# Reliability and Safety Analysis

**Year:** 2014 **Semester:** Fall **Team:** 8 **Project:** Fantasy Hue
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**Assignment Evaluation:**

| Item | Score (0-5) | Weight | Points | Notes |
|---|---|---|---|---|
| **Assignment-Specific Items** | | | | |
| Reliability Analysis | | | | |
| MTTF Tables | | | | |
| FMECA Analysis | | | | |
| Schematic of Functional Blocks (Appendix A) | | | | |
| FMECA Worksheet (Appendix B) | | | | |
| **Writing-Specific Items** | | | | |
| Spelling and Grammar | | | | |
| Formatting and Citations | | | | |
| Figures and Graphs | | | | |
| Technical Writing Style | | | | |
| **Total Score** | | | | |

**5: Excellent 4: Good 3: Acceptable 2: Poor 1: Very Poor 0: Not attempted**

**Comments:**

## 1.0 Reliability Analysis

Components in this design selected to be most likely to fail are the LM317 Voltage Regulator, PIC18F46J11-I Microcontroller, LM3404 RGB LED Driver, and the LD1117 Low-Dropout Voltage Regulator. The LM317 Voltage Regulator, implemented on bulb, was selected because it runs hot and must be able to switch very rapidly to produce the 3.3V power supply with a 13 volts input. The LM3404 RGB LED Driver was selected since each channel is sinking current from two LED RGBs and has the potential to sink more current than recommended in the data sheet. The LD1117, implemented on ceiling light, is selected because it runs hot and must be able to switch very rapidly to produce the 3.3V power supply with a 5 volts input.

Models and Assumptions

The model used to determine the failure rate was found in the Military Handbook (MIL-HDBK-217f) [1]:

$$\lambda_P = (C_1\ \pi_T + C_2\ \pi_E)\ \pi_Q\ \pi_L$$

And mean time to failure (MTTF) in years:

$$MTTF = 10^6 / (24 * 365 * \lambda_P)\ \text{years}$$

For this analysis, three coefficients are fixed. Specifically, it is assumed that the component quality factor ($\pi_Q$) is 10 for commercial components. This is quite a conservative assumption, especially when many commercial products at this time are being manufactured at close to military quality. All of the components we are using have been out for more than two years, so the learning factor ($\pi_L$) that will be used is 1. The environmental coefficient ($\pi_E$) is 2.0 for ground, fixed ($G_F$). The fixed environment coefficient was selected based on the description of mobile environment on ground. In our case, mobile seemed to be referring more towards motor vehicles while our board will be largely stationary during play. Therefore, we selected 2.0 rather than 4.0.

For the microcontroller, the die complexity coefficient was determined to be 0.14 based on the Military Handbook, since it is 8-bit. The temperature $\pi T$ coefficient is 0.98 since it is a digital MOS microcircuit and its max recommended temperature is 85 C. The packaging failure C2 coefficient is 0.032 since our micro has 44 pins and is a surface mount device. By this analysis, the failure rate for the microcontroller is 1.70552 failures per million hours. The mean time to failure is 67 years.

For the LM317 voltage regulator, it seems that microcircuit section in military handbook appeared to be the best fit section. At an estimated 101 to 300 linear MOSFETs, the regulator would have a die complexity coefficient of 0.02. The packaging failure coefficient is 0.00092 since it has 3 pins and is a surface mount device. The temperature factor for this device, assuming the temperature is in the worst case, not above 125 C, is 5.8. The failure rate for this device is 1.1784 failures per million hours. The mean time to failure is 97 years.

For the LM3404 RGB driver, microcircuit section in military handbook appeared to be the best fit section. At an estimated 3001 to 10000 gates, the LM3404 RGB driver would have a die complexity coefficient of 0.08. The temperature factor for this device operating at the worst case, not higher than 85 C, is 0.98. The packaging failure coefficient is 0.0086 with an 8 pin SMD package. The failure rate for this device is 0.956. The mean time to failure is 119 years.

For the LD1117 voltage regulator, the best fit in the military handbook appeared to be the microcircuit section. At an estimated 100 to 300 bipolar transistors gates, the LD1117 voltage regulator would have a die complexity coefficient of 0.02. The packaging failure coefficient is 0.00092 since it has 3 pins and is a surface mount device. The temperature factor for this device, assuming the temperature is in the worst case, not above 125 C, is 5.8. The failure rate for this device is 1.1784 failures per million hours. The mean time to failure is 97 years.

