Power Module Integration into SPARTAN Superway Utilizing Supercapacitors and Lithium-Ion Batteries Energy Storage for ATN Vehicle Applications

SPARTAN Superway
A Solar Powered Automated Transportation Network
San Jose State University, Department of Mechanical Engineering – 195A
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1. Abstract

The Power Modules sub-team has worked on designing a module to power the SPARTAN Superway project and its housing. The Power Modules team has made CAD designs for the housing and placement for the various components necessary, such as supercapacitors, Lithium-ion batteries, BMS, chargers, and other components. These would be used to power two motors connected to a bogie. A PCB will be used to reduce the wiring seen in last year's design, and to help power other electronics in the system. Designs for the housing of the power module and simulations were conducted to predict the behavior of the cells, and a cooling system was designed.

To better understand the use and benefits of supercapacitors, research was first conducted. Calculations were made regarding energy and capacity of energy storage devices, such as the supercapacitors and Lithium-ion batteries that are planned to be used for the power module. From these calculations, simulations were made in Microsoft Excel to determine the profile and time to charge the system. SolidWorks was used to design the housing for the power module system, along with its components. P-CAD 2001 was used to design the PCB schematic and PCB. The team worked with the Wayside Power Team closely to determine the required power necessary to be picked up from their system and at what amperage.

During the Fall of 2019, simulations were made to help the team gain a better understanding of the behavior of the supercapacitor battery packs. Designs for the housing of the module were also completed during this time and the team was expected to begin construction the following semester. Unfortunately, due to the Covid-19 pandemic, the scope of the project was changed in response to this. Instead of designing and constructing a power module capable of accelerating a 100 kg mass at 0.25g through a 10 m track, the 2020 Power Module Team has reassigned its purpose to designing a power module for the full-size system. Using the simulations created from Fall 2019, the Power Module Team was able to simulate and design a power module capable of accelerating a 1500 kg bogie at 0.25g up to a cruise speed of 30 MPH.

2. Acknowledgments

To Tynan Winters from 2018-2019 SPARTAN Superway Power Modules Team for providing clarification on 2018-2019 Power Modules design.

To Prof. Burford Furman from SJSU Mechanical Engineering Department for providing assistance and inputs through 2019-2020.

To Ron Swenson from SWENSON Builder for providing a space for our senior project.

To Prof. Ping Hsu from SJSU Electrical Engineering Department for providing inputs on circuit diagrams.

To Ed Porter from Santa Cruz Personal Rapid Transit (PRT) for providing a mock bogie with linear induction motor on-board.

To Husain Bootwala from San José State University for providing background on supercapacitor and Lithium-ion batteries.

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6. Executive Summary

The powertrain design for this year's model will incorporate both the use of supercapacitors along with Lithium-ion batteries. This power module will be responsible for accelerating a 1500 kg bogie at 0.25g up to a cruising speed of 30 MPH. In cooperation with the Power Wayside team, a conductive rail will be used to charge the supercapacitors at the end of the track. The design of the power module's housing was constructed with a minimum safety factor of 10.

6.1. Problem with public transportation today

As the purpose of public transportation is to provide those from diverse financial backgrounds a convenient form of transportation, due to the lack of government support, many are turning towards private vehicles as their primary form of transportation. With increasing vehicles on the street, not only would greenhouse emission increase, but transportation would become more time consuming for those from less fortunate backgrounds. In hopes to mend for these problems, SPARTAN Superway has proposed an overhead transportation system that will run entirely on solar energy.

6.2. Solutions to our transportation problems

Spartan Superway is a public transportation system that runs solely on solar energy. Due to its reliance on solar panels, it is important for Spartan Superway to design an energy storage system to store all the incoming solar energy to allow post-sunset operation. The Power Module Team is responsible for designing a battery pack that is capable of being fully charged within minutes and contains the capacity needed to accelerate a 1500 kg bogie at 0.25g up to a cruising speed of 30 MPH. Contrary to the design from the 2019 Power Module Team's battery pack, the 2019-2020 Power Module Team has decided to incorporate both supercapacitors and Lithium-ion batteries into the system. The 2020 power module consists of 64 supercapacitors in series along with 8 modules of 35 parallels of 6 Lithium-ion batteries in series. The purpose behind this design is to utilize the supercapacitors' ability to quickly discharge current to power the acceleration of the bogie and use the Lithium-ion batteries to maintain the bogie's cruising speed.

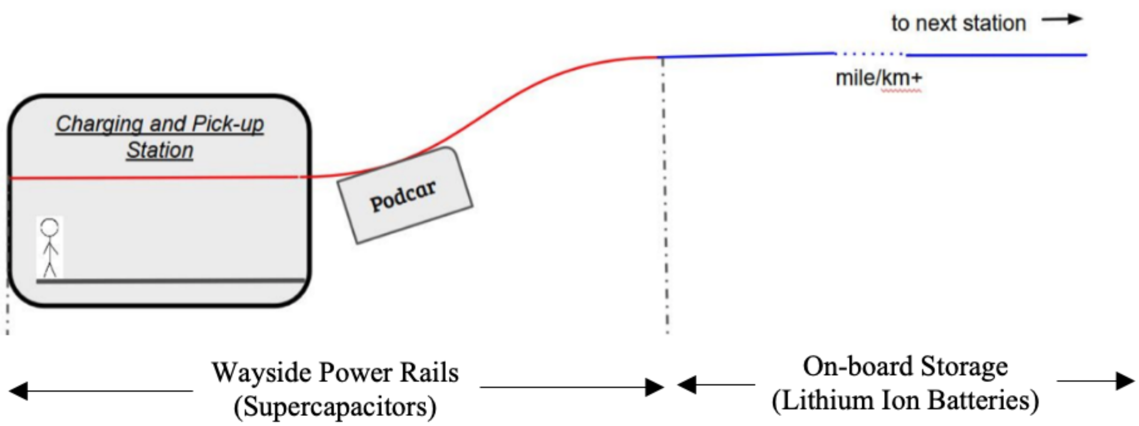

Figure 1: Proposed use of On-board Energy Storage.

6.3. Actions that have been taken

Energy calculation has been done to estimate the capacity of energy storage devices. A system of supercapacitors was simulated in order to predict charging and discharging time. Lithium-ion battery packs have been designed to provide power during the cruise. The overall circuit design has been finalized to include the current sensor and relays. The power module has been designed on SolidWorks and simulated using Finite Element Analysis under appropriate loads. In addition to the simulation work done on the system, the switching mechanism responsible for switching between Lithium-ion battery and supercapacitor use has been built and programmed.

7. Introduction and Project Description

7.1. Background

7.1.1 General Problem Being Addressed By SPARTAN Superway

Greenhouse gas emissions are a growing concern since the effects it has on our atmosphere and environment are becoming more apparent. The transportation industry and various other modes of vehicular transport are large contributors to greenhouse gas emissions. Such modes of transportation cause heavy levels of traffic congestion on our roads in urban areas, which also contributes to the emission of greenhouse gases. In highly dense and urban areas, space and real estate are limited, so an efficient method for transport is required. SPARTAN Superway, aims to use existing transportation routes to reduce the emission of greenhouse gases and reduce the amount of traffic congestion in an environmentally sustainable approach.

The two core issues that have led to the inception of SPARTAN Superway have significant impacts across the globe as climate change is becoming a larger concern and its effects more apparent, and traffic congestion in urban areas adding to the negative effects of climate change. The production of greenhouse gases from transportation methods is a large contributor to climate change, accounting for 30% in the US (Mashayekh et al, 2019). There are various methods to reduce emissions of greenhouse gases; however, many motorized vehicle solutions do not help to reduce traffic congestion. Traffic congestion is the result of an increase in levels of economic activity and productivity, so the two are highly correlated, which can negatively affect productivity and industry (Mondschein, Osman, Taylor, & Thomas, 2018). Land is an important but finite resource, so using it effectively is paramount for the quality of life of residents, productivity, and activity in local industries.

7.1.2 Introduction to Automated Transit Network (ATN)

Various solutions have been proposed to address these issues. An Automated Transit Network (ATN) is a system where automated vehicles are on elevated guideways above existing roads, which provide on-demand, origin-to-destination, and non-stop service over an area network (MTI, 2014). Such a system can utilize solar, a valuable resource for power, to move the vehicles. In most public transportation systems, mass transit is used to move many people from one station to another. ATNs offer the ability for users to use personal rapid transit (PRT) systems, that would allow them to omit stops at many stations and go to their intended destination more rapidly and in an effective manner. Pod cars would be used as the compartment for passengers to sit comfortably for their journey to their destination.

7.1.3 Social Impact of ATNs

SPARTAN Superway would implement the concepts of ATNs and PRTs for an automated-rapid transit system for commuters in high urban environments to reduce greenhouse gas emissions and decrease the amount of traffic congestion on the roads. Much of the land in use for transportation could be used more effectively. Superway aims to implement its system of ATNs along already existing roadways to increase the effectiveness of land use for transportation. This solution will decrease the amount of traffic congestion that plagues highly dense and urban areas and increases productivity. Reduction in greenhouse gas emissions will also occur, because of the sustainability and environmental impact of the system.

7.1.4 Prior Work on ATNs at SJSU

SPARTAN Superway began in 2012 under the supervision of Dr. Burford Furman, a professor at San José State University, along with Ron Swenson, who is part of the International Institute of Sustainable Transportation (INIST). The project, also known as Solar Powered Automated Rapid Transit Ascendant Network (SPARTAN), targets to design and construct the system at 1/12th, half, and full-scale. Over the course of seven years, progress has been made in designing the system, where each year makes improvements to the previous year's design. In the past seven years, designs for the guideway and switching mechanisms, and the power module and wayside power systems have been improved with successive iterations. The power module and wayside pick-up system are necessary to provide power to the motors on the bogie. Considerable progress on these systems has been made since the project's inception in 2012. Last year's power module and wayside power pick-up were combined, using a four-bar linkage for the wayside pick-up system, and a supercapacitor pack to provide and store power for the motors. This year, the teams were split, allowing for teams to provide their efforts in a more concentrated manner on their respective aspects of the overall project. The Power Module Team this year focused on designing a Lithium-ion and supercapacitor hybrid power system, along with designing the housing for the system. A cooling system was also designed to reduce the temperature to optimal operating conditions, and a PCB was designed to connect the supercapacitor pack to reduce the amount of wiring needed.

This report continues with the structure of the project, goals, and objectives of the Power Modules Team that were considered from the beginning of the academic year. The design requirements and specifications, for the initial small-scale model design and then the full-scale, with the power curve calculations and cooling system calculations. The research done by the team regarding supercapacitor applications and automated transit networks (ATNs) is provided in the State-of-the-Art and Literature Review section. The body of the report consists of the Description of Design section, which describes in full detail the work done with the supercapacitors and Lithium-ion battery packs this year and the designs for the housing, along with the cooling system, and PCB. Analysis of this year's system design is addressed in the Analysis section. Finally, the Result and Discussion section address the accomplishments, providing insight into the work completed this year. This is followed by the team's conclusions and recommendations for future work.

7.2. Structure of the Project

The Power Modules Project is a sub-team whose tasks and responsibilities have been divided among the three team members as follows:

1. CAD, thermal analysis and cooling system, Steven Goh
2. PCB Design & Electrical system design, Eric Near
3. Capacitor charging & FEA Analysis, Joe Lau

Other tasks, such as researching relevant topics for the project, alternative designs, and various tasks were conducted together and with the consultation of the other team members. Designated tasks above were given for those members to be responsible for those tasks, but steps were consulted with the team and relevant experts.

8. Objectives of the Project

1. Design a rigid battery pack capable of accelerating a 1500 kg bogie at 2.45 m/s^2 up to a cruising speed of 30 MPH or 48 KPH.
2. Simulate an electrical system that would safely transmit power from conductor rails to onboard motors.
3. Simulate a hybrid power module that incorporates the use of supercapacitors and Lithium-ion batteries.
4. Design and build a switching mechanism to switch between two power sources.
5. Design a Printed Circuit Board (PCB) to minimize wiring in the system.
6. Simulate a cooling system for the power module battery and supercapacitor packs.
7. Redesign the 2019 Power Module to promote easier access to components for better maintenance.

The Power Module sub-team is responsible for developing a battery pack capable of accomplishing the objectives stated above. The Power Module Team worked closely with the Power Wayside Team, who is responsible for designing the charging mechanism needed to fully charge the power module's supercapacitor pack within minutes. The charging/discharging of the Lithium-ion and supercapacitor packs will be monitored by multiple BMSs to prevent excess current flow that may damage the components. In addition to this, a cooling system will be incorporated to allow optimal battery function.

9. Design Requirements and Specifications

Design Specifications		
	Small-Scale	**Full-Scale**
Mass of Power Module	100 kg	1500 kg
Total track length	10 m	1.6 km
Maximum Bogie Velocity	1 m/s	13.41 m/s
Acceleration of Bogie	2.45 m/s^2	2.45 m/s^2
Estimated Power required to move bogie	110 W	350 kW
Voltage of Supercapacitor Pack	43.2 V	43.2 V
Capacitance of Pack	17.5 F	70 F
Energy Capacity of Supercapacitor Pack	11.1 kJ	45.4 kJ
Voltage of Lithium-ion Battery Pack	14.4 V	21.6 V
Energy Capacity of Lithium-ion Battery Pack	5000 mAh	122.5 Ah

Table 1: Design Specifications for Bogie, Supercapacitors, and Lithium-ion Batteries.

9.1. Power Curve Calculation

The power module will receive electricity from the wayside power pickup mechanism. It will combine supercapacitors and Lithium-ion (li-on) batteries as energy storage. Supercapacitors were chosen due to their high power density, while Lithium-ion batteries were chosen for their energy density. Power density is defined as the amount of energy that a system can deliver. Energy density is defined as a system's energy storage capacity. The integration of the two varying batteries allowed the creation of a system that can deliver power without having to compromise its energy density. In specifics, the team will use supercapacitors to accelerate the bogie up to speed, and the Lithium-ion batteries will be used to maintain bogie's cruising speed. The calculation used to determine the sizing of the 2020 Power Module is as follows:

$$F_{motor} = (m \cdot a_{max} + \frac{1}{2}\rho C_D A_f (a_{max}{}^2 \cdot t^2 + v_w{}^2) + F_R \qquad (1)$$

F_R is the rolling resistance of the system. It contains two parts.

$$F_R = F_{R_{static}} + F_{R_{dynamic}} \qquad (2)$$

$$F_{R_{static}} = n_{fudge} \times (\frac{0.09N}{kg}) \times m \qquad (3)$$

$$n_{fudge} \approx 1.20$$

Where n_{fudge} accounts for collector shoe and guide wheel drag. The static rolling resistance is assumed to be polyurethane on steel.

$$F_{R_{dynamic}} = c_2 \cdot m \cdot v = c_2 \cdot m \cdot a_{max} \cdot t \qquad (4)$$

$$c_2 \approx 0.0004935 \ \frac{N}{kgm/s}$$

$$F_R = m(n_{fudge}\left(\frac{0.09N}{kg}\right) + 0.0004935 \cdot a_{max} \cdot t) \qquad (5)$$

Similarly, the torque motor equation in (1) can be adjusted for deceleration and constant speed.

$$F_{motor,deceleration} = (m \cdot a_{max} + \frac{1}{2}\rho C_D A_f (v_w{}^2 - a_{max}{}^2 \cdot t^2)) - F_R \qquad (6)$$

$$F_{motor,cruise} = (\frac{1}{2}\rho C_D A_f (v_w{}^2 + v_{linear}{}^2) - F_R \qquad (7)$$

The power required to move the system can then be calculated by:

$$Power = F_{motor} \cdot v_{shaft} = F_{motor} \cdot 2\pi a_{max} t \qquad (8)$$

For the scope of this project, the team used the following assumptions listed below. Kinematics calculations were done to calculate the time needed for each process. The complete datasheet of the power calculation is listed in Appendix B. The estimated power curve for both demonstration and full-scale models are shown below.

Design Parameters	Small-Scale	Full-Scale
Mass of Bogie (m)	100 kg	1500 kg
Total Track Length (s)	10 m	1600 m

Desired Acceleration (a_{max})	2.45 m/s^2	2.45 m/s^2
Density of Air (ρ)	1.225 kg/m^3	1.225 kg/m^3
Drag Coefficient (C_D)	0.51	0.51
Frontal Area (A_f)	4 m^2	4 m^2
Wind Speed (v_w)	3.576 m/s	3.576 m/s

Table 2: Parameters used to calculate the power needed to move the system

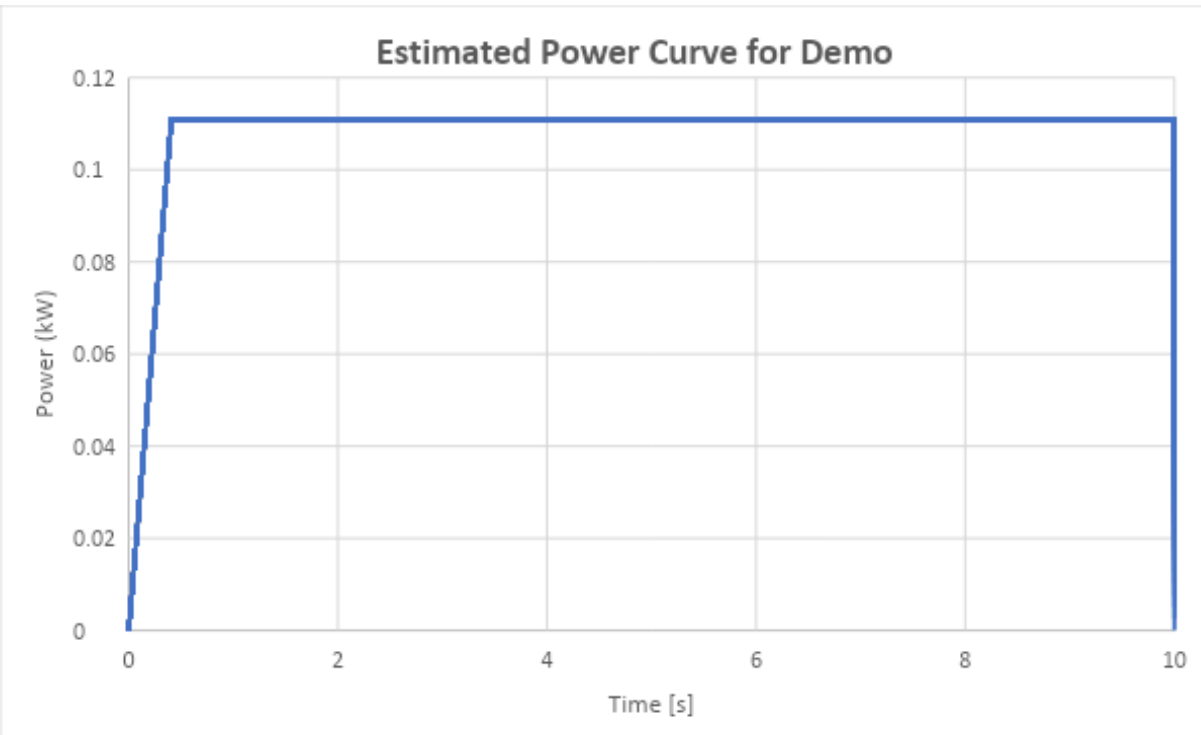

Figure 2: Estimated Power Curve for SPARTAN Superway Demo.

