A10 - Reliability and Safety Analysis

Year: _2024_ Semester: _Spring_ Team: __1__ Project:___The Dungeon Crawler____
Creation Date: ______02/28/2024______ **Last Modified:** April 24, 2024
Author: ___________Neil Brown____________ **Email: ____brow1950@purdue.edu_____**

Assignment Evaluation: See the Rubric in the Brightspace Assignment

1.0 Reliability Analysis

All equations used to calculate the failure rate and mean time to failure are taken from the Military Handbook[1]. Any coefficients that are not cited in the comments section of the tables below came from the section of the military handbook that corresponds to that part. The datasheet for each part was also used in determining the values calculated below. All parts below were chosen because of their relative likelihood to fail compared to the other parts in the system. All failure rates were calculated as follows:

$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$ [1]

The MTTF (Mean Time To Failure):

$MTTF = 10^6/(24 * 365 * \lambda_P)$

1.1 STM32F405VGT6[2]

The first part selected for reliability and safety analysis was the microcontroller being used for our project. This processor does not deal with high voltages or current but instead is very complex with can lead to potential failures.

Parameter name	Description	Value	***Comments*** *regarding choice of parameter value, especially if you had to make assumptions.*
C1	Die complexity	0.56	32-bit microprocessor
π_T	Temperature coeff.	1.4	TTL at 85°C operating temperature
C2	Package failure rate	0.047	Non-hermetic SMT w/ 100 pins
π_E	Environmental Factor	0.5	G_B
π_L	Learning Factor	1.0	>2 years in production
π_Q	Quality factor	10	Commercial Part
Entire design:			
$\boldsymbol{\lambda_p}$	Failure rate / 10^6 units / hour	8.498	
MTTF	Mean time to failure	13.43 years	

Table 1. Microcontroller Analysis

1.2 MCP23017-E/SP[3]

The next part selected was the I2C I/O expander used to interface with the hall effect sensors on our game board. This part does not take much power, however it is an IC with 28 pins and transistor logic contained within. As a result, of this complexity it will be considered for the safety analysis.

Parameter name	**Description**	**Value**	***Comments** regarding choice of parameter value, especially if you had to make assumptions.*
C1	Die complexity	0.080	3,000-10,000 MOS logic gates
π_T	Temperature coeff.	0.17	Operating at 35°C
C2	Package failure rate	0.013	Non-hermetic SMT 28 pins
π_E	Environment factor	0.5	G_B
π_L	Learning factor	1	>2 years in production
π_Q	Quality factor	10	Commercial part
Entire design:			
$\boldsymbol{\lambda_p}$	Failure rate / 10^6 units / hour	0.201	
MTTF	Mean time to failure	567.9 years	

Table 2. I2C Expander Analysis

1.3 Pololu D24F5V3[4]

The next part to be analyzed for failure so the pololu D24F5V3 voltage regulator breakout board. This part was chosen because it is responsible for converting at a maximum, 5V and 8A down to 3.3V at 500mA. Dealing with a wide range of power that could be changing based on the intake from the LED board could cause potential failure in this part. Since this a board with many parts the focus of the analysis will be on the buck regulator used on the board which is the intersil ISL85415[5].

Parameter name	**Description**	**Value**	***Comments** regarding choice of parameter value, especially if you had to make assumptions.*
C1	Die complexity	0.010	1 to 100 MOS digital gates
π_T	Temperature coeff.	0.1	Typical operation at 25°C for digital MOS
C2	Package failure rate	0.0053	Nonhermetic SMT 12 pins
π_E	Environment factor	0.5	G_B
π_L	Learning factor	1	>2 years in production
π_Q	Quality factor	10	Commercial Part
Entire design:			
$\boldsymbol{\lambda_p}$	Failure rate / 10^6 units / hour	0.0365	

MTTF	Mean time to failure	3,127.5 years	

Table 3. Voltage Regulator Analysis

1.4 WS2812b[6]

The final part included in the reliability analysis is the WS2812b IC. This IC contains logic that interprets PWM signal into color for the LED contained on the chip. This was chosen because of the logic contained in the IC as well as the potential power consumption of 60mA. This part was also chosen because there are 256 of them on the board which increases the probability of one of the chips failing.

Parameter name	**Description**	**Value**	***Comments*** *regarding choice of parameter value, especially if you had to make assumptions.*
C1	Die complexity	0.01	1 to 100 digital MOS gates
π_T	Temperature coeff.	0.6	Maximum rating at 70°C for digital MOS
C2	Package failure rate	0.0016	Non-hermetic SMT 4-pin
π_E	Environment factor	0.5	G_B
π_L	Learning factor	1	>2 years in production
π_Q	Quality factor	10	Commercial Part
Entire design:			
λ_p	Failure rate / 10^6 units / hour	0.068	
MTTF	Mean time to failure	1,678.75 years	

Table 4. LED Analysis

In conclusion, the parts that have been chosen for this project are reliable. Following the linear model from the military handbook[1], the parts will not fail for hundreds even thousands of years. This is likely unrealistic since the true model is a bathtub curve, but these calculations prove the parts to be sufficient for the project. The reason for this is the tame operating conditions upon which the parts are being used. If the parts were used in rougher conditions at high temperatures they would be much more likely to fail. The only part that had a lower MTTF was the microcontroller. This part is very complex so the die complexity is noticeably higher than the other parts. To improve the MTTF for this part, a less complicated microcontroller would need to be selected.

