# Canadian CubeSat Project
## Custom Boards

by

Patrick Zwinkels

Andrew Wong

James Sands

Keith Mody

(Advisor: Dr. Jayshri Sabarinathan)

ECE 4416 Electrical/Computer Engineering Project

## Final Report

Submitted in partial fulfillment of the requirements

for the degree of Bachelor of Engineering Sciences

Department of Electrical and Computer Engineering

Western University

London, Ontario, Canada

**Friday April 3, 2020**

# Abstract

This document brings the reader through the design process of creating custom boards to be integrated into the cubesat satellite. Design objectives, requirements and constraints are stated in order to provide clarity and ensure optimal progression through the project. Concept generation and selection was conducted to compare potential designs in order to achieve the most impactful solution. From these, a prototype was fabricated and tested in order to confirm the effectiveness of our design. Finally, product evaluation was done to interpret the feasibility of the design under the environmental conditions presented in the problem statement.

# Contribution of the Team Members

Below is a list of tasks completed by the team members over the course of the semester:

**James Sands**

- Brainstormed with group over Discord to finalize the Block Diagram
- Viewed recommended Webinars 1, 11, 10, 2, 8, 7
- Read about changes to the CubeSat structural design
- Read Powerpoint PDR_PowerPoint_Modified_NM.pptx
- Research Monopole Antenna
- Researched burn wires, one vs multiple
- Researched MAD_1801_Final.pdf from interface.xlsx
- Researched Cubesat Attitude Determination via Kalman Filtering of Magnetometer and Solar Cell Data document
- Created antenna burn wire circuit with Keith using MicroCap
- Researched Coarse Sun Sensing for Attitude Determination of a CubeSat document
- Work with group to create block diagram of CubeSat boards
- Finalized antenna burn wire circuit
- Researched advantages and disadvantages of nichrome wire
- Researched photodiode_angle_analysis document
- Tested burn wire circuit

**Patrick Zwinkels**

- Worked with group to create block diagram of CubeSat boards
- Watched recommended webinars
- Researched information on grounding circuits
- Completed webinars
- Read interface document
- Created PC 104 presentation
- Researched data bus systems (SPI, I2C, etc.)
- Reformatted wiring interface document
- Researched picoblade implementation
- Selected connection methods for gyroscopes and magnetorquers
- Researched Nichrome wire specifications for burn-wire circuit
- Found voltage requirements for many major components including battery supply
- Sourced and acquired components from electronics shop
- Assisted in designing microcap circuit
- Assisted in performing Microcap simulation analysis
- Assisted in testing breadboard circuit
- Designed EAGLE circuit and PCB schematic
- Soldered PCB
- Coded Arduino program for testing purposes

- Performed PCB tests
- Documented PCB design and testing process

**Andrew Wong**
- Relayed information and minutes from previous meeting to members who were not present
- Helped prepared diagrams and presentations for upcoming meetings
- Watched recommended webinars
- Researched 555 timers and other alternatives, as well as their applications
- Determined necessary mode and external components for timers for cubesat application
- Began reviewing general documents on OBC and ADCs
- Designed circuit for the timer using MicroCap
- Added all created documentation and reference documents to GitHub
- Reached out to ADCs team about component voltage and current requirements

**Keith Mody**
- Helped group create block diagram over video chat
- Watched recommended webinars
- Researched information on PC 104 stack
- Watched remaining webinars
- Researched high frequency board design
- Created powerpoint on high frequency board design
- Researched antenna burn wire background information
- Created antenna burn wire circuit
- Reviewed GitHub documentation
- Researched nichrome wire properties
- Finalized antenna burn wire circuit
- Reviewed Attitude Determination and Control Systems report
- Tested burn wire circuit

## Acknowledgments

A special acknowledgement must go out to the University of Western Ontario and the people involved in the CubeSat mission. One person in particular, Nick Mitchell, a graduate student who has been working on the CubeSat mission for the University basically since the idea came into fruition. Nick has provided us with the proper materials to research and bring our part of the CubeSat mission into materialization. We have met with Nick weekly to demonstrate our research and receive guidance. We would also like to thank our advisor Jayshri Sabarinathan and Matt Cross for leading the CubeSat project and giving us the opportunity to work under them all year.

# Nomenclature

No specific symbols requiring additional explanation were used in this report.

All technical terms beyond the scope of general knowledge were defined in the context mentioned.

# Table of Contents

# List of figures/tables

# 1. Introduction/Background

## 1.1 Problem Statement

The custom made boards within the Cubesat must be designed to contain all of the necessary components, including an automatic timer, burn wire circuit, and magnetorquers, amongst other pre-selected components. The boards must also integrate properly with the existing selected hardware, such as the on board computer (OBC) and the power supply. Our design, and the parts we select for them, must also meet the safety requirements set by the Canadian Space Agency (CSA) in order to be safely used in space. [1]

## 1.2 Background Information/ Detailed Literature Review

The University of Western Ontario, in collaboration with Nunavut Arctic College, has received a grant among several other post-secondary institutions from the Canadian Space Agency, to build a satellite as part of their CubeSat Program. This satellite is 10cm x 10cm x 10cm in total volume, weighing about 1kg in a square shape (roughly the size of a rubix cube). [2] The Canadian CubeSat Project (CCP) was announced in April 2017 and has already begun. [3] It will be completed with the launch of the satellite in 2021.

The first, and most important, documents we reviewed when starting our capstone project was the safety guidelines set out by CSA. As our designs would be sent into an extreme environment, we needed to ensure it met all of the specifications to not only function properly, but also not endanger or compromise any people or other equipment involved. This mainly involved watching webinar videos we were provided by our advisor [4], as well as speaking with our advisor and CSA representatives when given the opportunity. [5]

After this, we began to look through the documentation of past and current parties involved with the Cubesat project, and their work. All of the documentation and their revisions for this project have been stored on a GitHub space, which we began looking through after we were given access. [6] We were especially interested in documents related to the magnetorquers, on board computer, and power supply, and antenna deployment system. Most of these major components had already been selected, so our design was directly affected by them. [7]

Once we had finished reviewing the current documentation, we began researching the components that we were required to select and add to the custom boards. Some of the major parts included the timer, the antenna release system, and power and computing systems we would be using. The timer would be needed to delay the supply of power to the CubeSat so that it would not interfere with the International Space Station from which it is planned to be launched. CSA guidelines state that a time of 30 minutes must pass after deployment before the device may activate. The antenna release system is also important for safety reasons. If the antennae deploy too early they could injure someone or damage other equipment.

## Space-Rated Parts

Upon the CubeSat launching from the ISS, an issue to be aware of is the effect of the vacuum of space. Due to no nearby source of heat, the temperature of space is around 3 Kelvin (-270.15°C). [8] This low temperature, as well as extremely low pressure due to lack of air can easily damage equipment, altering and worsening the project. Pieces of the circuit board electronic equipment will struggle to work as intended attributed by a concept known as outgassing.

Circuit board materials running at a high frequency, unless well protected, will suffer from outgassing. Outgassing is the release of internal gases inside of solid material, in this case electronic equipment. The gases simultaneously condense onto the outgassed equipment among other parts, making them not to work accurately, maybe not at all. [9] This cannot happen for the CubeSat mission as once the satellite is sent up to the ISS and launched, there will be no direct contact between the user and the miniature satellite. Therefore, it is necessary to have parts deemed as space-rated.

For a piece of equipment to be regarded as space-rated, it must follow three specifications. The given apparatus must not have any performance loss and survive through the launch and deployment, the apparatus must be compatible with space to not face degradation or threaten other systems and finally to achieve absolute performance throughout the entire mission. [10] Materials commonly used for space-related missions are aluminum (and aluminum composite), as it is light but also durable, titanium because of its very high strength and ceramic composites which provide heat protection. [11]

Our CubeSat design for the 555 timer and burn wire circuit on the PCB must have all space-rated parts when the construction of the satellite is completed. The burn resistors we are already using are made out of thick ceramic molds, to be able to limit heat through it, lowering potential damage to other equipment as well as being protected from the vacuum of space. The burn wire itself made out of Nichrome, which is a mix of Nickel and Chromium, has a hardened exterior limiting outgassing and therefore classifying it as space-rated. The fluorocarbon line throughout testing was a fishing line, but a space-rated version of it is needed for the actual mission. When the fluorocarbon is baked (hours long curing process at 200°C), the fluorocarbon elastomer veritably has a lesser rate of outgassing than aluminum.[12]

The relay and the capacitors and resistors of the 555 timer circuit are common general-use, so they would not function in the vacuum of space. The resistors we will use will be the same as the burn wire resistor, a ceramic-covered resistor of specific values. The capacitors will most likely be SnPb solder coating, which also limits outgassing release. [13] The relay that will be used on the mission will either be ceramic or solder coating in order to protect the internal relay, which is no different than a general-use relay.

## 1.3 Project Objectives

We wish to design, build and test two custom electronic boards to be used in the CubeSat satellite. These boards will contain three magnetorquers that will control the satellite's orientation, as well as detumble it after it is launched from the International Space Station. The boards will also interface with all of the CubeSat components, allowing data to be sent and received as required. The end goal of this is to produce 360 degree photos from the orbiting satellite using two 180 degree cameras mounted on both ends. [14] A design is to be created for a 30 minute timer but the constructed prototype will incorporate a 5 minute timer for testing purposes.

By collaborating with other teams, we will integrate all parts of the CubeSat together. Having knowledge of the ADCS team’s work is crucial for the success of our part. By having the specifications of the magnetorquers, we can design our board around the size of the components. [15] We also want to connect the on board computer with the output of the 555 timer to activate the burn wire circuit; the antennae are required to safely deploy after 30 minutes.

From this capstone project, we wish to gain a better understanding of space-rated circuit design as well as working with large organizations. By gaining experience in this domain, we complement our degrees and learn valuable information that can later be applied in industry. Our goal is to successfully integrate our custom electronic boards and fulfill our duty to the electrical portion of the project. As this is a three-year long project to be completed by multiple groups, the objective of this project is to develop a working prototype which can be outfitted using space-rated components and installed for use in a CubeSat. Within this report, two key designs will be discussed. The “prototype design” will be built in order to test the functionality of the system. The “final design” represents the spacerated version to be used within the final CubeSat, and will be based off of the prototype designed throughout this project.

# 2. Design Approach

## 2.1 Concept Generation

The CubeSat circuit boards act as the connection between the major components of the CubeSat. These components include magnetorquers, gyroscopes, on-board computer (OBC) and electrical power system (EPS) among others. The OBC has many connection methods which allow many components to be run by it. The EPS is the main power supply for the device and all components. The gyroscopes detect the attitude of the CubeSat and the magnetorquers allow the CubeSat to adjust its attitude when required. All components must be space-rated to account for the unique conditions the CubeSat will face in orbit.

These connections have been outlined in an excel spreadsheet for organizational purposes.

**CubeSat Wiring Interface**

| Component | Connecting to | Pins | Interface | Method | Notes |
|---|---|---|---|---|---|
| | | | | | |
| OBC | EPS - Data | H1-39 & H1-40 | UART | Stack | |
| | EPS - Power | H2-25-32 | n/a | Stack | |
| https://www.endurosa | Camera 1 | H2-9,10,11 | SPI | Wires connected to stack | |
| | Camera 2 | H2-47,48,49 | SPI | Wires connected to stack | |
| | Temp sensor 1 | | GPIO | Stack | EPS can connect to 3 temp sensors |
| | Temp sensor 2 | | GPIO | Stack | |
| | Temp sensor 3 | | GPIO | Stack | |
| | Temp sensor 4 | | GPIO | Stack | |
| | Temp sensor 5 | | GPIO | Stack | |
| | Temp sensor 6 | | GPIO | Stack | |
| | Sun Sensor 1 | N/A | | | |
| | Sun Sensor 2 | N/A | | | |
| | Sun Sensor 3 | N/A | | | |
| | Sun Sensor 4 | N/A | | | |
| | Sun Sensor 5 | N/A | | | |
| | Sun Sensor 6 | N/A | | | |
| | Gyroscope 1 | PAN1 - 4,5,9,10 | SPI | branch off of picoblade 12 connector | Includes power |
| | Gyroscope 2 | PAN2 - 4,5,9,10 | SPI | branch off of picoblade 12 connector | Includes power |
| | Gyroscope 3 | PAN3 - 4,5,9,10 | SPI | branch off of picoblade 12 connector | Includes power |
| | Magnetorquer 1 | PAN4 - 1&2 | PWM | branch off of picoblade 12 connector | |
| | Magnetorquer 2 | PAN5 - 1&2 | PWM | branch off of picoblade 12 connector | |
| | Magnetorquer 3 | PAN6 - 1&2 | PWM | branch off of picoblade 12 connector | |
| | GPS Transceiver | JP2/14 - H1-19,20 | UART | JP2/14 | 3.3V from OBC JP2/14 - get from stack |
| | Transceiver | H1-33 & H1-35 | USART | Stack | |
| | Burn-Wire Initiation Signal | | GPIO | Stack | |

*Excerpt of CubeSat Wiring Interface Document*

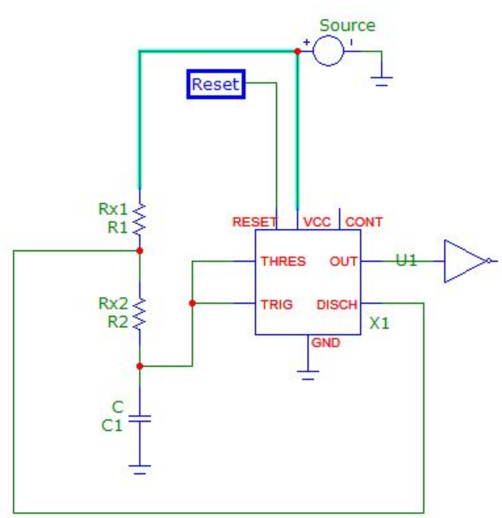
Some of the components listed in the table above are to be developed and implemented by other CubeSat groups, but many will be discussed in this report. Regardless, it was important to specify the layout of the entire system to develop a better understanding of how our boards would interact with the rest of the satellite.

After the CubeSat is switched on, there will be a delay before our boards receive power. This is so that it does not power on prematurely, and can be launched from the International Space Station safely. Based on the Canadian Space Agency's requirements, a thirty minute timer needs to be added between our boards and the main power supply. Through discussions with our advisor, as well as analyzing past CubeSat and similar missions, we selected to use a 555 IC timer. [16] We then researched into the different modes and configurations of these timers, settling on two of them, monostable and astable modes. From these, we proceeded to test and compare these two to determine which was most suitable for our project.