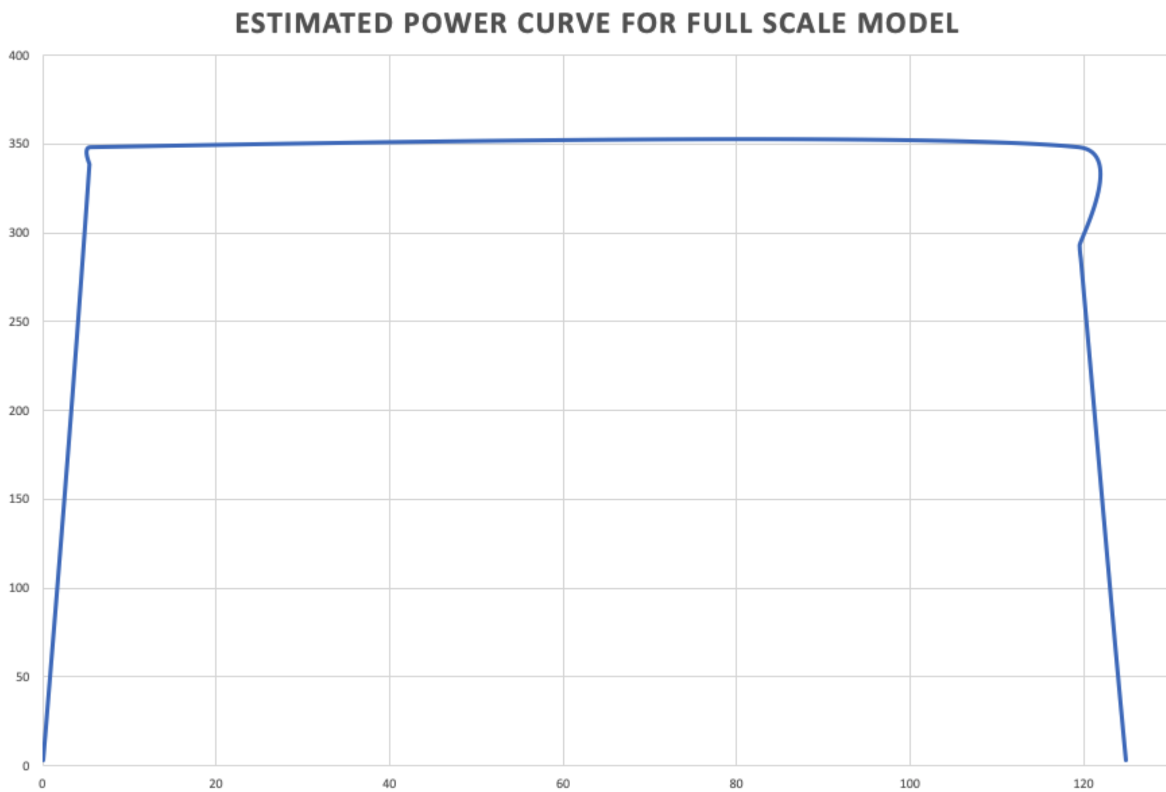

Figure 3: Estimated Power Curve for SPARTAN Superway Full-Scale.

9.2. Energy Storage Design Specifications

9.2.1. Supercapacitor

As previously mentioned, supercapacitors have a large power density. Compared to batteries, supercapacitors can deliver power 10 times faster. This can be achieved due to its ability to store its energy through a magnetic field. In addition to this, with this method of storage, supercapacitors are also able to maintain its storage capacity even after millions of discharges.

This year, the Power Modules team used the Maxwell BCAP0350 Supercapacitors provided to by the 2019 Power Module Team. Each capacitor has a voltage rating of 2.7 V and a capacitance of 350 Farads. By connecting multiple supercapacitors in series, not only can we increase its voltage output, but also decrease its capacitance:

$$V_{total} = V_{cell,1} + V_{cell,2} + \dots + V_{cell,n}$$

$$C_{total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}}$$

In addition to this, capacitance is linearly proportional with the energy in a system.

$$E = \frac{1}{2}CV^2$$

Ideally, by adding more supercapacitors in series, one can achieve a supercapacitor pack with a higher energy density. The small scale power module's supercapacitor pack consists of 16 supercapacitors connected in series, while the full-scale model will incorporate the use of 64 supercapacitors (4 parallel, 16 series configuration). It is important to note that although the low ESR (Equivalent Series Resistance) present in each supercapacitor is small enough to be neglected, they have been accounted for in simulations created by the 2020 Power Module Team. The charging model of the supercapacitor pack is modeled as below.

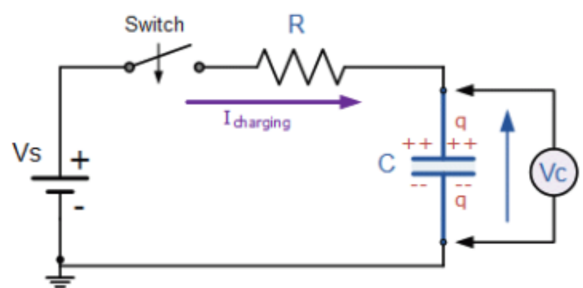

Figure 4: Supercapacitor RC Charging Circuit

With these ideas in mind, the 2020 Power Module Team was able to create a simulation to help visualize the charging characteristic of the supercapacitor pack. In Figure 4, the voltage source represents the supercapacitor charger we received from the 2019 Power Module Team. The described charger, which was provided by Howland Technologies, has a power rating of 1200 W, accepts AC voltage, and has the capacity to switch between different three charging profiles (24 V, 36 V, and 48 V). The charging profile of both small scale and full-scale power module will be explained below.

9.2.1.1. Small Scale (Demonstration Version)

The small scale supercapacitor pack consists of 16 supercapacitors in series, has a voltage rating of 43.2 Volts, and a capacitance rating of 21.875 Farads. It can also store up to 14 kJ of energy. Based on the simulations, Howland Technology's charger's 36 V configuration will be sufficient to charge this system. With this charger, the team is confident that the supercapacitor pack can be charged in 120 seconds.

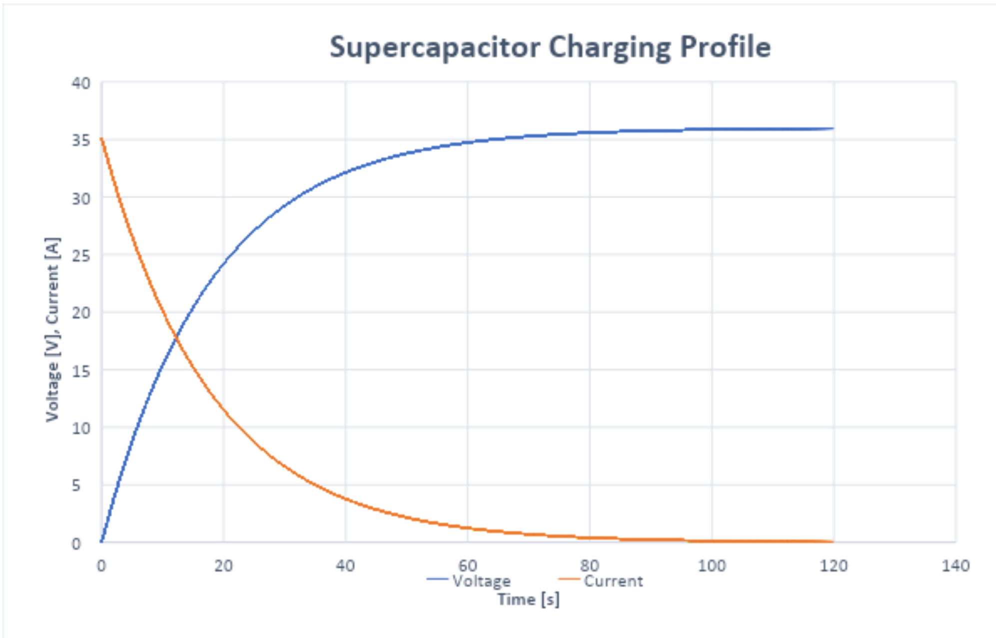

Figure 5: Charging Profile of Small Scale Power Module

*(***Full Data set can be seen on Appendix A)**

9.2.1.2. Full-Scale Model

The full-scale supercapacitor pack consists of 64 supercapacitors connected in a 4 parallel, 16 series configuration. The full-scale supercapacitor pack has a voltage rating of 43.2 V and a capacitance rating of 87.5 Farads. It can store up to 56.7 kJ of energy. In order to fully charge this system within 120 seconds, a 43.2 V charger capable of outputting 140 A will be required. For this reason, the charger provided by Howland Technology will be insufficient for this system. The charging profile of the full-scale power module is shown below.

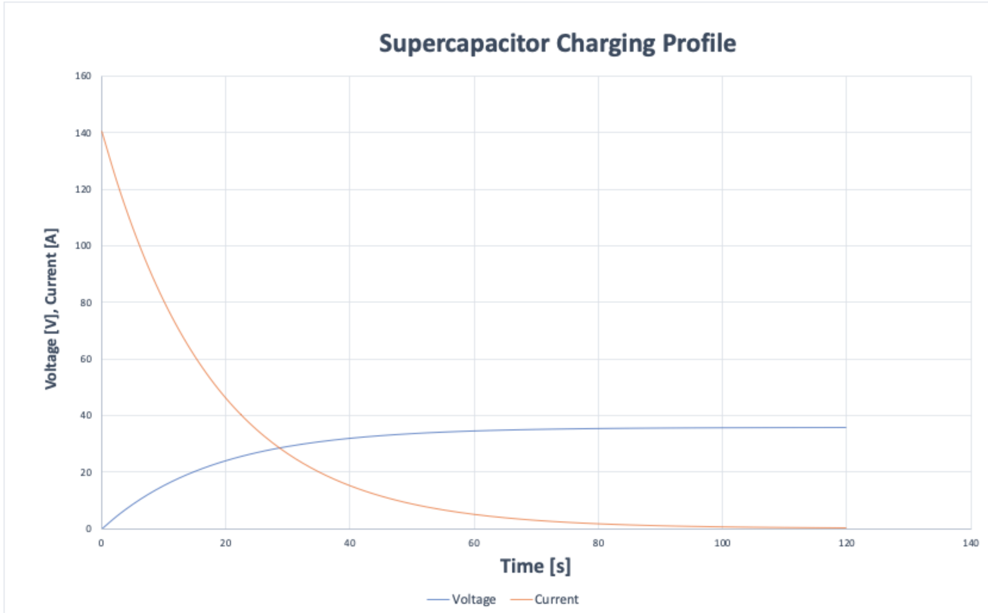

Figure 6: Charging Profile of Full-scale Power Module.

(Full data set can be seen in Appendix A)

9.2.2. Lithium-ion Batteries

While supercapacitors can deliver a significant amount of power in a short amount of time, its energy density is too small for long and constant power delivery. Since Lithium-ion batteries are known for their high energy density, the 2019-2020 Power Module Team has decided to incorporate Lithium-ion battery packs into the system. This year, the Samsung IDE 18650-35E Lithium-ion battery was chosen for the Lithium-ion battery pack. Each cell has a rated voltage of 3.7 V and a capacity of 3500 mAh. The universal unit for the capacity of batteries is in mAh. This term represents how much current (Amps) the system can supply in an hour. To create a pack with a larger voltage bank, the cells are connected in series. When the cells are connected in series, their voltage will increase with the number of cells.

$$V_{total} = V_{cell,1} + V_{cell,2} + \dots + V_{cell,n}$$

Also, to increase the bank capacity, the cells will be connected in parallel. When cells are connected in parallel, their current will be increased, thus increasing capacity.

$$I_{total} = I_{cell,1} + I_{cell,2} + \dots + I_{cell,n}$$

The small scale power module will have 12 li-on batteries connected in a 3 series, 4 parallel configuration. The pack has a rated capacity of 155.4 Wh.

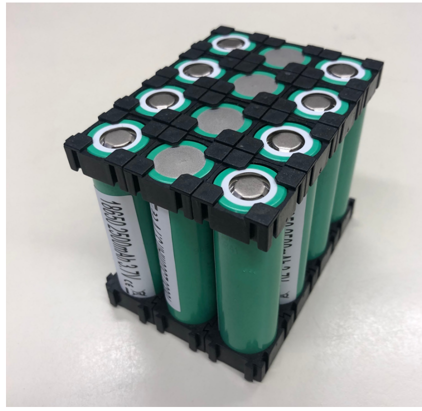

Figure 7: Small Scale Lithium-ion Battery Pack.

Meanwhile, the full-scale power module will have 8 modules of the Lithium-ion battery pack. Each module consists of 210 li-ion batteries connected in 6 series, 35 parallel configuration. The pack has a rated capacity of 21.75 kWh.

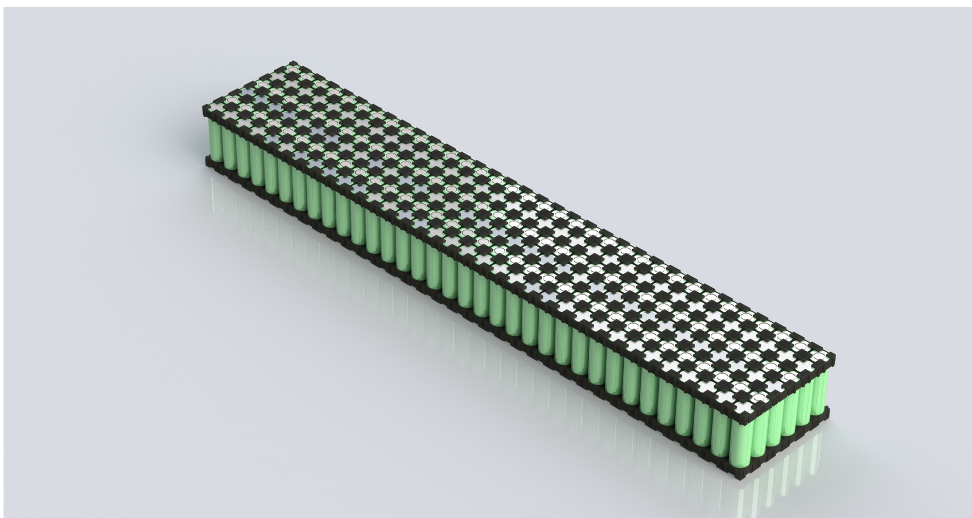

Figure 8: One module of Full-scale Lithium-ion batteries.

The Lithium-ion battery pack must be pre-charged before its operation. Unlike the supercapacitors, these batteries require longer charge times. Moreover, since it involves chemical reactions, there are a lot of limits regarding its charging. The manufacturer recommended charging the battery using 1.7 Amps of current with a charging time of 4 hours. Due to the shelter-in-place order, the team was unable to test this feature. We recommend future teams to purchase a Lithium-ion battery charger to test these batteries. In order to maintain the longevity of the Lithium-ion battery packs, future teams should limit the batteries' depth of discharge percentage to only 80%.

Depth of discharge	Discharge cycles	
	NMC	$LiPO_4$
100% DoD	~300	~600
80% DoD	~400	~900
60% DoD	~600	~1,500
40% DoD	~1,000	~3,000
20% DoD	~2,000	~9,000
10% DoD	~6,000	~15,000

Figure 9: Battery Cycle life as a function of depth of discharge.

9.3. Electrical System Design

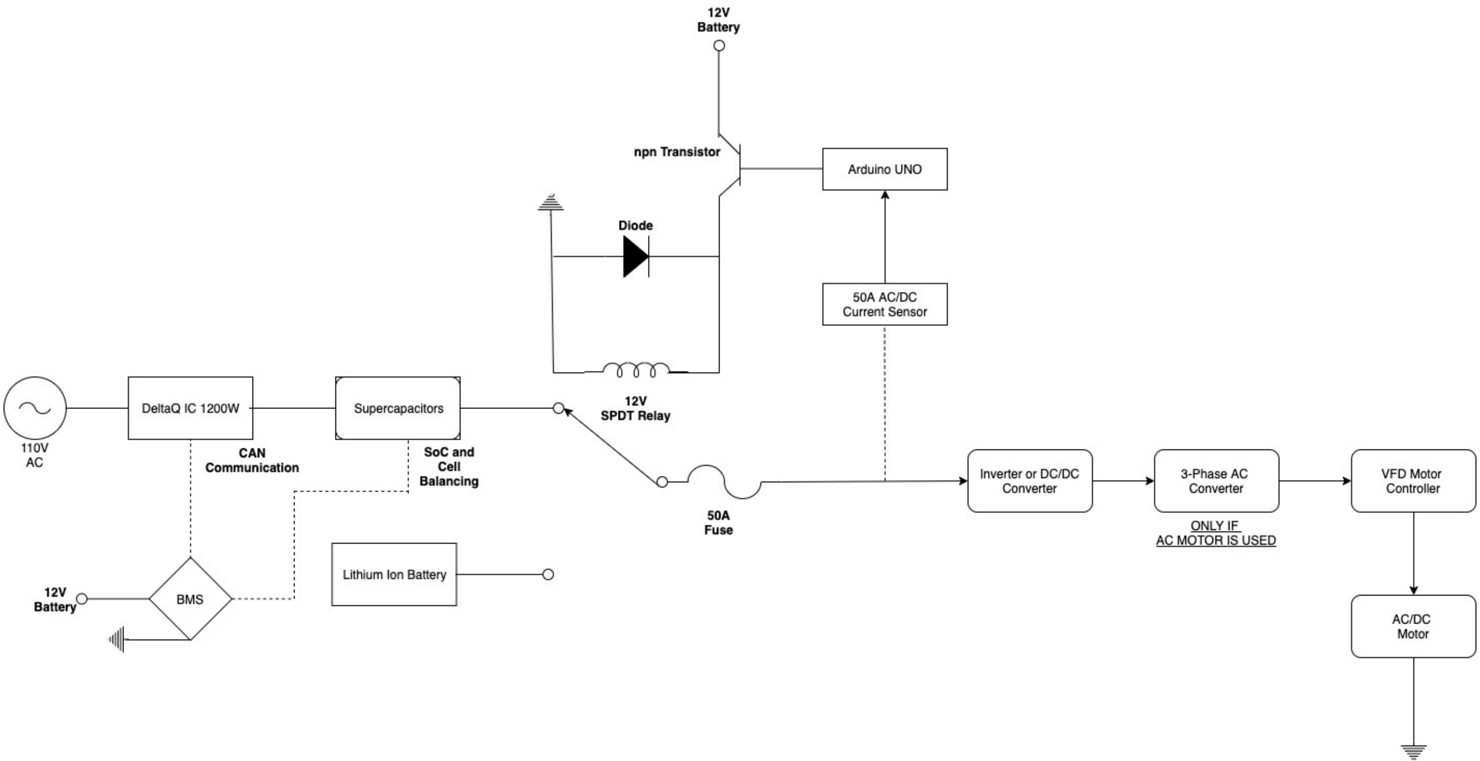

Figure 10: 2-D Electrical System Schematic of 2019-2020 Power Module.

