Homework 11: Reliability and Safety Analysis

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Evaluation:

SEC	DESCRIPTION	MAX	SCORE
1.0	Introduction	5	
2.0	Reliability Analysis	40	
3.0	Failure Mode, Effects, and Criticality Analysis (FMECA)	40	
4.0	Summary	5	
5.0	List of References	10	
	TOTAL	100	

Comments:

1.0 Introduction

The Beat Square is an 8x8 push button matrix that will support multi-tone audio playback and corresponding LED lights. It is a desktop audio project with few moving parts but several visual and audio outputs. The matrix will light up each column, left to right, using a “persistence of vision” based flashing method and produce the tone associated with any button that has been enabled on for that column. Possible safety issues may arise when a user is sensitive to the audio or visual feedback. There may be situations that put the user at risk of injury when sensitive to these outputs such as a ruptured eardrum or possibly even an epileptic seizure. These situations should be prevented at all costs. On top of the safety issues there are general reliability concerns due to component failures that may make the project work in unexpected ways or not at all.

2.0 Reliability Analysis

Several components were chosen as possible causes of safety or reliability concerns. These parts are ones that could cause surges of power to other components or make the project operate in an unwanted way. Failure of these components may lead to harm to the user or failure of the Beat Square.

- TM4C123GH6PM Microcontroller

The first major component to watch is the Tiva C Microcontroller this project is using. A microcontroller failure will cause many issues but one to be wary of is a slower clock to the LED shift registers. If the clock to these registers becomes slower than 60 frames per second needed to induce “persistence of vision,” the flashing of individual columns will be visible. If this happens the flashing may still be fast enough an epileptic seizure from a user that is sensitive to flashing lights. This is an extremely unlikely failure but must be accounted for. A damaged GPIO pin for the shift register clock would create this error and could be caused by too much current or just a failure of the microcontroller. On top of this safety issue are possibilities that would produce unexpected output from the project if there were to be a microcontroller failure.

When calculating the number of failures per 10^6 hours and mean time to failure (MTTF) for the microcontroller, the gate/logic array and microprocessors model was used from the Military Handbook ([1], pg. 5-3).

Parameter name	Description	Value	*Comments*
C1	Die complexity	.56	32-bit MOS
π_T	Temperature coeff.	.19	40 °C
C2	Pin constant	.032	64 pins SMT
π_E	Environmental constant	.50	Ground, benign
π_Q	Quality factor	1.0	Assumed Class B
π_L	Learning factor	1.0	7 years old
Entire design:	$\lambda_P = (C1 \times \pi_T + C2 \times \pi_E) \times \pi_Q \times \pi_L = 122.4 \times 10^{-3}$		
	$MTTF = 1/(\lambda_P \times 10^{-6}) = 8.17 \times 10^6$ h		

Data compiled using the TM4C123GH6PM [2] datasheet and Military Handbook [1]

The MTTF for the microcontroller is over 932 years, so the project is relatively safe from encountering a microcontroller failure.

- LM2940N Voltage Regulator

The LM2940N is the project's 5V regulator capable of sourcing up to 1A of current. If this component failed all other components would be affected. There could be either too much current sourced or a complete failure to provide current. In the first case, other components could be damaged as well as a case where the audio amplifiers provide too much power to the speakers and risk rupturing the user's eardrums. In the second case, no damage will occur to other components but the LM2940N will most likely need replacement.

Parameter name	Description	Value	*Comments*
C1	Die complexity	.01	1-100 linear transistor array
π_T	Temperature coeff.	.49	45 °C
C2	Pin constant	.0016	4 pins SMT
π_E	Environmental constant	.50	Ground, benign
π_Q	Quality factor	1.0	Assumed Class B
π_L	Learning factor	1.0	14 years old
Entire design:	$\lambda_P = (C1 \times \pi_T + C2 \times \pi_E) \times \pi_Q \times \pi_L = 5.7 \times 10^{-3}$		
	$MTTF = 1/(\lambda_P \times 10^{-6}) = 175.4 \times 10^6$ h		

Data compiled using the LM2940N [3] datasheet and Military Handbook [1]

Using the gate/logic array model, the LM2940N is safe with a very long MTTF of over 20,000 years. Only intentional overloading of the part or a failure before the mean will lead to issues with the 5V power source.