## 2.2 Concept Evaluation and Selection

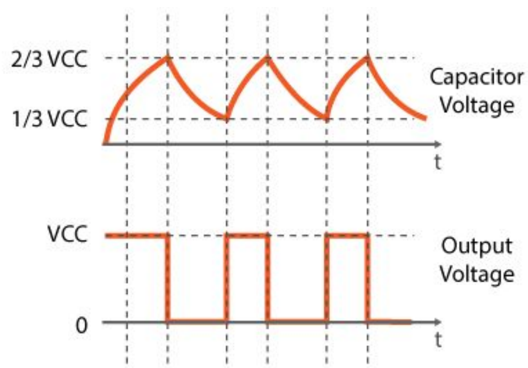
**PCB Specifications**

Before beginning the preliminary PCB designs, it was important to first research the rules for creating multi-layered circuit boards, because we had no experience creating any in the past. The first thing we learned is that it is recommended to only use an even number of layers on our boards. This prevents unwanted warping or damage during soldering or usage. With this in mind, we had the options to design two 2-layer or 4 layer boards. [17] We decided to select the 4-layer option as it offered more physical space to develop on, and a power and ground plane to power our components. A power plane is a flat layer of a conductive material, often copper, that is connected to the power supply. A ground plane is similar except it instead connects to ground. In order to connect our components to these planes, we will route to them using ‘via’s’ or ‘vertical interconnect accesses.’ These are essentially a hole in the board, lined with a conducting material to carry a current. Our final two layers would be the signal layers which would be made up of routes from components to the other planes. The signals planes lie on the outer layers of each board and the power and ground layers are located between them for ease of access. Our design will use components that operate at 5V and 3.3V so we have chosen to implement a split power plane. [18] This is a power plane with two isolated regions, each connected to a different voltage supply. This will allow us to access both necessary voltages without needing to convert using resistors.

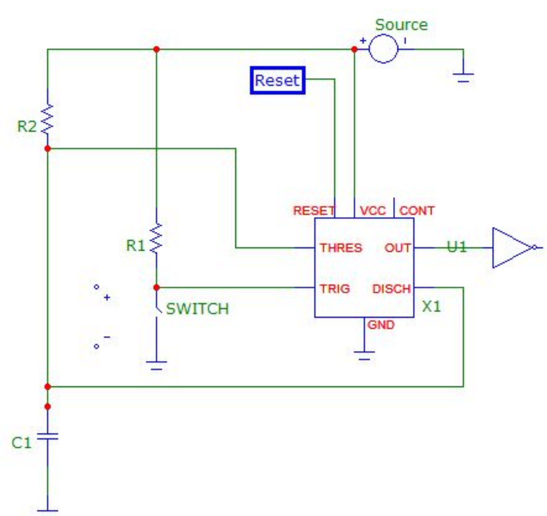



**555 Timer**

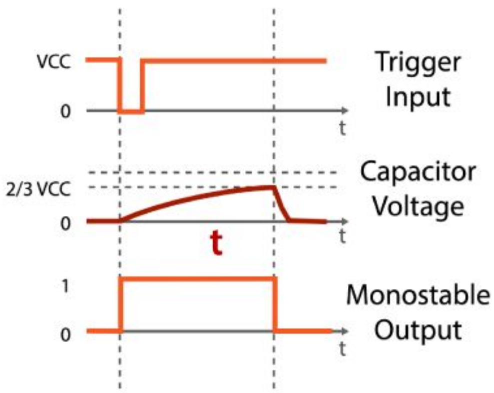
For our 555 timer, we began by comparing the two possible modes. The first option was astable mode. This is set up by connecting a resistor between the voltage source and the discharge pin of the timer, and another between the discharge pin and the threshold and trigger pins of the timer. A capacitor is also added between the threshold and trigger pins, and ground. When the circuit is powered, the capacitor is slowly charged. When it reaches ⅔ of the supplied voltage, it will begin discharging. Because of the configuration of the circuit and the pins that are connected, while the capacitor is discharging, the output of the timer circuit switches from high to low. When the charge in the capacitor reaches ⅓ for the supplied voltage, it begins charging again, which causes the output to switch back to high, and repeat the process. [19] By manipulating the size of the resistors and capacitor, you can control the period at which it is outputting a high or low result. [20] The width of the high portion of the output is defined by $T_h = 0.693*(R_1 + R_2)*C$, where $T_h$ is the time in seconds, $R_1$ and $R_2$ are the resistance of the resistors, and C is the capacitance. The width of the low portion of the output is defined by $T_h = 0.693*R_2*C$. [21] Astable mode is completely autonomous, requiring no external inputs from the user, but produces a periodic square waveform, which was not as ideal for our application.




The other mode we considered using was monostable mode. To set the timer in monostable mode, a resistor is added between the voltage source and the trigger pin, with a switch between the trigger pin and ground. Another resistor is placed between the voltage source and discharge and threshold pins, in parallel with the first resistor. A capacitor is placed in series with the second resistor, between the discharge and threshold pins, and the ground. [19] This mode is once again controlled by the charging of the capacitor. After the circuit is connected to power,



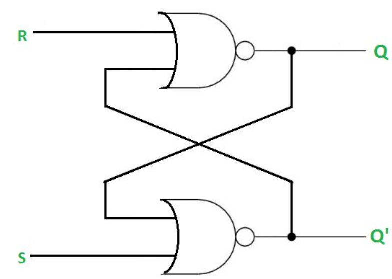
after the push button below the trigger pin is pushed, the capacitor will begin charging. As it begins charging, the output of the circuit switches from low to high. It will remain this way until the capacitor reaches ⅔ of the supplied voltage, after which the capacitor rapidly discharges, and the output returns to low. The circuit remains like this until the switch is pressed again. [20] The width of this pulse pulse is defined by $t = 1.1*C*R_2$, where t is the time in seconds, C is the capacitance, and R2 is the resistor in series with the capacitor. [22] Monostable mode produces a single pulse, before remaining constant, which fit our design better, but had a short period during its startup that would potentially power up the boards too early.

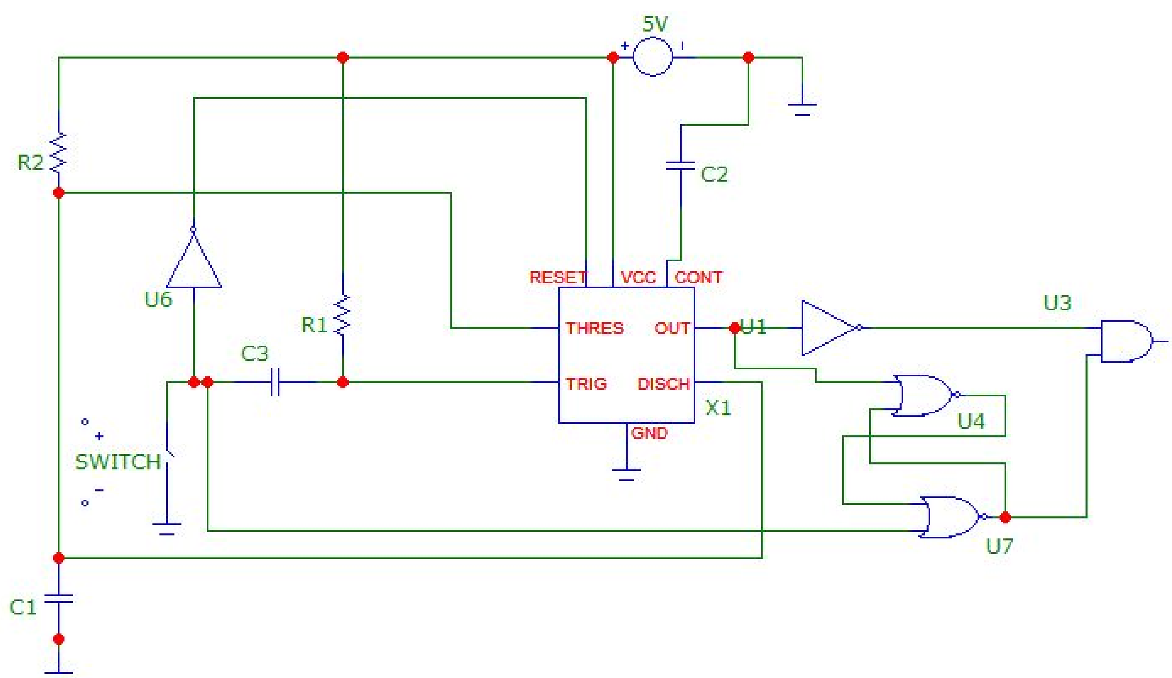



After consulting with our advisor, we decided to proceed with the monostable mode design, as the startup period could be easily controlled and shortened, and the single pulse was easier to design around versus the periodic waveform. It was also recommended to integrate the reset of the timer into our circuit, separate from the overall reset system of the satellite. This was so that should the timer be triggered too early, the rest of the satellite would not be required to be reset alongside it. To achieve this, a not gate was integrated between the push button and the reset pin, as the reset will trigger if the pin receives a low signal.[23] An additional capacitor was also added to the trigger pin as per our advisor’s recommendation. After the push button is pressed, the capacitor is charged, bringing the voltage of the trigger pin back up. This ensures that after the timer is completed, it does not restart due to the push button being held down, which would otherwise effectively ground the pin.

| S | R | $\overline{Q}$ |
|---|---|---|
| 0 | 0 | latch |
| 0 | 1 | 1 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

As previously mentioned, the initial start up period of a 555 timer in monostable mode outputs a high signal, which we want to avoid in our design, as this will cause the circuit to activate immediately upon startup. In order to prevent this false positive signal from registering, we implemented an SR latch circuit after the output of the timer using nor gates. The Q' output of this latch is compared with the inverted output of the timer though an AND gate. The inputs of the latch, were connected to the uninverted output of the timer, and the push button, connected to R and S respectively. In this initial state, the push button will not be pressed, resulting in R having a high value. This will result in latch outputting a low value, regardless of the value of S, consequently causing the AND gate to output a low value. After the button is pressed, R will be grounded, but the inverted output of the timer will be high, causing the latch to output high. Despite this, the inverted output of the timer will be low, thus the AND gate will still not produce an output. Finally, after the timer finishes, the inverted output of it will output a high value, allowing the AND gate to do the same. A general version of the full circuit can be seen below.

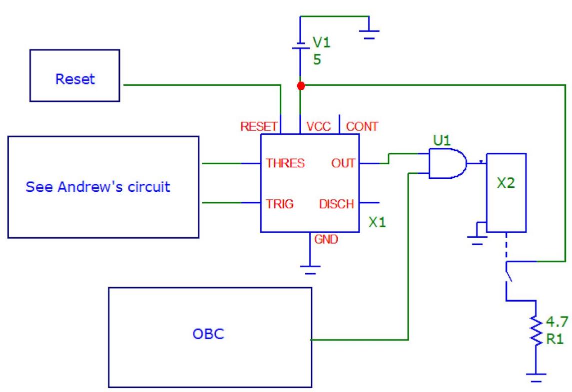



*Microcap Timer Circuit Design*

**Burn-Wire Circuit**

A burn-wire circuit consists of a wire that is heated up to a point where it breaks, to release a mechanism. Once the 555 timer has completed, a release mechanism is activated to deploy the antenna on the corners of one side of the CubeSat. This is where the concept of a burn-wire addition to the circuit comes into play. This wire, made from Nichrome (Nickel-Chromium, sometimes with small alloy impurities) has a 4.7-Ohm resistor intertwined in its threads. [24] This release solution is chosen due to it being able to be cleanly actuated with inexpensive electronics, and it can be operated with standard CubeSat bus power (5-volt source). This burn wire, pulled tight under high tension, is simplistic enough to implement, and is affordable under our budget. The mechanism uses a compression spring system to apply a stroke as well as a force to the nichrome wire. In order for the nichrome wire to begin burning, an AND-gate is required to have the thirty-minute timer completed its time, as well as confirmation from the OBC (On-Board-Computer) via a microcontroller to be managed from Earth. When the battery source is connected and has its current flow through this wire, it will thermally cut through the Vectran cable tie–down, a manufactured LCP (Liquid-crystal polymer). Once the Vectran tie-down is severed, it deploys the antennas of the CubeSat.




*Microcap Burn Wire Circuit Design*

Above shows the system involving the 555 timer and the burn wire mechanism, in the form of MicroCap circuit. The source voltage $V_1$ (5 volts) enters the 555 timer and begins the thirty-minute countdown. Due to the output of the timer as well as a microcontroller on the OBC (On-Board-Computer) being inputted into an AND gate, the wire, represented as $R_1$, will not begin to burn from the sources current confirmed by both the thirty minutes being concluded as well as verification from the OBC. This then closes the switch and sends current through the represented nichrome wire [25].

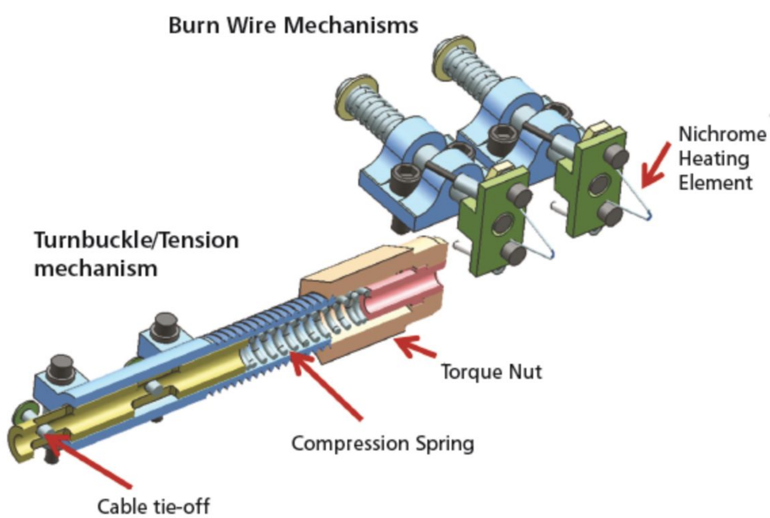



*Figure: Isometric view of Burn Wire Mechanism*

The figure shown above is an isometric view of the system of the burn wire system. Its three most significant components are the cable tie-down, a tension apparatus as well as a mechanism for burn wire actuation. The nichrome heating element rises in temperature until it burns the nichrome and breaks the Vectran tie-down cable. This is not the final design option, as the weight might be too high or have a lack of space on the CubeSat. The final design will be put forward during the testing phase.

**Interfaces**

The components included on our PCB boards make use of a variety of communication interfaces. These include SPI, PWM and I2C. The gyroscopes operate via SPI or Serial Peripheral Interface. SPI is a synchronous bus which includes a clock to keep the distributing and receiving ends in sync with one another. The clock is an oscillating signal which notifies the receiver when it must sample bits on the data line (either at the rising or falling edge). For SPI, only the transmitter creates a clock. PWM stands for Pulse Width Modulation, and is essentially a rapidly cycling switch to regulate the power distributed to a device. Our ADCS system sends power to our board via PWM to the magnetorquers to adjust the CubeSat's attitude. I2C is a two wire system allowing a 'master' device to send signals to multiple 'slave' devices which each have a unique address associated with them. By including this address in the data line, the master can transmit information exclusively to a selected device. I2C will be used by our antennae, GPS and transceiver systems.

# 3. Design Analysis

## 3.1 Engineering Techniques/Software tools

Many software tools have been used to communicate and perform appropriate analysis. *Slack* has been used to communicate with other teams and the project managers. Weekly progress reports have been posted to the #boards section and our project lead, Nick, has updated us with information. We were also made aware of CubeSat meetings put on by other parties such as the Canadian Space Agency. *Github* has also been used to upload and review all the documentation created along the duration of the project. [26] Circuits, specifications, and reports can be found on this platform. A wiki of all the groups' most updated information is also located here for reference. *MicroCap* was used to simulate the burn wire circuit and the 555 timer circuit.