The electrical schematic of the 2019-2020 power module is shown above. The system's final objective is to transfer power stored in the supercapacitor cells and Lithium-ion batteries to AC/DC motors. The flow started by converting AC power from electrical outlets to DC using Delta IC 1200 W charger. The power will then be transferred to conductor rails. An arm mechanism designed by SPARTAN Superway Wayside Power Team will harness energy from the conductor rails and transfer it to the supercapacitors. The physical connection between the supercapacitor and the arm mechanism is a Molex connector. The DC power will then be used to charge the supercapacitors during acceleration. The supercapacitors are also connected to a Battery Management System (BMS) to monitor the state-of-charge (SOC) and perform balanced charging between all supercapacitors. Meanwhile, the Lithium-ion batteries will not be charged during operation, instead, it will be pre-charged due to the project's scope. A 12 V industrial grade relay will perform switching between two energy storage devices. The switching mechanism consists of a relay, an Ardunino, a diode, a transistor, and a current sensor. Details about how the switching mechanism works are explained in Section 12.2. After the switching is performed, the power will be converted to AC/DC depending on the motor requirements. A VFD Motor controller and inverter are present to control the speed of the motor in case an AC motor is used.

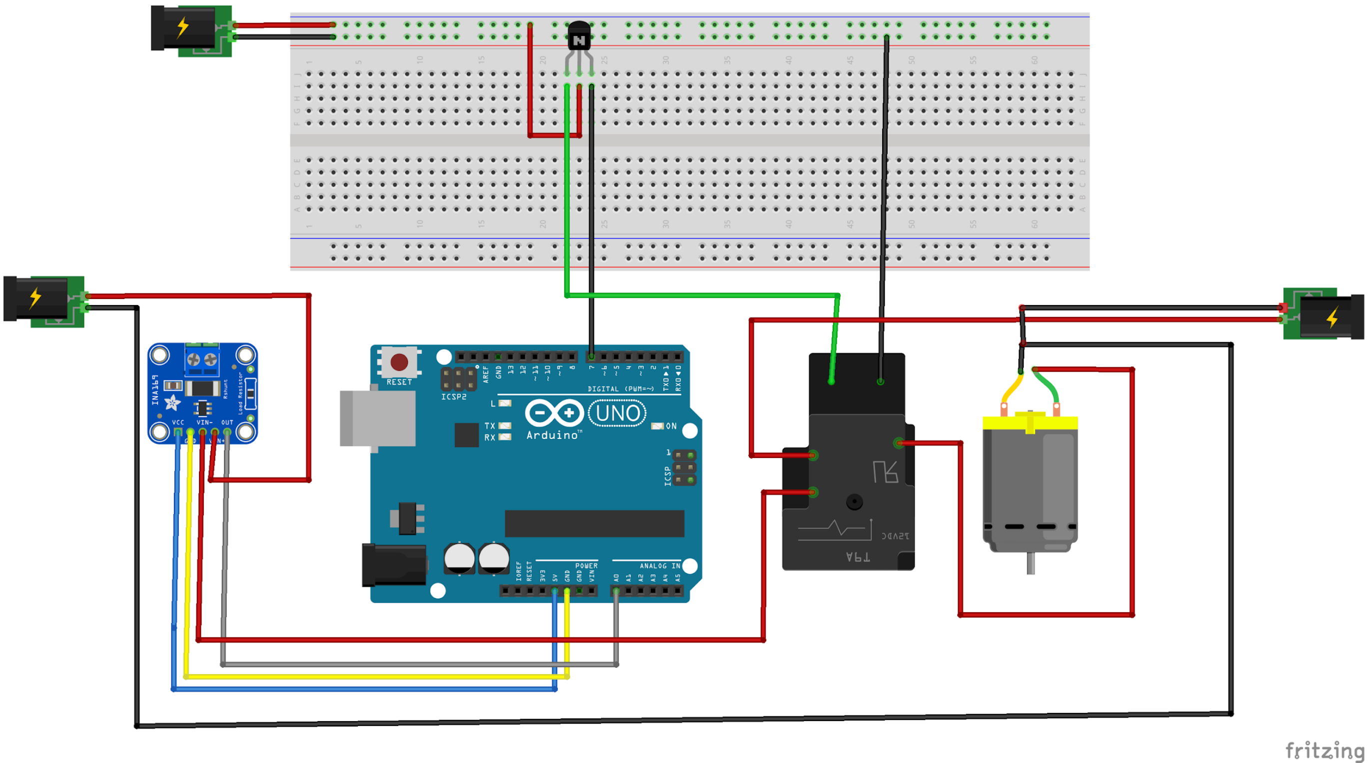

Figure 11: Electrical Schematic of the 2019-2020 Power Module.

9.4. Cooling System Design

In order to ensure the viability of our electrical components, a cooling system is designed for this power module. When the system runs at full capacity, it is estimated that the electrical components will produce the heat equivalent to I^2R. The system is designed to have a maximum current of 50 A. The internal resistance of electrical components is listed below.

Components	Internal Resistance
Supercapacitors	0.032 Ω
Lithium-ion Battery	0.035 Ω

Table 3: Individual Internal Resistance of Electrical Components on the system.

The supercapacitors are connected in 4 parallel-16 series configurations, while the 8 modules of Lithium-ion batteries are connected in 35 parallel-6 series configurations. When the electrical components are connected in series, the internal resistance increases with each component in the system. On the other hand, connecting electrical components in parallel decreases the internal resistance. The total internal resistance on the system is shown below.

$$Total\ Supercapacitor\ Resistance\ = \frac{0.032 \times 16}{4} = 0.128\Omega$$

$$Total\ Lithium\ Ion\ Battery\ Resistance\ = \frac{0.035 \times 6 \times 8}{35} = 0.048\Omega$$

$$Total\ Resistance\ of\ System\ = 0.128 + 0.048 = 0.176\Omega$$

The sensible heating of electrical components can be estimated by I^2R. In this system, the heat produced by the components is:

$$Q_{sensible} = I^2R = (50^2)(0.176) = 440W = 1501.28\ Btu/hr$$

A fan was designed such that the heat will be dissipated to the outside. The equation below has two unknown parameters, which are the airflow and change of temperature. Since our power module has a thick wall, it was decided to install multiple fans for cooling. Four fans with an airflow of 160-cfm (cubic feet/minute) were attached to the walls of the module. The change of temperature between inside and outside the housing is shown below:

$$Q_{sensible} = 1.1(airflow)(\Delta T)$$

$$\Delta T = \frac{Q_{sensible}}{1.1 \times airflow} = \frac{1501.28}{1.1(640)} = 2.132\ ℉ = 1.185℃$$

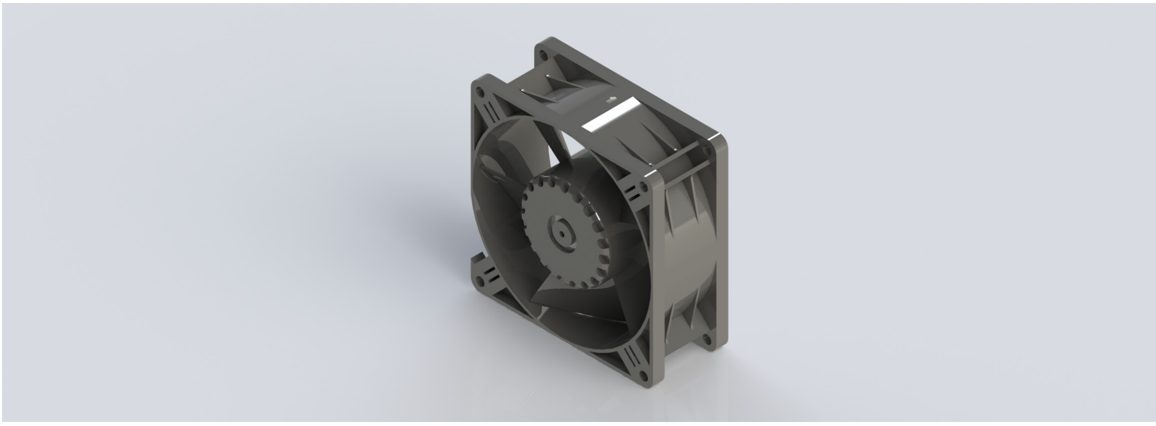

Figure 12: 160-cfm fan was added to dissipate heat out of the Power Module.

The calculation estimates that the change of temperature between the system and outside is 1.185℃. Since the maximum discharge temperature of a Lithium-ion battery is 60℃, it was concluded that the fans will be sufficient. However, to make certain the system is safe, in case of an unexpected temperature surge, redundancy cooling coils are added to the system. The cooling coils will be filled with either refrigerant or water to further cool the outside temperature before going into the system.

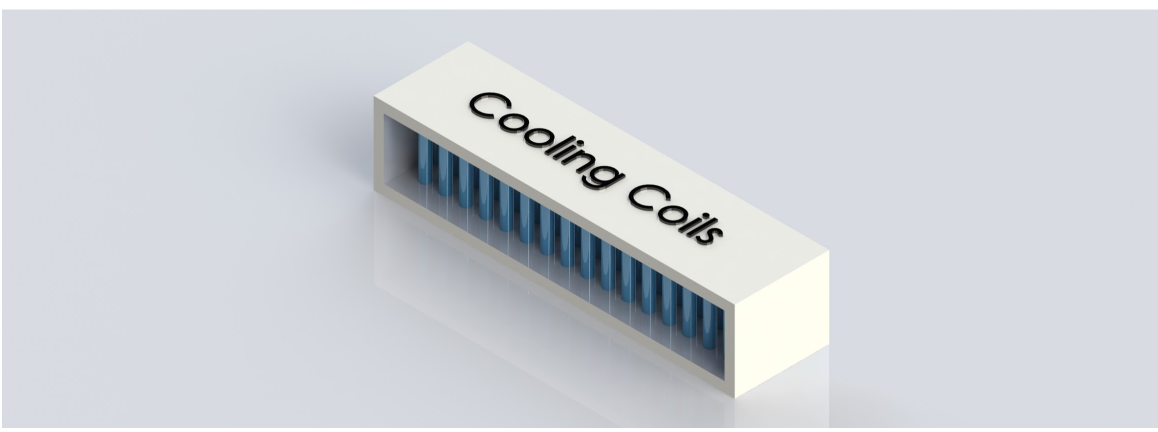

Figure 13: Redundant Cooling Coils filled with either Water or Refrigerant.

9.5. Printed Circuit Board (PCB) Design

Last year's Power Module and Wayside team used a complex system of wiring and circuitry to connect the different electrical components of the system. This resulted in excessive use of wiring and difficulty in following the paths of different wires. The wiring in the system connected the BMS, the lead-acid battery, all of the supercapacitor cells, the connections for the supercapacitor cells and the BMS, motor drivers, and the cooling system. This year's design includes a PCB design that connects the supercapacitor cells, BMS, and will have a pathway for energy to be received from the Wayside system. The PCB will also have another connector to deliver this energy to the Lithium-ion battery packs after acceleration to cruising speed has been achieved.

The first step for designing the PCB is to create an electrical schematic that the board will follow. The schematic only illustrates the components and their connections, and how the components would be connected. In the schematic, a set of 16 supercapacitors will be used for the design, being connected in series. These supercapacitors will be connected to a power source, which is to be the wayside power source. Connections to the BMS for cell balancing and monitoring. It must be noted that the placement of the electrical components on the schematic is not indicative of the actual physical placement on the PCB design.

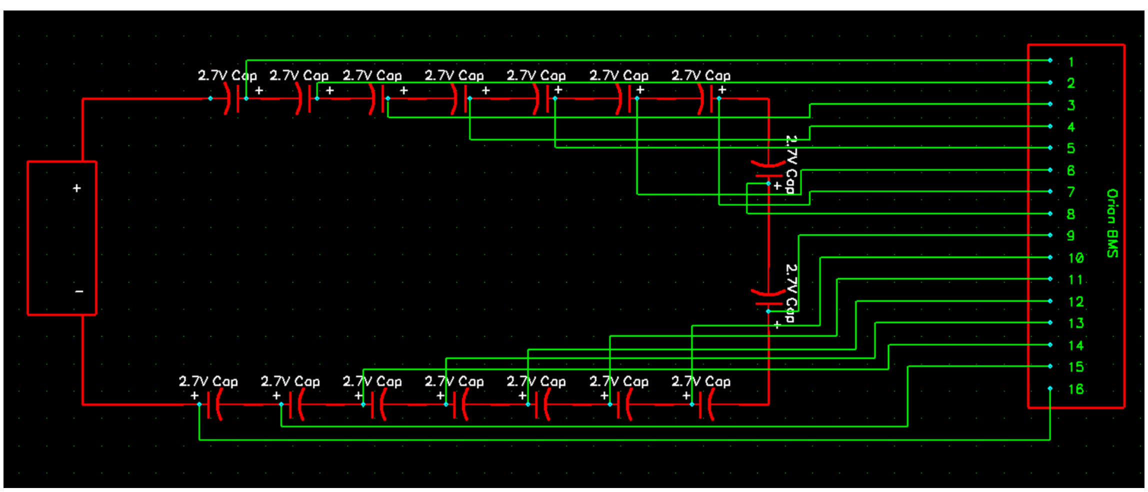

Figure 14: PCB schematic with 16 supercapacitor cells in series and connected to a BMS in P-CAD.

The PCB design follows the electrical schematic design for the connecting of the BMS, supercapacitor cells, and the connections for the power source and where the power will be transferred via connectors to the Lithium-ion battery packs. The 16 supercapacitor cell holder from the previous year's design was used for dimensioning the PCB, along with the spacing of each of the cells. The wide green and red traces are external traces to handle the high current, while the thin white and gray traces are internal traces connecting each supercapacitor cell to the BMS. The dimensions and specifications of the PCB are as shown:

Length	245 mm
Width	165 mm
Depth	1.6 mm
Supercapacitor Spacing (Columns; Center-to-Center of Supercapacitor)	66.5 mm
Supercapacitor Spacing (Rows; Center-to-Center of Supercapacitor)	38.3 mm
PCB Material	Fibre-glass FR4
Current	50 Amps
Thickness of Trace	6 ounces/ft^2
Internal Layer	28.7 mm
External Layer	11 mm

Table 4: Dimensions of the PCB and its required trace widths, thickness, and spacing for the supercapacitor cells.

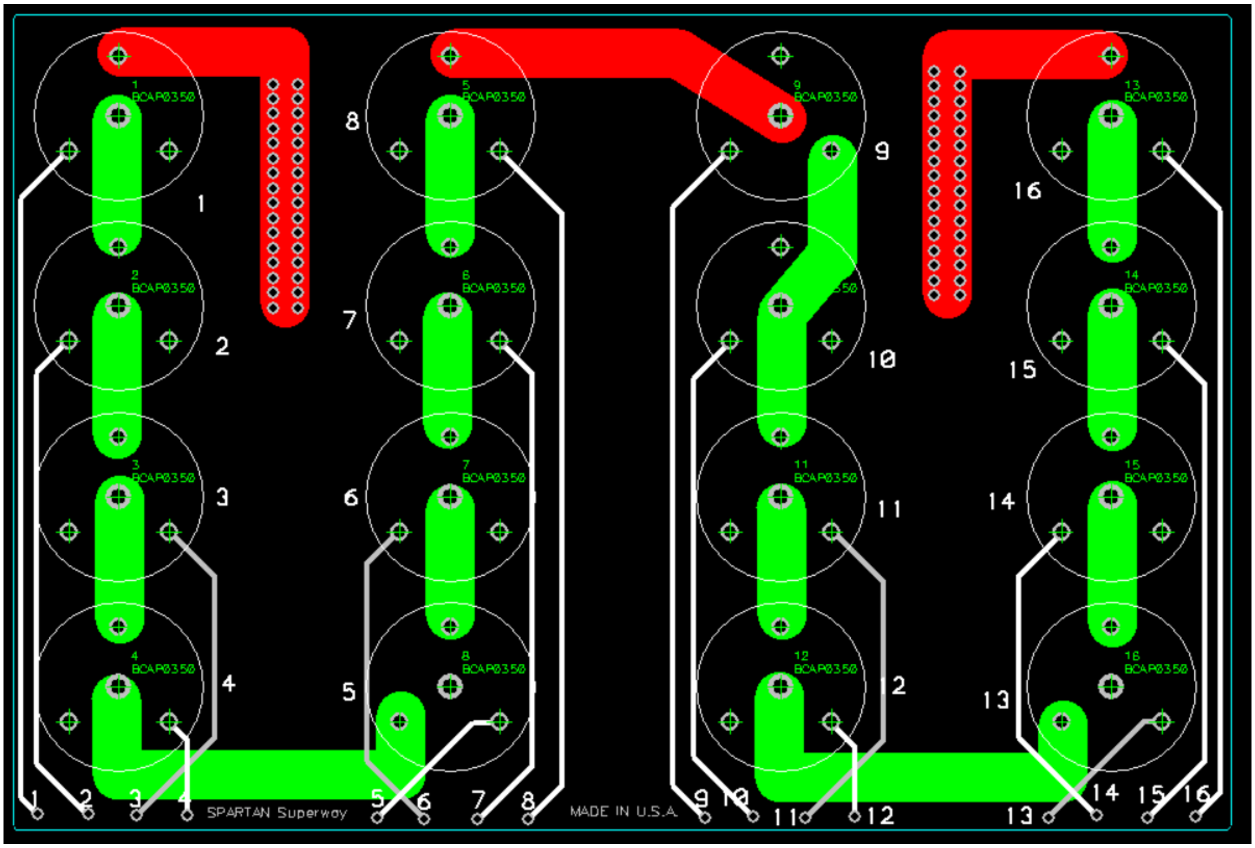

Figure 15: Final PCB design to handle 50 Amps.