- TPS73633 Voltage Regulator

The TPS73633 provides the power for the 3.3V logic and pulls its power from the LM2940N. Like the 2940, the 73633 can either provide too much or too little power to its components. The microcontroller is the biggest component pulling from this power source but the audio circuit and the pushbutton shift registers are also powered from 3.3V. If this were to fail and provide extra current, the same issue of rupturing an eardrum could occur as well as damaging the microcontroller and digital-to-analog converter. Again, a failure that leads to no current sourcing would be fixed by replacing the regulator.

Parameter name	Description	Value	*Comments*
C1	Die complexity	.02	101-300 linear transistor array
π_T	Temperature coeff.	.49	45 °C
C2	Pin constant	.0025	6 pins SMT
π_E	Environmental constant	.50	Ground, benign
π_Q	Quality factor	1.0	Assumed Class B
π_L	Learning factor	1.0	11 years old
Entire design:	$\lambda_P = (C1 \text{ x } \pi_T + C2 \text{ x } \pi_E) \text{ x } \pi_Q \text{ x } \pi_L = 11.1\text{x}10^{-3}$		
	$\text{MTTF} = 1/(\lambda_P \text{ x } 10^{-6}) = 90.5 \text{ x } 10^6$ h		

Data compiled using the TPS73633 [4] datasheet and Military Handbook [1]

The TPS73633 is also a safe component with an MTTF of 90.5 x 10^6 h using the gate/logic array model.

- LM4902 Audio Amplifier

The last components that may cause issues are the LM4902 audio amplifiers. With two powering a speaker each, the chance for overloading the speakers and producing dangerously loud audio is high if the amplifiers provide too much power. This could be from an internal error or propagated from a voltage regulator failure. Too much power may also blow out the speakers themselves.

The same gate/logic array model was used to determine the λ and MTTF for this component. It also passed with a $\lambda < 10^{-9}$ and is suitable for the project.

Parameter name	Description	Value	*Comments*
C1	Die complexity	.02	101-300 linear transistor array
π_T	Temperature coeff.	.49	45 °C
C2	Pin constant	.0034	64 pins SMT
π_E	Environmental constant	.50	Ground, benign
π_Q	Quality factor	1.0	Assumed Class B
π_L	Learning factor	1.0	7 years old
Entire design:	$\lambda_P = (C1 \times \pi_T + C2 \times \pi_E) \times \pi_Q \times \pi_L = 11.5 \times 10^{-3}$		
	$MTTF = 1/(\lambda_P \times 10^{-6}) = 87.0 \times 10^6$ h		

Data compiled using the LM4902 [5] datasheet and Military Handbook [1]

The reliability of the parts examined passes the expectations set out for them. Any issues mentioned above will not be expected in an average case. There are not many improvements that could be made for these parts that would noticeably increase the safety of the design.

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

There are several failure modes that could occur should a component fail. A couple of these are high criticality and might injure a user. The failure rate of these should follow industry standard and fulfill a $\lambda < 10^{-9}$. A few other failure cases are less critical, and their failure rates can be defined by how often they should occur. Choosing a $\lambda < 10^{-6}$ will be sufficient for the less critical failures. Mentioned below are a few of the more serious issues that might occur. A more comprehensive list of failure modes is listed in Appendix B.

