A10 - Reliability and Safety Analysis

Year: 2025 **Semester:** Spring **Team:** 1 **Project:** Electronic Skee Ball
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1.0 Reliability Analysis

This section outlines three of the most likely failure points in Team 1's Electronic Skee Ball machine. These components were chosen due to high operating temperature (a known cause of failure) along with general complexity of circuitry. For each component, the models for determining the number of failures per 10^6 hours and the mean time between failures (MTTF) are stated along with any relevant parameters. Then, using these parameters, results are presented in a tabular format.

1.1 STM32F091RCT6

The most complex component in the Electronic Skee Ball machine is its microcontroller. This device (STM32F091RCT6) has a high concentration of complex digital CMOS circuitry along with a relatively high operating temperature (up to 85℃) [1].

The equation for failure rate (denoted λ_p) measures in failures per million hours for the microcontroller was chosen from the suggested equation in section 5.1 (Microcircuits, Gate/Logic Arrays, and Microprocessors) in MIL-HDBK-217F [2]:

$$\lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L \tag{1}$$

where C_1 is the die complexity failure rate, π_T is the temperature factor, C_2 is the packaging failure rate, π_E is the environment factor, π_Q is the quality factor, and π_L is the learning factor. This equation was chosen because it is tailored specifically to microcontrollers. C_1 was chosen to be 0.56 since the device is a 32-bit MOS device (see section 5.1 in MIL-HDBK-217F). The temperature factor was chosen 0.98 since the device is a digital CMOS device with maximum recommended operating temperature of 85℃ (section 5.8). The package failure rate was chosen to be 0.0267 since the microcontroller is a surface-mounted device with 68 functional pins (see section 5.9 in the MIL-HDBK-217F for the relevant equation). The environment coefficient was chosen to be 2.0 since the Electronic Skee Ball machine has a fixed-ground connection (see section 5.6 for recommended environment factors). The quality factor was chosen to be 10 since the device is a commercial product (see section 5.10). The learning factor was chosen to be 1.0 since the device has been in production for longer than two years. These parameters and the resulting failure rate per million hours and mean time between failures are summarized below in Table 1.

Table 1: Reliability Analysis for STM32F091RCT6

Parameter Name	Description	Value	Comments
C_1	Die complexity	0.56	32-bit microprocessor
π_T	Temperature factor	0.98	32-bit MOS operating at 85℃
C_2	Packaging failure	0.0267	68-pin SMD
π_E	Environment factor	2.0	Consistent connection to ground
π_Q	Quality factor	10	Commercial product
π_L	Learning factor	1.0	Time in=n production >= 2 years
λ_p	Failures per million hours	6.214	N/A
MTTF	1 unit total	160,932	~18.37 years

Note that the mean time between failures is calculated by scaling the failure rate per million hours to a rate per unit per hour, i.e.:

$$MTTF = \frac{10^6}{\lambda_p} \tag{2}$$

1.2 LD1117

Another likely source of failure in the Skee Ball Machine is the LD1117 linear drop-off regulator. The LD1117 is a potential point of failure because as a voltage converter, it must dissipate heat consistently and thus operate at a relatively high temperature throughout its lifetime. This device can be described as an implementation of bipolar junction transistor technology, so it is also classified under the microcircuit section (section 5.1 in the handbook) [3]. Therefore, its failure rate is also calculated using Equation 1 [2]. For this device, the exact number of transistors cannot be known, but the block diagram in Section 1 of the datasheet suggests that the number would be fewer than 100 [3]. Therefore, the die complexity failure rate of this device is chosen as 0.01 as a BJT device with between one and one hundred transistors. The temperature factor of this device is chosen to be 58 since it is a bipolar device operating at temperature up to 125℃. The packaging failure rate is calculated to be 0.000125 using the same equation for surface-mounted microcircuits mentioned above in the STM32F091RCT6 analysis. The environmental factor is chosen to be 2.0 since the device has a fixed ground connection. The quality factor is chosen to be 10.0 since the device is commercially available. The learning factor is chosen to be 2.0 since the device has been in production for over two years. These parameters along with the resulting failure rate per million hours and mean time between failures are summarized below in Table 2.

