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E344 Assignment 4

Abraham Albertus Cilliers

23252162

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.

September 5, 2021

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Nomenclature

Variables and functions

V_{out}	Output Voltage
R_{sense}	Current Sensing Resistor
I_{load}	Load Current
V_{ref}	Reference Voltage

Acronyms and abbreviations

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

Chapter 1

Low-side load control

1.1. Literature

In order to design a low-side switch that uses logic level voltages (0-5V or 0-3.3V) we can make use of a NMOS MOSFET. Pull-down resistor R3 is added to provide a large enough voltage drop over V_{gs} in order to fully turn the NMOS on when required and to keep the NMOS off in unkown states. If the voltage at the gate of the NMOS is at a high of 5V the n-channel MOSFET will be turned on, thus allowing current to flow through the drain-source channel, which means the load is now active. If the voltage at the gate of the NMOS is at a low, the NMOS will turn off and the load will be disconnected. According to the 2N7000 n-channel MOSFET datasheet [1] the maximum current that can flow through the drain-source channel is 200mA, however the maximum current that will flow through the NMOS in our circuit is 100mA (from the 5 super-bright LEDs), thus a current limiting resistor is not required.

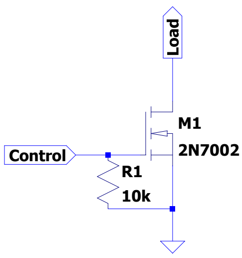


Figure 1.1: Circuit Diagram of Low-Side Switch Portion

1.2. Design

The pull-down resistor R3 was arbitrarily selected as $10k\Omega$. Each super bright LED will be current limited by using a resistor connected in series, thus each LED will draw a maximum of 20mA each, giving a total of 100mA that will flow through the load and through the NMOS drain-source channel.

Chapter 2

Bidirectional current measurement

2.1. Overview

The circuit can be split into two sub-circuits, namely the TSC213 current sensing amplifier and the load together with it's low side switch. These sub-circuits can be identified in figure 2.1 with subcircuit (a) representing the TSC213 current sensing amplifier and sub-circuit (b) the load together with it's low side switch. The TSC213 is used as a current sensing amplifier, which will provide an analog output voltage proportional to the current flowing through a current sensing resistor connected at its input. This current sensing resistor is called R_{sense} and is chosen to be really small at $100m\Omega$ in order to prevent power losses.

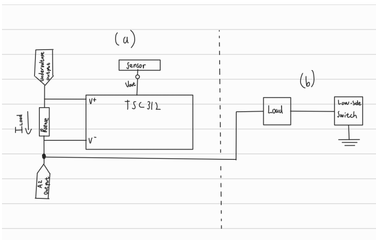


Figure 2.1: Conceptual Block Diagram Of Circuit

2.2. Bidirectional Current Sensing Circuit Design

The voltage drop across the R_{sense} resistor is so small that it would require an OpAmp with a very high common mode voltage. Thus, we were given a TSC213 bidirectional current sensing amplifier which has a common mode voltage of -0.3 to 26V and a gain of 50 [2]. We were required to design for a current input range of -150mA (discharging) to 450mA (charging) and the resulting output voltage had to be biased for optimal output swing.

The output voltage of the TSC213 can range from 0 to 5V, thus the reference voltage can be calculated as follows:

$V_{out} = (R_{sense})(I_{load})(Gain) + V_{ref}$ Set V_{out} =0V and I_{load}=-150mA

$\therefore V_{ref} = 0.75V$ Now set V_{out}=5V and I_{load}=450mA

$\therefore V_{ref} = 2.75V$

Since we need optimal output swing, take the middle of the two voltage references

$\therefore V_{ref} = 1.75V$

This reference voltage results in an output of 1V when the current is at -150mA and an output of 4V when the output is at 450mA.
As seen in the circuit diagram figure B.1 resistors R_1 and R_2 are used as voltage dividers in order to the the reference voltage at the required level. These resistors are calculated as follows:

$$V_{ref} = \frac{R_2}{R_2 + R_1} Vcc \qquad \text{Choose } R_2 = 10k\Omega$$
$$\therefore R_1 = 18.571k\Omega$$

The output of the TSC213 needs to be filtered in order to suppress noise. The requirement is that there is less than $2mV_{pk}$ noise on V_{out}, however the circuit must still remain responsive and be able to respond to an abrupt change in current within 2s. The choice of filtering was to make use of a decoupling capacitor on the output and the reference voltage nodes as seen in figure 2.2. Decoupling capacitors can be used as low pass filters and are used to stabilize voltages by preventing quick voltage changes, thus smoothing the output voltage [3]. The reason that the capacitor was placed at the output and not over the R_{sense} resistor is because of impedance mismatching. When selecting a decoupling capacitor for a low-pass filter a low-impedance series component should face a high impedance capacitor [4]. The current sensing resistor is very small and thus would require a very big capacitor in order to provide an appropriate level of filtering. C_2 in figure 2.2 was chosen as 10uF and C_1 was suggested in the TSC213 datasheet [2] to be used as 0.1uF.