**PIC18F46J11-I Microcontroller** [2]

| **Parameter name** | **Description** | **Value** | **Comments** |
|---|---|---|---|
| C1 | Die complexity failure rate | .14 | Based on the MIL-Hdbk-217f [1] for 8 bit microcontrollers |
| $\pi_T$ | Temperature factor | .98 | Assuming a worst case junction temperature of 85C based on worst operating temp of microcontroller |
| C2 | Package failure rate | .016676 | Based on equation from MIL-Hnbk-217f page 5-14 [1] for SMT with 44 pins |
| $\pi_E$ | Environment factor | 2 | Handbooks value for mobile devices |
| $\pi_Q$ | Quality factor | 10 | Commercial part |
| $\pi_L$ | Learning factor | 1 | Number used for devices older than 2 years in production |
| $\lambda_P$ | Failures rate per million hours | 1.70552 | |
| **MTTF** | Mean Time To Failure | 586331.4414 | Approximately 67 years to a failure for one device |

**LM317 Voltage Regulator [4]**

| **Parameter name** | **Description** | **Value** | ***Comments*** |
|---|---|---|---|
| $C_1$ | Die complexity | 0.02 | Based on the MIL-Hdbk-217f [1] for devices with 100 to 300 bipolar transistors |

| | | | |
|---|---|---|---|
| $\pi_T$ | Temperature factor | 5.8 | Assuming a worst case junction temperature of 125C based on worst junction temp of the regulator |
| $C_2$ | Packaging Failure coeff. | 0.00092 | 3-pin SMD |
| $\pi_E$ | Environmental Factor | 2.0 | Handbooks value for mobile devices |
| $\pi_Q$ | Quality Factor | 10.0 | Commercial part |
| $\pi_L$ | Learning Factor | 1.0 | Number used for devices older than 2 years in production |
| $\lambda_P$ | Failures rate per million hours | 1.1784 | |
| **MTTF** | 1 Buck on board | 848608.2824 | Approximately 97 years to a failure for one device |

**LM3404 RGB LED Driver [5]**

| **Parameter name** | **Description** | **Value** | ***Comments*** |
|---|---|---|---|
| $C_1$ | Die complexity | 0.08 | Based on the MIL-Hdbk-217f [1] for devices with 1000 to 3000 bipolar transistors |
| $\pi_T$ | Temperature factor | 0.98 | Assuming a worst case junction temperature of 85C based on worst operating temp of microcontroller |
| $C_2$ | Packaging Failure coeff. | 0.0086 | 8-pin SMD |
| $\pi_E$ | Environmental Factor | 2.0 | Handbooks value for mobile devices |
| $\pi_Q$ | Quality Factor | 10.0 | Commercial part |

| | | | |
|---|---|---|---|
| $\pi_L$ | Learning Factor | 1.0 | Number used for devices older than 2 years in production |
| $\lambda_P$ | Failures rate per million hours | 0.956 | |
| **MTTF** | with 3 Drivers on board | 1046025.1046 | Approximately 119 years to a failure for one device |

**LD1117 Low Dropout Regulator** [3]

| **Parameter name** | **Description** | **Value** | **Comments** |
|---|---|---|---|
| C1 | Die complexity failure rate | .02 | Based on the MIL-Hdbk-217f [1] for devices with 100 to 300 bipolar transistors |
| $\pi_T$ | Temperature factor | 5.8 | Assuming a worst case junction temperature of 125C based on worst junction temp of the regulator |
| C2 | Package failure rate | .00092 | Based on equation from MIL-Hnbk-217f page 5-14 [1] for SMT with 3 pins |
| $\pi_E$ | Environment factor | 2.0 | Handbooks value for mobile devices |
| $\pi_Q$ | Quality factor | 10 | Commercial part |
| $\pi_L$ | Learning factor | 1 | Number used for devices older than 2 years in production |
| $\lambda_P$ | Failures rate per million hours | 1.1784 | |
| **MTTF** | Mean Time To Failure | 848608.282417 | Approximately 97 years to a failure for one device |

**Reliability Summary**

The overall system of this project is reliable. All of the parts have reliability within the same scale of $10^{-6}$ failures per hour. Also, the system will not be a highly bought solution; therefore a slightly higher failure rate is acceptable. The best way to improve reliability of the design would be to buy military parts, which would reduce each by a factor of 5. This could be an acceptable increase in price because the niche for the market of this product is so small, so someone buying this would be willing to pay more.