Table 2: Reliability Analysis for LD1117

Parameter Name	Description	Value	Comments
C_1	Die complexity	0.01	Bipolar device with between 1 and 100 transistors
π_T	Temperature factor	58	Bipolar device operating at 125℃
C_2	Packaging failure	0.000125	4-pin SMD
π_E	Environment factor	2.0	Consistent connection to ground
π_Q	Quality factor	10	Commercial product
π_L	Learning factor	1.0	Time in=n production >= 2 years
λ_p	Failures per million hours	5.803	N/A
MTTF	1 unit total	172,312	~19.67 years

1.3 NHD-0440AZ-FL-YBW

A third potential source of failure in the Electronic Skee Ball machine is the NHD-0440AZ-FL-YBW LCD display. This display is a likely failure point due to its high complexity (extensive IO pins and high concentration of onboard digital circuitry). Due to the high concentration of MOSFET devices in the onboard controllers, this device can likewise be classified as a microcircuit [2]. Since the device contains two onboard display drivers and a builtin input interface, it can be conservatively assumed that the device contains between 30,000 and 60,000 digital gates (this estimate is conservative as opposed to liberal since a higher number of gates results in a lower time between failures) [4]. Thus, its die complexity failure rate is chosen to be 0.29. Its temperature coefficient is chosen to be 0.6 since it is primarily a digital MOS device operating at a maximum of 70℃. Its package failure rate is calculated as 0.00635 since the device's IO interface consists of 18 DIP soldered header pins. The environmental factor is 2.0 since the device has a fixed ground connection. The quality factor is 10 since the device is commercially available. The learning factor is 1.0 since the device has been in production for more than two years. These parameters along with the resulting failure rate per million hours and mean time between failures are summarized below in Table 3.

Table 3: Reliability Analysis for NHD-0440AZ-FL-YBW

Parameter Name	Description	Value	Comments
C_1	Die complexity	0.29	Bipolar device with between 1 and 100 transistors
π_T	Temperature factor	0.6	Bipolar device operating at 125℃
C_2	Packaging failure	0.00635	4-pin SMD
π_E	Environment factor	2.0	Consistent connection to ground
π_Q	Quality factor	10	Commercial product
π_L	Learning factor	1.0	Time in=n production >= 2 years
λ_p	Failures per million hours	1.91	N/A
MTTF	1 unit total	522,845	~59.66 years

1.4 Reliability Summary

The results of sections 1.1, 1.2, and 1.3 indicate that the electronics of the Electronic Skee Ball machine are reliable far beyond the needs of the machine. Each of the three most complex components on the device are expected to consistently perform for over ten years, far beyond the intended lifetime of the product. One possible means of improving the reliability of the design would be to purchase military-grade or industrial-grade parts, which would improve the quality factor of each component and thus increase their mean time between failures. Another possible means of improving the reliability of the Electronic Skee Ball machine is the implementation of a cooling mechanism via in-package fans or liquid cooling. This would mitigate the high-temperature operations of some of the components, thus improving their temperature factors and therefore their reliability.

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

2.1 Failure Mode Criticalities

Failure mode criticalities for the Electronic Skee Ball machine can be divided into three categories: 1) low, indicating partial but not complete loss of product functionality; 2) medium, indicating significant or complete loss of functionality; 3) potential harm to the user.

2.2 Failure Modes in Subsystems

The Electronic Skee Ball machine schematic can be divided into four major subsystems. These include the power network, the microcontroller and associated circuitry, the ultrasonic sensor network, and the LCD display circuitry.

The power network consists of a 24V input barrel jack connector, two buck converters, and one linear drop-off regulator. The 24V DC input to the PCB is immediately regulated to 5V DC and 6V DC by the two buck converters. The output of the 5V converter is used as the input power to the LD1117 LDO to generate 3.3V DC. The 24V source does not power any components on the board other than the two aforementioned buck converters. The 6V power plane is used to power the control signal for an offboard servo motor. The 5V power plane is used to power the shift registers which interface with the LCD display and the sensor network. The 3.3V power plane is used to power the microcontroller. Therefore, the failure modes associated with this subsystem are low 24V failure, high 6V failure, low 6V failure, high 5V failure, low 5V failure, high 3.3V failure, and low 3.3V failure. The high 5V failure is classified as a high criticality failure mode since the exposure of the LD1117 to an excessive amount of power could cause it to catch fire and potentially cause harm to the user. The other failure modes would all cause a loss of product functionality but would not ignite any of the associated circuitry, thus posing no harm to the user, so they are classified as medium criticality.