2.3. Circuit Diagram

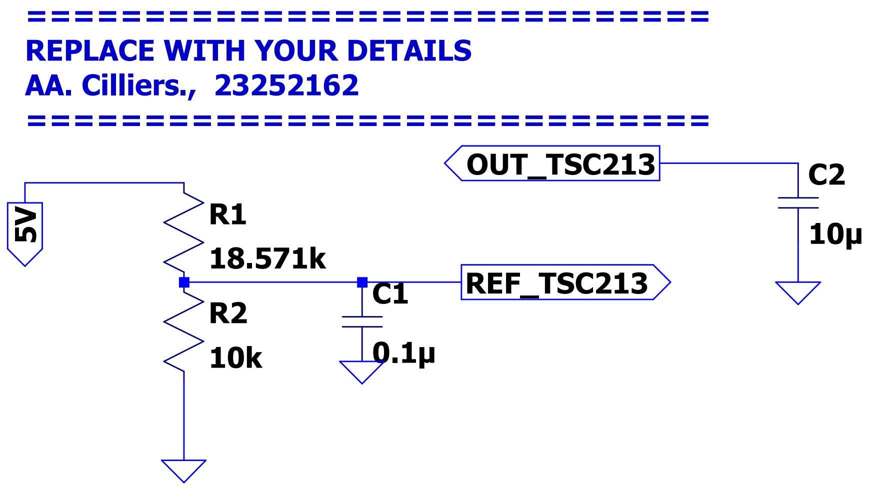
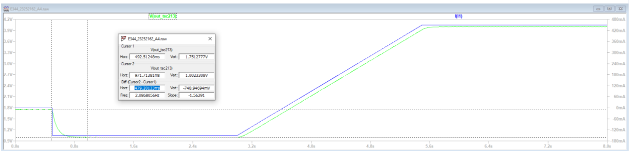


Figure 2.2: Full Circuit Diagram of Bidirectional Current Sensor Only

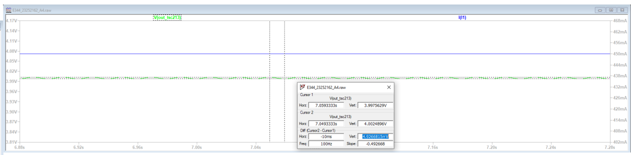
2.4. Results

2.4.1. Simulated Results

Figure 2.3a shows the output of the TSC213 versus the current I1 flowing through R_{shunt} and it also shows the response time after an abrupt change in current as 479.20ms. Figure 2.3b shows the noise of the TSC output to be $4.93mV_{pk-pk}$, which is $2.465mV_{pk}$, which is under the $5mV_{pk}$ specification.



(a) TSC213 Output vs Current and Response Time

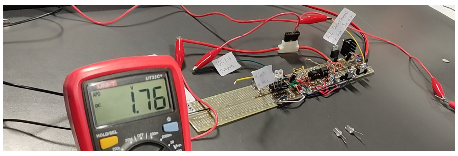


(b) Output Graph of LTSpice Simulation Showing Noise of TSC Output

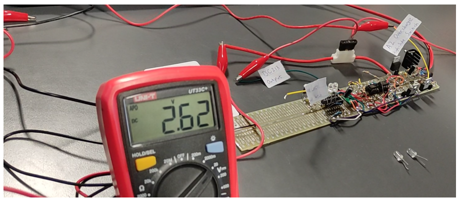
Figure 2.3: LTSpice Simulation Results

2.4.2. Measured Results

Figure 2.4a shows the multimeter reading of the TSC213 output while no current is flowing through the current sensing resistor and figure 2.4b shows the output while the battery is charging. Switching the load on is shown in figure 2.5a with 3 LEDs and figure 2.5b with 5 LEDs.

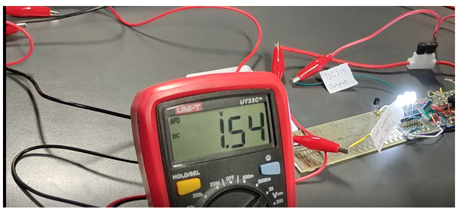


(a) Multimeter Measurement Showing Voltage
of TSC213 (No Current)

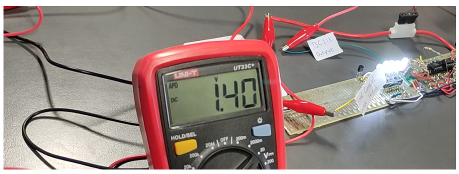


(b) Multimeter Measurement Showing Voltage
of TSC213 (While Charging)

Figure 2.4: Multimeter Measurement Showing Output Voltages of TSC213 While Charging/No Current



(a) Multimeter Measurement Showing Voltage
of TSC213 (3LEDs)



(b) Multimeter Measurement Showing Voltage of TSC213 (5LEDs)

Figure 2.5: Multimeter Measurement Showing Output Voltages of TSC213 Under Load

Bibliography

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

[2] *High/low-side, bidirectional, zero-drift current sense amplifiers*, TSC210, TSC212, TSC213 Datasheet, STMicroelectronics.