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

The schematic for Fantasy Hue can be divided into four subsections. These subsystems are the power supply, sensors, Xbee module, and microcontroller. The division of our design is a little complicated because we have two PCBs, one for bulb and the other for ceiling light. Therefore, I rearranged components on two boards into these four sections above. The microcontroller and Xbee module behave exactly the same on two boards. The sensors are only implemented on PCB of ceiling light. The power supply is quite different between two boards, including different voltage regulators implemented.

The power supply for bulb is relatively simple. An AC to DC converter will be implemented in order to generate stable13 voltages 9 watts input. Then, a voltage regulator, LM317, will be connected to continuously convert the voltage to 3.3 volts. The power supply for ceiling light is a little complex. An AC to DC converter will be implemented to generate a 24 volts input. The LED driver, LM3404, is required a 24 volts voltage to work appropriately. Due to the consideration of heat dissipation, a 7-pin DC to DC converter will be connected to convert the voltage from 24 volts to 5 volts. The required voltage for sensors is 5 volts, which is satisfied here. The required voltage for LEDs and microcontroller is 3.3 volts, so a low-dropout voltage regulator, LD1117, will be used to solve the problem. Therefore, failure modes for the entire power supply can be generalized as low 24 voltages, high 24 voltages, low 3.3 voltages, high 3.3 voltages, and high 5.0 voltages, low 5.0 voltages on the board. The high 3.3, 5 and 24 voltage is a high critical failure, meaning an overheated voltage regular could ignite and cause harm to the user. The other power supply failure modes are medium critical, since they have the potential to damage other components on the board.

All the sensors are premade breakout boards with relatively high reliability. There are two different failure modes. One is that sensors are not able to send data back to microcontroller; the other is misdetection, not stable detection. The first mode could lead to all information, including brightness, smoking, and sound, are missed. The microcontroller is unable to communicate with different sensors. As a result, the state of microcontroller will stuck in idle state forever, and the LEDs will behave never changed. The second mode could lead to information obtained in microcontroller unstable. The LEDs will behave unexpectedly changing the color and brightness. In order to simplify the detection of these failures, a troubleshooting test sequence can be run to verify that all sensors on the board are working properly.

The Xbee module has good reliability. However, given decoupling capacitors shorted, Wi-Fi module would be shorted with 3.3V power and GND and gets damaged. Antenna on the module can also be worn out due to user’s inappropriate postures and use. Both failures would completely eliminate the communication between the microcontroller and raspberry Pi module. So users wouldn’t be able to retrieve data and send the instructions on smartphone. However, such transmission failures can be quickly detected through checking the data stream status on raspberry Pi.

When the microcontroller behaves unexpectedly, it is often because the reset is incorrectly triggered and the board has been reset. Another consideration is the passive components (such as capacitors and resistors) may affect the microcontroller’s behavior. For example, microcontroller may overheat if decoupling capacitors get shorted. Although the failure of microcontroller wouldn't hurt the user, and would be considered with low or medium criticality, it makes the device very inconvenient for the user to use.

## 2.1 Levels of Criticality

Levels of criticality are used to differentiate which failure modes should have a lower failure rate, and which failure modes are less harmful.

'Low' criticality specifies that the failure mode is not harmful to the user or destructive of the rest of the board. For instance, sensor or communication failures would fall into this category. The product may still be unusable until the part is replaced. Low critically errors are intended to have a failure rate of $10^{-6}$ or less.

'Medium' criticality is defined as a failure that does not harm the user, but has a potential to damage the system. A failure in the power system could be medium criticality since it has the potential to damage the entire board. Medium criticality failures are aimed to have a failure rate of $10^{-7}$ or less.

'High' criticality is reserved for failures that present potential harm to the user. Related failures for this project would be the voltage regulator catching fire. While highly unlikely, it is still a possibility. High critical errors should only occur will a failure rate of $10^{-9}$ or less.