Initially, before the lockdown order caused by the Covid-19 pandemic, the maximum current value necessary for the supercapacitor pack was 33 A. This is value important, since the trace width is dependent on how much current the board would need to handle. The trace width is also dependent on the thickness of the trace, being the amount of copper, in ounces, per square foot of copper. An online PCB Width Tool Calculator by Advanced Circuits was used to calculate the thickness of the traces for the board, both internal and external. If higher voltage is needed, then the thickness of the board itself would need to be increased. However, in this case, since there is a high current, only the trace width needs to be increased. After the lockdown, the full-scale design of the PCB was increased to 50 A. The results for the PCB trace width calculation for both the 33 A design and 50 A design are shown below:

Inputs:

Current	50	Amps
Thickness	6	oz/ft^2

Optional Inputs:

Temperature Rise	10	Deg C
Ambient Temperature	25	Deg C
Trace Length	6	inch

Results for Internal Layers:

Required Trace Width	28.7	mm
Resistance	0.000446	Ohms
Voltage Drop	0.0223	Volts
Power Loss	1.12	Watts

Results for External Layers in Air:

Required Trace Width	11.0	mm
Resistance	0.00116	Ohms
Voltage Drop	0.0581	Volts
Power Loss	2.90	Watts

Inputs:

Current	33	Amps
Thickness	4	oz/ft^2

Optional Inputs:

Temperature Rise	10	Deg C
Ambient Temperature	25	Deg C
Trace Length	21	mm

Results for Internal Layers:

Required Trace Width	24.3	mm
Resistance	0.000109	Ohms
Voltage Drop	0.00360	Volts
Power Loss	0.119	Watts

Results for External Layers in Air:

Required Trace Width	9.34	mm
Resistance	0.000284	Ohms
Voltage Drop	0.00937	Volts
Power Loss	0.309	Watts

Figure 16: Trace width calculations. On the right, the demonstration calculation is shown, resulting in 9.34 mm External trace widths at 33 Amps and 4 ounces of copper. The left depicts the calculation for 50 Amps and 6 ounces of copper.

Pins will be used to connect the supercapacitors to the PCB, while connectors will be used to connect the PCB to the Wayside Power Molex connector and to the Lithium-ion battery packs. The BMS will be connected by screws and lug nuts. The supercapacitors would be plug-ins, using 5050864-1 pins by TE Connectivity, and the connectors. The 1658621 connector by TE Connectivity would be used for the PCB to be connected to the Wayside Power Molex connector and Molex connector to the Lithium-ion battery packs. DOI-9923246 headers by Harwin, Inc. would be used to connect the connectors to the PCB.

9.6. Battery Management System

A battery management system (BMS) is used to ensure the safe charge and discharge of each battery cell. Many BMSs have balance charging and state of charge (SOC) features, which are both important for the system. Due to the large number of cells in the battery packs, there is a high chance each cell will be charged at an uneven rate, resulting in the possibility of overcharging of cells and battery life reduction. A BMS can eliminate this risk by evenly distributing the supplied current to each cell. In addition, some BMSs will have a physical Controller Area Network (CAN) Bus, which can be used to control the charge and discharge profile of each battery cell connected to the BMS.

Since 2019, SPARTAN Superway has been using a BMS provided by Orion. This BMS is capable of monitoring up to 16 battery cells in series and has been used to monitor the charging profile of the 2019 Power Module's supercapacitor pack. According to the 2019 Power Module Team's report, this specific BMS has a preloaded charging curve of 50% DoD, meaning the system can only access 50% of the stored energy within the monitored battery pack. The 2019-2020 Power Module Team believes it is possible to lower this discharge curve by reconfiguring the BMS, but due to the global events that occurred during the 2019-2020 Power Module Team's term, the team was unable to confirm this. Future teams should continue the usage of this specific BMS for future supercapacitor packs while looking into simpler BMSs for each individual Lithium-ion battery pack.

Figure 17: Orion Jr. Battery Management System that was used in the system

10. State-of the Art/Literature Review

Automated Transit Network (ATN) is an on-demand transportation system that has been in use since the 1950s. Although its popularity has been on a decline, this form of transportation has been proven to be less costly, more environmentally friendly, and capable of providing service to areas traditional forms of transportation cannot reach (Transweb.sjsu.edu). This method of transportation opens another avenue for users to travel safely while local municipalities could use the land surrounding the area network more effectively. However, there is resistance to allow these systems and their technology to move forward. For example, the technology is seen as less mature and thus risky compared with conventional modes of mobility, and there is no infrastructure for wide implementation (Holdcroft & Young, 2011). ATNs are not necessarily new technology and can be seen in small, specific applications. At Heathrow Airport in the UK, an ATN system is being used to replace shuttle buses and transfer passengers to different terminals, car rental facilities, transport to remote aircraft and gates, and the transfer of baggage (Holdcroft & Young, 2011). This system of transportation around the airport allows for the easy mobility of people to various destinations across an area network of guideways and proves that the system can be implemented effectively.

Figure 18: An example of an ATN network in an urban residential area.

In hopes to reduce traffic congestion, reduce greenhouse gas emissions, and increase accessibility to public transportation, Spartan Superway is developing an Automated Transit Network that will run entirely on solar energy. Through Spartan Superway's overhead transportation system, the team will be able to make use of free air space without placing a burden on ground-based transportation systems. The Power Module Team is responsible for designing a power pack that is capable of being fully recharged within seconds, powering each of the individual pods to its next station, and can repeat this process indefinitely. Much of the Power Module Team's approach to this design goal has taken inspiration from China's supercapacitor buses.

Rechargeable electric bus : 10 seconds to charge thanks to supercapacitors

Figure 19: An example of a rechargeable electric bus in China.

Since the early 2010s, China has been revolutionizing public transportation through the use of supercapacitor buses. To serve the 2010 World Expo in Shanghai, Sunwin, a joint company between Volvo and China's largest automaker SAIC, released 61 buses that incorporated both the use of supercapacitors and batteries. These buses' power modules were designed to be fully charged within 80 seconds and capable of running a full 10-hour day ("China takes the lead in adopting the all-electric bus equipped with supercapacitors", 2017).

These applications of supercapacitors inspired the 2018-2019 Wayside Power & Power Module Team to incorporate this technology for the power module. Work on developing an ATN at San José State University started in 2012 with the inception of SPARTAN Superway. The team designed and constructed a wayside power pickup system with the ability to extend and retract by using a pantograph system (Naidu, Schoenstein, Winters, 2018). This was part of the Summer

2018 Research and Development Project. The project and its design would continue into the academic year 2018-2019. A power module consisting of 64 supercapacitor cells in a configuration of 4 parallel, 16 series (Coaquira, Ka Lau, Winters, 2019). The team's design also incorporated a BMS for cell management and balancing, a pantograph system for the wayside power pick-up system, a cooling system, and a bogie that also had housing for the components of the system.

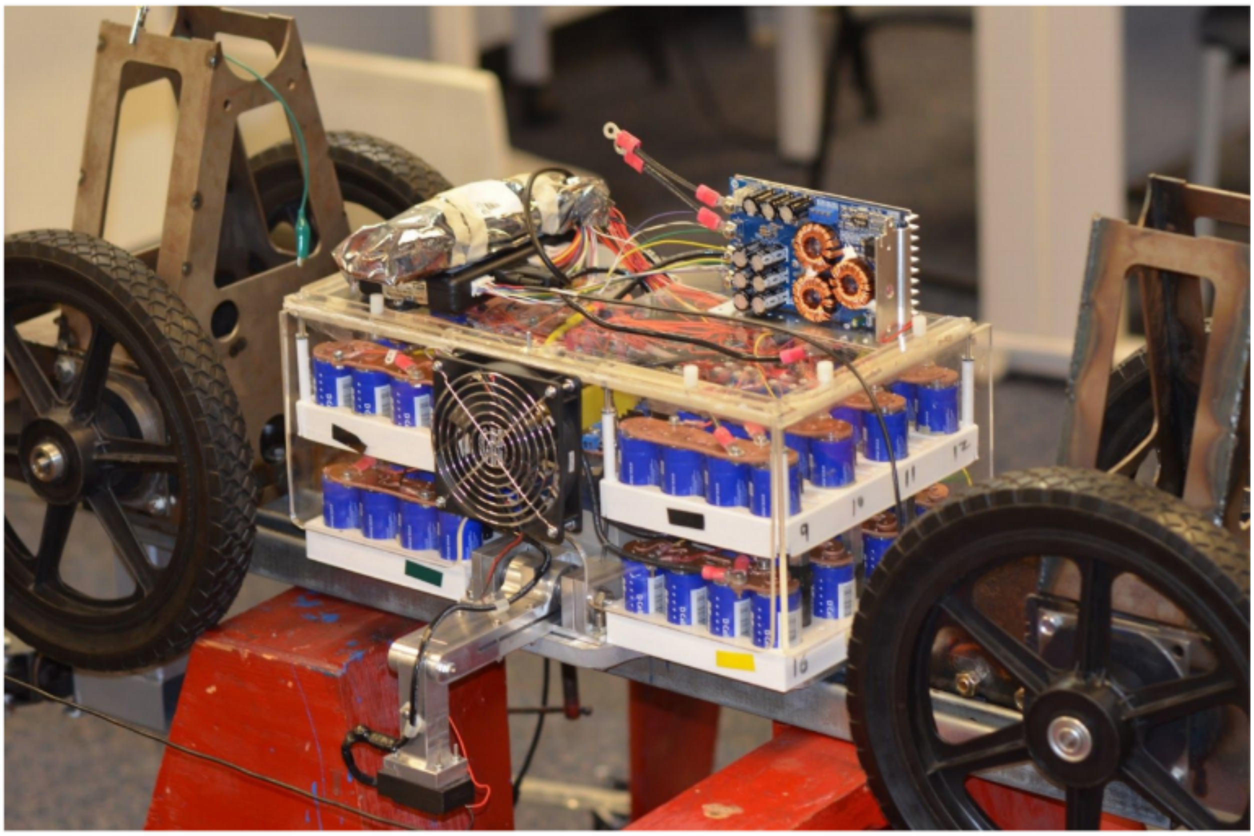

Figure 20: The 2018-2019 Full-scale Wayside Power/Power Module.

Lithium-ion batteries are widely used for powering electric vehicles. This battery type is known for its high energy density and increased power per mass battery unit, allowing for competitive prices and reduction of weight and dimensions compared to other battery types (Burnete et al, 2017). The amount of energy that can be stored in these batteries determines the range capability of the electric vehicle they are being used to power, which also makes the vehicle more expensive than conventional internal combustion engines (Coffin & Horowitz, 2018). Lithium-ion batteries are also used primarily to power Tesla's electric vehicles. Projects at Tesla are further developing battery technology. The lifespan of a battery is determined by the measurement of its discharge cycle, where 100% of the battery's charge used is one full cycle (Cohen, 2019).

In using these batteries in combination with the supercapacitor cells currently available at the SPARTAN Superway facility, the range that the pod would be able to travel would be extended, and the amount of time between necessary charging would be increased. However, the team also found the development of a combination of these two energy storage units, Lithium-ion batteries, and supercapacitors, creating a hybrid. This hybrid storage device, the Li-ion capacitor, also known as hybrid capacitors, use one electrostatic electrode and one electrochemical, which results in better energy density than electrical double-layer capacitors (EDLC), and higher durability without the concern of a self-charge characteristic and danger of thermal runaway potential for capacitors and batteries respectively (Keenan, 2017). This concept may prove useful for future teams, as it would combine the two energy storage devices being used from the 2018-2019 and 2019-2020 teams. However, this technology is not as widely available as supercapacitors and Lithium-ion batteries are on the market. Further development will be needed before it can be incorporated into any system.

11. Description of Design

The power module for the full-size power module consists of:

1. 4 parallel-16 series Supercapacitors
2. 8 Modules of 35 parallel-6 series Lithium-ion Batteries
3. 4 Cooling Fans (160-cfm each)
4. Multiple Relays and Battery Management System (BMS)
5. 12 V Lead-Acid Battery
6. Arduino and Current Sensor
7. Terminal Blocks
8. Inventer
9. Cooling System

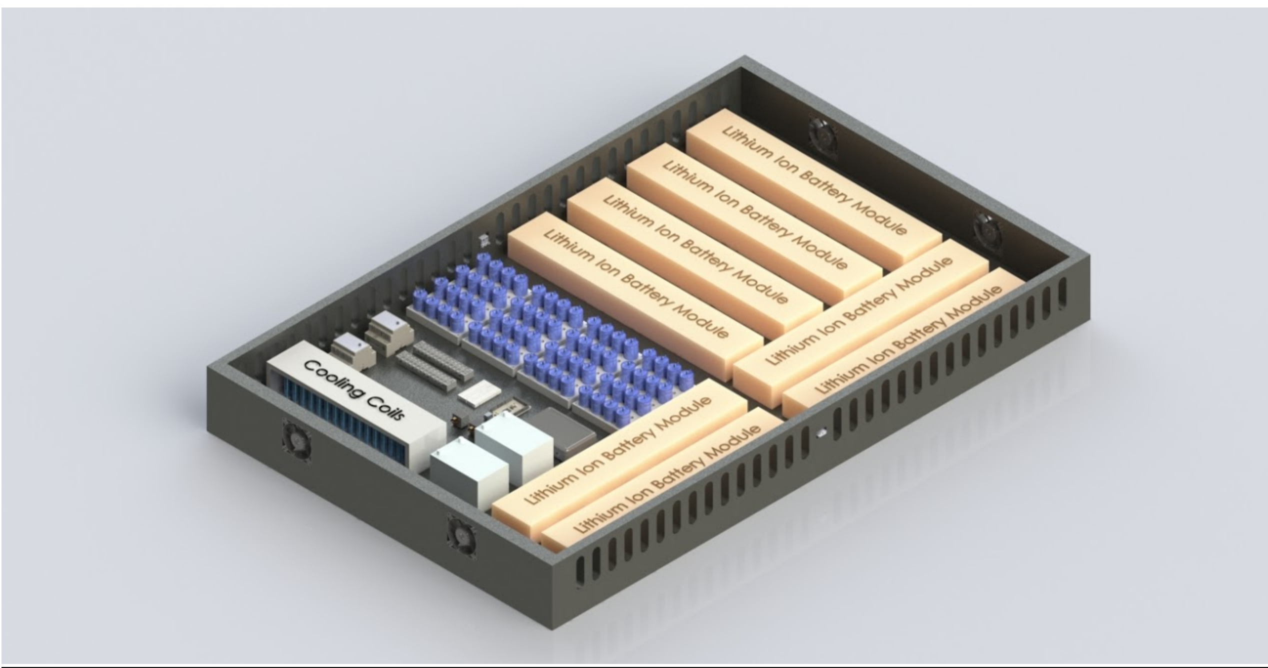

Figure 21: Full-size Power Module with all-electric components.

The goal of the 2019-2020 Power Module Team is to create a power module capable of providing the necessary power needed to move the traveling bogie while also being designed in such a way where the components can be easily accessed for easier maintenance and serviceability. Since heat is an issue that must be addressed, free air cooling will be incorporated into the system to allow for better heat dissipation without the need for more expensive cooling systems. An additional cooling system is recommended for redundancy purposes, in case more heat is generated than expected. The power module has two Molex connectors on each side to connect to the power rails. Molex connectors were chosen for their high durability, anti-vibration locks, and are used in many other electric vehicles. In order to make sure each component stays in place, the power module housing was customized with holes for each component.

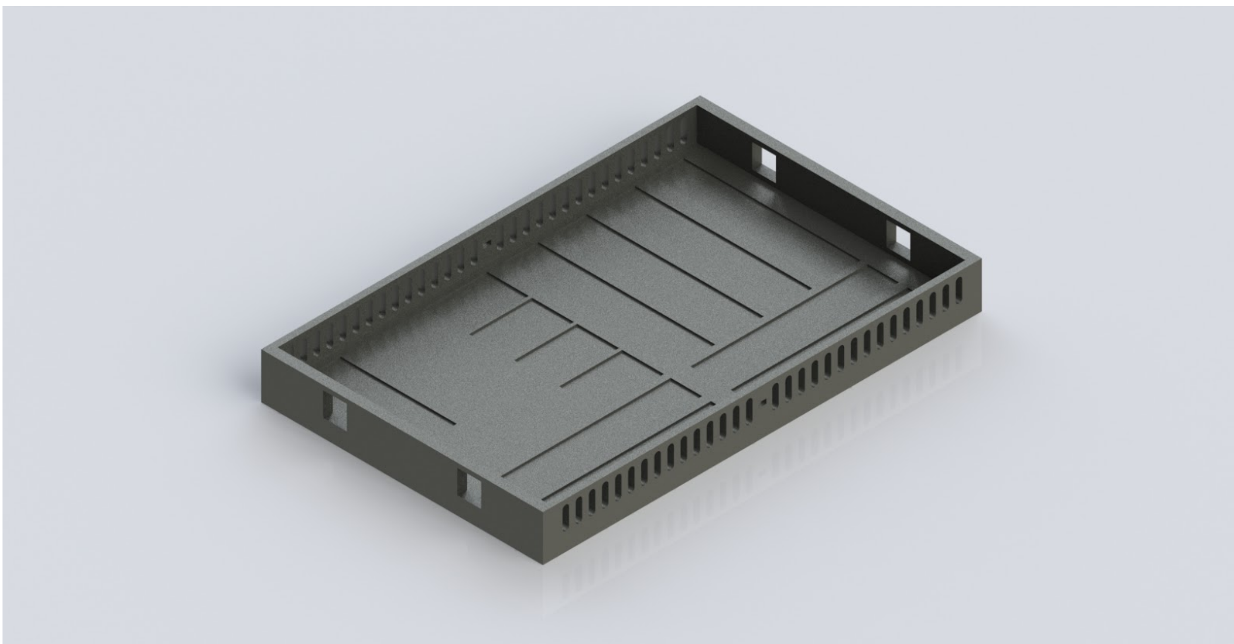

Figure 22: Full-size Power Module. Dimensions: 72 in. x 42 in. x 3 in.

During the power module design process, a double-layered power module was also considered (refer to **Figure 23**). The two-layer power module utilizes multiple sliding shelves to promote organization and easier access for maintenance. Although the two-layer power module would allow for a thinner bogie, the single-layered design was selected for the following reasons:

1. Cost: Single-layer module's design is simpler and requires fewer chassis parts.
2. Chassis rigidity: Single-layer module is more rigid, which would allow better shape retainment even after being acted upon by various loadings.
3. Heat: The double-layer module lacks thermodynamic conscious features for heat flow in the vertical axis.

