervoltage Protection and Voltage Regulator

2.6. Results

Do Physcial Measurements Part Still

Here you include your simulation results and your measured results. For the measured results, it would be most beneficial to show on the same oscilloscope screen-grab (or CSV plot), how the switch went through the stages of the hysteresis loop (similar to what you had to do for the video). You are welcome to use subplots to save space.

Figure 2.4a shows the output of the simulated circuit where V(batteryterminal) is the voltage at the battery terminals and I(Rsensebattery) is the output current through the battery terminal and V(NMOSGate) is the output voltage from the schmitt trigger at the gate of the NMOS MOSFET. As shown the circuit is discharging when the battery voltage is higher than 6.2, this can be seen be the negative current of I(Rsensebattery) and stops discharging when the battery voltage is lower than 6V.
Figure 2.4b shows that the 5V regulator only draws around $849\mu A$, which meets the requirement that it should not draw more than 10mA.
Figure 2.5 shows that the circuit switches in $7.84ms$ after a threshold is exceeded, which is below the requirement of $10ms$.
Thus this design is working as intended and meets all the requirements during the simulation.



(a) Output Graph of LTSpice Simulation Showing Voltage Switching and Discharge Current

(b) Output Graph of LTSpice Simulation Showing Current Used by 5V Regulator

Figure 2.4: Output Graph of LTSpice Simulation

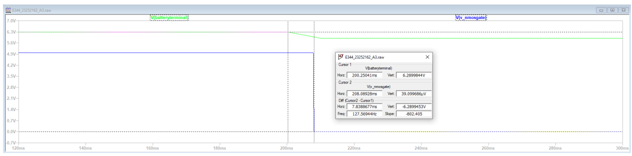


Figure 2.5: Output Graph of LTSpice Simulation Showing Voltage Switching Time

Bibliography

[1] *ATOF® BLADE FUSE RATED 32V*, ATOF® BLADE FUSE RATED 32V datasheet, Littelfuse, 2012.

[2] *FUSEOLOGY*, FUSEOLOGY, Littelfuse, 2012.

[3] *LM2940x 1-A Low Dropout Regulator*, LM2940x Datasheet, Texas Instruments.

[4] *µA7800 SERIES POSITIVE-VOLTAGE REGULATORS*, LM7805 Datasheet, Texas Instruments.

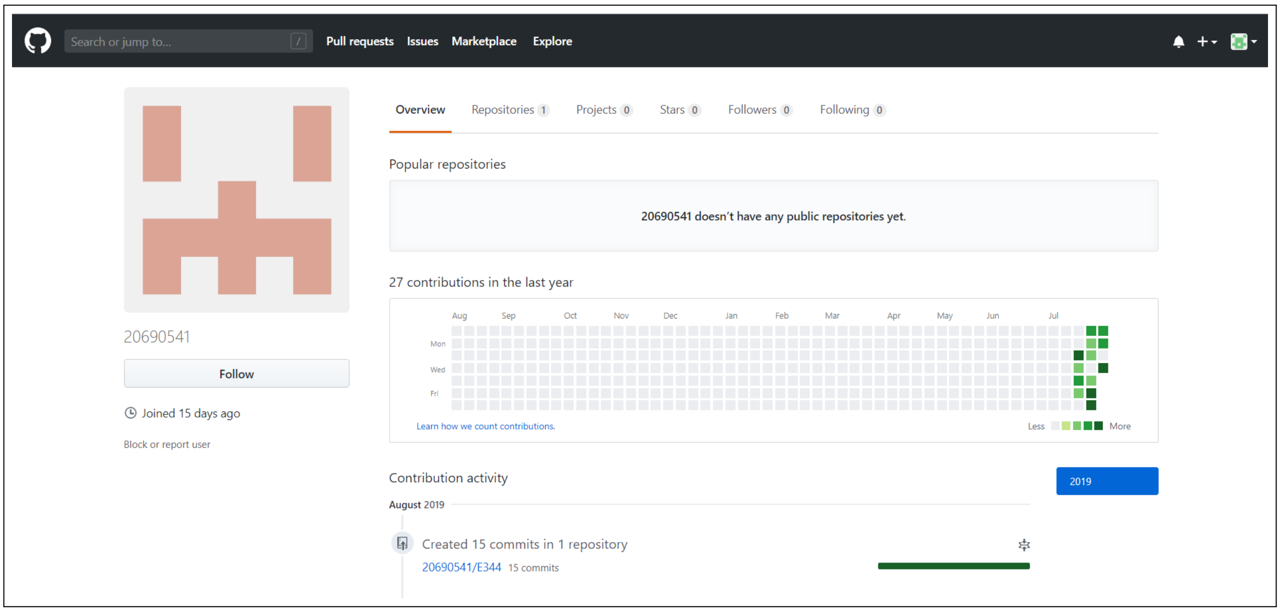
[5] *N-Channel Enhancement Mode Field Effect Transistor*, 2N7000 / 2N7002 / NDS7002A Datasheet, ON Semiconductors.

[6] *50 µA, 550 kHz Rail-to-Rail Op Amp*, MCP6242 Datasheet, Microchip.

Appendix A

GitHub Activity Heatmap

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



Appendix B

Additional Figures

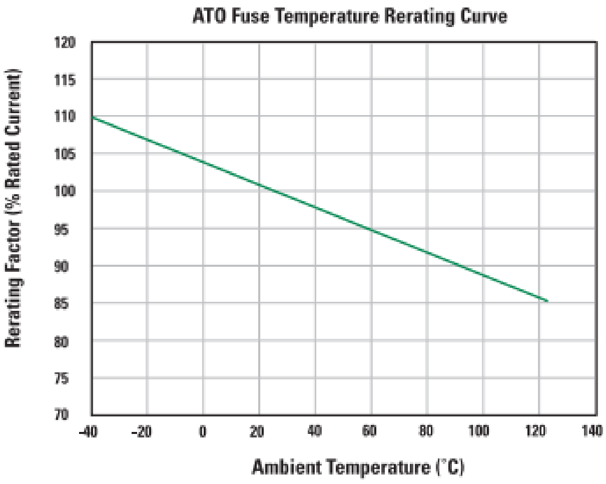


Figure B.1: Temperature Rerating Curve [1]

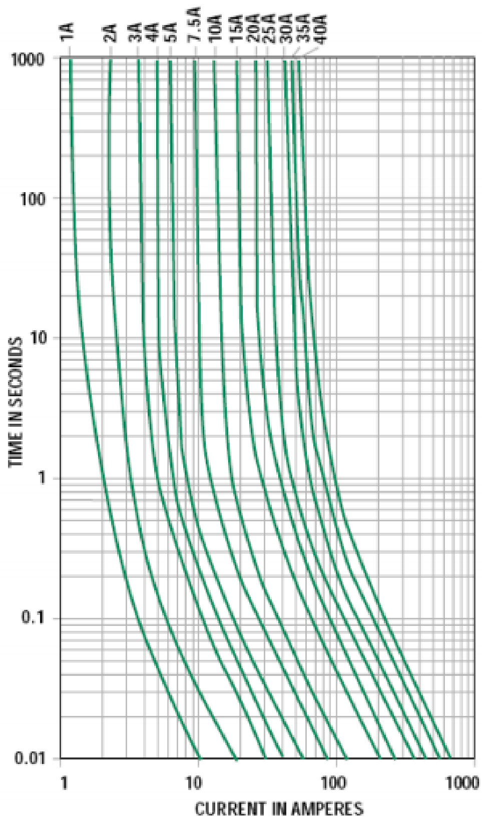


Figure B.2: Time-Current Characteristics [1]