## 2.2 Observation Techniques

In order for the user to troubleshoot problems with the board, observation will not be enough dealing with sensors. The board itself has photo-resistor sensor, sound sensor, and smoking sensor that would need to be verified. In order to aid in this process, a troubleshooting option which uses microcontroller to monitor sensors behavior.

**3.0 Sources Cited:**

[1] "Military Handbook,"1 1990. [Online]. Available: http://snebulos.mit.edu/projects/reference/MIL-STD/MIL-HDBK-217F-Notice2.pdf [Accessed 11 5 2014].

[2] Microchip, "PIC18F46J11 Family Data Sheet" 3 2012. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/39932b.pdf [Accessed 11 5 2014].

[3] Life.argmented, "Adjustable and fixed low drop positive voltage regulator," 4 2004. [Online]. Available: http://www.st.com/web/en/resource/technical/document/datasheet/CD00000544.pdf [Accessed 4 4 2013].

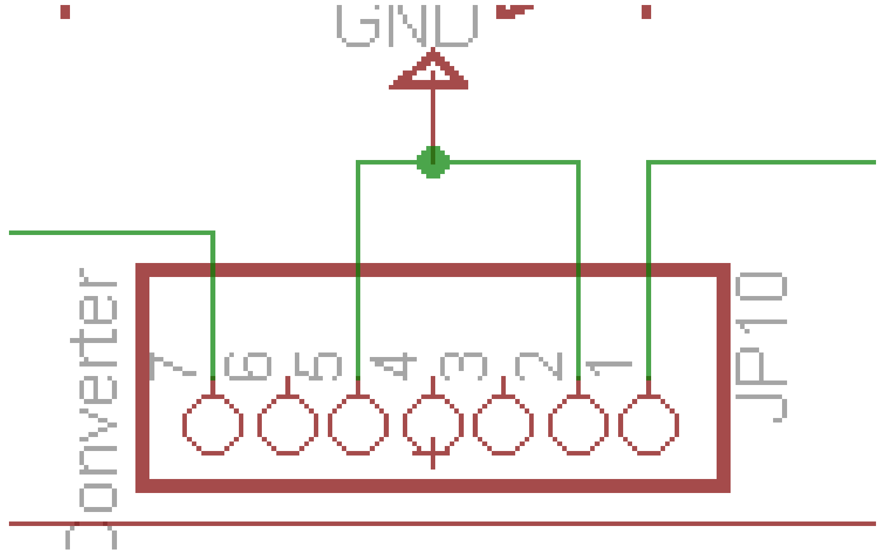
[4] Texas Instruments, "3-TERMINAL ADJUSTABLE REGULATOR" 2 2013. [Online]. Available: http://www.ti.com/lit/ds/symlink/lm317.pdf [Accessed 11 6 2014].

[5] Texas Instruments, "1.0A Constant Current Buck Regulator for Driving High Power LEDs" [Online]. Available: http://www.ti.com/lit/ds/symlink/lm3404.pdf [Accessed 11 6 2013].