- Slowed LED Clock

If a failure were to occur that would slow the clocking signal for the LEDs low enough that persistence of vision no longer applies, the flashing of the columns will be visible. If the flashing is still at a high enough frequency, it could induce an epileptic seizure in a user that is prone to them. This is a high criticality situation that could be caused by either the clock source pin from the microcontroller or the either of the two output latches of the HC595 shift registers. As computed above the failure rate for the microcontroller $\lambda = 122.4 \times 10^{-9}$ is not within the safety specification. Also when the same analysis is used for the HC595, the failure rate is $\lambda = 7.4 \times 10^{-9}$. These values are on the same magnitude of the specification but could be improved to reduce the risk of this situation happening. This is a very specific failure though, and the probability that it this exact error happening will be lower than the overall failure rate.

- Excess Speaker Power

If either of the voltage regulators or the audio amplifiers were to supply too much current to the speakers they may output enough pressure to rupture an eardrum or damage hearing. Since the user's hearing is at risk, this situation will be labeled as a high criticality one. The failure rate for the important regulators and amplifiers are $\lambda = 5.7 \times 10^{-9}$ for the LM2940N, $\lambda = 11.1 \times 10^{-9}$ for the TPS73633, and $\lambda = 11.5 \times 10^{-9}$ for the LM4902. These rates are again all the same magnitude of the specification but slightly higher than desired. Fortunately, the rated power of the speakers is at most 24W whereas the pressure needed to burst an eardrum is around 35 kPa [6] which corresponds to 3 million W/m^2[7]. Even if this amount of energy were even possible to be sent to the speakers, the speakers themselves would burst first.

- All LEDs power on

There is an unlikely event that may occur where the data to the shift registers gets stuck in a state that has every color of every LED on at the same time. This would draw an immense amount of power, most likely overloading one of the voltage regulators. Unlike the previous two failure modes, this failure does not result in an injury to the user so it is only considered low criticality. The error would occur with either the microcontroller or shift registers which again have failure rates of $\lambda = 122.4 \times 10^{-9}$ and $\lambda = 7.4 \times 10^{-9}$ respectively. While this was not sufficient for a high criticality situation, it is more than enough for a low criticality one.

4.0 Summary

In conclusion, there are several safety and reliability concerns that this project needs to take into account. The possibility of epileptic seizure and ruptured eardrums exist as high criticality failures that could happen more often than the industry standard specifies. In a commercial product, hardware monitors could be added to prevent these negative effects due to a component failure. For this purpose though, the probabilities of failure are low enough to continue with the project design.

5.0 List of References

[1] Military Handbook Reliability Prediction of Electronic Equipment. Department of Defense. Washington, DC. [Online]. Available: https://engineering.purdue.edu/ece477/Course/Assignments/Reference/Mil_Hdbk_217F.pdf

[2] Tiva™ TM4C123GH6PM Microcontroller. Texas Instruments. Austin, TX. [Online]. Available:https://engineering.purdue.edu/477grp1/docs/ref/TM4C123GH6PM%20Microcontroller.pdf

[3] LM2940-N/LM2940C 1A Low Dropout Regulator. Texas Instruments. Dallas, TX. [Online]. Available: https://engineering.purdue.edu/477grp1/docs/ref/LM2940N%20Voltage%20Regulator.pdf

[4] Cap-Free, NMOS, 400mA Low-Dropout Regulator with Reverse Current Protection. Texas Instruments. Dallas, TX. [Online]. Available: https://engineering.purdue.edu/477grp1/docs/ref/TPS73601%20Voltage%20Regulator.pdf