This software was necessary to use before implementing the circuit on PCB software so that appropriate simulations could take place.

The preliminary designs for the PCB were created using *AutoDesk Eagle*. We have experience using this program from past engineering design courses, and it is a quick and easy way to develop basic PCB layouts. We received access to licenses for *Altium,* which is a common software used in industry. This was more effective for designing multiple layered boards and offers many more options such as 3D viewing. [27]

## 3.2 Complete Analysis/Calculations

### <u>Timer circuit calculations</u>

t = 1.1*C*R

<u>30 minute timer</u>

**2 Capacitors, 4 Resistors**

| Capacatance (µF) | Tolerance | Quantity | Total Capacatance (µF) |
|---|---|---|---|
| 1800 | 10 | 2 | 3600 |
| Resistance (kΩ) | Tolerance | Quantity | Total Restance (kΩ) |
| 132 | 0.01 | 3 | 396 |
| 110 | 0.01 | 1 | 110 |
| | | | 506 |

| | | Capacatance (µF) | | |
|---|---|---|---|---|
| | | min. value | given value | max. value |
| Resistance (kΩ) | | 3240 | 3600 | 3960 |
| min. value | 505.95 | 30.05 | 33.39 | 36.73 |
| given value | 506.00 | 30.06 | 33.40 | 36.74 |
| max. value | 506.05 | 30.06 | 33.40 | 36.74 |

Note: Times are in minutes

**3 Capacitors, 3 Resistors**

| Capacatance (µF) | Tolerance | Quantity | Total Capacatance (µF) |
|---|---|---|---|
| 1800 | 10 | 3 | 5400 |
| Resistance (kΩ) | Tolerance | Quantity | Total Restance (kΩ) |
| 132 | 0.01 | 2 | 264 |
| 73 | 0.01 | 1 | 73 |
| | | | 337 |

| | | Capacatance (µF) | | |
|---|---|---|---|---|
| | | min. value | given value | max. value |
| Resistance (kΩ) | | 4860 | 5400 | 5940 |
| min. value | 336.97 | 30.02 | 33.36 | 36.70 |
| given value | 337.00 | 30.03 | 33.36 | 36.70 |
| max. value | 337.03 | 30.03 | 33.37 | 36.70 |

Note: Times are in minutes

**4 Capacitors, 2 Resistors**

| Capacatance (µF) | Tolerance | Quantity | Total Capacatance (µF) |
|---|---|---|---|
| 1800 | 10 | 4 | 7200 |
| Resistance (kΩ) | Tolerance | Quantity | Total Restance (kΩ) |
| 132 | 0.01 | 1 | 132 |
| 121 | 0.01 | 1 | 121 |
| | | | 253 |

| | | Capacatance (µF) | | |
|---|---|---|---|---|
| | | min. value | given value | max. value |
| Resistance (kΩ) | | 6480 | 7200 | 7920 |
| min. value | 252.97 | 30.05 | 33.39 | 36.73 |
| given value | 253.00 | 30.06 | 33.40 | 36.74 |
| max. value | 253.03 | 30.06 | 33.40 | 36.74 |

Note: Times are in minutes

Based on these calculations, in order to minimize the number of components, while producing a timer closest to the target goal of 30 minutes, a combination of three capacitors and three resistors will be used.

<u>5 minute timer</u>

| Capacatance (µF) | Tolerance | Quantity | Total Capacatance (µF) |
|---|---|---|---|
| 1800 | 10 | 1 | 1800 |
| Resistance (kΩ) | Tolerance | Quantity | Total Restance (kΩ) |
| 0 | 0.01 | 0 | 0 |
| 75 | 0.01 | 2 | 150 |
| | | | 150 |

| | | Capacatance (µF) | | |
|---|---|---|---|---|
| | | min. value | given value | max. value |
| Resistance (kΩ) | | 1620 | 1800 | 1980 |
| min. value | 149.99 | 4.45 | 4.95 | 5.44 |
| given value | 150.00 | 4.46 | 4.95 | 5.45 |
| max. value | 150.02 | 4.46 | 4.95 | 5.45 |

Note: Times are in minutes

With a single capacitor and two resistors of smaller values, we are able to produce an approximately 5 minute timer in order to make testing the other parts of the circuit easier and less time consuming.

$$NiCrC\ (model\ 60\ wire)[Nichrome]$$
$$30\ AWG\ (American\ Wire\ Gauge$$

$$Source\ Voltage\ of\ 5V$$
$$Resistance\ of\ 2\Omega$$
$$Current(I) = \frac{5}{2} = 2.5\ A$$
$$2.52\ A\ of\ current\ pushing\ through\ the\ wire\ raises\ it\ to\ approximately\ a$$
$$temperature\ of\ 760\ Degrees\ Celsius, allowing\ easy\ cut\ of\ the\ fluorocarbon\ line$$

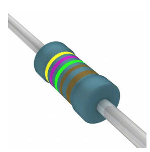
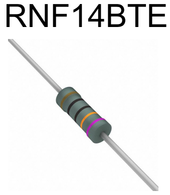
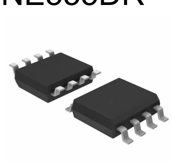
# 4. Results and Validation

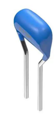
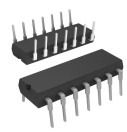
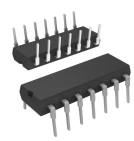
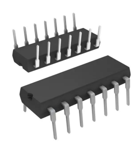
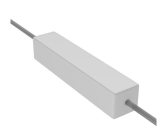
## 4.1 Prototype

The parts list for our prototype and final design are listed below, along with the individual prices per component. Components were sourced using digikey.ca and links to the datasheets for each component have been compiled within the 'Product Data Sheets' appendix at the end of this report.

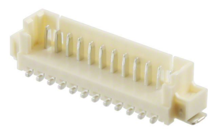
The prototype design was intended for demo purposes and cost-effectiveness. As a result, the resistor and capacitor values produce a 5 minute timer, and all components are consumer-grade rather than the space-rated components of the final design.

**Board 1 Prototype Design Component List**

| Component | Prototype Model | Price per Component |
|---|---|---|
| 1800uF Capacitor x2 | UHW1C182MPD  | $1.62 x 2 = $3.24 |
| 75kΩ Resistor x2 | SFR16S0007502FR500  | $0.03 x 2 = $0.06 |
| 100kΩ Resistor | RNF14BTE100K  | $0.21 |
| 555 Timer | NE555DR  | $0.12 |

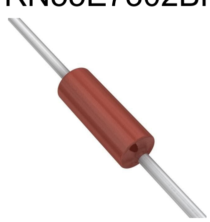
| | | |
|---|---|---|
| 0.1uF Capacitor | C315C104M5U5TA7303  | $0.06 |
| 10uF Capacitor | FG16X7R1E106KRT06  | $0.31 |
| Six-Channel NOT Gate | CD4069UBE  | $0.86 |
| Quad 2-Input OR Gate | SN74LS32N  | $0.99 |
| Quad 2-Input AND Gate x2 | CD4081BE  | $0.86 x 2 = $1.72 |
| Relay | G5LE PCB Power Relay  | $2.07 |
| 2Ω Cement Resistors x4 | SQP10AJB-2R0  | $1.16 x 4 = $4.64 |

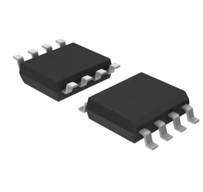
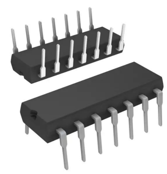
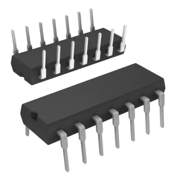
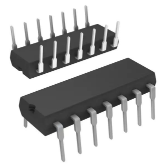
**Board 2 Prototype Design Component List**

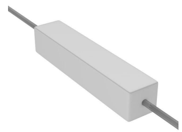
| Component | Prototype Model | Price per Component |
|---|---|---|
| Magnetorquer x3 | Custom-Built by Different CubeSat Group | TBA |
| 12-Pin Wire-to-Board Connector x3 | 0533981271  | $1.06 x 3 = $3.18 |

The final design intended to be used in space has not been built due to costs, but has been designed to implement a 30 minute timer and consist of space-rated components to prevent outgassing.

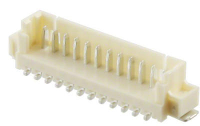
**Board 1 Final Design Component List**

| Component | Final Model | Price per Component |
|---|---|---|
| 1800uF Capacitor x4 | 135D188X9008K2  | $80.13 x 4 = $320.52 |
| 73kΩ Resistor | RN55E7302BR36  | $0.46 |
| 132kΩ Resistor x2 | RN65C1323BRE6  | $0.78 x 2 = $1.56 |

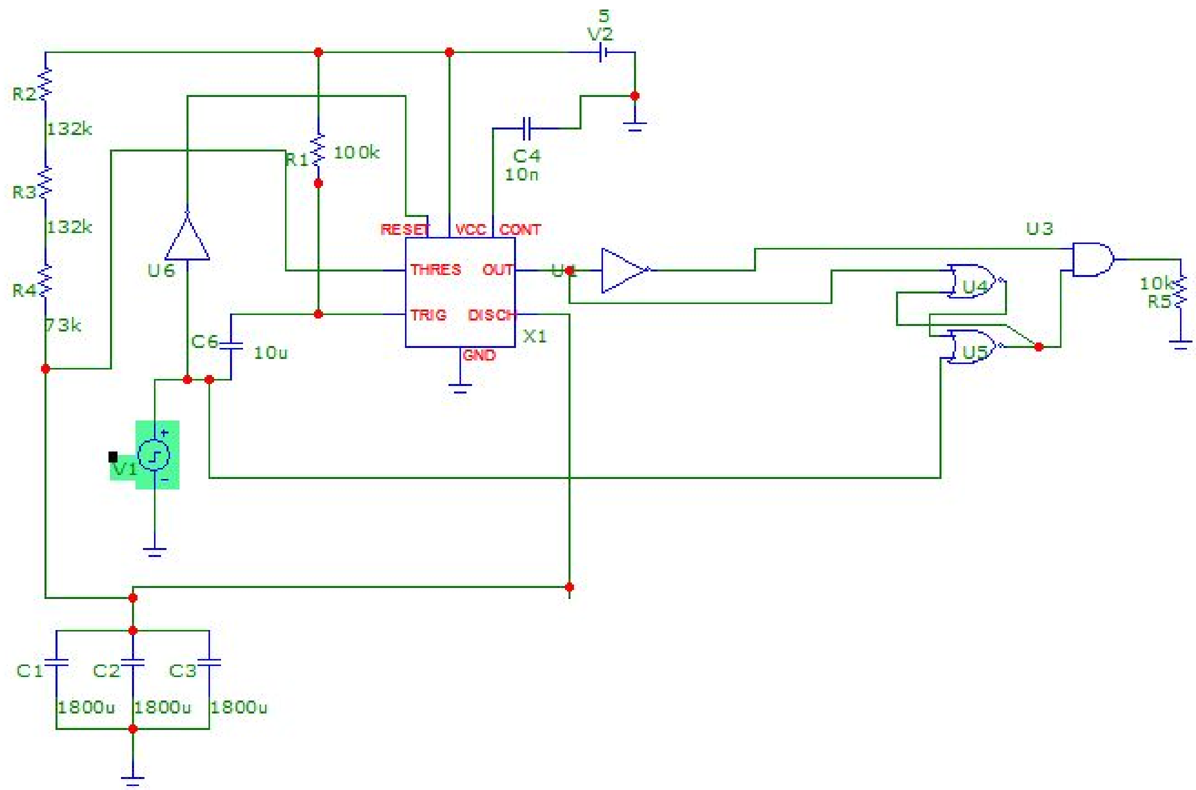
| | | |
|---|---|---|
| 555 Timer | NE555DR  | $0.12 |
| 0.1uF Capacitor | 150D104X9125A2B | $30.76 |
| 10uF Capacitor | M39006/25-0074 | $34.50 |
| Quad NOT Gate | CD4069UBE  | $0.86 |
| Quad 2-Input OR Gate | SN74LS32N  | $0.99 |
| Quad 2-Input AND Gate x2 | CD4081BE  | $0.86 x 2 = $1.72 |
| Relay | G5LE PCB Power Relay  | $2.07 |
| | | |

| | | |
|---|---|---|
| 2Ω Cement Resistors x4 | SQP10AJB-2R0  | $1.16 x 4 = $4.64 |

**Board 2 Final Design Component List**

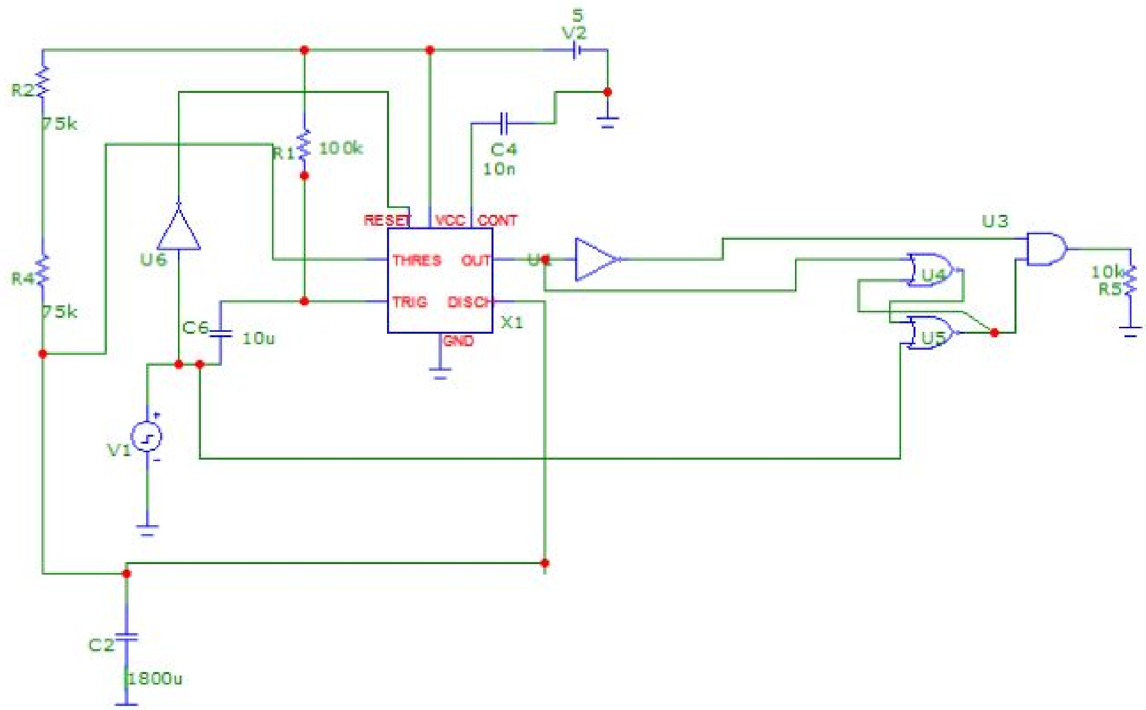
| **Component** | **Final Model** | **Price per Component** |
|---|---|---|
| Magnetorquer x3 | Custom-Built by Different CubeSat Group | TBA |
| 12-Pin Wire-to-Board Connector x3 | 0533981271  | $1.06 x 3 = $3.18 |