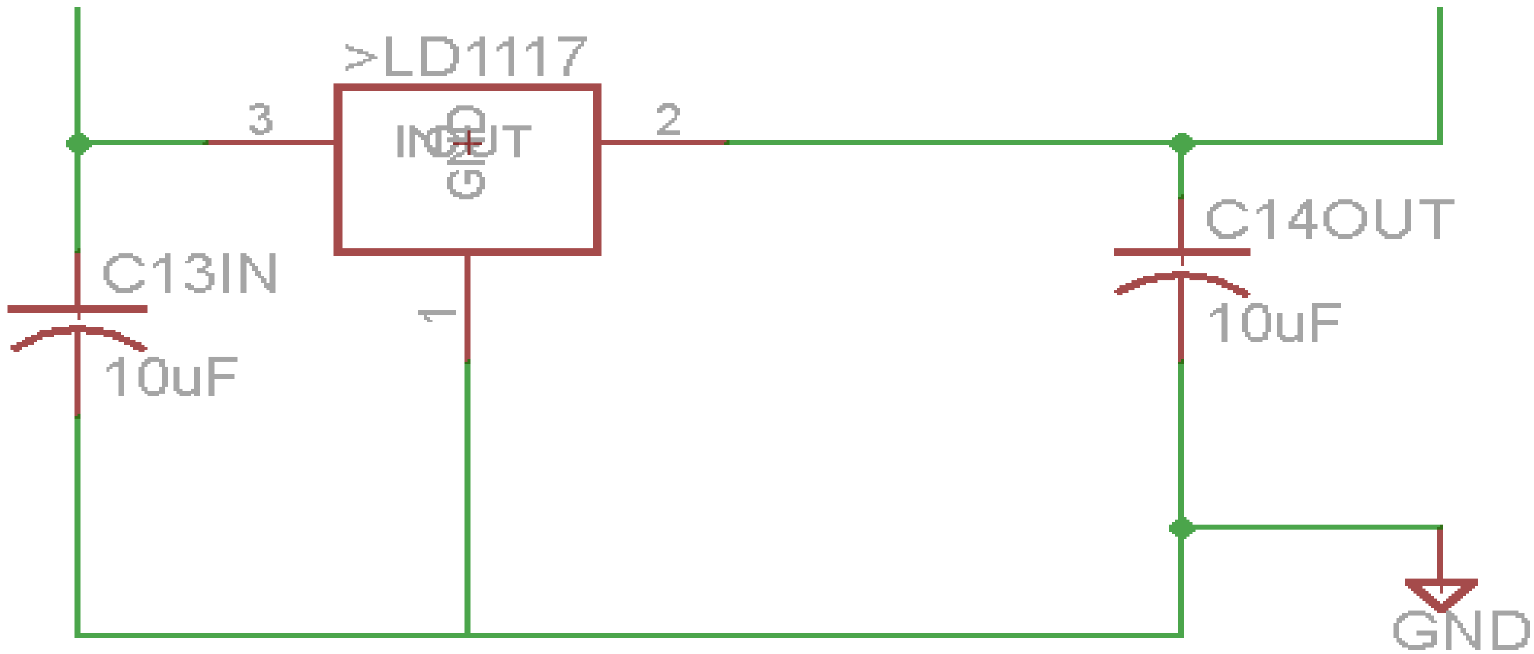
## Appendix A: Schematic Functional Blocks