2.0 Failure Mode, Effects, and Criticality Analysis (FMECA)

There are three levels of criticality for the design created for this project. The level of criticality are low, medium and high. There is only one aspect of the design that reached high criticality. The failure mode given a high criticality is the burning of the power electronics contained within the board. While unlikely, in theory a burning component could ignite the wooden box which would put the wellbeing of the user at risk. The failure rate λ for the high failure rate should be < 10^{-9} to greatly reduce the likelihood of this happening. Perhaps in another iteration of this prototype a safeguard could be added to prevent this from causing issues and reducing the failure rate as much as possible. The next criticality level, medium is found in a few different components in the system. The medium level would mean that a part failed that caused itself or other parts to be damaged beyond repair. This would render the product useless, but the wellbeing of the customer would not be affected. The acceptable failure rate for this is $< 10^{-8}$ because the destruction of this product would result in a loss of money for the user and the producer which want to be avoided. The final criticality level is low and is found in most components in this system. Low criticality is the least severe as it brings no risk to the users wellbeing and will not damage the system beyond repair. This involves malfunctioning parts that result in a change in the way they function such as an LED being the wrong color on the game board. The acceptable failure rate for this level of criticality will be $< 10^{-6}$.

3.0 Sources Cited:

[1] "Military Handbook Reliability Prediction of Electronic Equipment" Department of Defense. Washington DC. MIL-HDBK-217F, Dec. 2, 1991.

[2] "STM32F405VG - STMicroelectronics," STMicroelectronics, 2024. https://www.st.com/en/microcontrollers-microprocessors/stm32f405vg.html#documentation (accessed Mar. 29, 2024).

[3] "MCP23017-E/SP Datasheet," Digikey. https://ww1.microchip.com/downloads/aemDocuments/documents/APID/ProductDocuments/DataSheets/MCP23017-Data-Sheet-DS20001952.pdf (accessed Mar. 29, 2024).

[4] "Pololu 3.3V, 2.6A Step-Down Voltage Regulator D24V22F3," www.pololu.com. https://www.pololu.com/product/2857 (accessed Feb. 02, 2024).

[5] "Wide V IN 500mA Synchronous Buck Regulator ISL85415." Accessed: Mar. 29, 2024. [Online]. Available: https://www.pololu.com/file/0J795/isl85415-datasheet.pdf

[6] "WS2812B Intelligent control LED integrated light source Features and Benefits." Available: https://cdn-shop.adafruit.com/datasheets/WS2812B.pdf