The microcontroller produces all of the control signals that are vital for any of the product functionality. Therefore, any failure of the microcontroller circuitry is likely to cause a complete or partial loss of functionality but would not cause any harm to a user, so this failure mode is classified as medium criticality.

The ultrasonic sensor network consists of an array of five ultrasonic sensors, each of which are connected to the microcontroller with two separate digital signals and also to 5V and ground. Therefore, failure of any one of these sensors would cause a cessation in communications with the microcontroller and therefore a partial loss of game functionality. Since there are five sensors, a loss of functionality in only a subset of them would allow the user to continue using the product with reduced functionality, so a partial failure of the sensor network is classified as low criticality. Failure in all five sensors would render the game unplayable and is thus classified as medium criticality failure mode.

The LCD display circuitry consists of two shift registers, a communication channel with the microcontroller, and connections to the LCD display's parallel input interface. Failure in any one of these systems would render the LCD display inoperable. The display is not critical to the functionality of the game and could never pose a threat to the user, so failure modes in this subsystem are classified as medium criticality.

3.0 Sources Cited:

[1] STMicroelectronics, "STM32F091CC datasheet – ARM Cortex-M0 Microcontroller," *STMicroelectronics*. Accessed: April 5, 2025. [Online]. Available: https://www.st.com/resource/en/datasheet/stm32f091cc.pdf

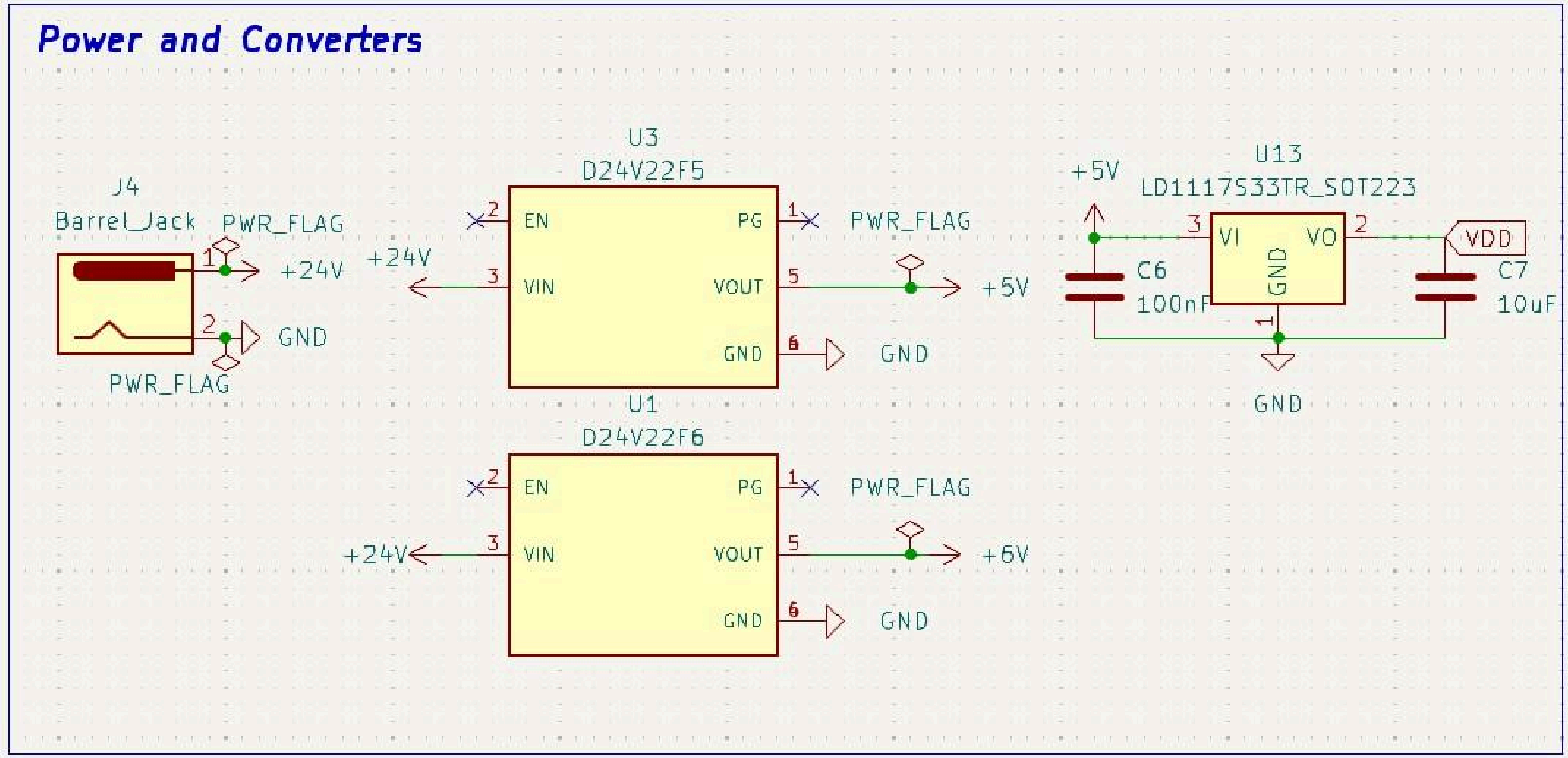
[2] U.S. Department of Defense, "Military Handbook: Reliability Prediction of Electronic Equipment, MIL-HDBK-217F." Accessed: April 5, 2025. [Online]. Available: https://snebulos.mit.edu/projects/reference/MIL-STD/MIL-HDBK-217F-Notice2.pdf