**30 minute timer microcap circuit**



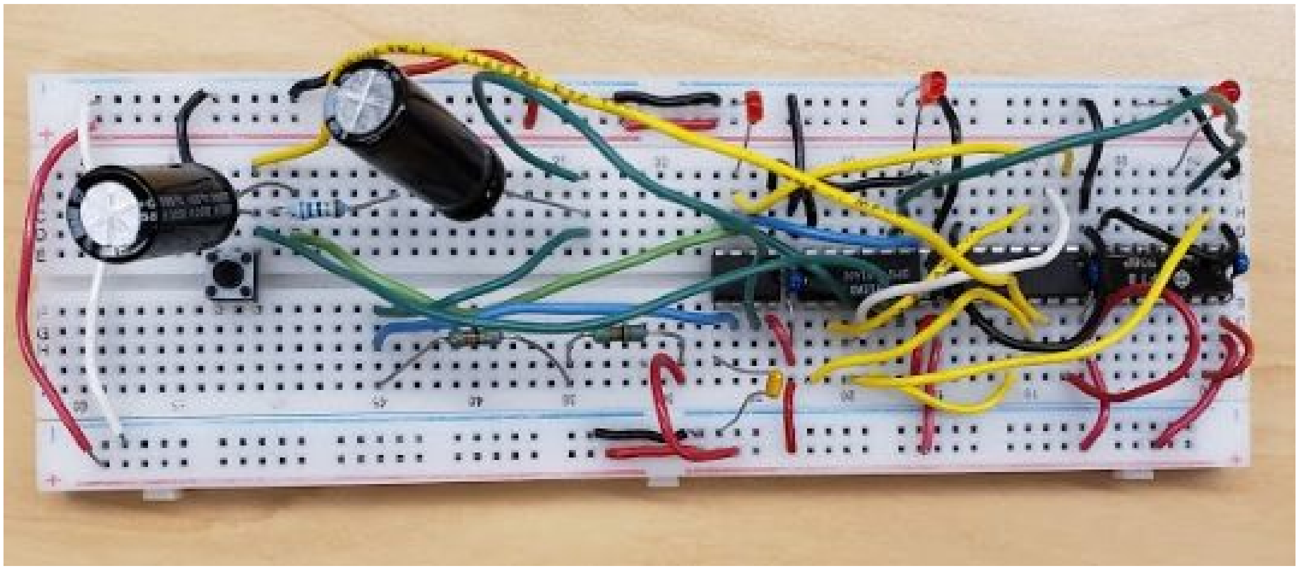

Square waveform voltage supply in place of switch to simulate pressing and holding of the push button. [28]

**5 minute timer Microcap circuit**




Square waveform voltage supply in place of switch to simulate pressing and holding of the push button.

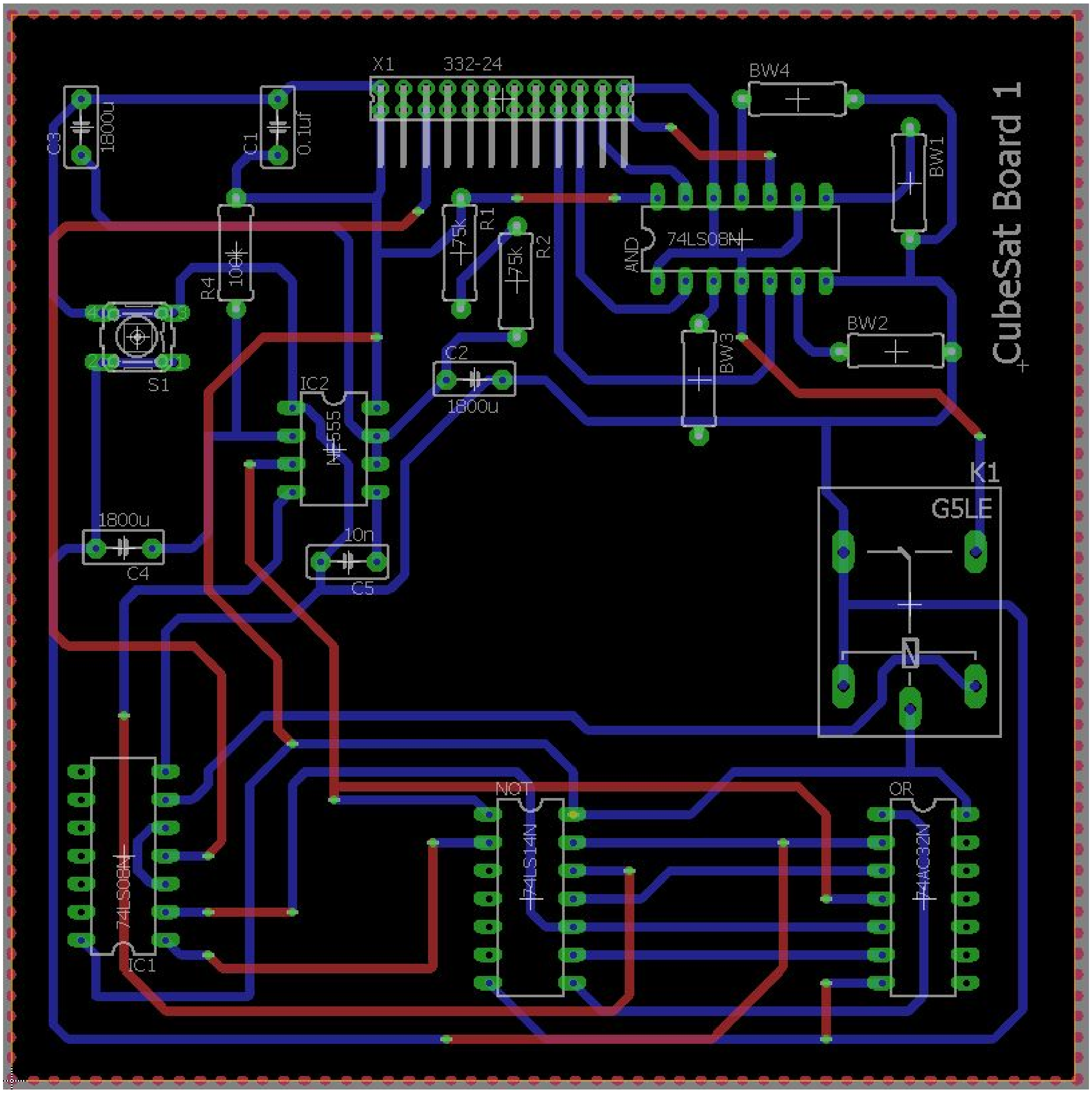
**Board 1 Breadboard Design**



*Board 1 breadboard prototype*

The prototype was initially constructed using a breadboard in order to verify the design and functionality of the components

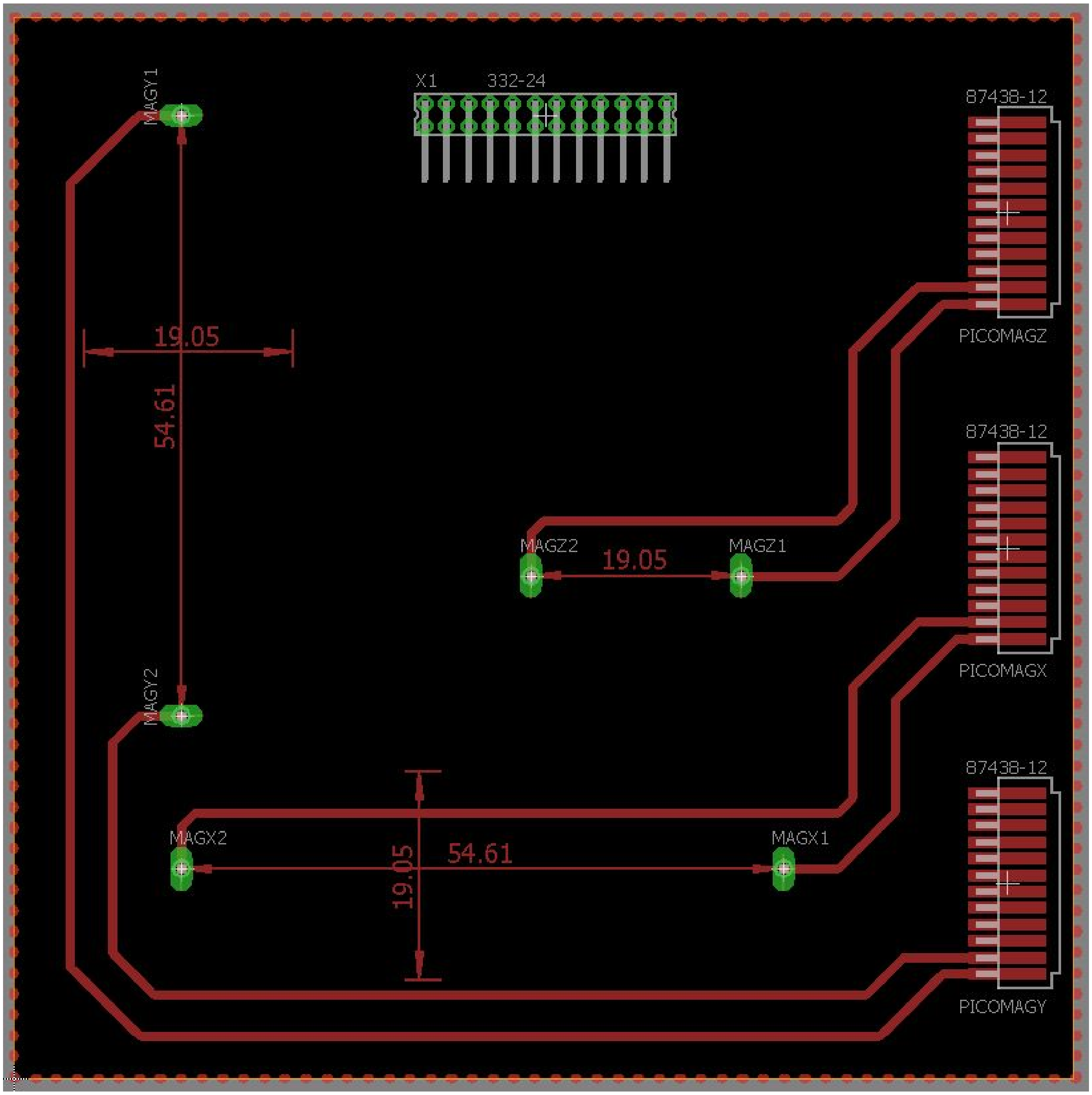
**Board 1 Finalized Design**




*CubeSat Board 1 EAGLE Schematic*

Board 1 is a two-layer PCB which contains all of the components and circuitry for the timer and burn-wire components of the CubeSat. It also reserves an empty space in the center which will be removed in the final design to allow the z-axis magnetorquer to stand upright.