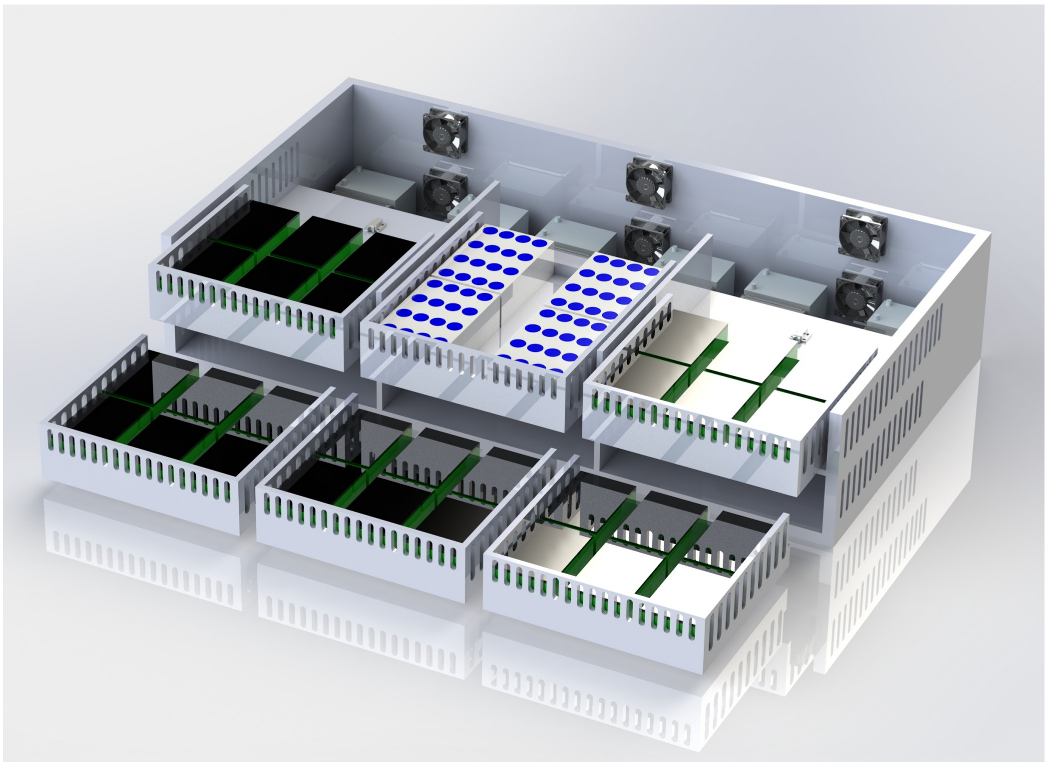

Figure 23: Double-layered Power Module.

12. Analysis and Testing of System

12.1. Finite Element Analysis (FEA) on Power Module

Finite Element Analysis (FEA) was performed to test the structural integrity of the power module housing (refer to **Figure 24**). The displayed housing is made of Aluminum 6061-t6 and has a length of 67 in, a width of 43 in, a height of 7 in, and a total weight of 626.88 lb. The assumption that the housing will be sitting flat on the designated location on the traveling pod was made, where the bottom face of the power module is fixed. Loadings from each component were applied onto their designated sections (refer to **Table 5**). Due to the absence of testing, the analyses were made with an estimated value for the cooling unit and supporting electronics' masses.

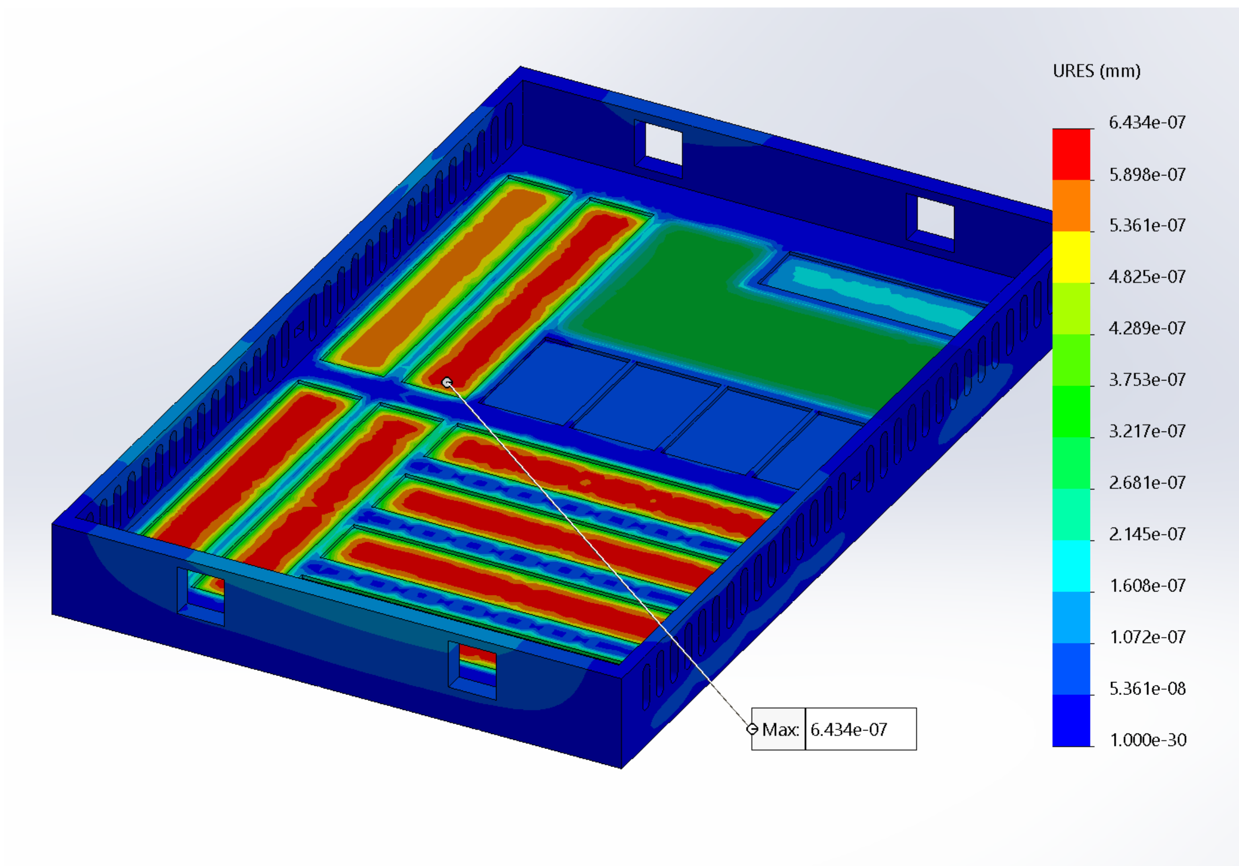

Figure 24: FEA displacement results.

Component Name	Total Applied load

Lithium-ion battery pack	10.5 kg (50 g/cell)
Supercapacitor pack	0.96 kg (60 g/cell)
Cooling Unit	2 kg
Supporting electronics (BMS, Relays, Arduino, Batteries)	15 kg

Table 5: Loading applied by each component.

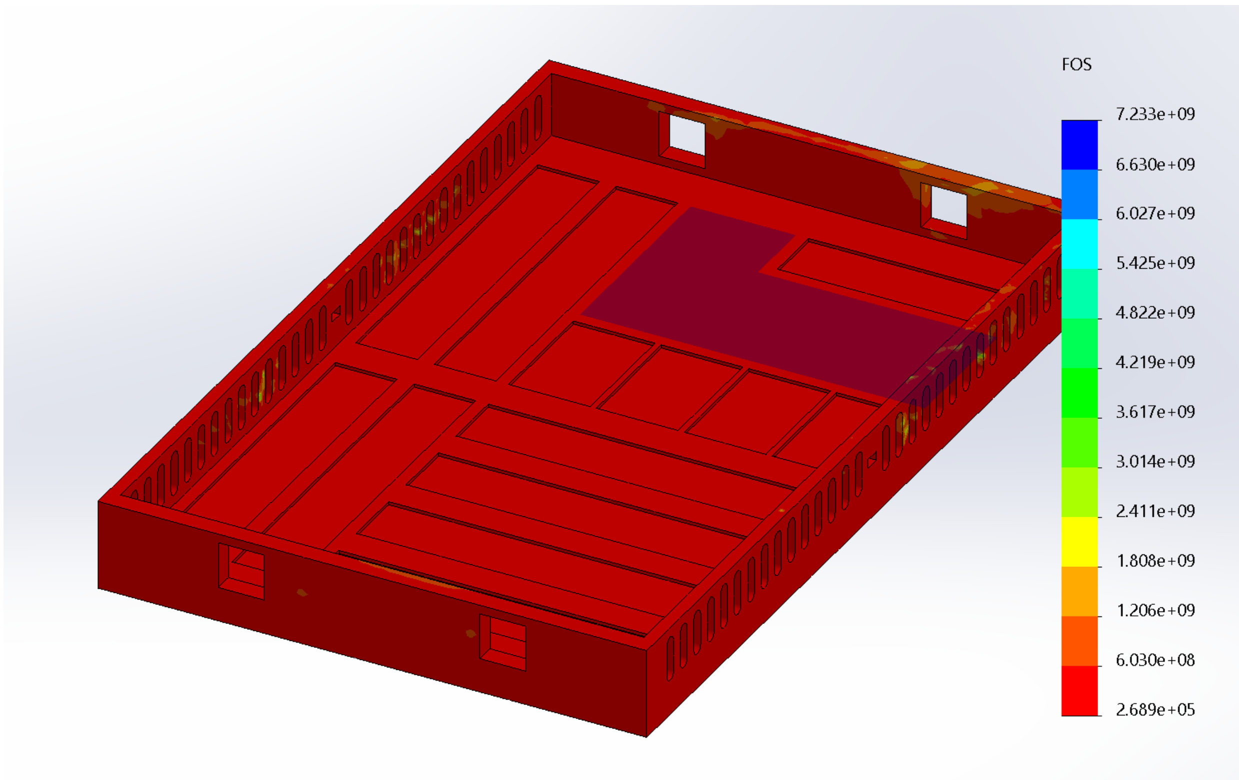

Figure 25: FEA Factor of Safety Results.

12.2. Switching Mechanism

Due to the COVID-19 pandemic, the team was unable to complete the fabrication and testing of the power module. Before the closure of campus lab rooms, the team was able to successfully design a mock switching mechanism that involved the use of a current sensor, relay, transistor, 12 V DC motor, and power supply. The 2-D electrical schematic of our switching mechanism is shown below:

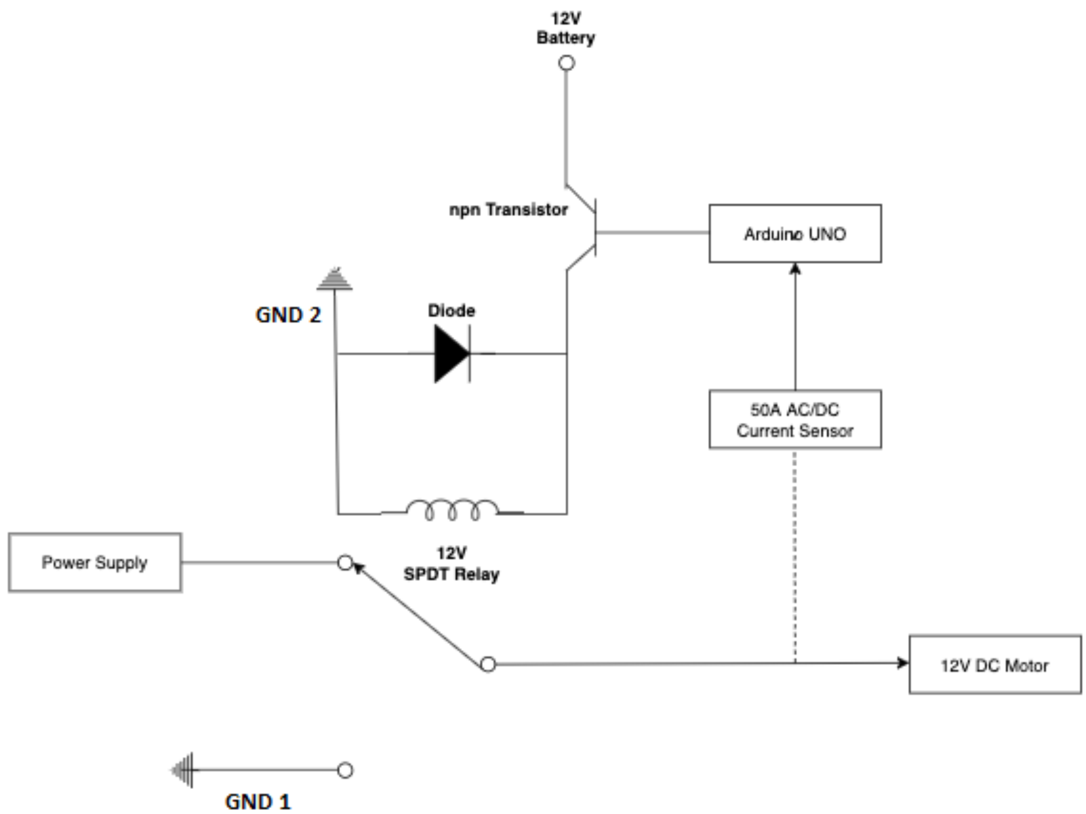

Figure 26: 2-D simplified electrical schematic of the switching mechanism.

For the mock switching mechanism, a 12 V DC motor is initially being powered by a power supply which will act as the supercapacitor pack in the power module. A current sensor will be used to monitor the amount of current being fed into the motor. Once the current sensor senses a current flow less than the threshold needed to maintain the motor's maximum rotational speed, the current sensor will send a signal to the Arduino to turn on the NPN transistor. The NPN transistor acts as a switch to allow current flow to the relay to switch the motor's power source from the power supply (supercapacitor pack) to GND 1 (Lithium-ion battery pack).

12. 3. Printed Circuit Board (PCB) Test

After the design of the PCB was created in P-CAD 2001, a test to check for shorts and proper clearance between traces was performed. The "Reconnect Nets" tool in P-CAD was used to check the design. This test was performed by "filling" the board with copper while maintaining a certain clearance, 0.5 mm, around connections, and the program would check for copper sharing. This means that if there are any areas on the board that may be out of clearance or too close to another trace or connection, it will be detected and the test would result in failure. The short would need to be located and addressed before performing the test again to check for copper sharing until there are no other problems or shorts. The check from this test resulted in no shorts after two iterations of the test.

13. Results and Discussion

As much of the physical testing of our systems was halted due to the stay-at-home order due to the Covid-19 pandemic, all testing was done through digital means. For example, the design and testing of the power module housing were done through SolidWorks, while the battery pack behavior analysis was done through Microsoft Excel. Although many restrictions were placed upon the 2019-2020 Power Module Team, many of the team's goals were achieved.

Studying the FEA analysis done on the power module housing, not only was the 2020 Power Module Team able to design a rigid housing but was also able to design a housing capable of withstanding the loading from the interior components with little deflection. As these objectives hold much importance to the project, the dimensions and mechanical properties of the housing were excessive. Based on the factor of safety chart and the weight of the power module, the current housing design utilizes an excessive amount of material. For this reason, if future teams wish to use the primary design, it is recommended to optimize the design and produce a lighter housing with a lower FOS.

The PCB for the power module was designed initially to handle 33 A. The trace width was calculated by determining the amount of copper needed for the traces to handle the amount of current. However, with the shelter-in-place order, the design specification for the current increased to 50 A. Another calculation was done for the trace width and it was determined to be 11 mm at 6 ounces of copper. The amount of copper needed is much higher than standard but will ultimately allow the PCB to handle the 50 A current with the proper clearances between traces at the expense of being more expensive for the fabrication of the PCB. The PCB design was checked using P-CAD's "Reconnect Nets" tool, which determines if there is a short in the board and whether or not the clearances between traces are sufficient. This test was successful, and fabrication may proceed but should be checked again, along with the connectors for the PCB.

14. Conclusions and Suggestion for Future Work

14.1 Conclusions

The 2019-2020 Power Module Team set out to design a power unit that used a supercapacitor and Lithium-ion battery pack hybrid to deliver power to the motor of the bogie. The supercapacitors would be used for acceleration of the bogie to reach cruising speed, while the Lithium-ion battery pack would be used to maintain that cruising speed. The team conducted research to learn about supercapacitors and how they are used and can be applied. The team originally designed a power module that would handle 33 Amps and deliver 110 W of energy to move a 100 kg bogie. However, these specifications changed with the COVID-19 pandemic. The new specifications for the full-scale power module are to provide 350 kW of energy to power a 1500 kg bogie.

Due to the Covid-19 pandemic that resulted in the closure of many facilities around the world, the Spartan Superway Power Module Team had to change their project scope in response to the new limitations. Since most of the Power Module's research, design, and simulation work was done in the first six months of the fall term, the 2020 Power Module Team was aiming to prototype and finalize the design during the 2020 Spring semester. The stay-at-home-order issued in March during the Power Module's prototyping phase, causing the early discontinuation of Power Module's physical work. In the hope to continue their contribution to SPARTAN Superway, the 2020 Power Module Team placed much more emphasis on consolidating their simulations and designs to better assist future teams. From these simulations, the team was able to predict how the system would function in the real world. However, it must be noted that these simulations are not the same as real physical tests.

14.2 Suggestions for Future Work

With the increased emphasis on digital work, the 2020 Power Module Team has created many simulations that can be used to assist future teams in the configuration of future power modules. With the assistance of the existing simulations, future Power Module Team should aim to begin prototyping and testing during the first half of their term. This early start will allow future teams to correct errors made due to the discontinuity between concept and reality. In addition to this, in the event a bogie and motor have been determined, future teams should use a tachometer as the switching mechanism's catalyst. The switching mechanism described earlier is dependent on the output of a current sensor. This system is calculation reliant since the switching mechanism will only activate once the supercapacitor pack has been completely drained.

In order for this system to accomplish its goals, the sizing and storage capacity of the supercapacitors must be maintained throughout its lifetime which may prove to be difficult in real-life applications. Having this in mind, with the assistance of a tachometer, future teams can continue to change the supercapacitor pack's configuration without having to encounter this problem. Although much of the calculation and simulation work was done by preceding teams, future teams should still focus on understanding the science behind different batteries as their comprehension of different energy sources is vital to the success and innovation of SPARTAN Superway.