[3] STMicroelectronics, "LD1117: Adjustable and Fixed Low Drop Positive Voltage Regulator," *STMicroelectronics*. Accessed: April 5, 2025. [Online]. Available: https://www.st.com/resource/en/datasheet/ld1117.pdf

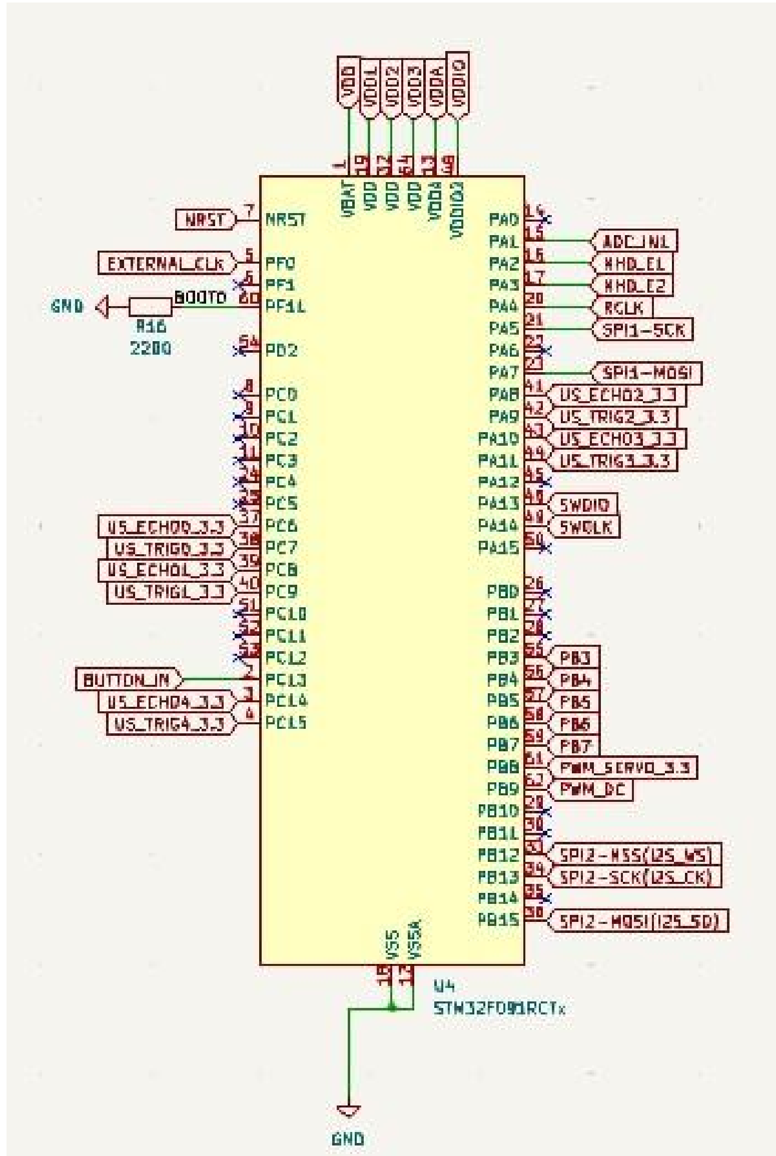
[4] Newhaven Display International, Inc. NHD-0440AZ-FL-YBW: Character Liquid Crystal Display Module, Rev. 1.0, Mar. 23 2018. Accessed April 5, 2025. [Online]. Available: https://newhavendisplay.com/content/specs/NHD-0440AZ-FL-YBW.pdf