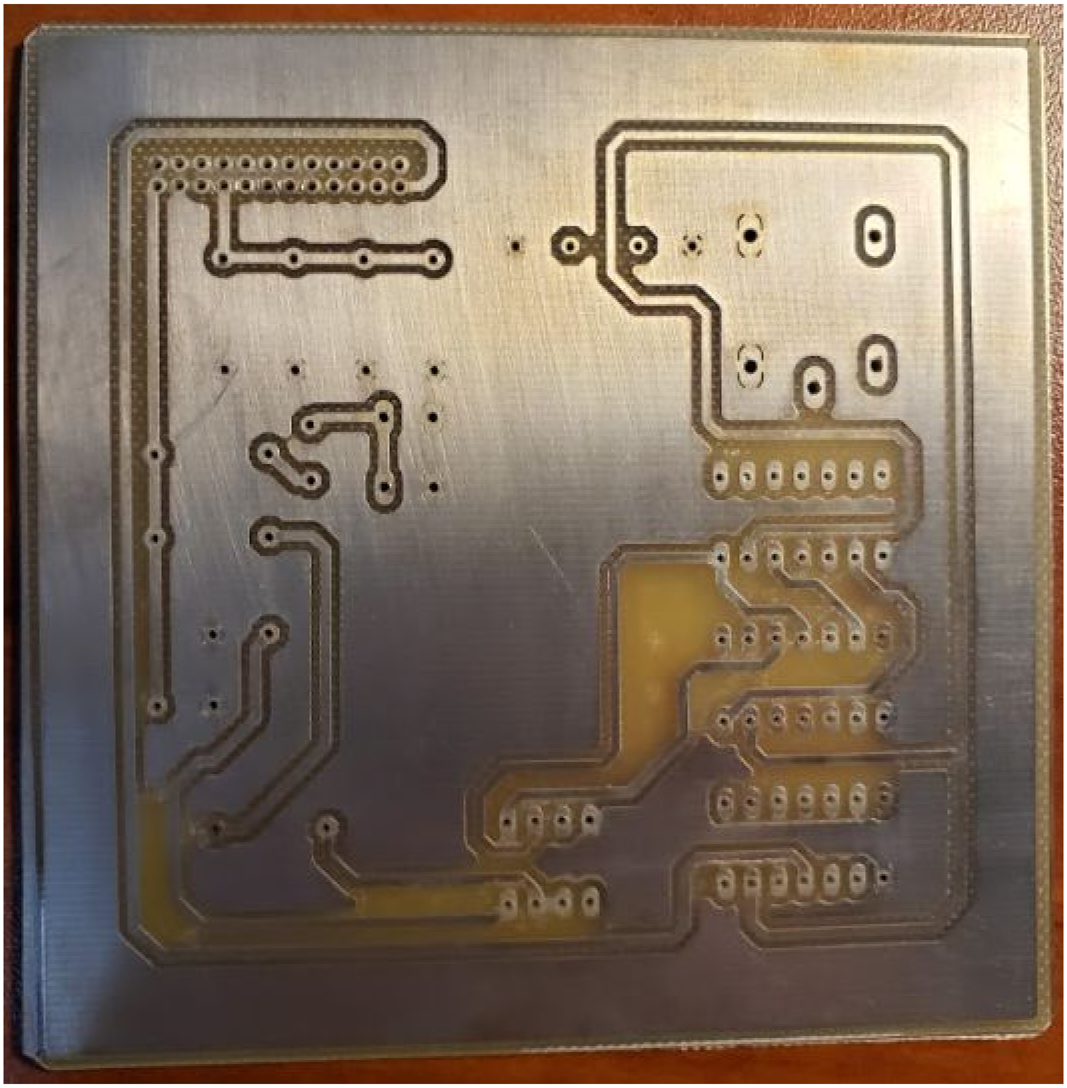
**Board 2 Finalized Design**



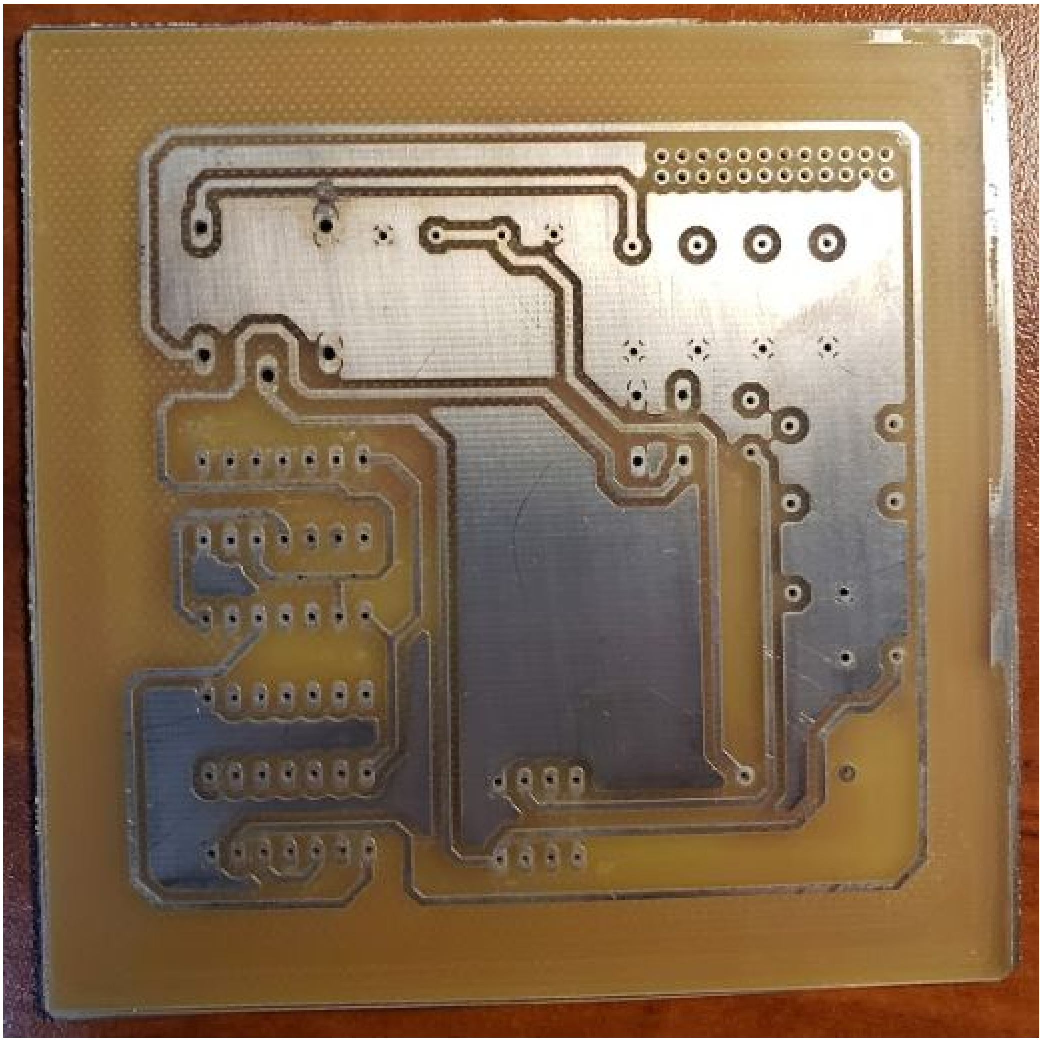

*CubeSat Board 2 Eagle Schematic*

Board 2 is a one-layer PCB containing the magnetorquers that allow the PCB to rotate. The components on the right are wire-to-board connectors which will allow the magnetorquers to interface with the OBC. The dimensions of the PCB plus tolerances have been labeled on the board. Board 2 will fit underneath board 1 using the pin connector at the top of the board. Magnetorquer Z will be standing upright and will pass through the cutout section in the center of board 1. Because the magnetorquers were created by another CubeSat group and were therefore inaccessible, it was decided that board two would not be printed, just designed in EAGLE.

**Prototype PCB Iteration 1**



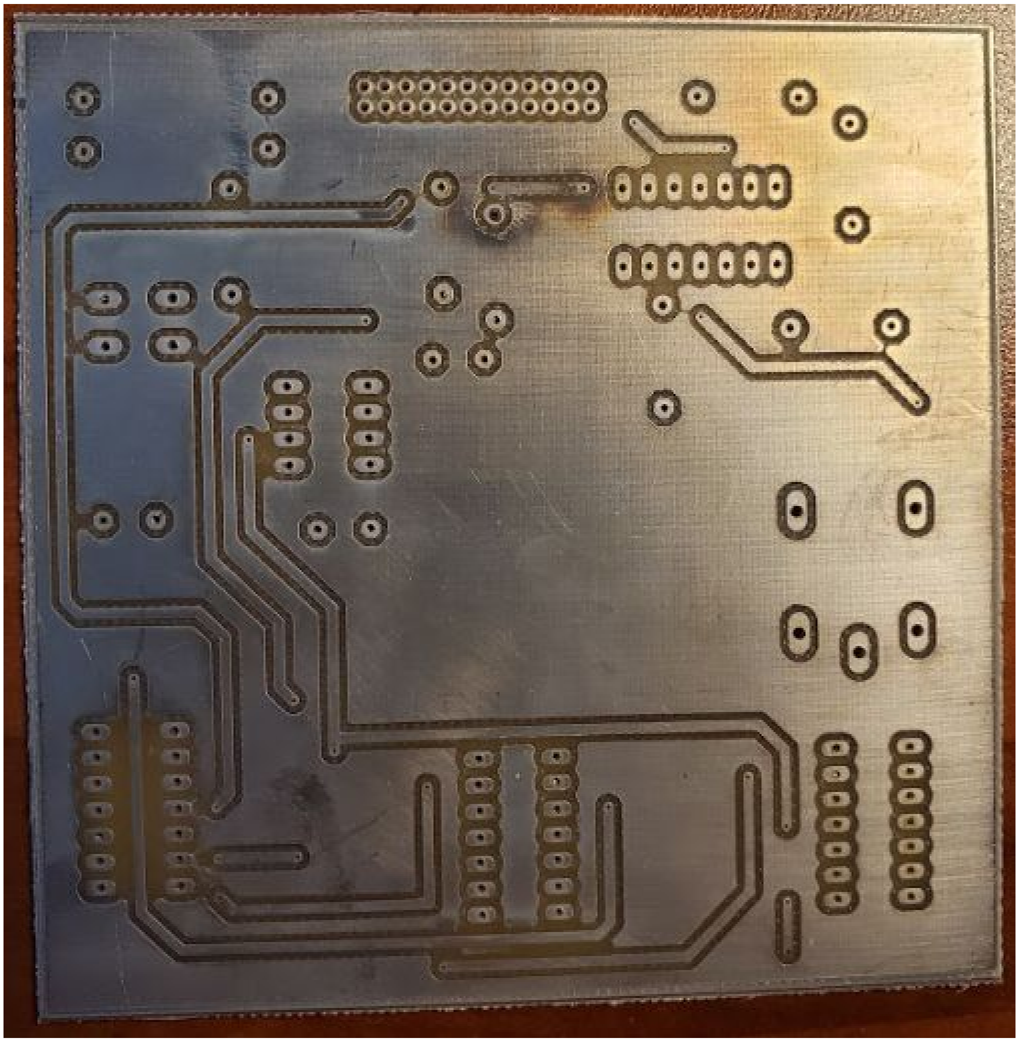
*Board 1 PCB Iteration 1 Frontside*



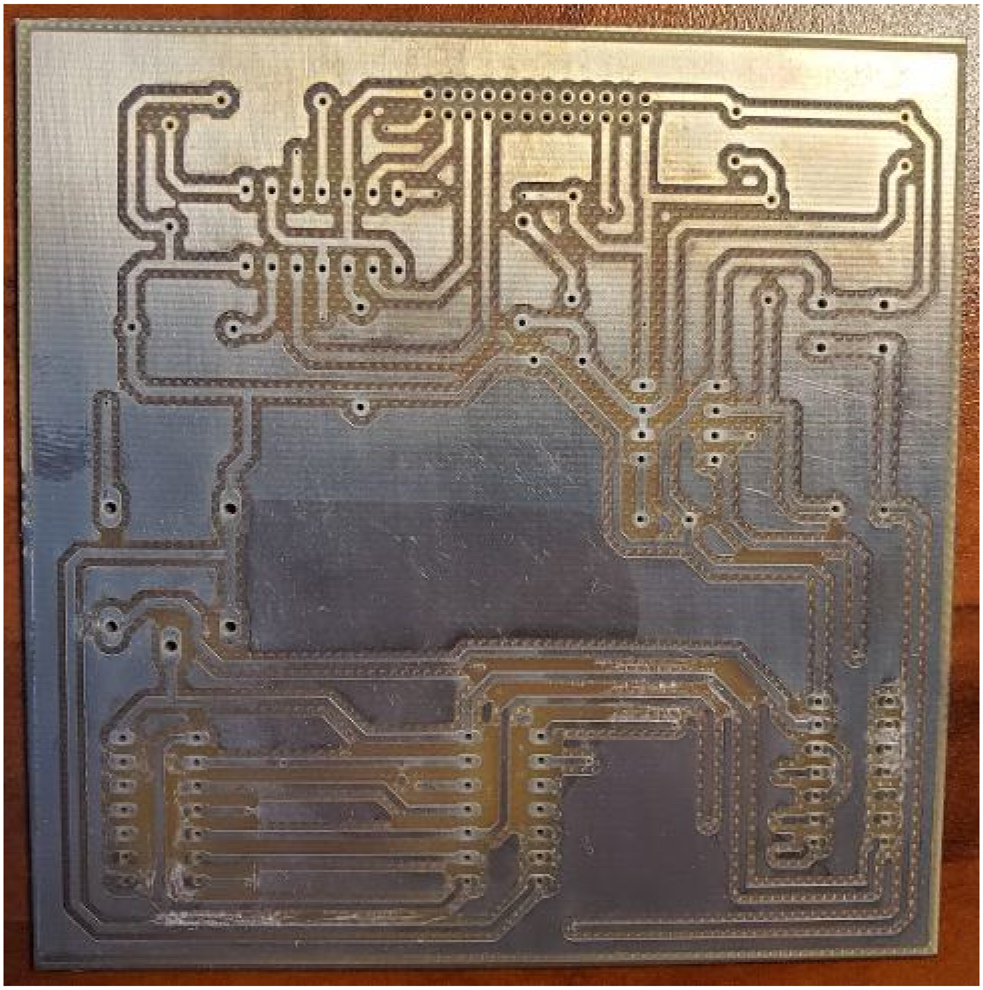
*Board 1 PCB Iteration 1 Backside*

Iteration 1 of board 1 is very similar to the final iteration in terms of circuit layout, however it was edited in order to add an additional AND gate before the burn-wire resistors, and to move the majority of the traces to the backside of the board for easier soldering.