Appendix A: Schematic Functional Blocks

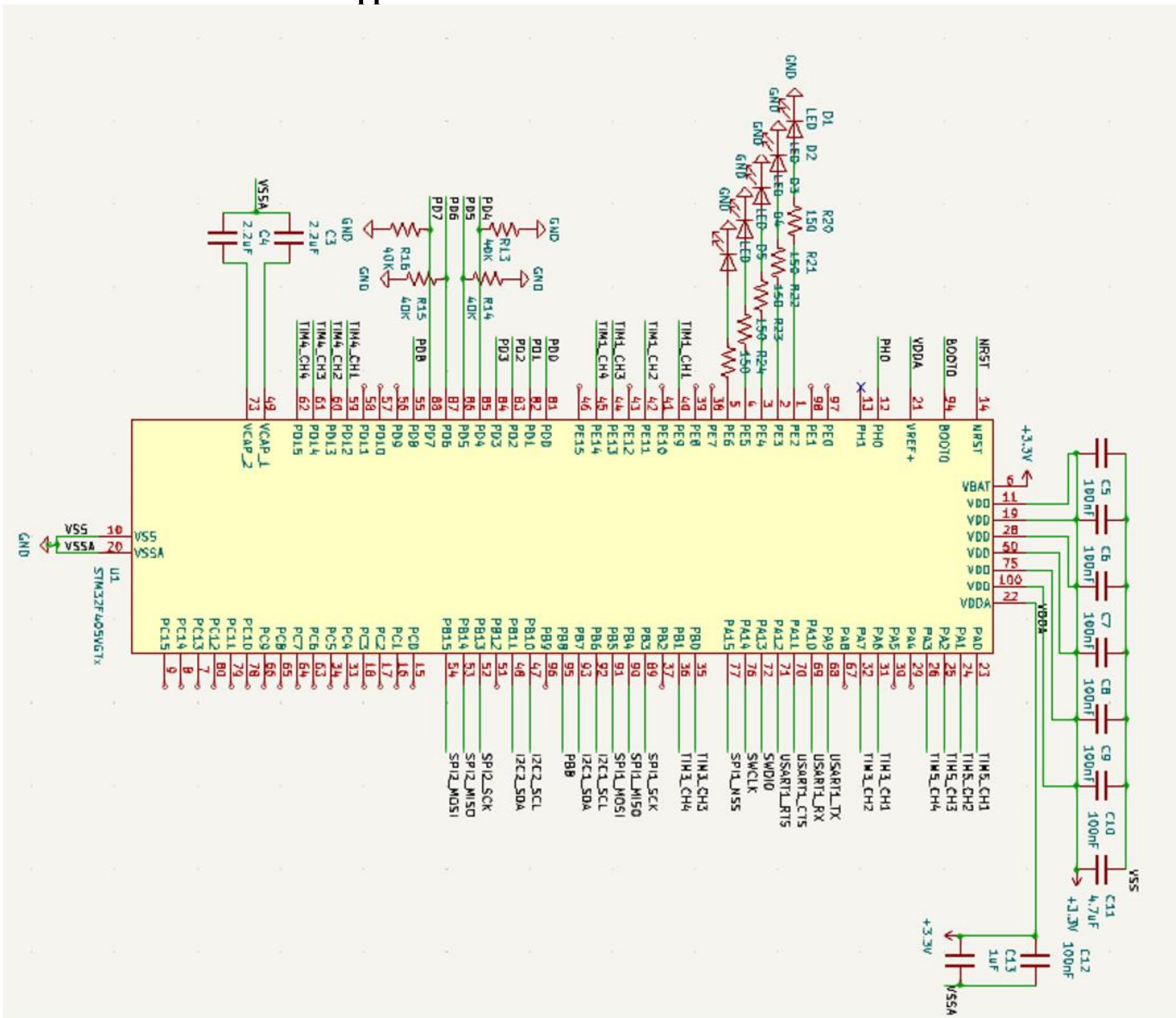

Figure 1. STM32F405VGT6 Microcontroller circuit

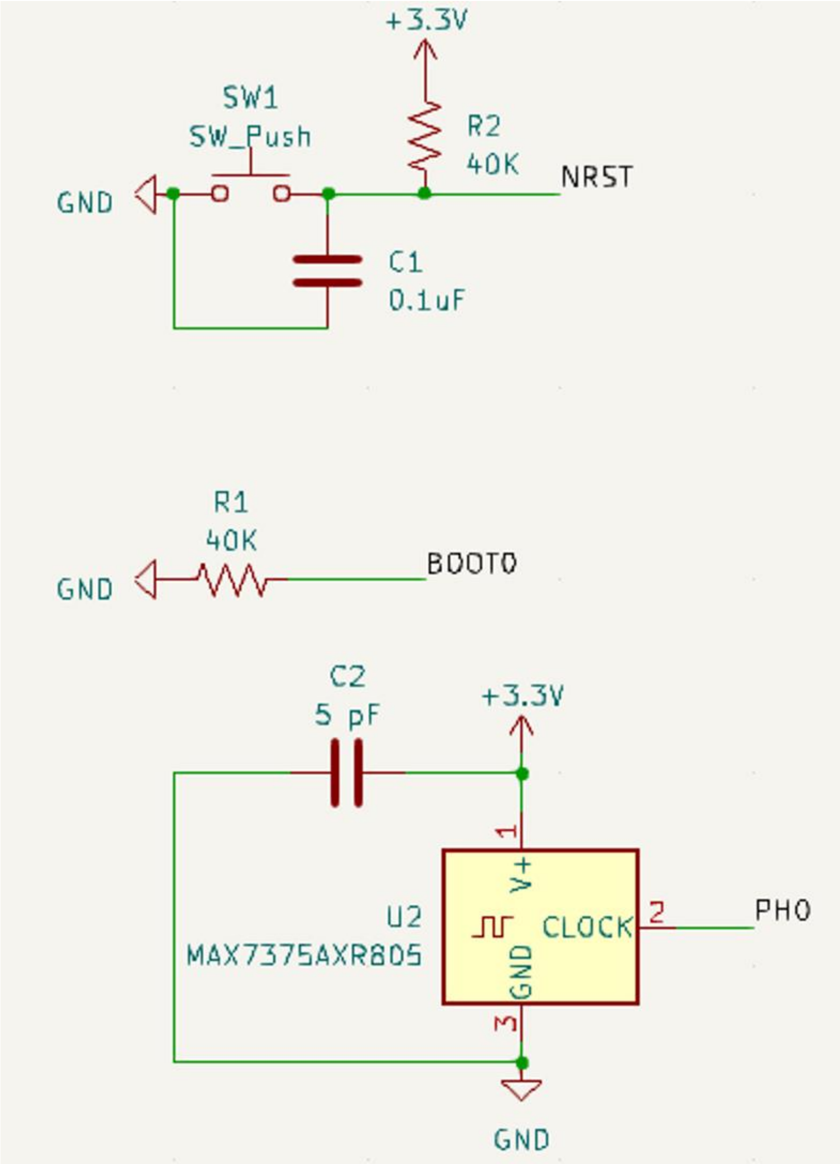

Figure 2. Reset, Boot, Clock circuit

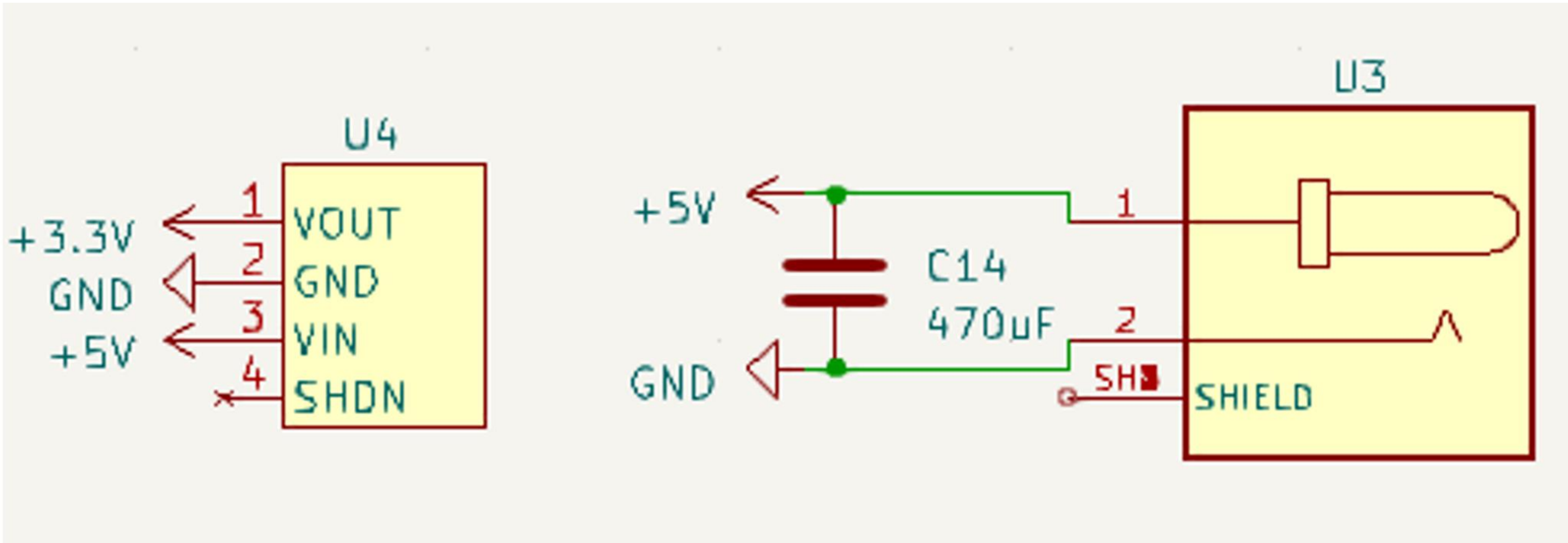

Figure 3. Power circuitry

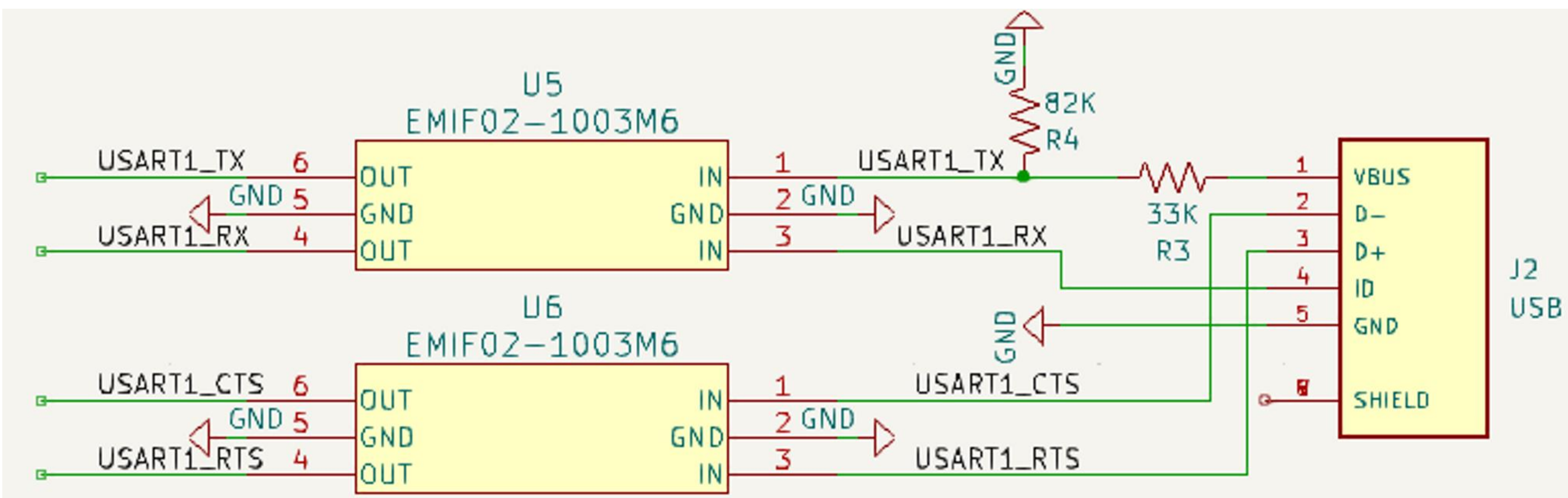

Figure 4. USB circuitry

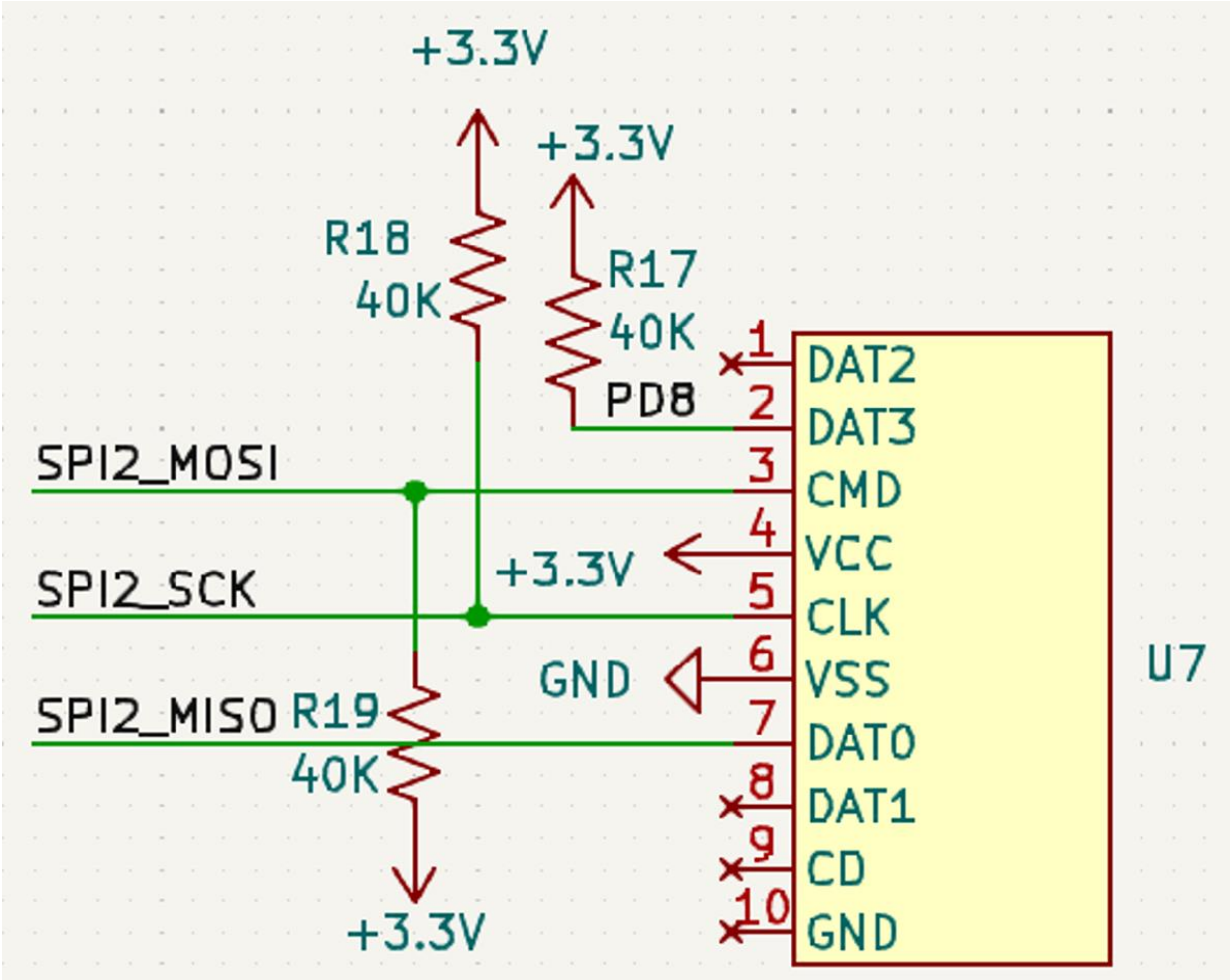

Figure 5. Micro SD reader

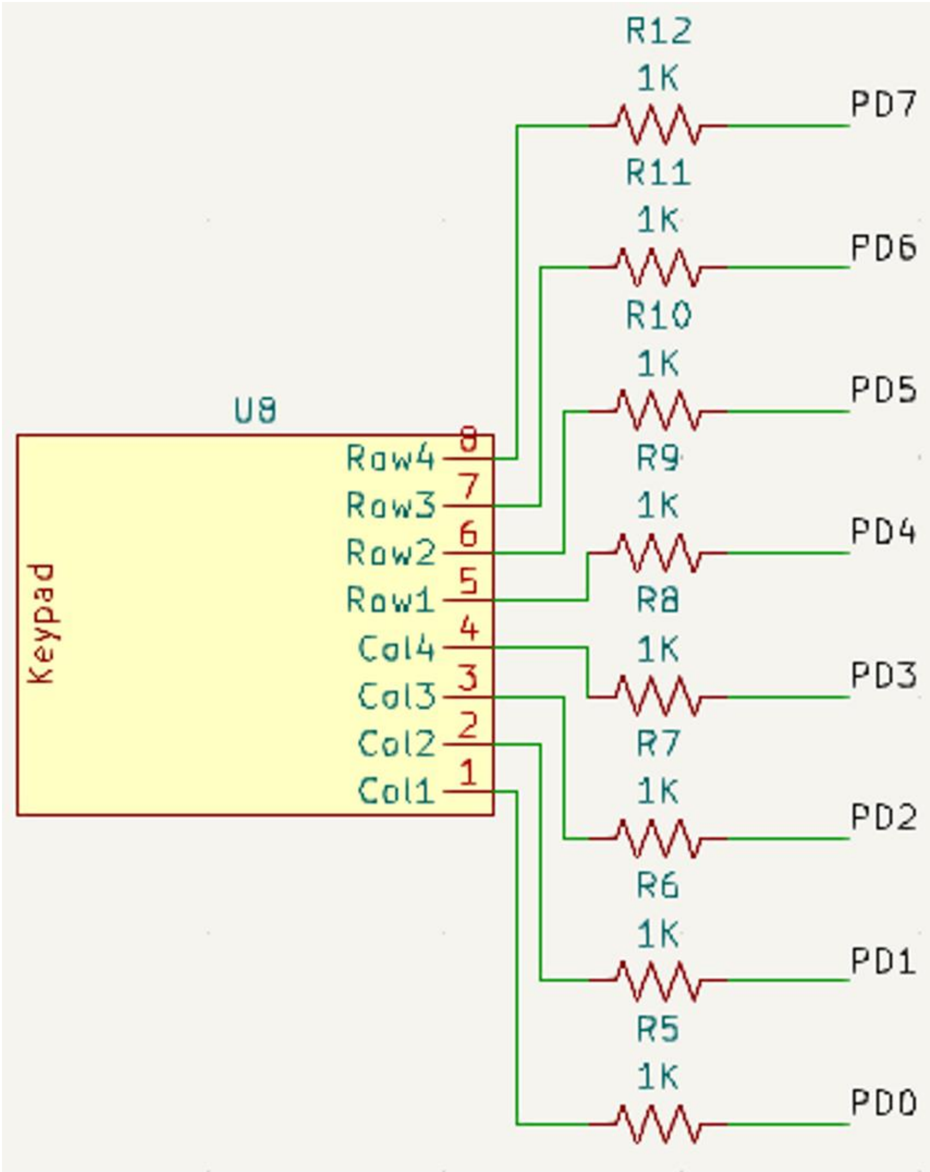

Figure 6. Keypad circuitry

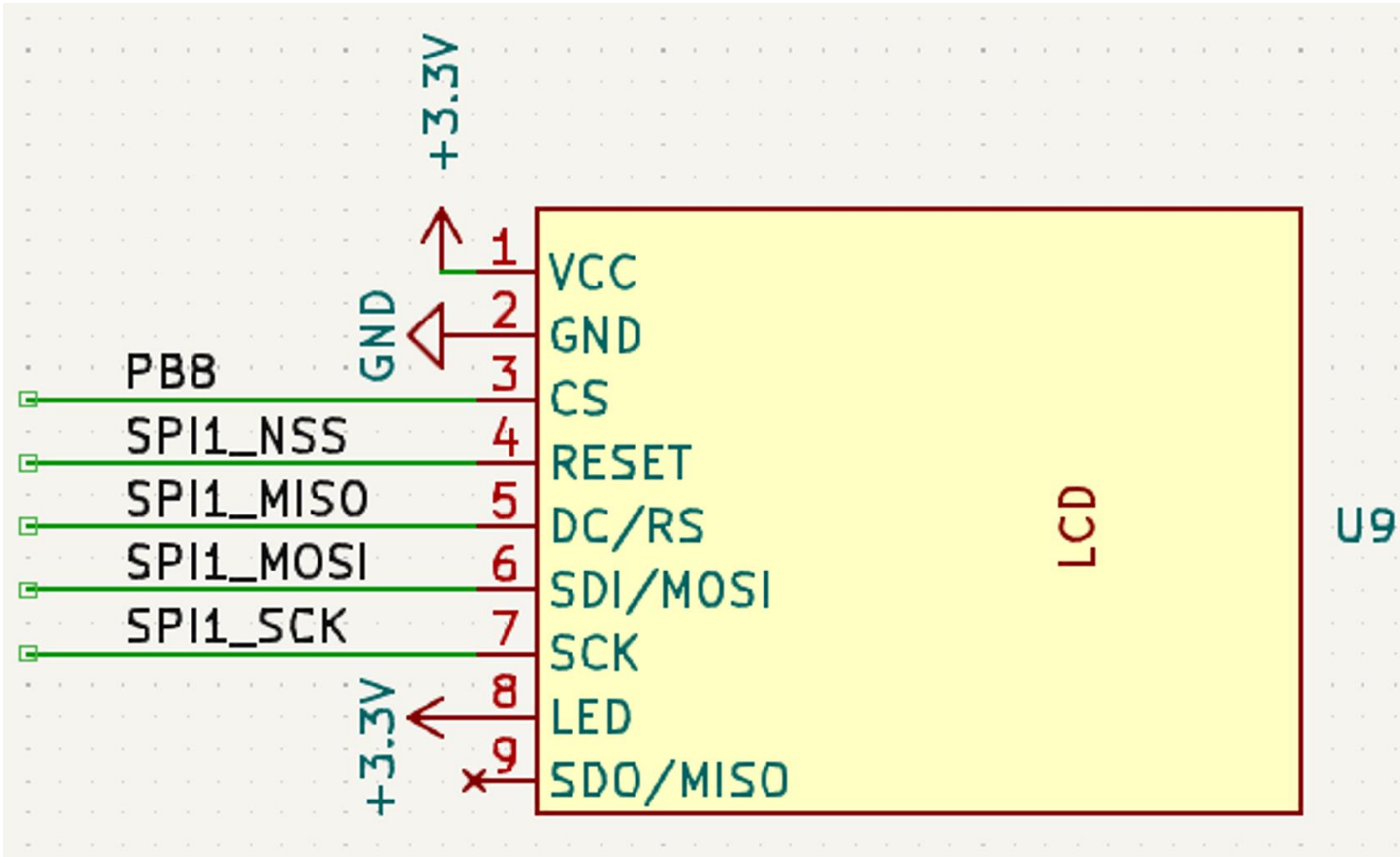

Figure 7. LCD Circuitry

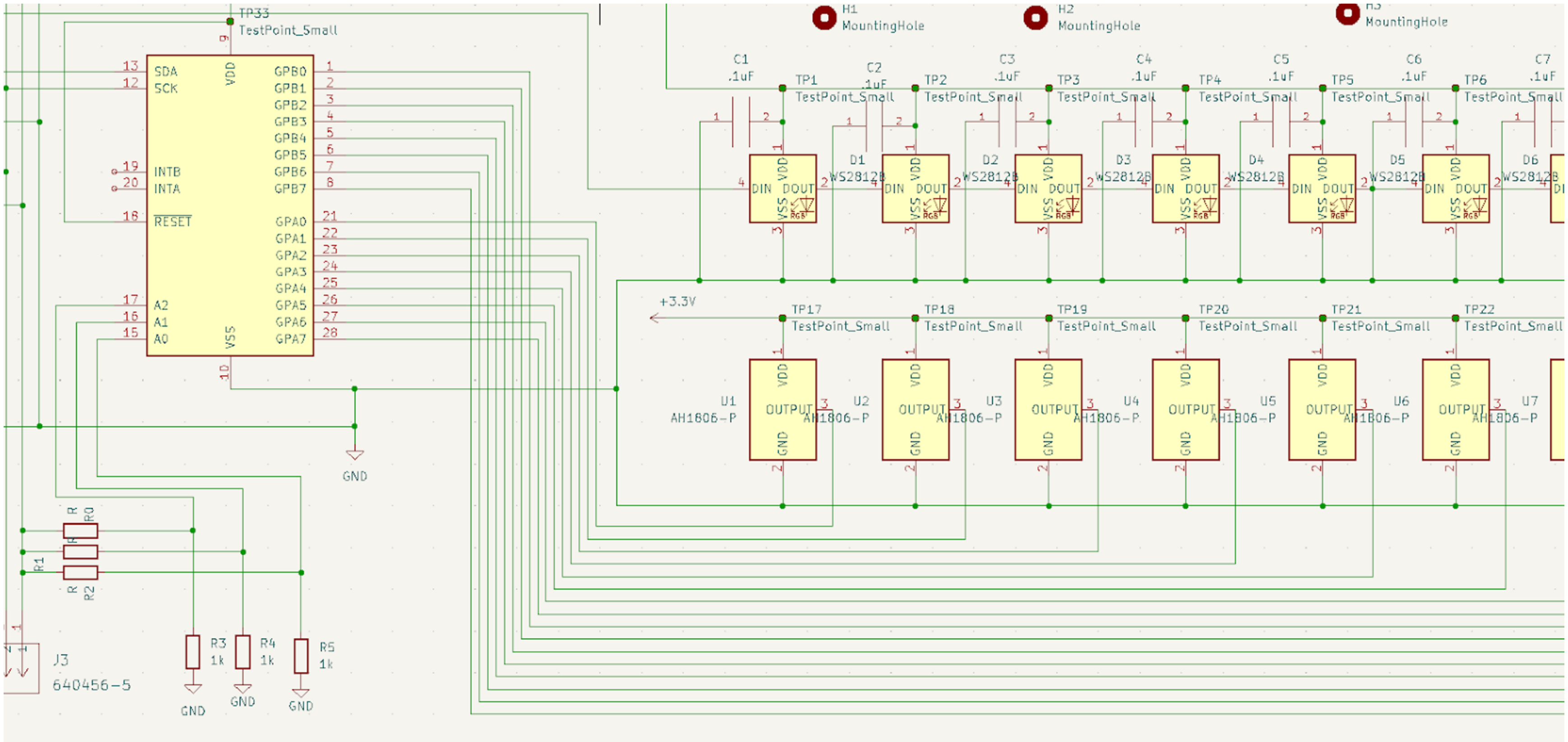

Figure 8. I2C expander, LED, Hall effect sensor circuitry

Appendix B: FMECA Worksheet

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