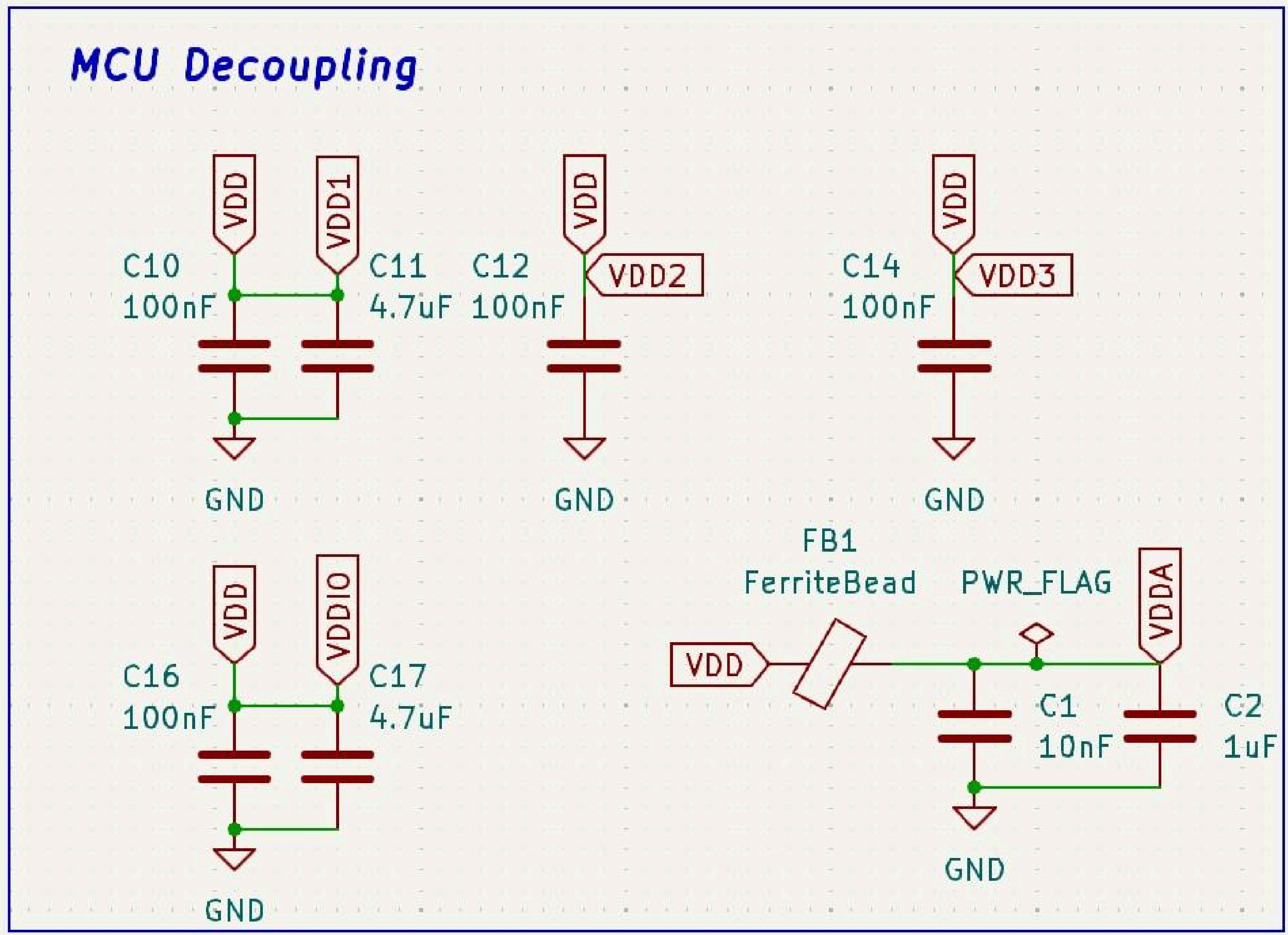
Appendix A: Schematic Functional Blocks

Subsystem A: Power Network

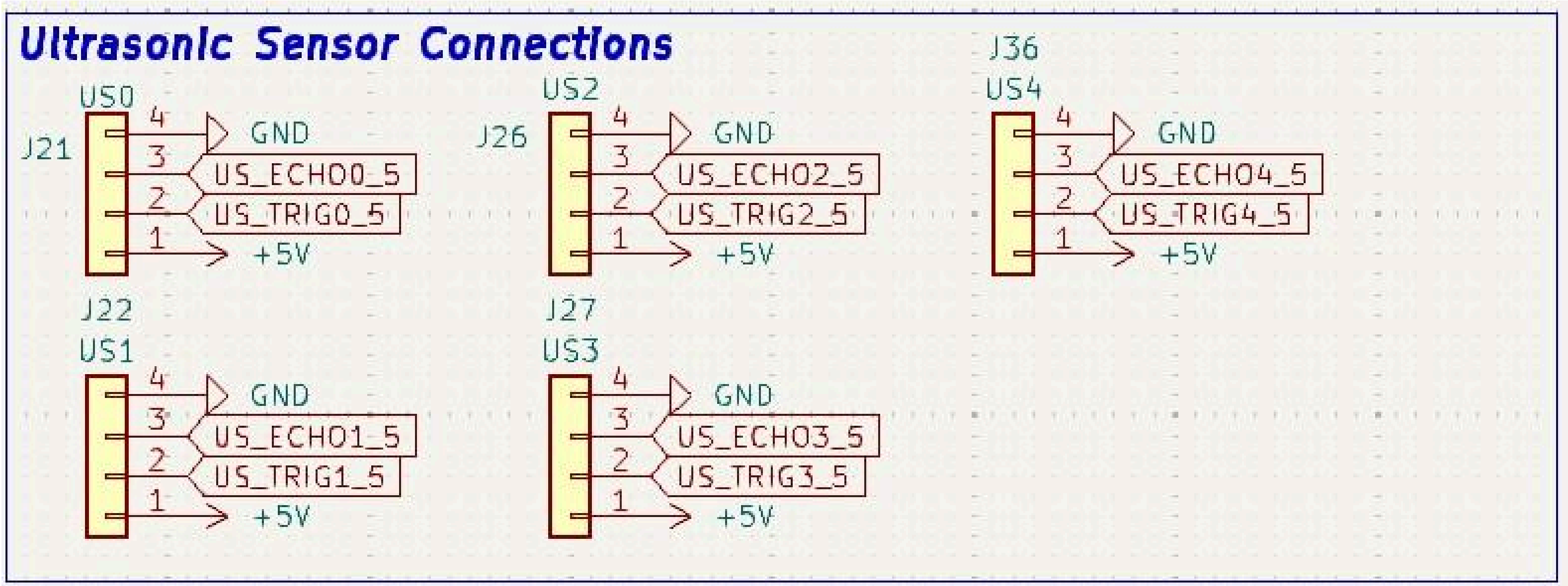


Subsystem B: Microcontroller

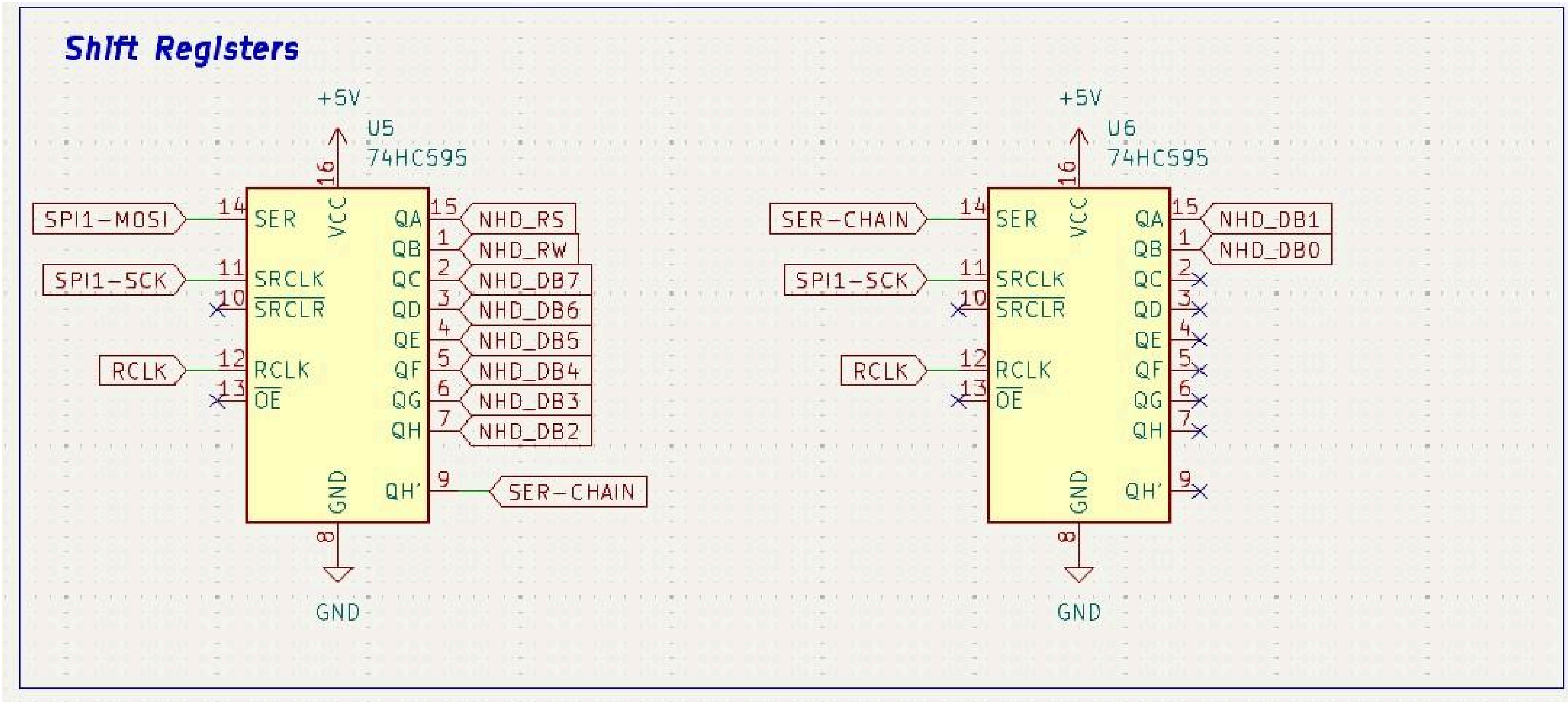


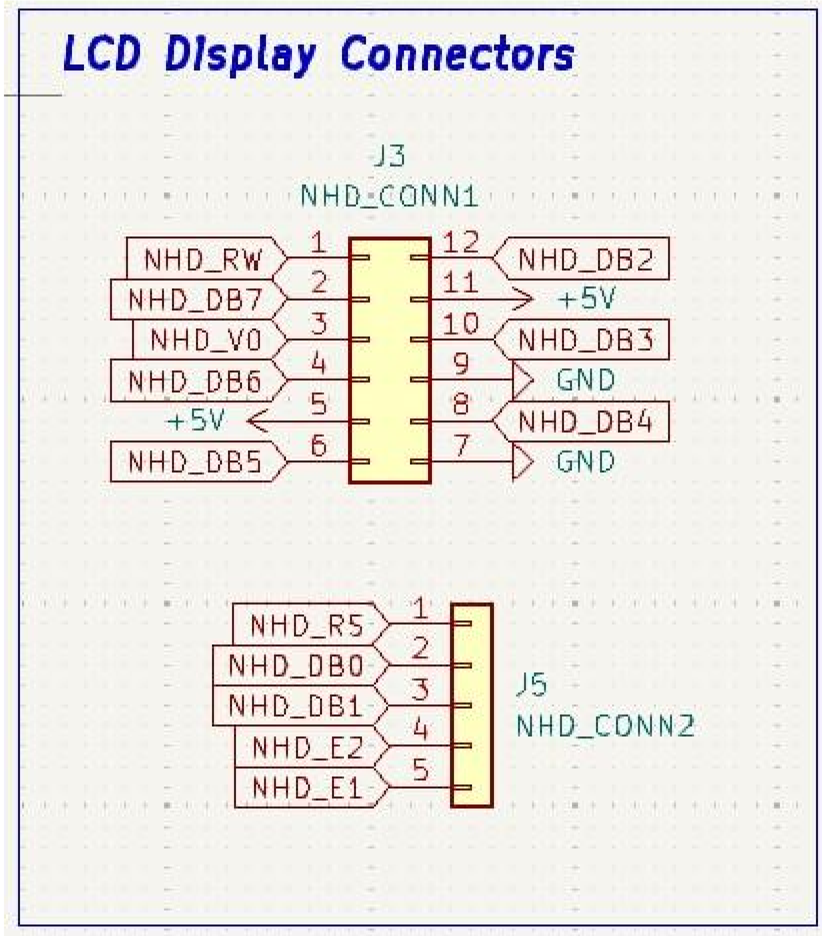

MCU Decoupling
VDD
VDD1
C10
100nF
C11
4.7uF
GND
VDD
VDD2
C12
100nF
GND
VDD
VDD3
C14
100nF
GND
VDD
VDDIO
C16
100nF
C17
4.7uF
GND
FB1
FerriteBead
PWR_FLAG
VDDA
VDD
C1
10nF
C2
1uF
GND

Subsystem C: Sensor Array



Subsystem D: LCD Display




LCD Display Connectors
J3
NHD_CONN1
NHD_RW
NHD_DB7
NHD_V0
NHD_DB6
+5V
NHD_DB5
NHD_DB2
+5V
NHD_DB3
GND
NHD_DB4
GND
NHD_RS
NHD_DB0
NHD_DB1
NHD_E2
NHD_E1
J5
NHD_CONN2

Appendix B: FEMCA Worksheet

Subsystem A: Power Network

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
A1	Low 24V voltage	Damaged barrel jack, damaged power supply	Total loss of functionality	Observation	Medium	No component will function at all