**Prototype PCB Final Iteration**



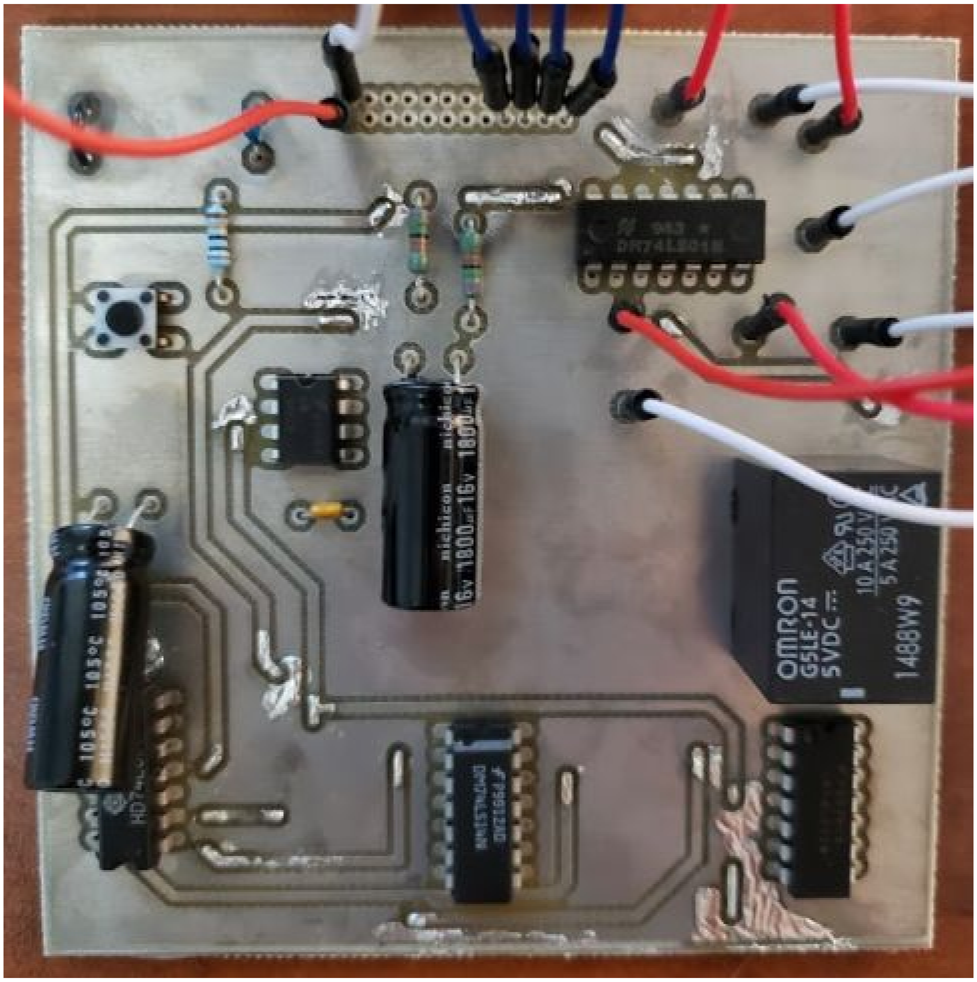
*Board 1 PCB Iteration 2 Frontside*



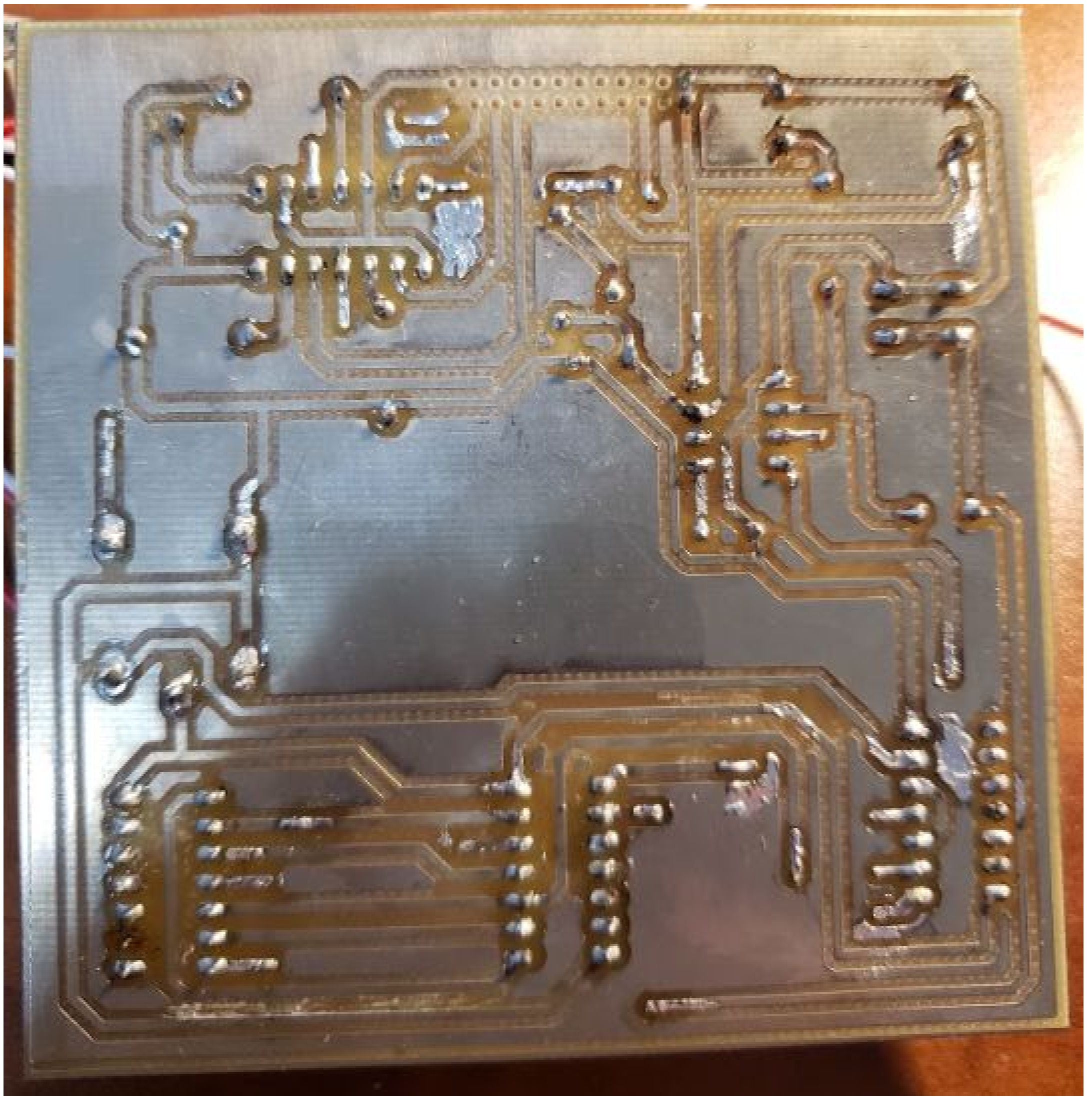
*Board 1 PCB Iteration 2 Backside*

The second iteration moves the pin header to the top-center of the board, adds another AND gate and moves most of the traces to the back of the PCB. In order to accomplish this, multiple vias were added to the board to connect the front of the PCB to the back.

**Soldered PCB Second Iteration**




*Board 1 PCB Iteration 2 Frontside After Soldering*



*Board 1 PCB Second Iteration Backside After Soldering*

## 4.2 Testing Strategy/ Validation Protocols

After the components have been sourced and arrived, we can begin assembling and testing our circuits. Due to the price and availability of space rated components, some non space rated ones with equivalent values were used in their place for the purposes of testing.

The assembly of the timer circuit was initially done on a breadboard, independent of the burn wire circuit. Leds were added to the circuit at both the inverted and uninverted outputs of the timer, as well as after the final AND gate in order to have a visual representation of when these outputs changed. They also allowed us to identify errors in the intermediate sections of the circuit when they occured. Multimeters were also used to find the exact voltage of these positions to ensure our outputs were of suitable and expected levels. The circuit was connected to a 5-Volt power supply in order to simulate the power source of the satellite, and a stopwatch was used to measure the timer's accuracy. The initial test was done with a 30 minute configuration in order to confirm our circuit was functional, and reached our desired time. Afterwards, the components in the circuit were reduced in order to achieve a 5 minute timer. This was done for efficiency, as we would be able to test the timer circuit's interactions with the other parts of our board in a more timely manner. When major changes were made, the 30 minute timer would be tested again to ensure that the changes were compatible with the full scale of our design.

The burn wire circuit used for testing included two 5-Volt power supplies, a general purpose relay, a 2-Ohm resistor, jumper wires, nichrome wire and two clamps. One of the equivalent power supplies was connected to the coil port of the relay and the other power supply will be connected to the 2-Ohm resistor. This 2-Ohm resistor may be altered in size upon testing, but remained under a value of 1 kilo-Ohm. The nichrome wire was in tension using the clamps and in contact with the resistor. The power supply connected to the coil port was switched on. To simulate the end of the 30-minute timer, the switch of the power supply was turned on and sufficient current of about 2.5 Amperes ran through the closed switch. The wire heated up in a matter of seconds from the resistor and successfully cut the wire. This test validated the design as the cutting of the wire simulated a wire cut in space. By simplifying the timer process, the testing process still accurately determined whether the burn wire was successful. The voltage energizing the relay coil was still 5 Volts in the test, which is the same as 5 Volts coming from the on-board computer.

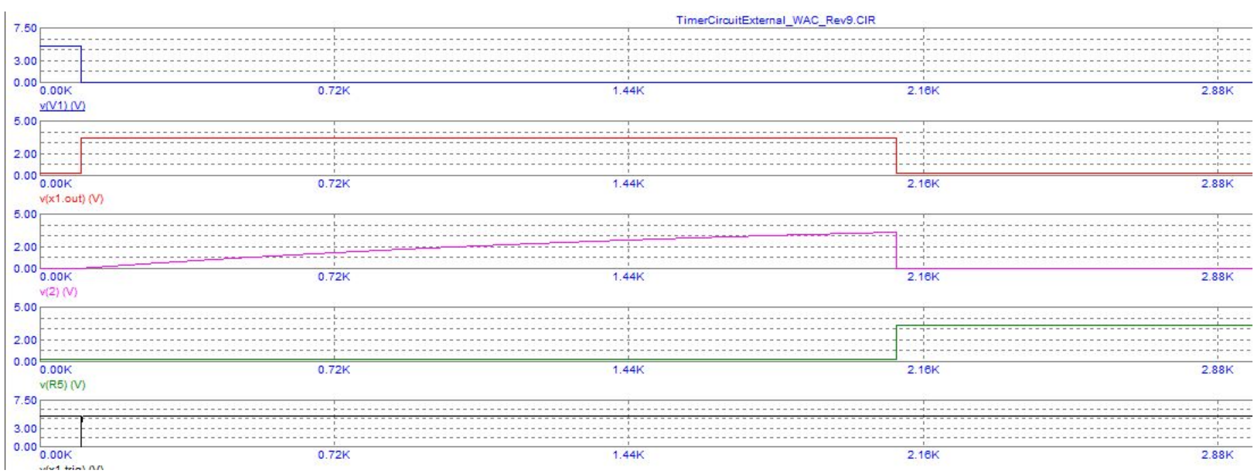
## 4.3 Final Results and Validation

As mentioned above, the initial tests of the timer circuit were with the entire 30 minute duration, in order to ensure our circuit functioned properly to the project's specifications. The results were as follows.

| Trial no. | Time | Uninverted timer output led | Inverted timer output led | AND gate output led |
|---|---|---|---|---|
| 1 | 32 mins | • Initially off<br>• Switched on after timer started<br>• Switched and remained off after timer finished | • Initially on<br>• Switched off after timer started<br>• Switched and remained on after timer finished | • Initially off<br>• Remained off after timer started<br>• Switched and remained on after timer finished |
| 2 | 31.5 mins | • Initially off<br>• Switched on after timer started<br>• Switched and remained off after timer finished | • Initially on<br>• Switched off after timer started<br>• Switched and remained on after timer finished | • Initially off<br>• Remained off after timer started<br>• Switched and remained on after timer finished |
| 3 | 31.5 mins | • Initially off<br>• Switched on | • Initially on<br>• Switched off | • Initially off<br>• Remained off |

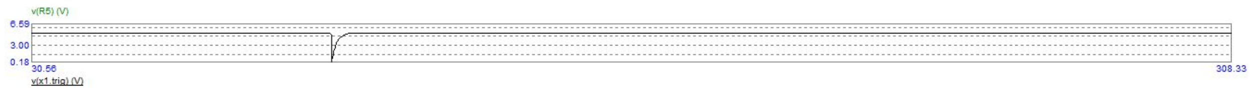
| | | | | |
|---|---|---|---|---|
| | | after timer started<br>● Switched and remained off after timer finished | after timer started<br>● Switched and remained on after timer finished | after timer started<br>● Switched and remained on after timer finished |

These results show the timer performing as intended. The variation from the predicted 30.02 minute timer is most likely due to the non space rated components having a larger tolerance than the space rated ones used in our calculations. These results fulfil the conditions of producing a 30 minute timer, with no risk of the timer triggering early. These results also show the concerns with regards to the initial start up period outputting a high signal too early were successfully being prevented with the SR latch and AND gate design. These results can also be seen in the microcap simulations below.




Microcap simulation of 30 minute (1800 seconds) timer circuit. Legend is as follows:

- Blue: Square waveform generator, simulating push button pressed and held.
- Red: Uninverted 555 timer output.
- Pink: 555 timer threshold pin
- Green: AND gate final output
- Black: 555 timer trigger pin

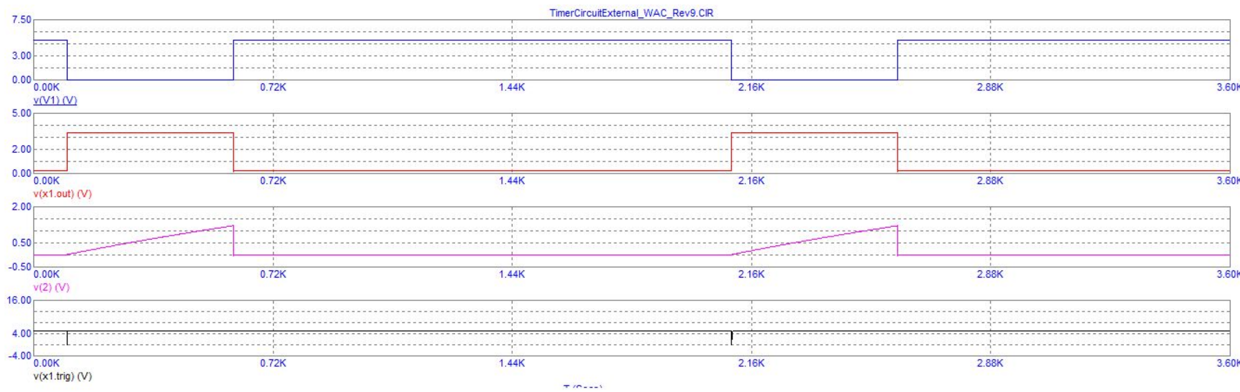



555 timer trigger pin expanded for enhanced detail

After testing that the circuit functioned properly when the push button was pressed, we repeated the experiment with the push button held down, before being released a set period of time after. This was done in order to simulate the button button being pressed too early, and had to ensure releasing the button would not only stop the timer, but it would restart again upon the button being pressed. The results of these trials are as follow:

| Trial no. | Total trial time | Initial button press | Button release | Secondary button press |
|---|---|---|---|---|
| 4 | 43 mins | • Button pressed and held for 5 minutes | • Button released for 5 minutes | • Button pressed again and held for remainder of trial |
| 5 | 41.5 mins | • Button pressed and held for 5 minutes | • Button released for 5 minutes | • Button pressed again and held for remainder of trial |
| 6 | 58 mins | • Button pressed and held for 10 minutes | • Button released for 15 minutes | • Button pressed again and held for remainder of trial |

The microcap simulation of this trial can be seen below:




Microcap simulation of 30 minute (1800 seconds) timer circuit. Legend is as follows:

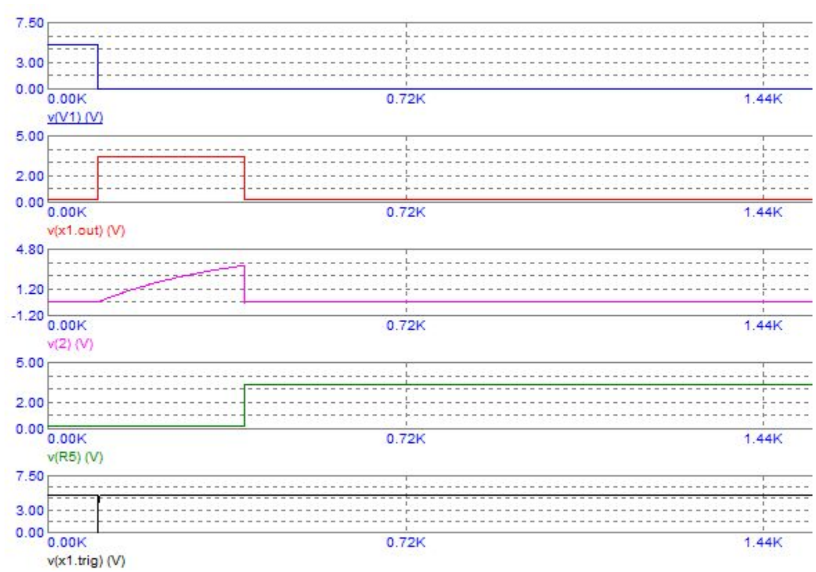
- Blue: Square waveform generator, simulating push button pressed and released before timer has finished
- Red: Uninverted 555 timer output.
- Pink: 555 timer threshold pin
- Black: 555 timer trigger pin

These results show that should the timer be started prematurely for any reason, if the timer will reset upon the button being released, and will restart upon it being pressed again.

After the results of the 30 minute timer were verified, a 5 minute timer circuit was constructed in order to make testing with other components more efficient. As this timer was built using the same configuration as the previous timer, with different resistor and capacitor values, it was functionally identical apart from the duration the timer ran for. The results of the trials and the microcap simulation of this timer can be seen below:

| Trial no. | Time | Uninverted timer output led | Inverted timer output led | AND gate output led |
|---|---|---|---|---|
| 1 | 5.2 mins | • Initially off<br>• Switched on after timer started | • Initially on<br>• Switched off after timer started | • Initially off<br>• Remained off after timer started |

| | | | | |
|---|---|---|---|---|
| | | • Switched and remained off after timer finished | • Switched and remained on after timer finished | • Switched and remained on after timer finished |
| 2 | 5 mins | • Initially off<br>• Switched on after timer started<br>• Switched and remained off after timer finished | • Initially on<br>• Switched off after timer started<br>• Switched and remained on after timer finished | • Initially off<br>• Remained off after timer started<br>• Switched and remained on after timer finished |
| 3 | 5.4 mins | • Initially off<br>• Switched on after timer started<br>• Switched and remained off after timer finished | • Initially on<br>• Switched off after timer started<br>• Switched and remained on after timer finished | • Initially off<br>• Remained off after timer started<br>• Switched and remained on after timer finished |




Microcap simulation of 5 minute (300 seconds) timer circuit. Legend is as follows:

- Blue: Square waveform generator, simulating push button pressed and held.
- Red: Uninverted 555 timer output.

- Pink: 555 timer threshold pin
- Green: AND gate final output
- Black: 555 timer trigger pin

Once again, the variation from the predicted timer is most likely due to the non space rated components having a larger tolerance than the space rated ones used in our calculations.