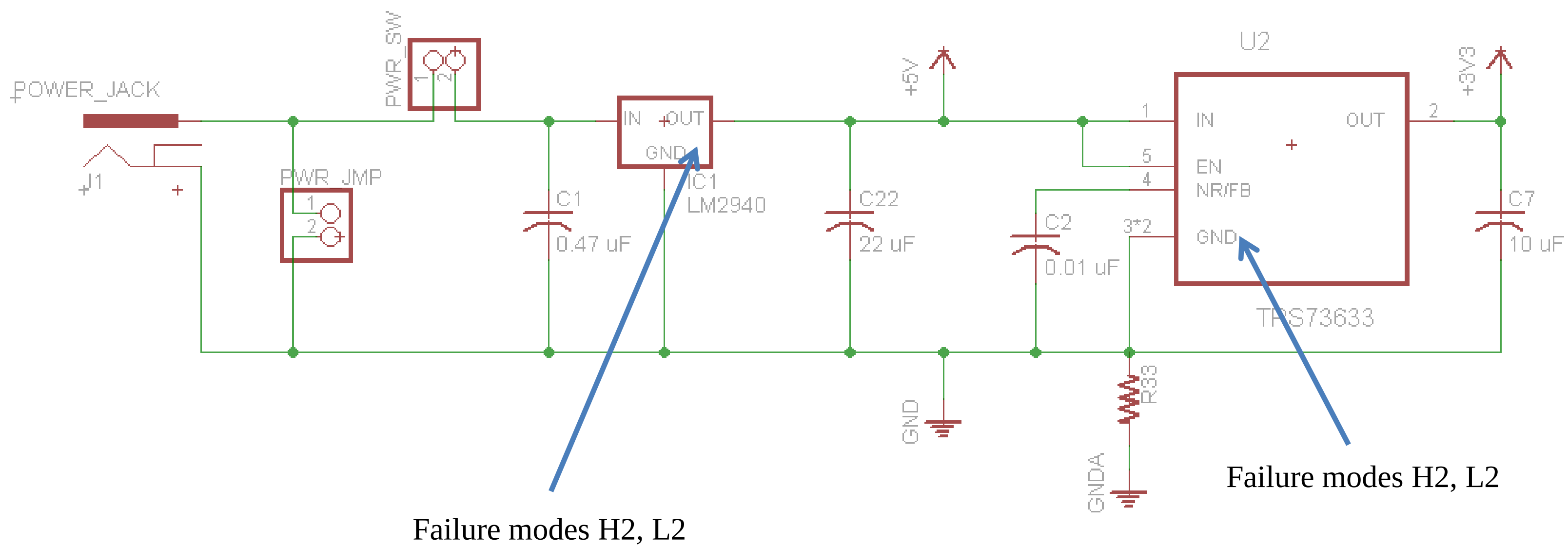
[5] LM4902 Boomer™ Audio Power Amplifier Series. Texas Instruments. Dallas, TX. [Online]. Available: https://engineering.purdue.edu/477grp1/docs/ref/LM4902%20Audio%20Amplifier.pdf

[6] Eardrum Rupture – At What Pressure?. Wayne Staab. [Online]. Available: http://hearinghealthmatters.org/waynesworld/2012/eardrum-rupture-at-what-pressure/

[7] Sound Power Calculator. Eberhard Sengpiel. Berlin, Germany. [Online]. Available: http://www.sengpielaudio.com/calculator-soundpower.htm