A2	High 6V Voltage	Damaged buck converter	Loss of control of servo motor	Observation	Low	Servo motor will not function; rest of game will remain functional and usable
A3	Low 6V Voltage	Damaged buck converter	Loss of control of servo motor	Observation	Low	Servo motor will not function; rest of game will remain functional and usable
A4	High 5V Voltage	Damaged buck converter	Loss of functionality in sensors, MCU, LCD, possible ignition of LDO	Observation	High	Threat of ignition of LDO poses threat to user
A5	Low 5V Voltage	Damaged buck converter	Loss of functionality in sensors, MCU, LCD, possible ignition of LDO	Observation	Medium	MCU will likely not function, rendering the product unusable

A6	High 3.3V Voltage	Damaged LDO	Loss of functionality for MCU	Observation	Medium	With input voltage other than 3.3V, MCU will likely not function, rendering the product unusable
A7	Low 3.3V Voltage	Damaged LDO	Loss of functionality for MCU	Observation	Medium	With input voltage other than 3.3V, MCU will likely not function, rendering the product unusable

Subsystem B: Microcontroller

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
B1	External pin damage	EOL wear and tear, ESD	Loss of functionality in most or all other systems	Observation	Medium	Damage to external pins will render most if not all of the other functionality inoperational, making the product unusable
B2	Damaged reset	Failure of pull-up resistor on reset button	Total loss of functionality	Observation	Medium	MCU will be completely dysfunctional; product will be unusable

Subsystem C: Sensor Array

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks

C1	Individual sensor damage	Struck by ball, general EOL wear and tear	Loss of ball detection in one scoring hole	Observation	Low	Some scoring holes will no longer work, but the game will function mostly as normal and can be continued to be used by the user
C2	All sensors fail	Repeated physical damage, long-term usage	Loss of ability to score points	Observation	Medium	User can no longer score points, so the game is unusable

Subsystem D: LCD Display

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
D1	Dysfunctional SPI communications	Damage to shift register pins, software misconfiguration	Loss of display functionality	Observation	Low	Display will not render text, but game is otherwise usable
D2	Damaged shift register output	Damage to shift register pins	Loss of display functionality	Observation	Low	Display will not render text, but game is otherwise usable