<u>Burn Wire Test Results (Session 1)</u>

| Trial No | Conditions | Time to Break Point | Success | Notes |
|---|---|---|---|---|
| 1 | - Relay and burn resistor connected | N/A | No | - Relay tripped (NC -> NO)<br><br>- No current went through the burn resistor<br><br>- Power supply 1 went from 5V to 0V, power supply 2 went from 5V to 2.44V |
| 2 | - Burn resistor connected without relay | N/A | No | - Power supplies still did not deliver enough current |
| 3 | - Burn resistor connected<br><br>- Changed power supplies | 27.39 seconds | Yes | - The power supplies were now able to supply enough current<br><br>- More tension was put on the burn wire |

| | | | | |
|---|---|---|---|---|
| 4 | - Burn resistor and relay connected | 49.62 seconds | Yes | - Again, more tension was applied to the burn wire<br><br>- Relay tripped and allowed enough current to pass through to heat up the resistor |

Burn Wire Test Results (Session 2 w/ Nichrome)

| Trial No | Conditions | Time to Break Point | Success | Notes |
|---|---|---|---|---|
| 1 | - Relay and burn resistor connected<br><br>- Nichrome wire wrapped around burn resistor | 10.76 seconds | Yes | - Relay tripped (NC -> NO)<br><br>- Voltage originally showed 3.4V and had to be increased to 5V |
| 2 | - Relay and burn resistor connected<br><br>- Nichrome wire completed the circuit; connected to negative terminal of power supply | 6.21 seconds | Yes | - The wire heated up substantially in a small amount of time<br><br>- The smell of the burn wire was present<br><br>- There was a clean cut in the line this time; no curling |

Burn Wire Test Results (Session 3 w/ four resistors)

| Trial No | Conditions | Time to Break Point | Success | Notes |
|---|---|---|---|---|
| 1 | - Relay and four burn resistors connected<br><br>- Nichrome wire wrapped around burn resistors | 8.13, 8.98, 9.21, 9.78 seconds | Yes | - Relay tripped (NC -> NO)<br><br>- Four group members; one timing each resistor with stopwatches<br><br>- All 4 burn resistors broke the line |
| 2 | - Same as above | 7.84, 8.02, 8.50, 9.64 seconds | Yes | - Relay tripped (NC -> NO)<br><br>- Four group members; one timing each resistor with stopwatches<br><br>- All 4 burn resistors broke the line |

We tested the burn wire circuit and obtained mixed results. The first trial had the relay and burn resistor connected but was unsuccessful. The relay tripped, however, no current went through the burn resistor as the power supply parameters were not configured properly. The next trial involved the burn resistor without the relay but was unsuccessful as the power supplies still did not deliver enough current. The power supplies were changed to more precise models and a third trial was conducted. This trial was a success as the burn resistor broke the wire in 27.39 seconds. More tension was put on the wire this time around. The fourth trial involved the relay again and once again, more tension was applied to the burn wire. The wire broke in about 50 seconds as the relay tripped and allowed sufficient current through the system. After conducting research, we decided to test a second time with nichrome wire wrapped around the burn resistor. This trial was more successful than the previous testing session as the wire broke under 11 seconds. The relay tripped as it changed from the normally closed position to the normally open position. The voltage originally showed 3.4 volts and had to be increased to 5 volts. The second trial was the most successful due to a circuit change. The nichrome wire completed the circuit by connecting to the negative terminal of the power supply. The wire heated up substantially in a small amount of time and broke in 6.21 seconds. There was a clean cut in the line this time and the smell of burn wire was present. This proved that wrapping the burn wire around the nichrome wire was more reliable than wrapping it around the resistor.

We decided to incorporate four burn resistors into the final design instead of one. This would reduce the potential error of antenna deployment. With the original design, if the burn wire did not break, then none of the antennae would deploy. With the revised design involving four resistors, if one burn wire did not break, the other three antennae would still deploy. We decided to test out the improved design using stopwatch timers and the results are shown above. Overall, the three testing sessions validated our design by proving the apparatus can handle the given conditions. The nichrome wire greatly assisted in the functionality of the entire system and drastically lowered the time to break point for the burn wire. Quantitatively, the four resistors increased the break point time slightly but ultimately increased the reliability of the system. If one or more mechanisms failed, the others still had a chance to deploy the antennae. This improved the overall design and prevented the system from failing completely.

Beginning the testing of the burn wire circuit, we ran into the obstacle of what placement of the Nichrome burn wire would be best suited for to produce quick and efficient results.  The options that were present were to use the heat of the burn resistor itself to melt the fluorocarbon wire wrapped around it, wrap the fluorocarbon line with

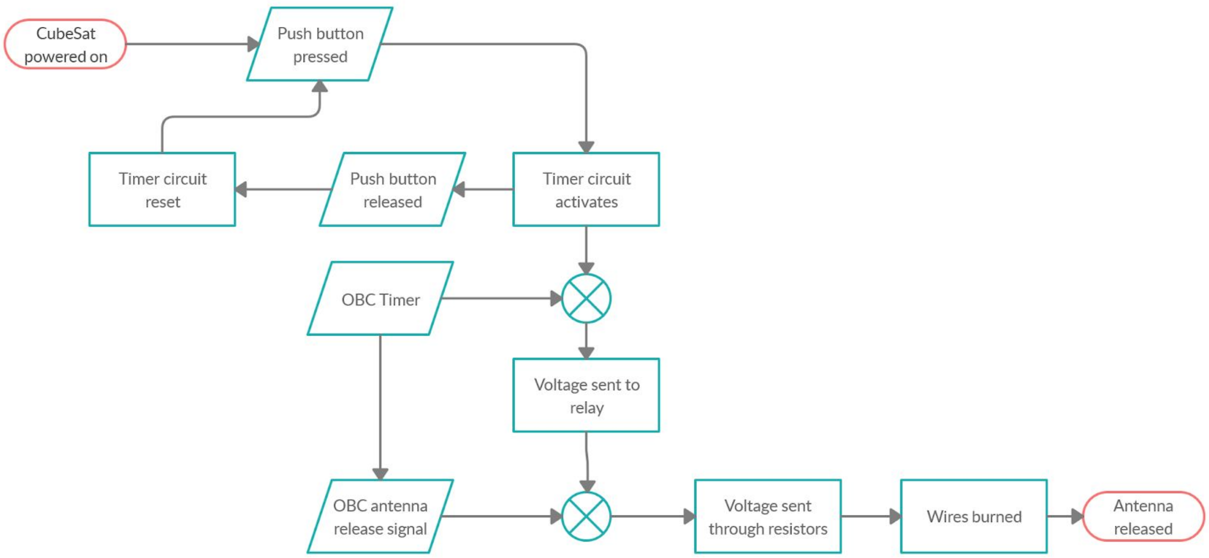
Nichrome wire over the base of the burn resistor, or to connect the Nichrome wire in series with the burn resistor and have the fluorocarbon wrapped around it.

The first test of just using the burn resistor worked successfully, although slowly. When the power was turned on the resistor obviously began to heat up, but due to the material it is composed of concrete, the temperature rise is gradual. The heat dissipation of the concrete resistor is much lower than of a free wire. The fluorocarbon wire, wound tightly around the resistor, did eventually snap due to melting, but the process took almost a minute. When the mission is beginning, the vacuum of space is much harsher than room temperature on earth, so the burn resistor may take minutes to fully burn the fluorocarbon line and release the antennas.

The second branch of testing, we used the burn wire to be wound around the burn resistor, with no source going to the Nichrome wire. The fluorocarbon line was then wrapped around the burn resistor and Nichrome, allowing the heat dissipation of the resistor to transfer to the Nichrome and melt the fluorocarbon line more sufficiently. Thus, this lowered the amount of time between the source being turned on and the fluorocarbon line being melted adequately, to just under eleven seconds. Although we had in mind that the burn wire circuit could act in an even more efficient manner.

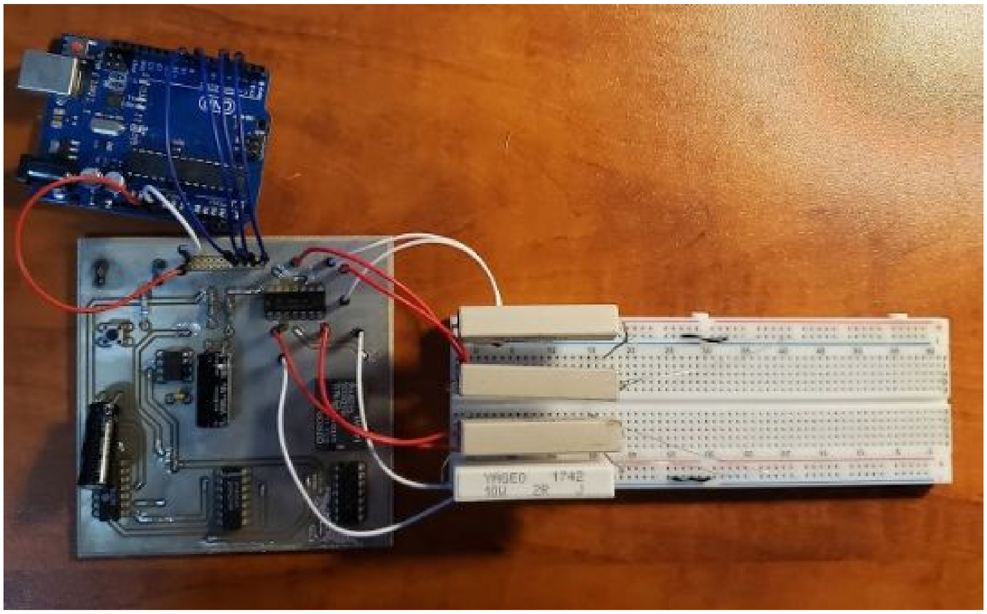
The third, and final method of testing was to attach the burn resistor to the Nichrome wire in series, so the power flow went through the Nichrome wire and produce quick, immense heat. The 5-volt source went through the burn resistor as usual, to lower the amperage to a safe level. The Nichrome wire had the fluorocarbon line wound to it. The result of this test was the quickest, most efficient burn only taking about 6.21 seconds. Having a burn that quick is what we need as the vacuum of space temperatures will lower the heat of the wire, but we would like the minimum amount of time possible for the mission to work efficiently and open the antennas quickly.

**Block Diagram of complete circuit**

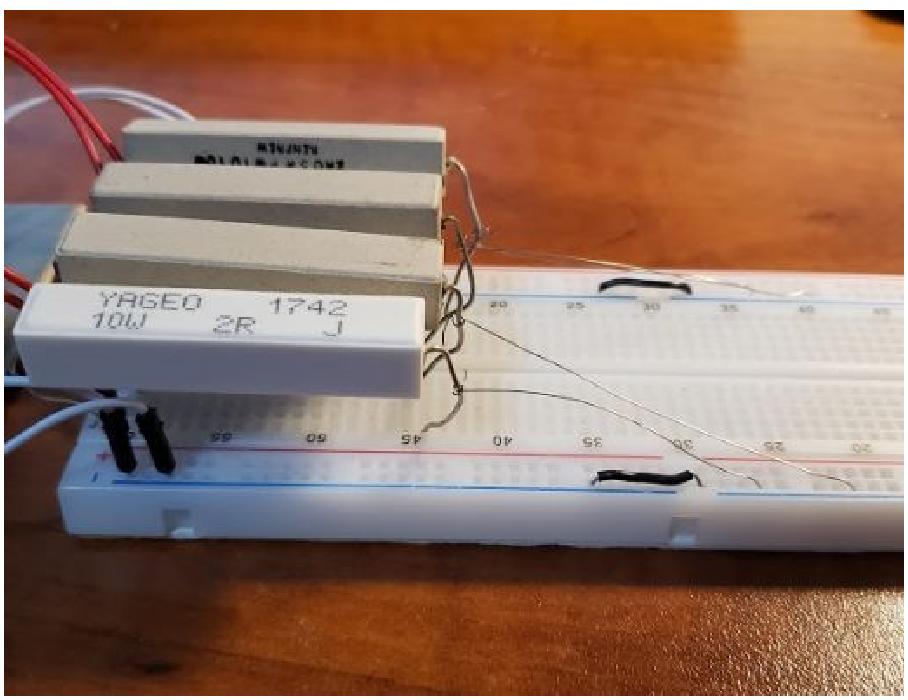



The final prototype should emulate the custom boards and their functions in the Cubesat satellite. After the Cubesat is powered on, there will be no activity on the boards until the push button is pressed. After that occurs, the timer circuit will begin. Should the timer need to be stopped for any reason, the push button simply needs to be released, and the timer will reset, awaiting the push button to be repressed in order to start again. Once the timer circuit finishes, it will output a high signal, which will then be sent through an AND gate alongside a signal from the OBC. Upon startup, the OBC will be running its own 30 minute timer, in order to safeguard against false triggering of the timer circuit. In our prototype, this is simulated by the arduino board connected to our circuit. The output of this AND gate is then sent to the relay, before once again entering another AND gate, this time with a signal from the OBC to release the antennas of the satellite. This is once again in place to ensure the antenna does not deploy early, should there be a failure in the physical circuit and relay. After this, the voltage is then sent to the resistors, which will break the burn wire. This will allow the antennae, which are being held down by the wires, to spring up.

**Prototype Test Setup**




*Final Iteration PCB Board 1 connected to Arduino and Burn-Wire Resistor Matrix*




*Close-up of Burn-wire Resistor Matrix*

Once the prototype had been assembled, it was tested to confirm our design functioned as intended. The burn-wire resistors were placed on a breadboard with nichrome wire connected in series leading back to the ground pins on the breadboard. In the final design, the burn-wires will be placed close to the antennae on the walls of the CubeSat but for the purposes of our prototype, we have placed them on a breadboard. The fluorocarbon wire was wrapped around the nichrome to simulate when it is used to hold down the antennae of the cubesat. An arduino was used to simulate the OBC system. The test required a basic timer which was created using delays to activate the AND gates at designated times. The arduino outputs a low value for the first 5 minutes before setting the outputs to high for 45 seconds. Our breadboard model tests resulted in times between 5 and 5.5 minutes so it was decided the Arduino should initiate the burn process at 5 minutes and continue past 5.5 minutes to guarantee the burning of the fluorocarbon wires. The code for this arduino program can be found in the "relevant code" appendix at the end of this report.

The results of testing using this design can be found in the table below:

| Trial no. | Duration between Button Press and All Wires Cut |
|---|---|
| 1 | 5 mins 32 seconds |
| 2 | 5 mins 37 seconds |

These results are ideal as the wires burn between 5 and 6 minutes. It was important that the wires did not burn before 5 minutes were up, and remaining within 6 minutes proves our resistor and capacitor values were selected correctly. With the tighter tolerances of the spacerated components, the time offset will shrink in the final design, allowing the wires to be cut very soon after the desired 30 minute mark.

# 5. Conclusions, Future Work and Recommendations

In conclusion, the obtained prototype results were considered a success as they met the criteria that was set. It can be assumed that the values will only become more precise in the final spacerated design, improving the design overall.

Much of the future work for this project relates to constructing the spacerated design and adding missing components to board 2. These include components sourced by the ADCS CubeSat team including the Magnetorquers and Gyroscopes. The ICs located on both boards should also have restraints over them to suspend them to the board during flight. Additionally, the burn-wire system should be positioned in locations within the cubesat to suspend the antennae until the timer is up. Finally, documentation will be created outlining how to understand and use the board so that next year’s CubeSat custom board team can finalize the design.

Overall, many new concepts were learned throughout the project including the design and soldering of two-layer boards, the difference between consumer-grade and space-grade components, and the many systems that interact to allow a CubeSat to function as a whole.