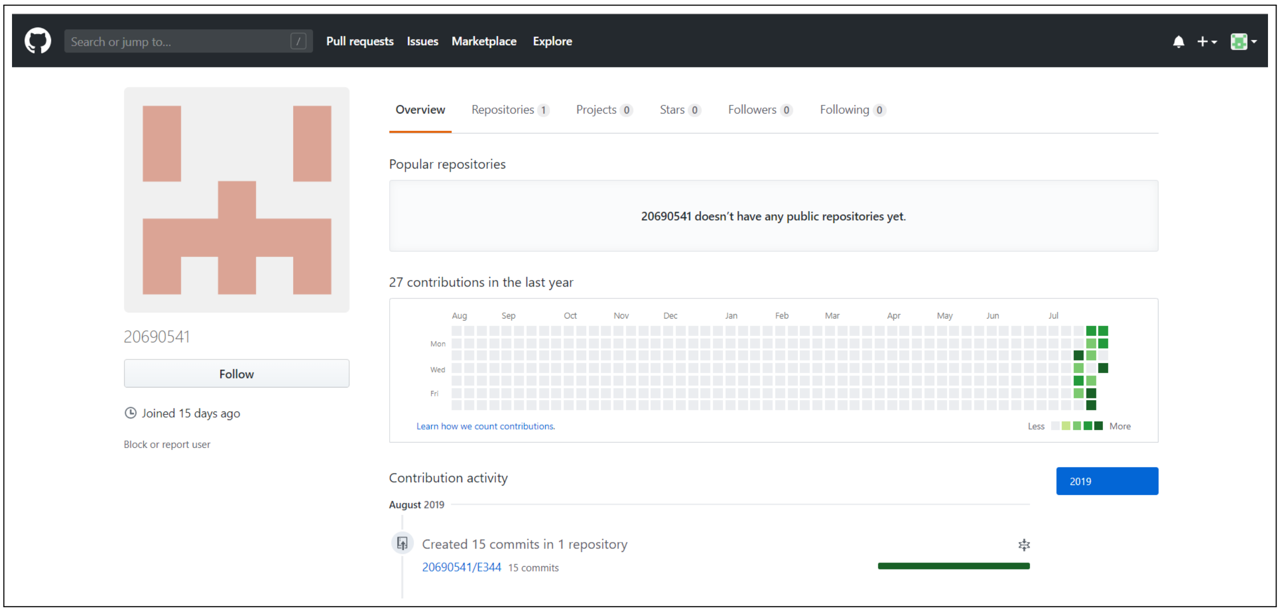
[3] P. B. Components, “Capacitor selection for coupling and decoupling applications,” https://passive-components.eu/capacitor-selection-for-coupling-and-decoupling-applications/, Apr. 2020.

[4] ——, “What-electronics-engineer-needs-to-know-about-passive-low-pass-filters,” https://passive-components.eu/what-electronics-engineer-needs-to-know-about-passive-low-pass-filters/, Dec. 2018.

Appendix A

GitHub Activity Heatmap

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



Appendix B

Additional Diagrams

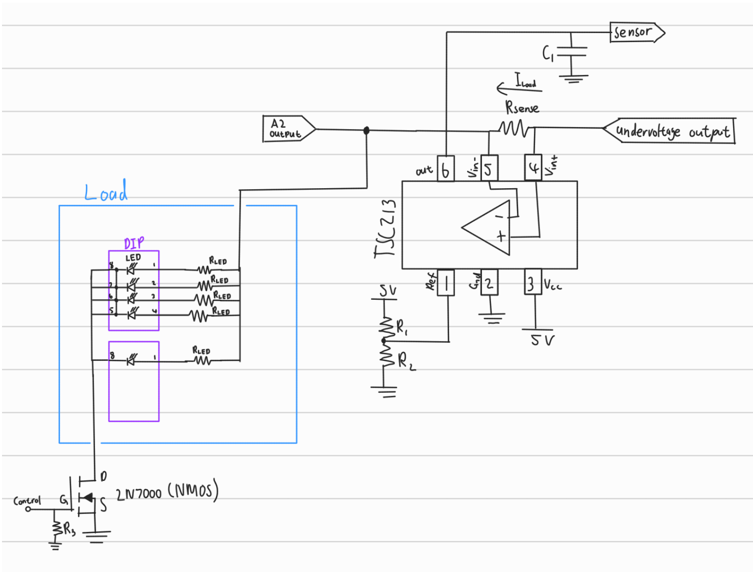


Figure B.1: Full Circuit Diagram of Bidirectional Current Sensor and Load