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16. Appendices

Appendix A: Supercapacitor Charging Profile

Demo

Full Scale

RESULTS

Time [s]	*Bogie Voltage [V]*	Current [A]
0	0	140.522079
2.5	4.68453345	122.236513
5	8.75948763	106.330373
7.5	12.3041846	92.4940342
10	15.3876246	80.4581621
12.5	18.0698291	69.988469
15	20.4030093	60.8811544
17.5	22.4325822	52.9589376
20	24.198055	46.0676067
22.5	25.7337941	40.0730165
25	27.0696937	34.858478
27.5	28.2317581	30.3224862
30	29.2426078	26.3767445
32.5	30.1219197	22.9444461
35	30.8868104	19.9587787

37.5	31.5521689	17.3616241
40	32.1309471	15.1024266
42.5	32.6344112	13.1372093
45	33.0723616	11.4277178
47.5	33.4533232	9.94067538
50	33.7847119	8.64713576
52.5	34.0729783	7.52191918
55	34.3237338	6.54312246
57.5	34.5418595	5.69169257
60	34.7316014	4.95105579
62.5	34.8966529	4.30679505
65	35.040227	3.74636934
67.5	35.1651184	3.25886955
70	35.2737581	2.83480612
72.5	35.368261	2.46592434
75	35.4504666	2.14504365
77.5	35.5219752	1.86591785
80	35.5841786	1.62311356
82.5	35.6382877	1.4119044
85	35.6853559	1.22817902
87.5	35.7262992	1.06836109
90	35.7619148	0.92933961
92.5	35.7928959	0.80840843
95	35.8198455	0.70321353

97.5	35.8432883	0.61170722
100	35.8636805	0.53210825
102.5	35.8814192	0.46286717
105	35.8968497	0.40263615
107.5	35.9102722	0.35024274
110	35.9219481	0.30466708
112.5	35.9321047	0.26502199
115	35.9409396	0.23053576
117.5	35.9486249	0.20053708
120	35.9553101	0.17444201

Appendix B: Bill-of-Materials

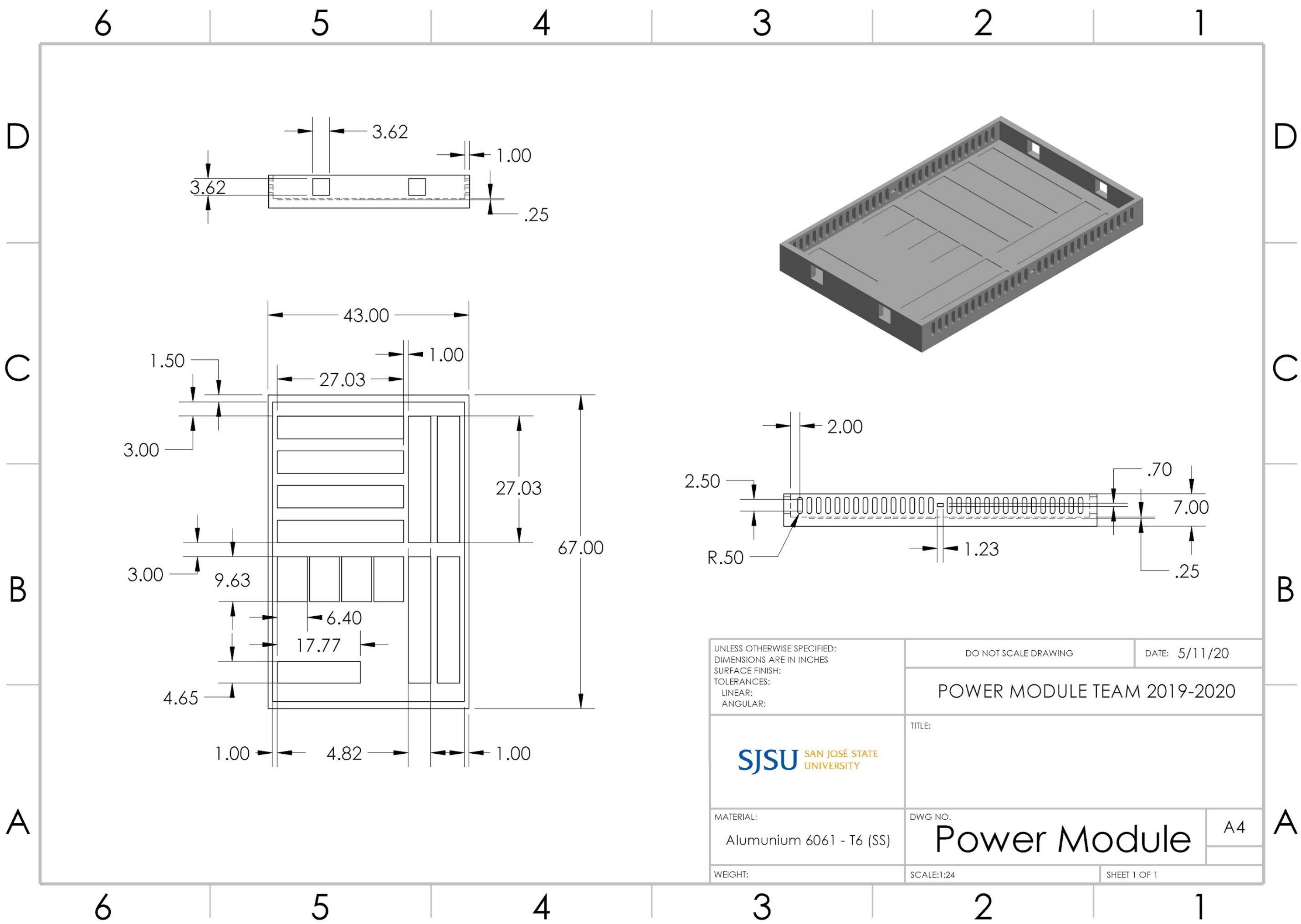
Date Purchased	Description	Quantity	Price/ Item	Price
14-Oct-19	Ampeak 2/10/25A Smart Battery Charger	1	$74.28	$74.28
17-Nov-19	Nickel Strips (3 meter)	10	$7.64	$76.40
17-Nov-19	Bestol 200pcs 18650 Battery Cell Holder Safety Spacer	9	$21.84	$196.56
14-Feb-20	Samsung SDI 18650-25R Li-on Battery	12	$2.89	$34.68
	Samsung SDI 18650-35E Li-on Battery	1680	$3.05	$5,124.00
	Terminal Blocks	1	$3.47	$3.47
	Fuse 50/100A	1	$2.04	$2.04
12-Mar-20	12 V Automotive grade Relay	1	$14.20	$14.20
	npn Transistor	1	-	-
	Diode	1	-	-
	Molex - 428160212	10	$2.50	$25.00
2-Mar-20	DFRobot 50A AC/DC Current Sensor	1	$19.56	$19.56
	Molex - 428180212	10	$2.50	$25.00
	Arduino	1	-	
	Li-On battery Smart Charger	1	$58.99	$58.99
	Power Module Case (Custom)	1		
	Inverters	1		
	PCB Fabrication	4	$196.50	$786.15
	Total Expenses			$6,440.34

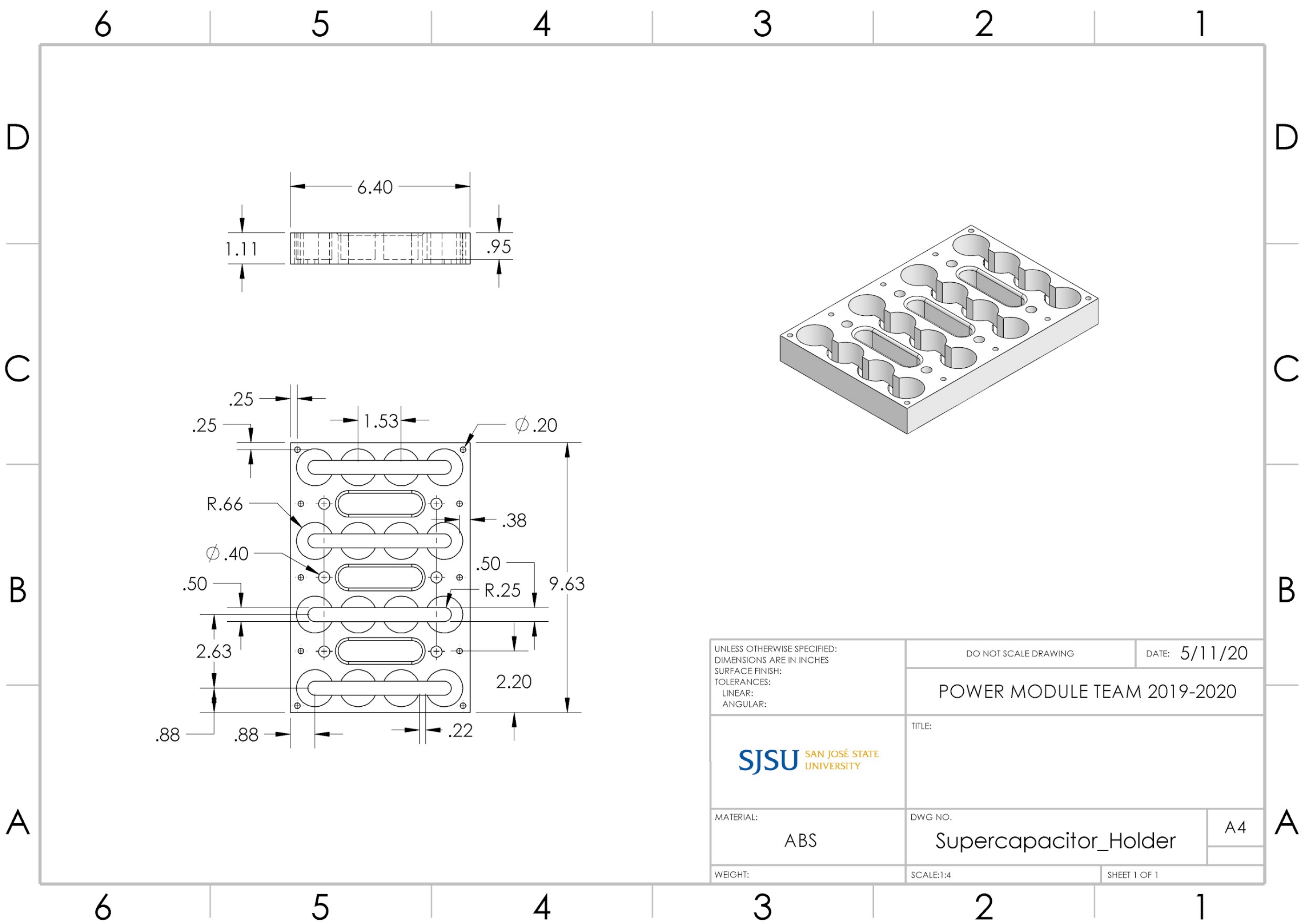
Appendix C: Arduino Code for Switching Mechanism

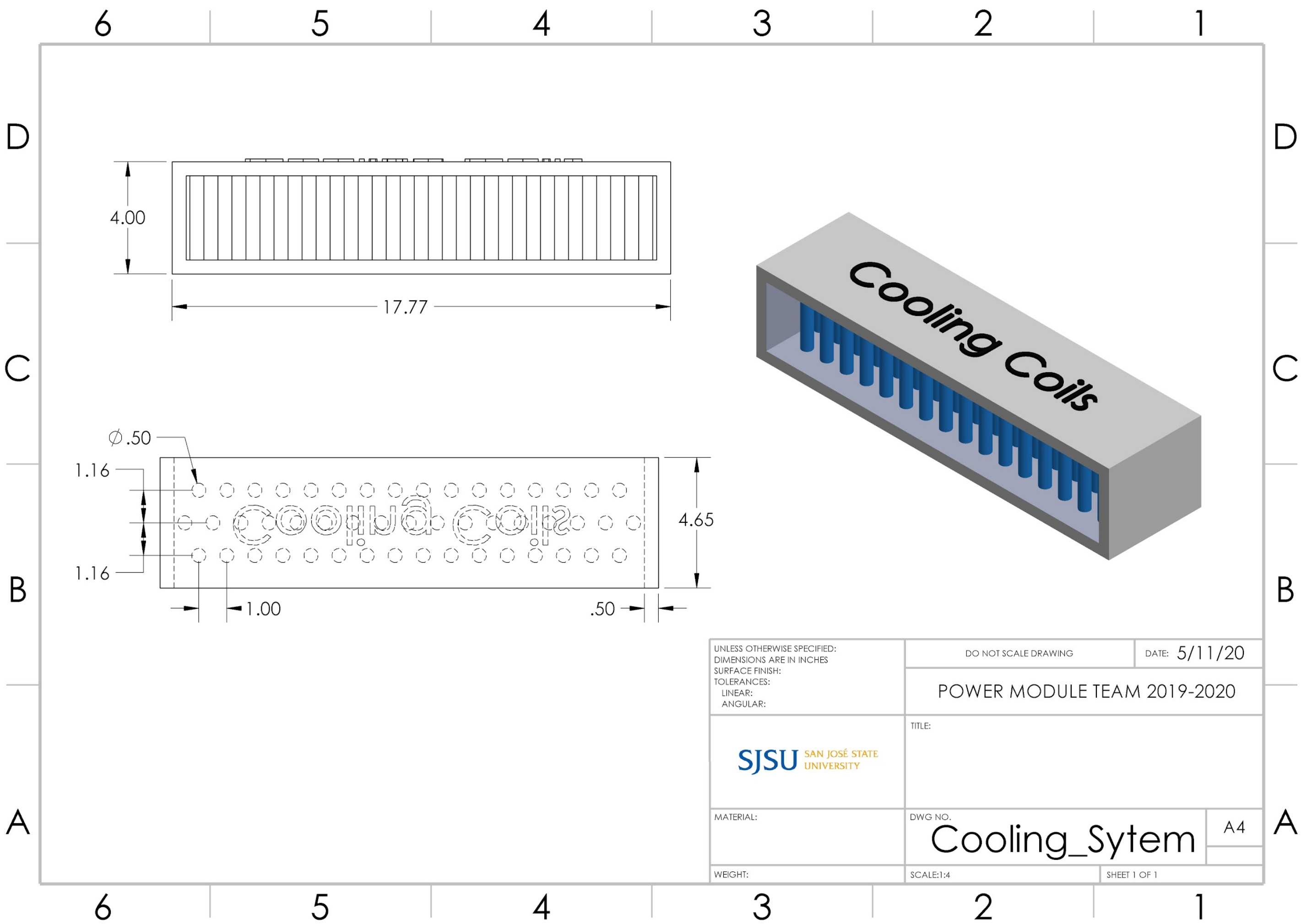
```
#define IN1
#define IN2

void setup()
{
  Serial.begin(9600);

  //L298 Motor Driver Setup
  pinMode(ENA, OUTPUT);
  pinMode(IN1, INPUT)l;
  pinMode(IN2, INPUT);
}

void loop()
{
//Read Value of Pressure Sensor
int PressureValue = analogRead(A0);
int WeightAnalog = analogRead(A2);

//Print Values for Troubleshooting
Serial.print("Pressure Value = ");
Serial.println(PressureValue);
Serial.print("WeightAnalog = ");
Serial.println(WeightAnalog);

//Convert Analog to Weight in grams, equation obtain from experiment
int WeightValue = (3.1464*WeightAnalog)-518.82;
Serial.print("WeightValue = ");
Serial.println(WeightValue);

//Display Weight on LED
delay (3000);

unsigned long TimeElapsed = millis();
Serial.print("TimeElapsed = ");
Serial.println(TimeElapsed);

//Drive the motor for a specific time (1/2 crank rotation)
if (PressureValue>0)
{
   //Time here is trial & error
   while (TimeElapsed < 6000);
   {
      //Set Current Direction to drive motor CCW/CW, may need to change to
      AnalogWrite PWM
      digitalWrite(IN1, HIGH);
      digitalWrite(IN2, LOW);
   }
}


else
{
  while(TimeElapsed<6000);
  {
```

```
      //Set Current Direction to drive motor CCW/CW, may need to change to
      AnalogWrite PWM
      digitalWrite(IN1, HIGH);
      digitalWrite(IN2, LOW);
    }
  }
}
```