1	No output from microcontroller	Bridged pins on microcontroller, Open circuit on Vdd, short circuit through capacitors	Microcontroller does not function, board does not do anything	Observation	Low	Bridging between Vdd and GND could be medium criticality due to damage to microcontroller
2	Microcontroller instructions stop executing	Issues with software, noise on Vdd pin	Microcontroller stops the gameplay from continuing	Observation	low	
3	Bypass software guards on LED brightness	Issues in the software, high voltage on PWM signal	All LEDs are set to full brightness sinking a large amount of current	Observation	Medium	Sinking all the current into the LEDs would brown out the rest of the board potentially damaging other compoenents

Table 5. Microcontroller FMECA

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
4	Reset pulled low	Short through button or capacitor	Constantly reseting microcontroller	Observation	Low	Makes game unplayable

5	Reset pulled high	Open circuit on capacitor or button	Microcontroller unable to be reset	Observation	Low	
6	Noise on clock signal	Short through capacitor on clock	Noise on clock signal messes with timing on microcontroller	Observation/oscilloscope probe on the clock signal	low	

Table 6. Reset Boot and Clock FMECA

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
7	5V past voltage regulator	Short through voltage regulator	High voltage on micro and other components significant damage possible	Observation/DMM	Medium	
8	Overheating of voltage regulator	Damage to circuitry, overvoltage, short to ground	Broken components, possible smoke, fire on board	Observation	High	Burning components could lead to danger to user
9	Failure of bulk capacitor	Voltage spike from wall outlet	Large current spikes throughout the board	Observation	Medium	Could lead to damaged components

Table 7. Power circuitry FMECA

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
10	Vbus supplies too much voltage	Overvoltage from computer, short through voltage division resistor	Damage to pins on the microcontroller	Observation	Medium	Damage to microcontroller breaks system