# 6. References

[1] A.Wong, J.Sands, K. Mody, and P. Zwinkels, "Cubesat Boards Electronic Design," Western University, London, Canada, 2019.

[2] "What Is a CubeSat." *Canada.ca*, 27 Nov. 2018, www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-a-cubesat.asp.

[3] "What Is the Canadian CubeSat Project." *Canada.ca*, 5 Dec. 2018, www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-the-canadian-cubesat-project.asp.

[4] Canadian Space Agency, "Webinar archive CSA group." *CSAGroup.org*, Oct. 2019, https://www.csagroup.org/article-category/webinars/

[5] Dr. Jayshri Sabariathan (private communication), 2019

[6] GitHub. (noreply@github.com) "[GitHub] @nmitch6 has invited you to join the @cubesat-project organization," Oct. 22, 2019

[7] Lauren Flanagan (private communication), 2019

[8] Sciencing, "The Temperatures of Outer Space Around the Earth." Apr. 2019, https://sciencing.com/temperatures-outer-space-around-earth-20254.html

[9] Microwave Journal, "What Is Outgassing And When Does It Matter?" *Microwavejournal.com,* Apr. 2019. https://www.microwavejournal.com/blogs/1-rog-blog/post/16667-what-is-outgassing-and-when-does-it-matter

[10] Thermal Space, "Is Space Qualification Product Or Process Based?" *thermalspace.com,* Apr. 2019. https://thermal-space.com/space-qualification-product-process/

[11] Smithsonian National Air and Space Museum, "What metals are used in a spaceship and

why?" Apr. 2019.https://howthingsfly.si.edu/ask-an-explainer/what-metals-are-used-spaceships-and-why

[12] Problem Solving Products Inc. "Outgassing and Weight Loss of Elastomers." Apr. 2019. http://www.pspglobal.com/outgassing-elastomers.html

[13] Catalog No. T2025_T493_SPACE. KEMET Tower, KEMET Electronic Components, Fort Lauderdale, FL.

[14] Dr. Jayshri Sabariathan and Dr. Matt Cross, "Preliminary Design Review," Western University,London, Canada, Tech. Rep. CCP-WAC-PRD-PPT1, 2019

[15] Shaemus Tracy. (Stracy6@uwo.ca) "ADC requirements," Nov. 20, 2019.

[16] Nicholas Mitchell, (private conversation), 2019

[17] A. Weiler, A. Pakosta, and A. Verma."High-Speed Layout Guide," Texas Instruments, Dallas, USA, Tech. Rep. SCAA082A, 2017

[18] Electrical Engineering, Stack exchange, "Splitting Power Planes on PCB," June 2017, https://electronics.stackexchange.com/questions/305787/splitting-power-planes-on-pcb?bclid=IwAR3hZpm5qFYLFylsCkx64N6JcOj1k_YBH0GBI3dY0NnwZaVhZl7lPGAzZ

[19] How it works, How to Mechatronics, "555 IC Timer - Working Principle, Block Diagram, Circuit Schematics," February 2018,https://howtomechatronics.com/how-it-works/electronics/555-timer-ic-working-principle-block-diagram-circuit-schematics/

[20] Timers, Arrow Electronics, "555 Fairchild Semiconductor," August 2016, https://www.arrow.com/en/products/lm555cn/fairchild-semiconductor

[21] Calculators, Ohms Law Calculator, "555 Astable Circuit Calculator," http://www.ohmslawcalculator.com/555-astable-calculator

[22] Calculators, Ohms Law Calculator, “555 Monostable Circuit Calculator,” http://www.ohmslawcalculator.com/555-monostable-calculator

[23] Catalog No. SNAS548D, LM555 Timer, Texas Instruments Incorporated, Dallas, TX

[24] Catalog No. RW0279, Nichrome 60 Wire, TEMCO Industrial, Fermont, CA

[25] Tae-Yong, Chae, Bong-Geon, and Hyun-Ung, “Development of 6  U CubeSat's Deployable Solar Panel with Burn Wire Triggering Holding and Release Mechanism,” International Journal of Aerospace Engineering

[26] Nicholas Mitchell, (private conversation), 2019

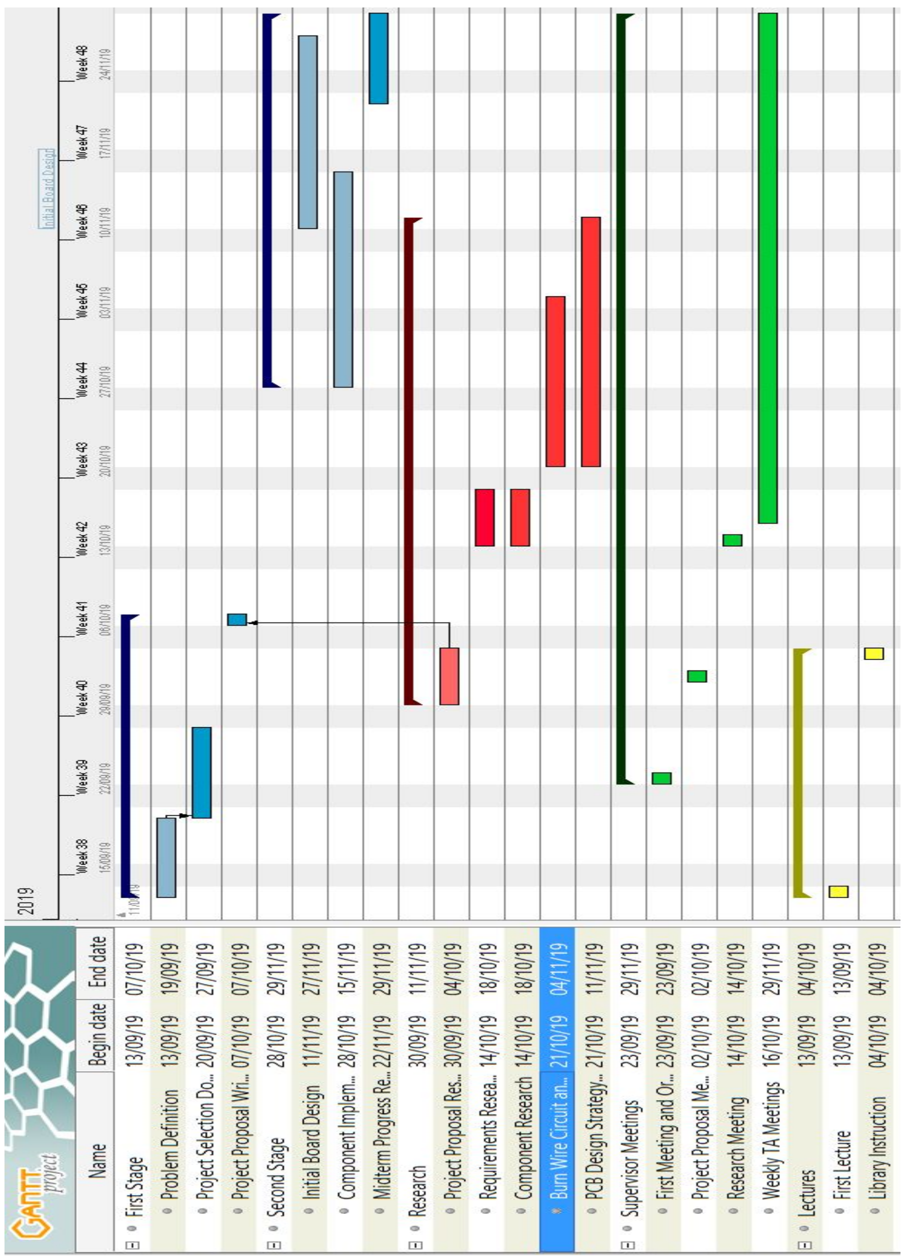
[27] CRC Registrar. (registrar@cmc.ca) “CMC Account Confirmation,” Nov. 26, 2019.

[28] Dr. Jayshri Sabariathan (private communication), 2019

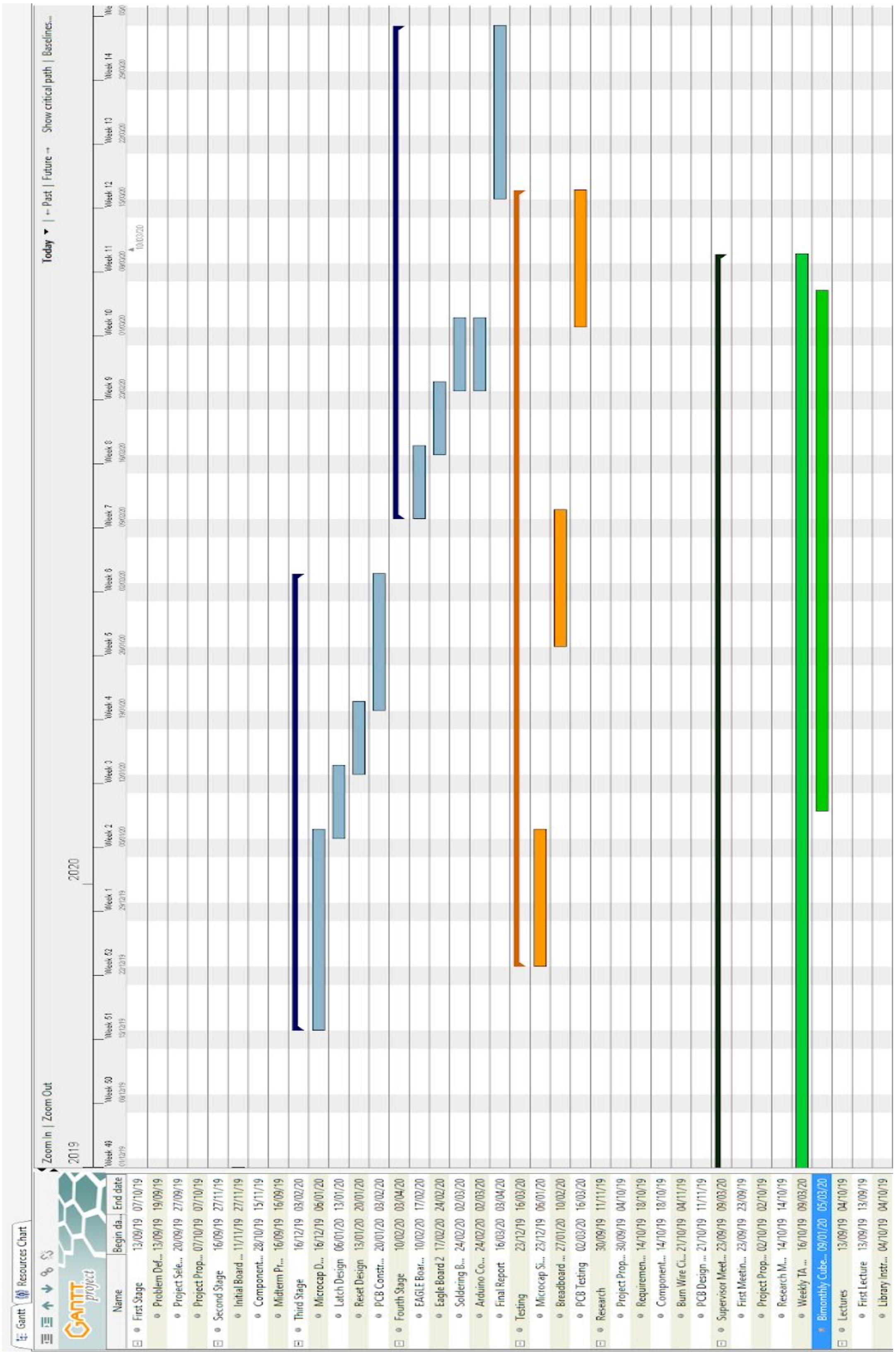
# 7. Appendices

## Gantt Charts

### Original Gantt Chart (Pre-Midterm)



## Updated Gantt Chart (Post-Midterm)



## Product Data Sheets

**Prototype Components**
1800uF Capacitor: https://www.nichicon.co.jp/english/products/pdfs/e-uhw.pdf
75kΩ Resistor: http://www.vishay.com/docs/28722/sfr16s25.pdf
100kΩ Resistor: https://www.seielect.com/catalog/sei-rnf_rnmf.pdf
555 Timer: http://www.ti.com/lit/ds/symlink/ne555.pdf
0.1uF Capacitor:
https://api.kemet.com/component-edge/download/specsheet/C315C104M5U5TA7303.pdf
10uF Capacitor:
https://product.tdk.com/info/en/catalog/datasheets/leadmlcc_halogenfree_fg_en.pdf
6-Channel NOT Gate: http://www.ti.com/lit/ds/symlink/cd4069ub.pdf
Quad-Input OR Gate: http://www.ti.com/lit/ds/symlink/sn74ls32.pdf
Quad-Input AND Gate: http://www.ti.com/lit/ds/symlink/cd4073b.pdf
Relay: https://omronfs.omron.com/en_US/ecb/products/pdf/en-g5le.pdf
Cement Resistor:
https://www.yageo.com/upload/media/product/products/datasheet/lr/Yageo_LR_SQP_NSP_1.pdf

**Final design Components**
1800uF Capacitor: http://www.vishay.com/docs/40024/135d.pdf
73kΩ Resistor: http://www.vishay.com/docs/31027/cmfmil.pdf
132kΩ Resistor: http://www.vishay.com/docs/31027/cmfmil.pdf
555 Timer: http://www.ti.com/lit/ds/symlink/ne555.pdf
0.1uF Capacitor: https://www.mouser.ca/datasheet/2/427/150d-1764082.pdf
10uF Capacitor: http://www.vishay.com/docs/40022/m3900622m3900625.pdf
6-Channel NOT Gate: http://www.ti.com/lit/ds/symlink/cd4069ub.pdf
Quad-Input OR Gate: http://www.ti.com/lit/ds/symlink/sn74ls32.pdf
Quad-Input AND Gate: http://www.ti.com/lit/ds/symlink/cd4073b.pdf
Relay: https://omronfs.omron.com/en_US/ecb/products/pdf/en-g5le.pdf
Cement Resistor:
https://www.yageo.com/upload/media/product/products/datasheet/lr/Yageo_LR_SQP_NSP_1.pdf

## Relevant Codes

### Arduino Code

```
void setup() {
  // put your setup code here, to run once:
  int pin2 = 2;//initialize pins
  int pin4 = 4;
  int pin7 = 7;
  int pin8 = 8;

  pinMode(2, OUTPUT);//initializes pins as output pins
  pinMode(4, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(8, OUTPUT);

  digitalWrite(2, LOW);//sets pin outputs to LOW
  digitalWrite(4, LOW);
  digitalWrite(7, LOW);
  digitalWrite(8, LOW);

  delay(300000); //Delay for 5 minutes

  digitalWrite(2, HIGH);//sets pin outputs to HIGH
  digitalWrite(4, HIGH);
  digitalWrite(7, HIGH);
  digitalWrite(8, HIGH);

  delay(45000); //Delay for 30 seconds

  digitalWrite(2, LOW);//sets pin outputs to LOW
  digitalWrite(4, LOW);
  digitalWrite(7, LOW);
  digitalWrite(8, LOW);
}

void loop() {
  // put your main code here, to run repeatedly:

}
```