**Subsystem A: Power Supply**

**This is the break-out 7-pin DC to DC converter**

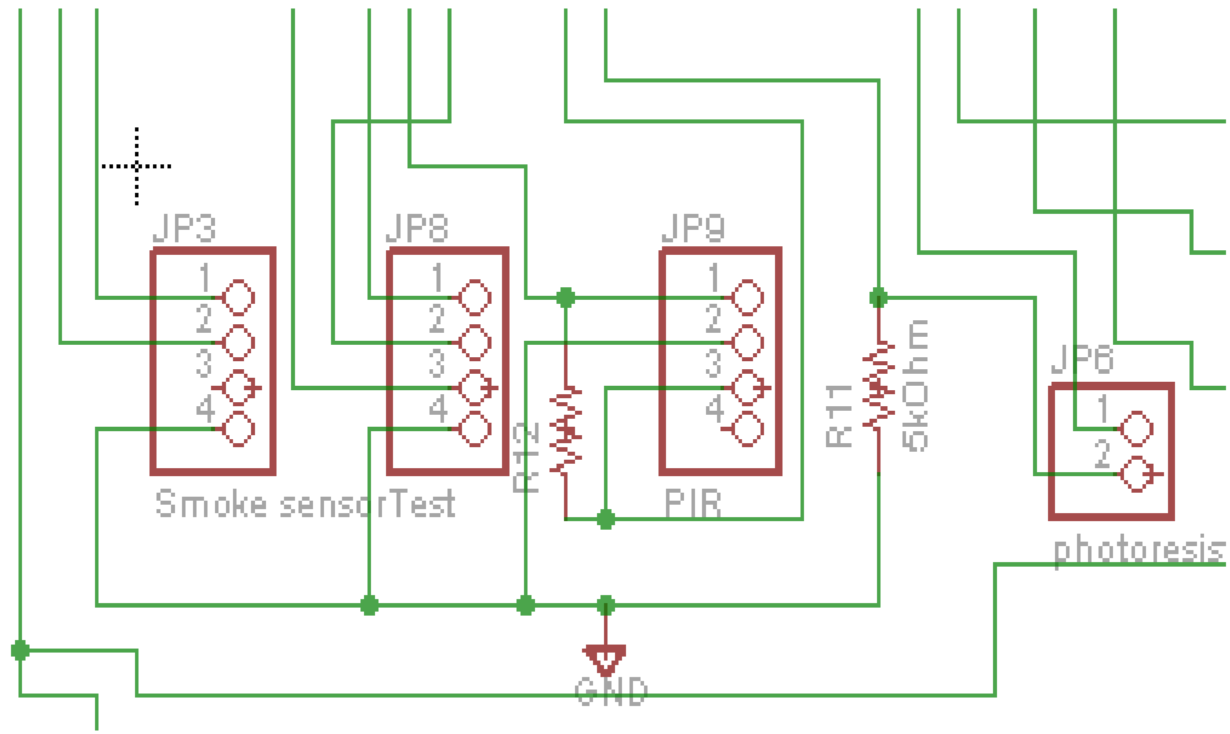


**This is the LD1117 voltage regulator**

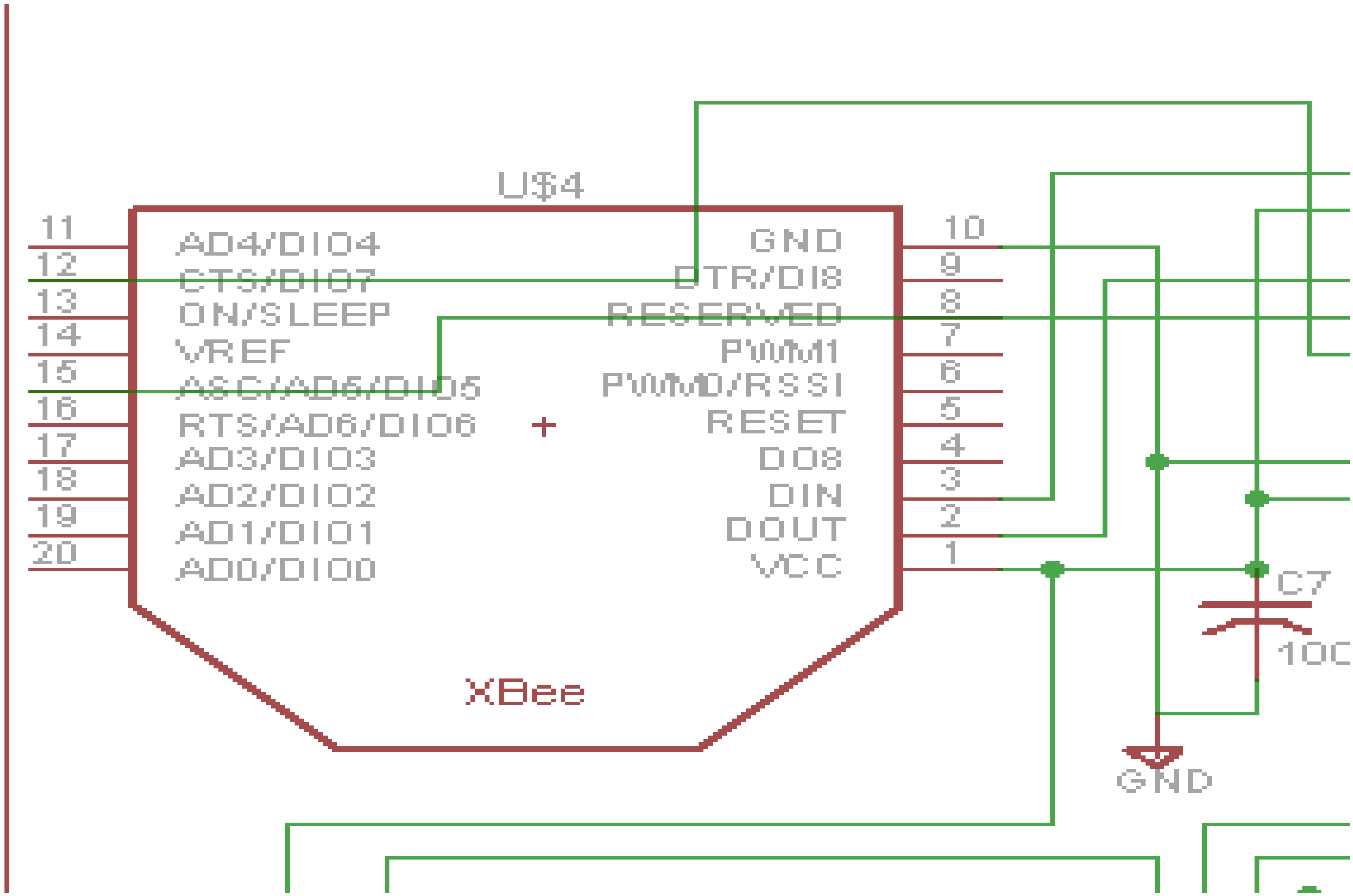