11	Broken SD card reader	Bridged pins on SD port, no supply voltage, open spi line, damaged SD card	Cannot store information on SD card	Observation	Low	
12	Broken USB port	Bridged pins on connector, broken USB cord, Vbus not active	USB not detected, communication not possible	Observation	low	
13	Broken LCD screen	No supply voltage, bridged communication lines	Nothing can be displayed on LCD	Observation	low	

Table 8. LCD, USB, SD card reader FMECA

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
14	Boards not communicating sending signals	Connector between boards broken	Part or all of board does not light up or work	Observation	Low	
15	LED not lighting up	Malfunctioning PWM signal, no power to LED, open circuit	LED does not light up or change color	Observation	Low	
16	5V in 3.3V plane	Short between power planes	Damage to i2c expander, microcontroller	Observation	Medium	Damage to other parts on board due to overvoltage
17	Broken hall effect sensor	I2C protocol not working correctly, open data line, short between power and ground	Cannot detect players using magnets	Observation	low	
18	Broken I2C expander	Overvoltage to IC, bridge between two pins on IC, address pins not configured correctly	Cannot read from hall effect sensors	Observation	low	
19	LED is wrong color	Miscommunication over PWM, decoupling capacitor short, software issue	Map display is not correct	Observation	low	

Table 9. LED, I2C and Hall effect sensors