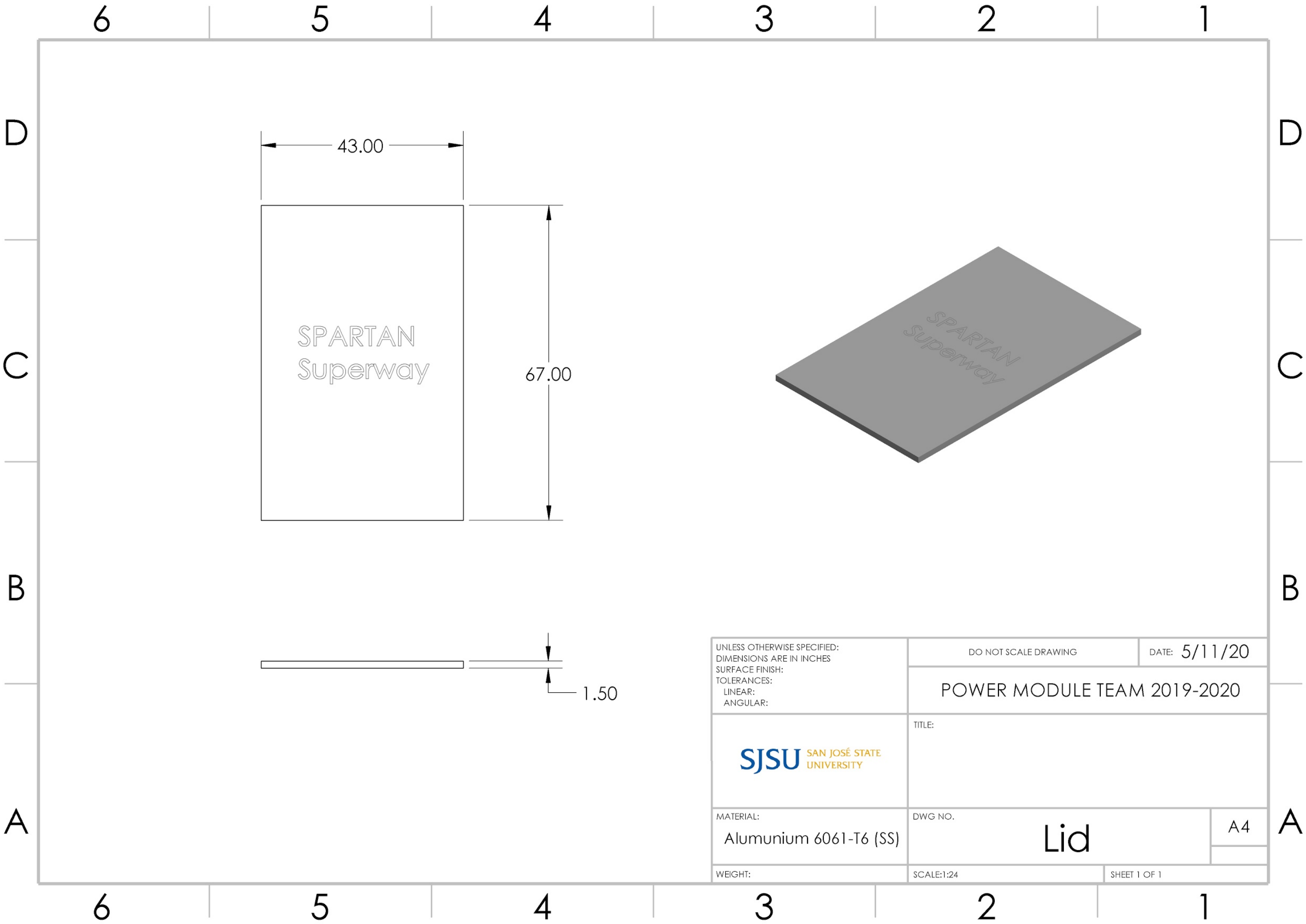
Appendix D: Part Drawings

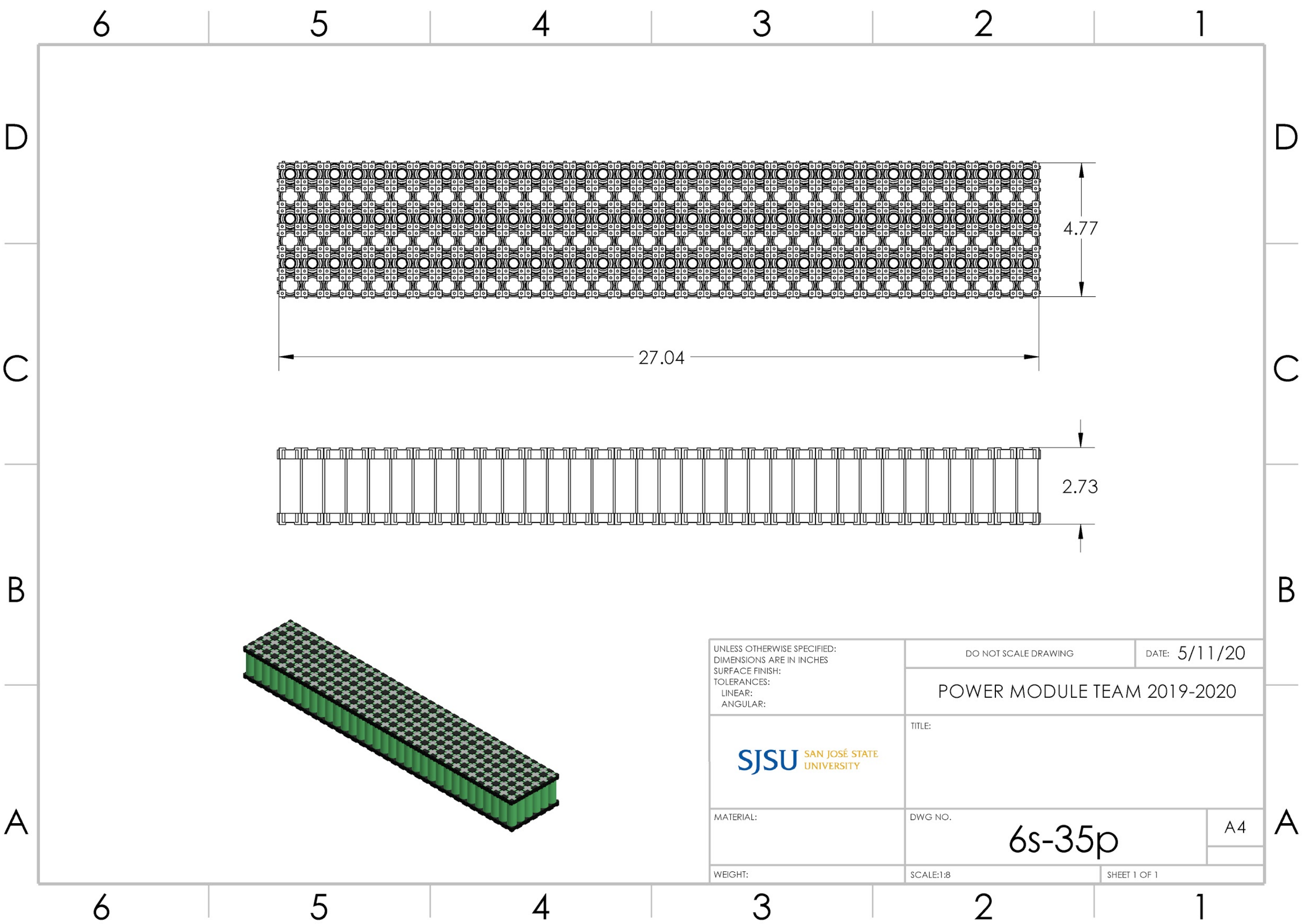


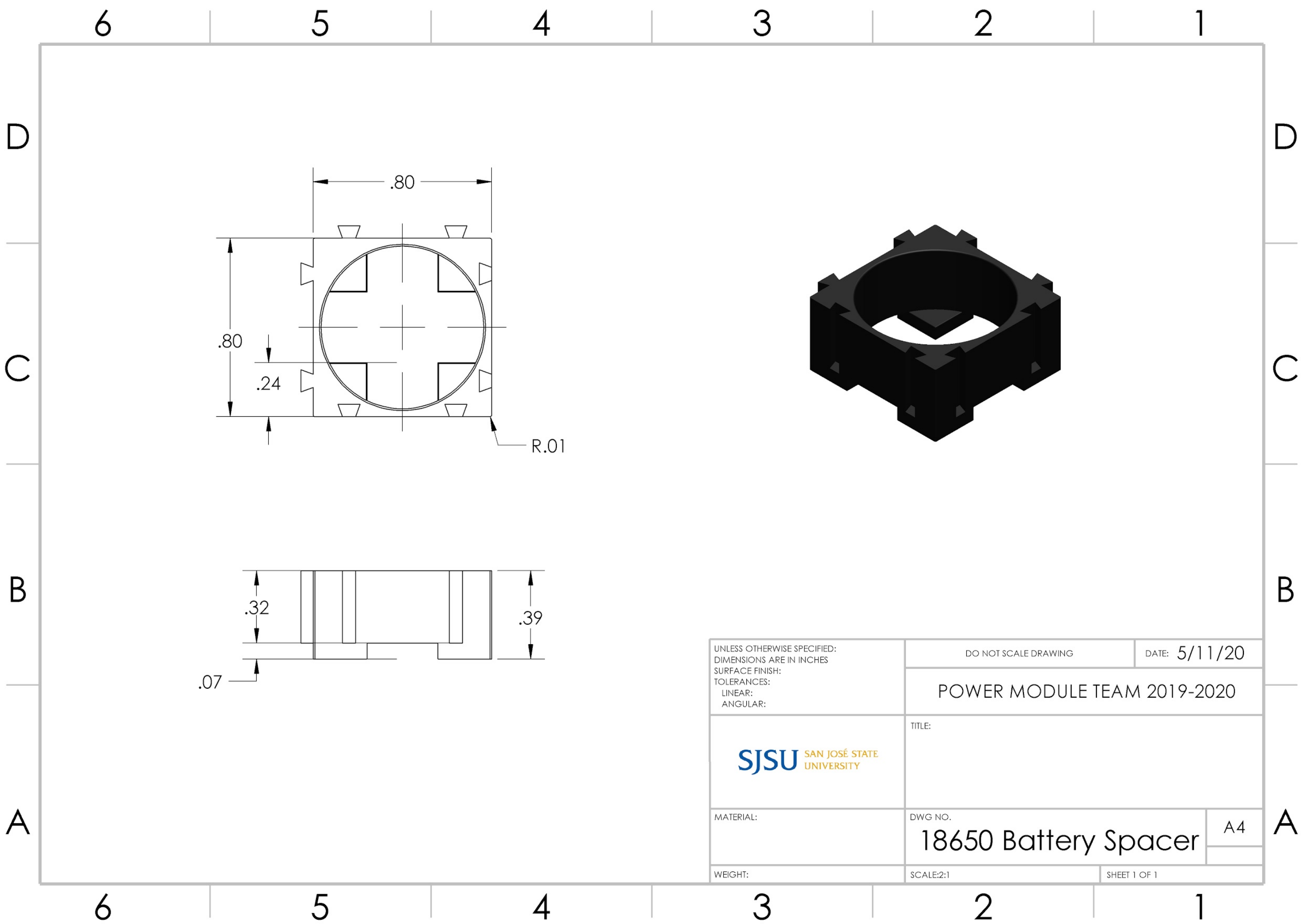

6.40
1.11
.95
.25
.25
1.53
∅.20
R.66
.38
∅.40
.50
.50
R.25
9.63
2.63
2.20
.88
.88
.22
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
DO NOT SCALE DRAWING
DATE: 5/11/20
POWER MODULE TEAM 2019-2020
TITLE:
SJSU SAN JOSÉ STATE UNIVERSITY
MATERIAL:
ABS
DWG NO.
Supercapacitor_Holder
A4
WEIGHT:
SCALE:1:4
SHEET 1 OF 1



4.00
17.77
Cooling Coils
∅.50
1.16
1.16
1.00
.50
4.65
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
DO NOT SCALE DRAWING
DATE: 5/11/20
POWER MODULE TEAM 2019-2020
SJSU SAN JOSÉ STATE UNIVERSITY
TITLE:
MATERIAL:
DWG NO.
Cooling_Sytem
A4
WEIGHT:
SCALE:1:4
SHEET 1 OF 1

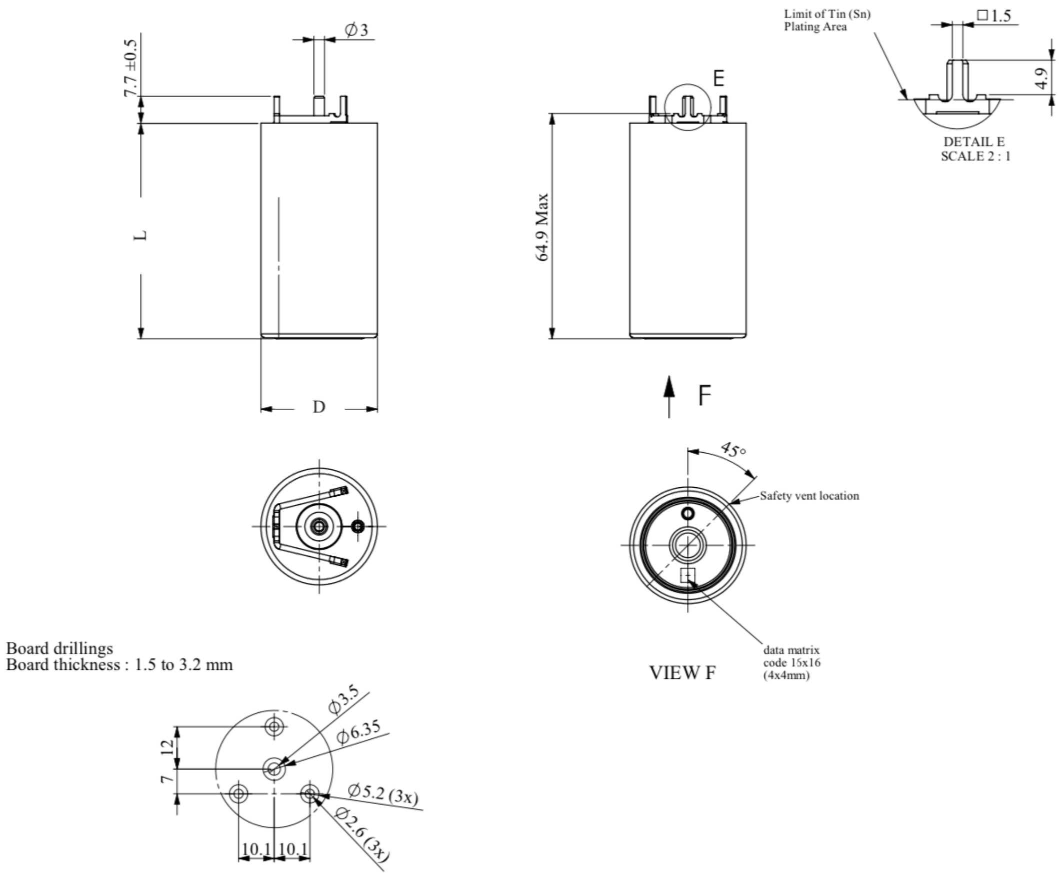

43.00
67.00
1.50
SPARTAN
Superway
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
DO NOT SCALE DRAWING
DATE: 5/11/20
POWER MODULE TEAM 2019-2020
SJSU SAN JOSÉ STATE UNIVERSITY
TITLE:
MATERIAL:
Alumunium 6061-T6 (SS)
DWG NO.
Lid
A4
WEIGHT:
SCALE:1:24
SHEET 1 OF 1


6
5
4
3
2
1
D
C
B
A
4.77
27.04
2.73
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
DO NOT SCALE DRAWING
DATE: 5/11/20
POWER MODULE TEAM 2019-2020
TITLE:
SJSU SAN JOSÉ STATE UNIVERSITY
MATERIAL:
DWG NO.
6s-35p
A4
WEIGHT:
SCALE:1:8
SHEET 1 OF 1


.80
.80
.24
R.01
.32
.39
.07
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
DO NOT SCALE DRAWING
DATE: 5/11/20
POWER MODULE TEAM 2019-2020
SJSU SAN JOSÉ STATE UNIVERSITY
TITLE:
MATERIAL:
DWG NO.
18650 Battery Spacer
A4
WEIGHT:
SCALE:2:1
SHEET 1 OF 1

Appendix E: Maxwell Supercapacitor BCAP0350

BCAP0350 E270 T11



Appendix F: Power Sonic PS-12120 Lead Acid Battery

POWER-SONIC
TRUSTED BATTERY SOLUTIONS

PS SERIES

General Purpose | Emergency Lighting | Medical | Fire & Security

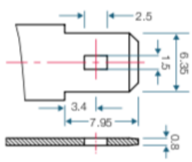
PS-12120

12V 12.0 AH @ 20-hr.
12V 11.0 AH @ 10-hr.

Rechargeable Sealed Lead Acid Battery
PS – General Purpose Series

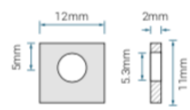
TERMINALS: (mm)

F2: Quick disconnect tabs, 0.250" x 0.032" – Mate with AMP. INC FASTON "250" series



Torque – Not Applicable

NB: Tin plated brass post with 'Nut & Bolt' fasteners



Torque: 2.0~3.0 Nxm

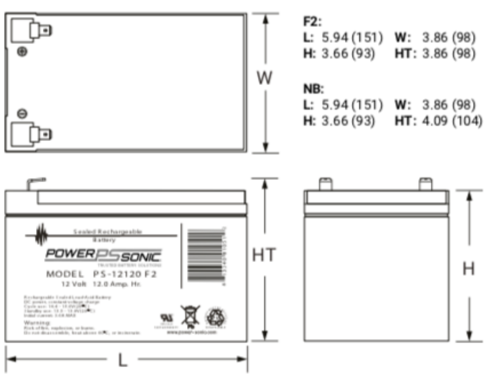
FEATURES

- Absorbent Glass Mat (AGM) technology for superior performance
- Valve regulated, maintenance free spill proof construction
- Power/volume ratio yielding excellent energy density
- Rugged vibration and impact resistant ABS case and cover
- Gas recombination technology
- 5 year design life

APPROVALS

- Approved for transport by air. D.O.T., I.A.T.A., F.A.A. and C.A.B. certified
- U.L. recognized
- ISO9001:2015 – Quality management systems

DIMENSIONS: inch (mm)



F2:
L: 5.94 (151) W: 3.86 (98)
H: 3.66 (93) HT: 3.86 (98)

NB:
L: 5.94 (151) W: 3.86 (98)
H: 3.66 (93) HT: 4.09 (104)

Tolerances are +/- 0.04 in. (+/- 1mm) and +/- 0.08 in. (+/- 2mm) for height dimensions.
All data subject to change without notice.

PERFORMANCE SPECIFICATIONS

Nominal Voltage	12 volts (6 cells)
Nominal Capacity	
20-hr. (600mA to 10.50 volts)	12.00 AH
10-hr. (1.10A to 10.50 volts)	11.00 AH
5-hr. (2.10A to 10.20 volts)	10.50 AH
1-hr. (7.25A to 9.00 volts)	7.25 AH
Approximate Weight	7.92 lbs. (3.59 kg)
Internal Resistance (approx.)	20.0 milliohms
Max Short-Duration Discharge Current (10 Sec.)	120.0 amperes
Shelf Life (% of nominal capacity at 68°F (20°C)	
1 Month	97%
3 Month	91%
6 Month	83%
Operating Temperature Range	
Charge	5°F (-15°C) to 122°F (50°C)
Discharge	-4°F (-20°C) to 140°F (60°C)
Case	ABS Plastic
Power Sonic Chargers	PSC-122000A-C PSC-122000-PC

CORPORATE HEADQUARTERS

(USA AND INTERNATIONAL EXCLUDING EMEA)
Power-Sonic Corporation
7550 Panasonic Way, San Diego,
California 92154
T: +1 (619) 661 2020
F: +1 (619) 661 3650
E: customer-service@power-sonic.com

POWER-SONIC EUROPE LIMITED

(EMEA – EUROPE, MIDDLE EAST AND AFRICA)
3 Buckingham Square,
Hurricane Way, Wickford,
Essex SS11 8YQ
T: +44 (0)1268 560686
F: +44 (0)1268 560902
E: salesEMEA@power-sonic.com

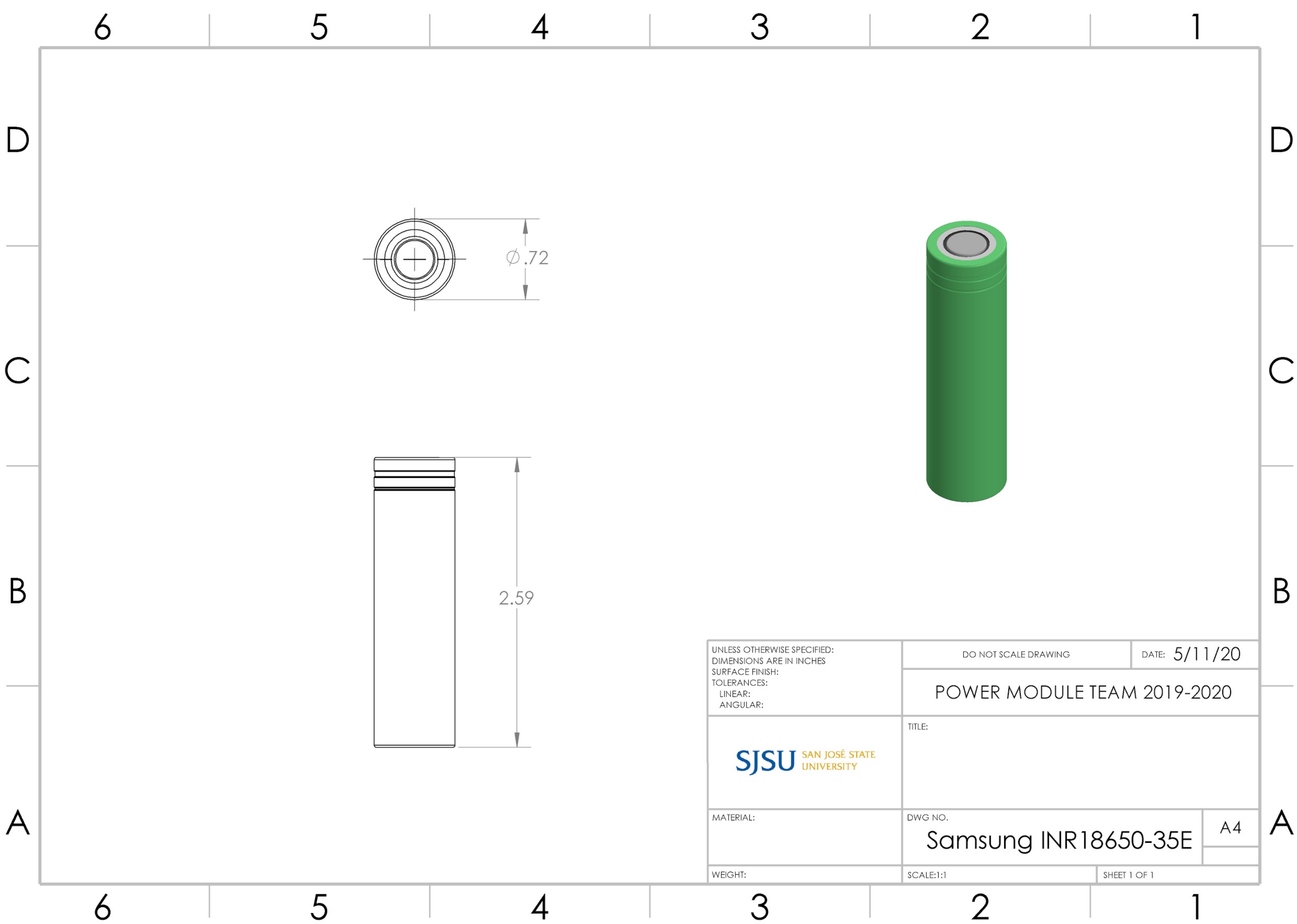
To ensure safe and efficient operation always refer to the latest edition of our Technical Manual, as published on our website.