**Subsystem B: Sensors**

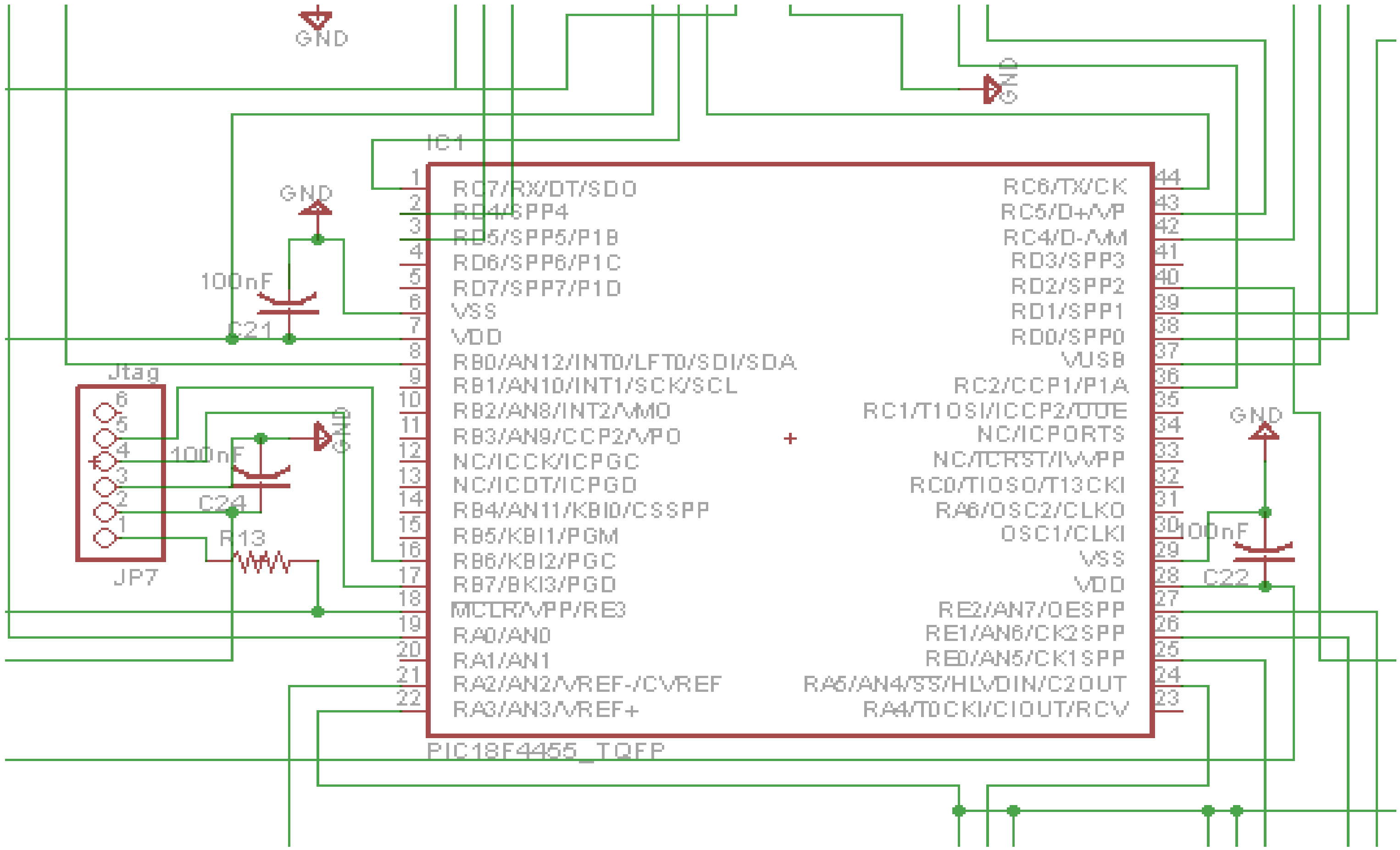
**The left is smoke sensor, the middle left is sound sensor, the middle right is motion detector sensor, and the right is photo-resistor sensor.**