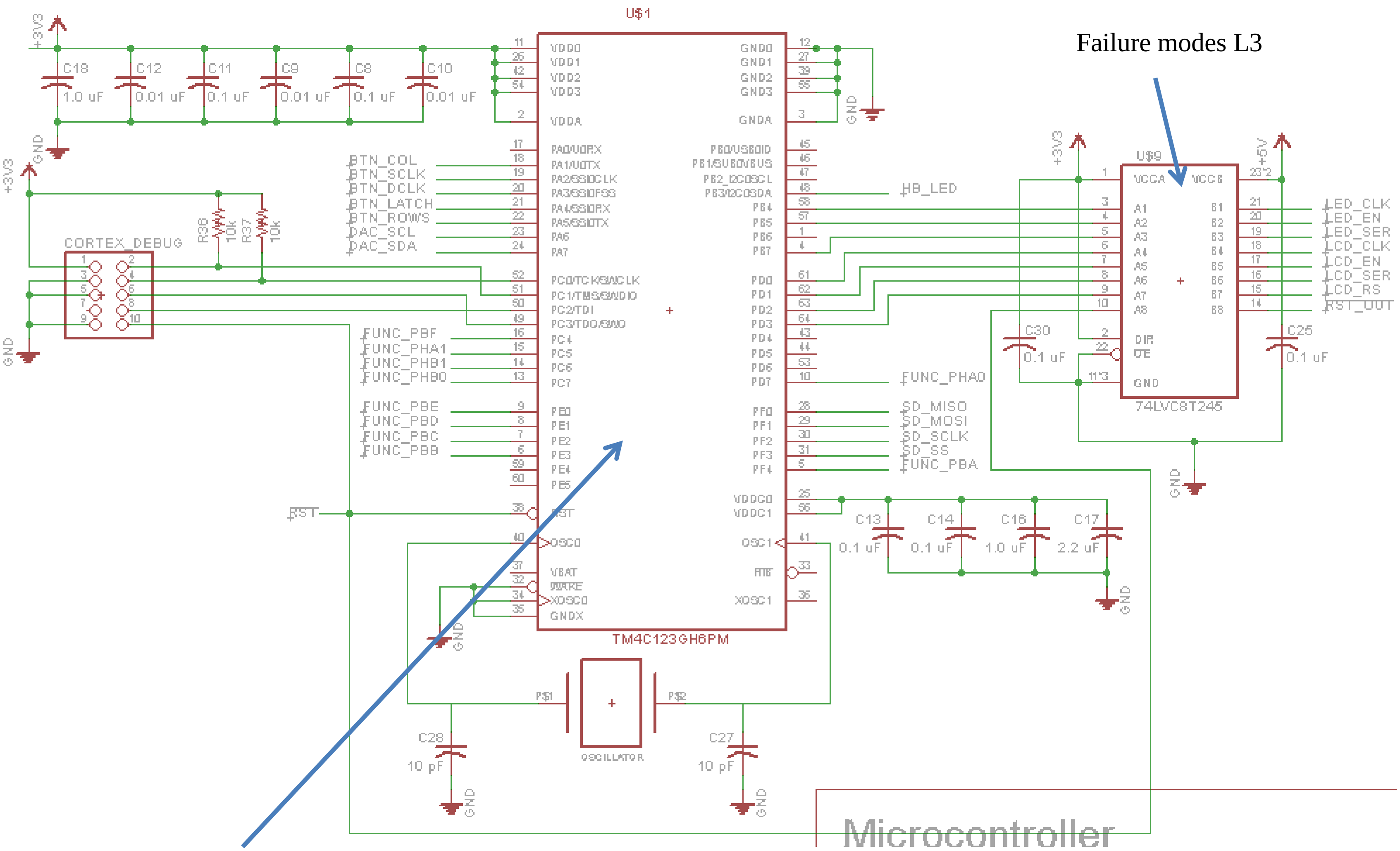
Appendix A: Schematic Functional Blocks

Power Circuit



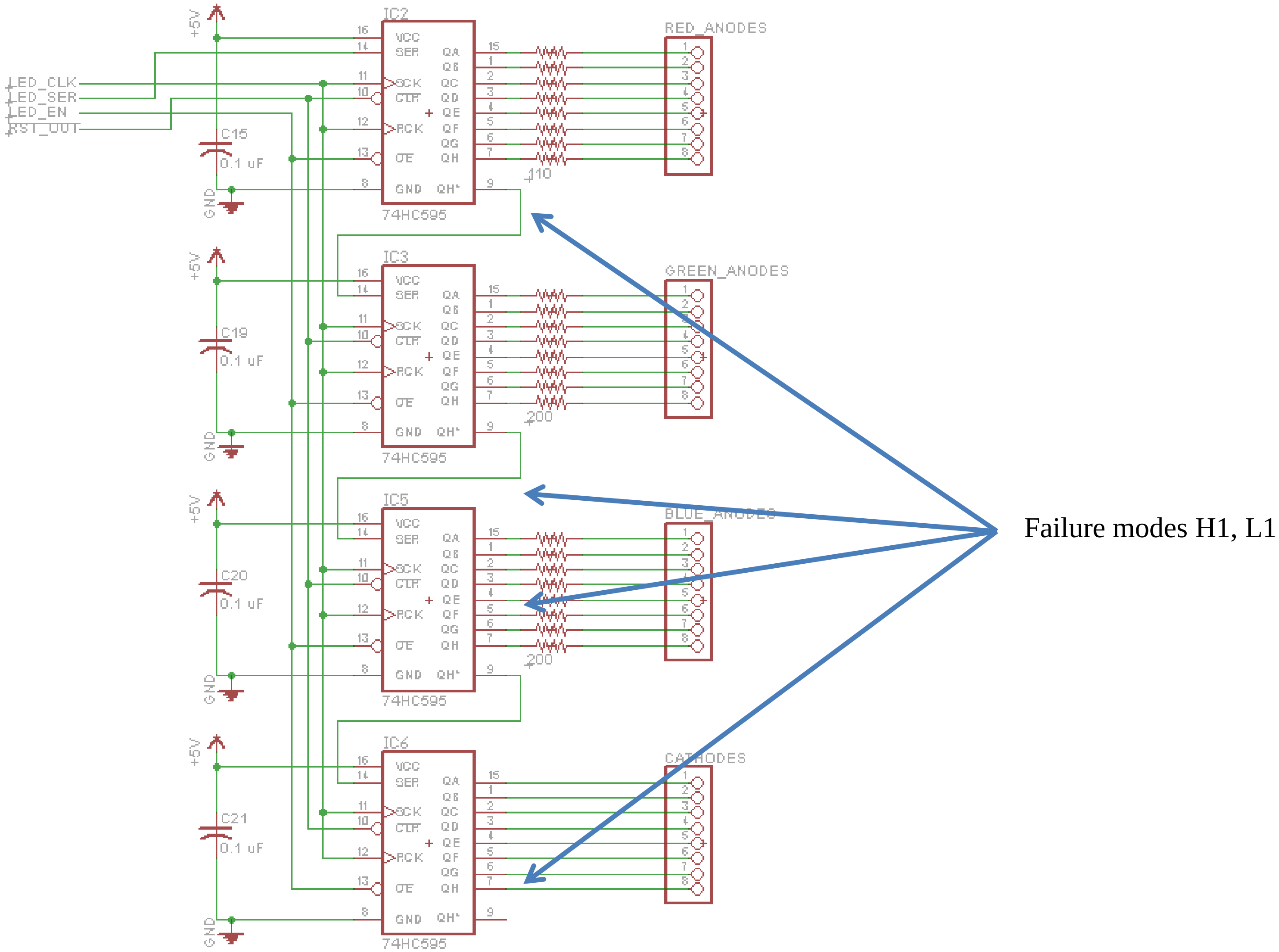
Microcontroller Circuit

Failure modes L3

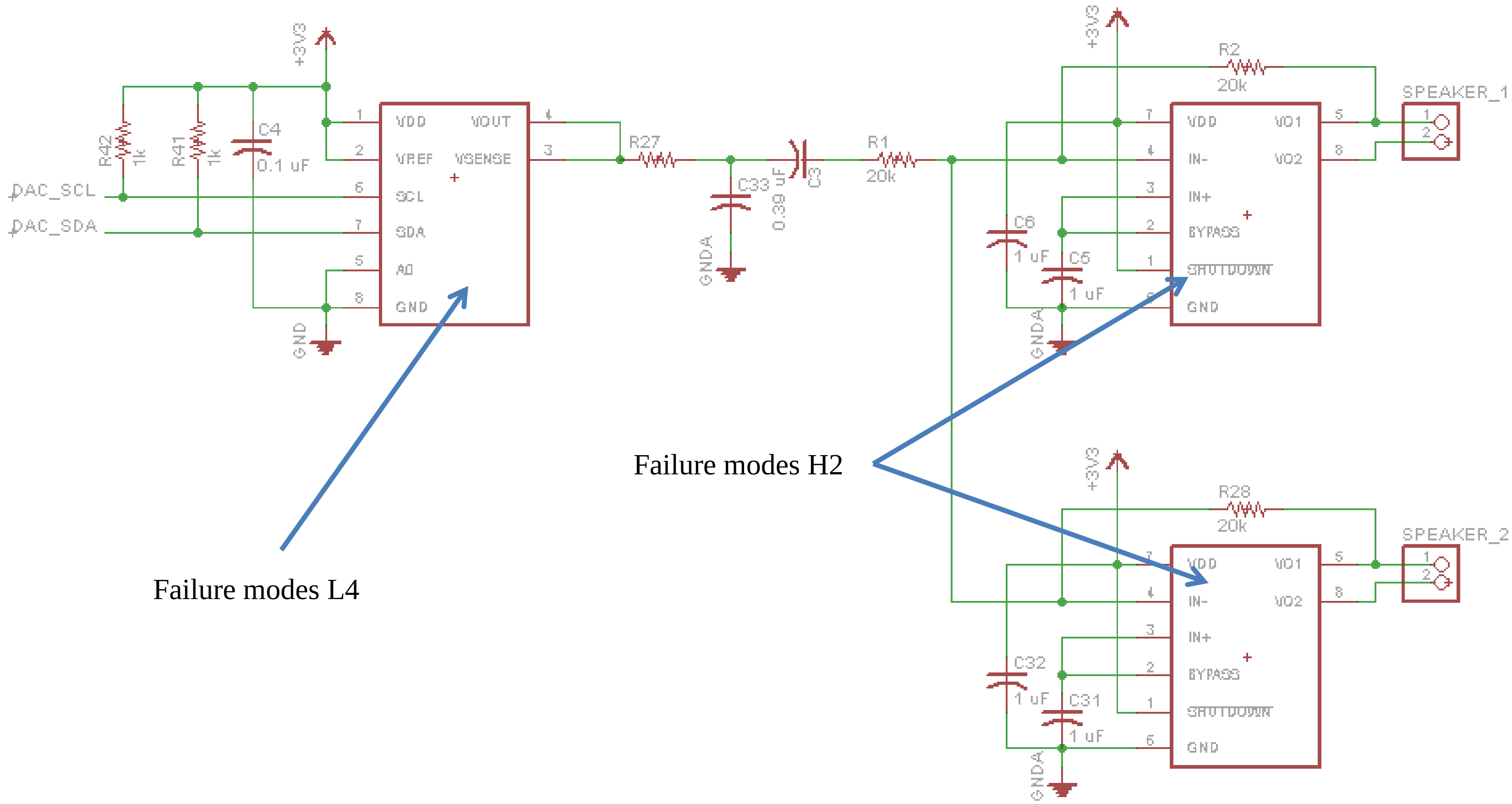


Failure modes H1, L1

LED Shift Register Circuit



Audio Circuit



Appendix B: FMECA Worksheet

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
H1	Slowed LED clock	TM4C123GH6PM (micro), HC595 (LED shift reg.)	Flashing columns visible to naked eye	Visual, clock speed detection	High	Could cause epileptic seizure
H2	Excess speaker power	LM2940N (5V reg.), TPS73633 (3.3V reg.), LM4902 (audio amp.)	Extreme speaker output	Hearing, current monitor	High	Could rupture eardrums
L1	All LEDs on	TM4C123GH6PM, HC595	Power draw too high, possible overloaded regulator	Visual, shift reg. data check	Low	
L2	Loss of power	LM2940N, TPS73633, Power cord	No response, unexpected behavior	No operation	Low	
L3	Loss of voltage translation	SN74LVC8T245 (voltage translator)	Fail to communicate to LEDs, LCD	Stuck in one state	Low	

Failure No.	Failure Mode	Possible Causes	Failure Effects	Method of Detection	Criticality	Remarks
L4	Loss of digital to analog translation	DAC8571 (digital-to-analog converter)	Failure to produce audio	Hearing	Low	