**Subsystem C: Xbee module**



**Subsystem D: Microcontroller**



## Appendix B: FMECA Worksheet

**Subsystem A: Power Supply**

| Failure No. | Failure Mode | Possible Causes | Failure Effects | Method of Detection | Criticality | Remarks |
|---|---|---|---|---|---|---|
| A1 | Low 3.3 Voltage on board | Voltage regulator failure, shorted bypass capacitor | Microcontroller does not power up, board is not responsive even after raspberry Pi powers up, RGB LEDs do not animate | Observation | Medium | May damage other components |
| A2 | High 3.3 Voltage on board | Voltage regulator failure, or resistor open circuit | Board does not power up, microcontroller and Xbee module take high voltage and become unresponsive | Observation | High | May damage other components, may overheat voltage regulator |
| A3 | High 5.0 Voltage on the board | DC to DC converter failure | Sensors take too high voltage. board freezes and becomes unresponsive | Observation | high | May damage other components |
| A4 | Low 5.0 Voltage on the board | DC to DC converter failure | Sensors don’t power up. They are not able to send data back to microcontroller; RGB LEDs will remain in same state. | Observation | Medium | May damage the Raspberry Pi |

| | | | | | | |
|---|---|---|---|---|---|---|
| A5 | high 24.0 Voltage on the board | AC to DC converter failure | LED drivers work in a relatively high voltage condition. | Observation | High | May damage LED drivers LM3404 |
| A6 | Low 24.0 Voltage on the board | AC to DC converter failure | LED drivers does not power up. Even all other parts work fine, LEDs may still be off. | Observation | Medium | May damage other components |

**Subsystem B: Sensor Network**

| **Failure No.** | **Failure Mode** | **Possible Causes** | **Failure Effects** | **Method of Detection** | **Criticality** | **Remarks** |
|---|---|---|---|---|---|---|
| B1 | Sensor not able to send back data | Sensor shorted to ground, power less than 5 volts, resistor network is open, microcontroller ADC pins used for sensors failure | Changes of brightness smoke and sound will not be able to send to microcontroller; microcontroller may stay in IDLE state forever | Observation | Low | |
| B2 | Sensors sending back non-stable data | The voltage is not stable to sensor, the environmental condition changes immediately back and forth | LEDs will be behaved unexpectedly | Observation | Low | |

**Subsystem C: Xbee module**

| Failure No. | Failure Mode | Possible Causes | Failure Effects | Method of Detection | Criticality | Remarks |
|---|---|---|---|---|---|---|
| C1 | Xbee not able to communicate with the microcontroller | Different baud rate, Failure of Xbee<br>Incorrect COM port settings in on the PIC board | Loss of ability to wirelessly communicate with microcontroller, and microcontroller will stay in IDLE state | Inspection of Xbee Tx, Rx pins via probe | low | |
| C2 | Xbee not able to communicate with raspberry Pi | The antenna may be damaged or interfered | Loss of ability to wirelessly communicate with raspberry Pi | Observation | Low | |

**Subsystem D: Microcontroller**

| Failure No. | Failure Mode | Possible Causes | Failure Effects | Method of Detection | Criticality | Remarks |
|---|---|---|---|---|---|---|
| E1 | Reset is triggered on the micro | Pull-up resistor for reset switch is open, decoupling capacitor is open, reset switch is stuck closed | board will restart | Observation | Low | |

| | | | | | | |
|---|---|---|---|---|---|---|
| E2 | The micro stops executing instructions | Passive resistors broke, noise on 3.3V power, software | board is frozen | Observation | Low | |