All data subject to change without notice. E&O.E

power-sonic.com

Appendix G: Samsung SDI INR18650-35E Lithium-ion Battery

Nominal Specifications:



Appendix H: Orion Jr. Battery Management System (BMS)

orionJr. BMS

Lithium Ion Battery Management System for 12V—48V Applications (Revision C)

Designed Use

- Designed for Lithium Ion battery packs up to 48V nominal (60V max)
- Individual cell voltage rating: 0.2v to 5v per cell tap
- Supports from 1 to 16 cells in series
- -40C to 80C operating temperature range
- Integrated low loss passive cell balancing to within 10mV
- Cell voltage resolution of about 1.5mV

Applications

- Light mobile applications (scooters, golf carts, etc.)
- Solar & wind energy storage
- Uninterruptible power supply
- Battery backup

Basic Functions

- Over-voltage and under-voltage protection
- Over-current protection
- Temperature protection
- Intelligent cell balancing
- State of charge monitoring
- State of health monitoring

Additional Functions

- Data logging capabilities
- Stored diagnostic information
- Programmable interfaces
- Current limit calculations (intelligent current limiting)
- Stored battery usage statistics including histogram data

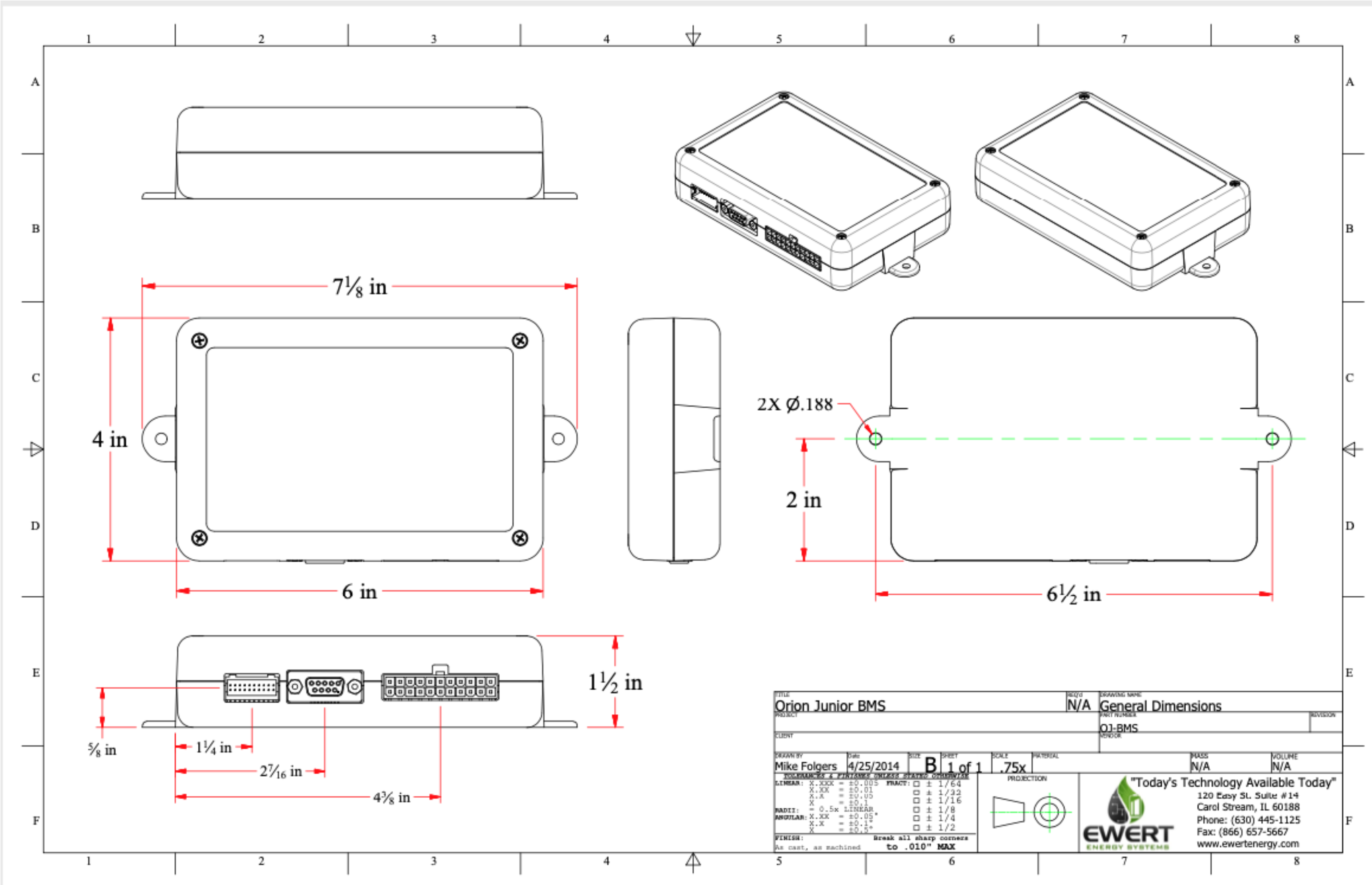
Display Options

- Interfaces with third party smartphone software (CAN version only)
- Optional basic state of charge display
- Optional data logging display

The Orion Jr. BMS is a product of Ewert Energy Systems, Inc.

Ewert Energy Systems is a research and development company focused on developing solutions for plug-in hybrid and electric vehicles and other energy storage applications.

EWERT ENERGY SYSTEMS


7⅛ in
4 in
6 in
2X Ø.188
2 in
6½ in
1½ in
⅝ in
1¼ in
2⁷⁄₁₆ in
4⅜ in
Orion Junior BMS
N/A
General Dimensions
OJ-BMS
Mike Folgers
4/25/2014
B
1 of 1
.75x
N/A
N/A
"Today's Technology Available Today"
120 Easy St. Suite #14
Carol Stream, IL 60188
Phone: (630) 445-1125
Fax: (866) 657-5667
www.ewertenergy.com
EWERT
ENERGY SYSTEMS

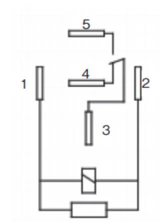
Appendix I: 12 V Industrial Grade Relay

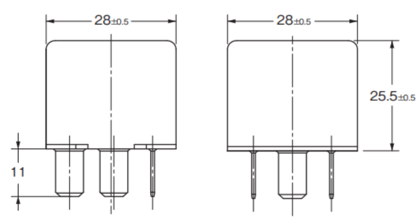
Item		Standard value
Voltage drop between terminals	N.O. side	50 mV or less, 10A
	N.C. side	50 mV or less, 10A
Operating time*2		Max. 10ms at 13.5V (Normally 5.4 ms)
Release time*2		Max. 10ms at 13.5V (Normally 1.6 ms)
Insulation resistance*3	Between coil and terminal	20MΩ or more
	Between homopolar contacts	20MΩ or more
Withstand voltage*4	Between coil and terminal	AC500V for 1minute
	Between homopolar contacts	AC500V for 1minute
Vibration tolerance	Durability	33Hz 43.1m/s²
	Malfunction	20 to 500Hz 43.1m/s²
Mechanical endurance		1,000,000 times
Electrical endurance		100,000 times
Ambient temperature		–40 to +125°C
Ambient humidity		35 to 95%RH
Weight		Approx. 34.0 g

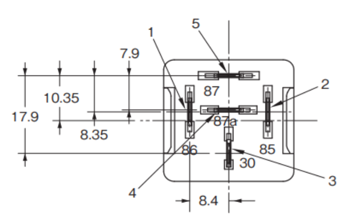
ISO Relay

G8JN-1C7T-R

Terminal arrangement / Internal connections
(BOTTOM VIEW)







* Tolerance unless otherwise specified Less than 1 mm: ±0.1 mm
Less than 1 to 3 mm: ±0.2 mm
3 mm or more: ±0.3 mm

Appendix J: Molex 428160212 Connector

molex
one company › a world of innovation

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PLEASE CHECK WWW.MOLEX.COM FOR LATEST PART INFORMATION

Part Number: 0428160212
Status: Active
Overview: Mini-Fit Sr. Power Connectors
Description: 10.00mm Pitch Mini-Fit Sr. Receptacle Housing, Single Row, 2 Circuit, Black

Series image - Reference only

Documents:
3D Model (PDF)
Drawing (PDF)
3D Model
Product Specification PS-42815-001-001 (PDF)
Packaging Specification PK-42816-002-001 (PDF)
Test Summary TS-42815-001 (PDF)
RoHS Certificate of Compliance (PDF)

Agency Certification	
CSA	LR19980
UL	E29179
General	
Product Family	Crimp Housings
Series	42816
Application	Power, Wire-to-Board, Wire-to-Wire
Overview	Mini-Fit Sr. Power Connectors
Product Name	Mini-Fit Sr.
UPC	800754381628
Physical	
Circuits (maximum)	2
Color - Resin	Black
Flammability	94V-0
Gender	Receptacle
Glow-Wire Capable	No
Lock to Mating Part	Yes
Material - Resin	Polyester
Net Weight	4.840/g
Number of Rows	1
Packaging Type	Bag
Panel Mount	No
Pitch - Mating Interface	10.00mm
Polarized to Mating Part	Yes
Stackable	No
Temperature Range - Operating	-40° to +105°C
Electrical	
Current - Maximum per Contact	50.0A
Solder Process Data	
Lead-freeProcess Capability	N/A
Material Info	
Reference - Drawing Numbers	
Packaging Specification	PK-42816-002-001
Product Specification	PS-42815-001-001
Test Summary	TS-42815-001

EU ELV
Not Relevant

EU RoHS **China RoHS**
Compliant
REACH SVHC
Not Contained Per - ED/71/2019 (16 July 2019)
Halogen-Free Status
Not Low-Halogen
For more information, please visit Contact US

China ROHS	Green Image
ELV	Not Relevant
RoHS Phthalates	Not Contained

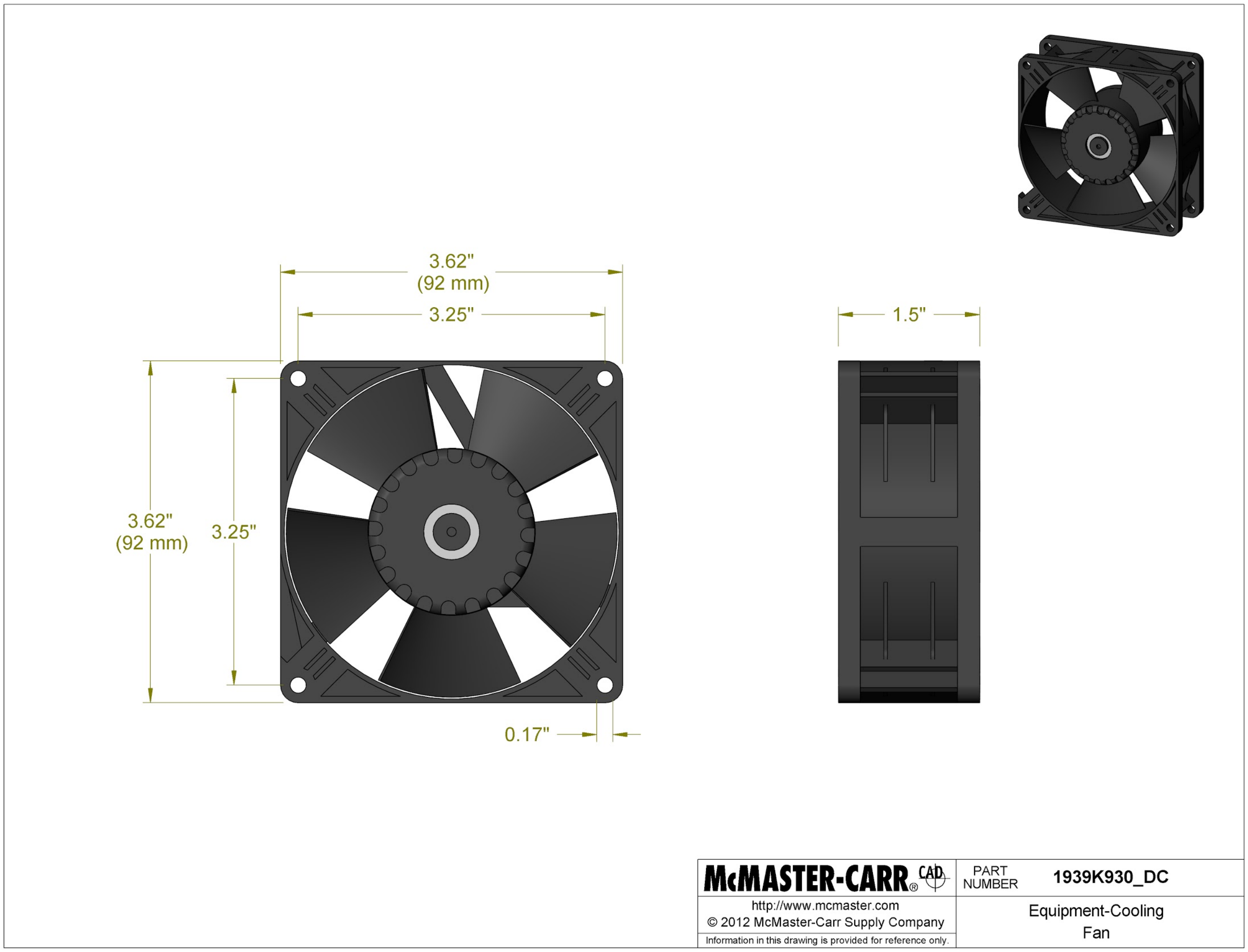
Search Parts in this Series
42816 Series

Mates With
2 Circuit Plug Housing 428180212
2 Circuit Right-Angle Headers 42820

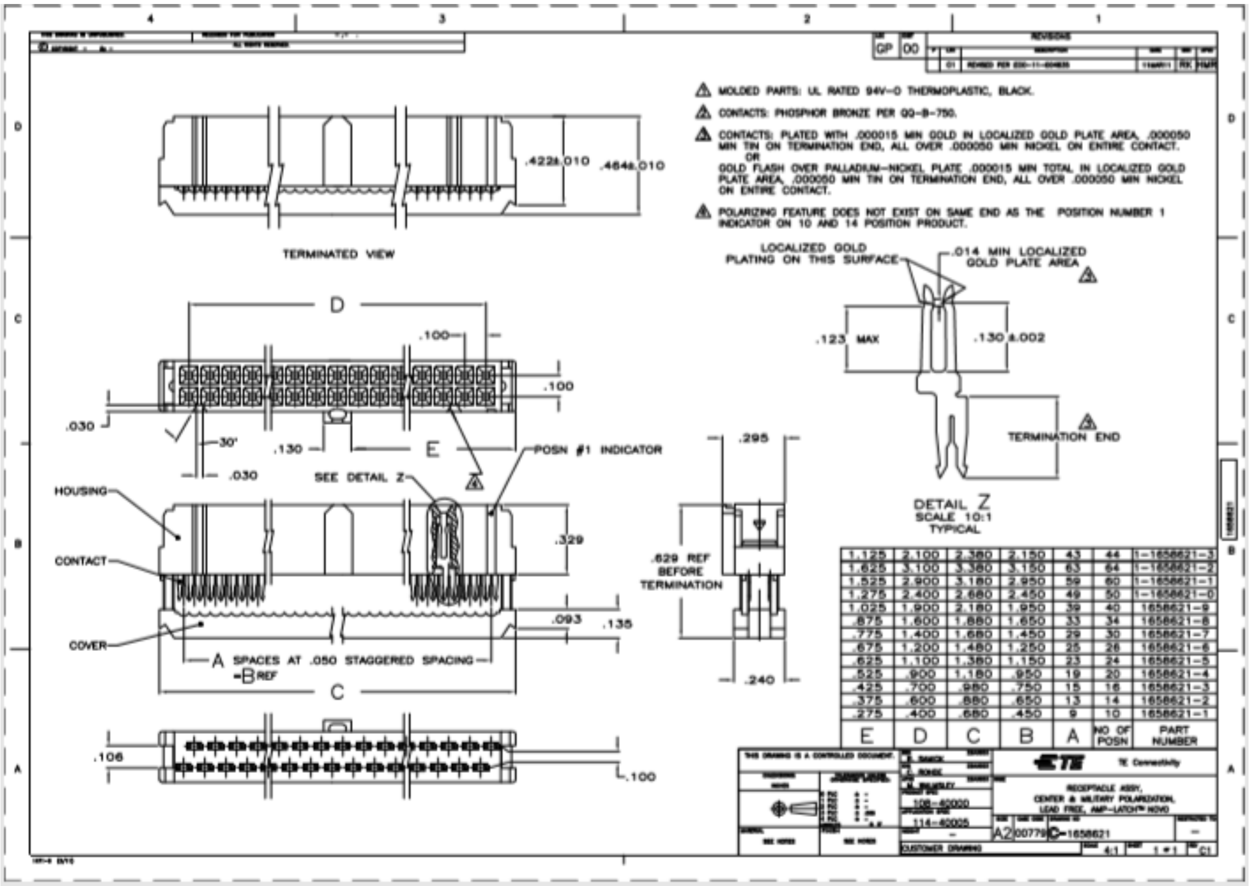
Use With
Terminal Position Assurance (TPA) Clip Included. 42815 Female Crimp Terminal

This document was generated on 11/14/2019
PLEASE CHECK WWW.MOLEX.COM FOR LATEST PART INFORMATION

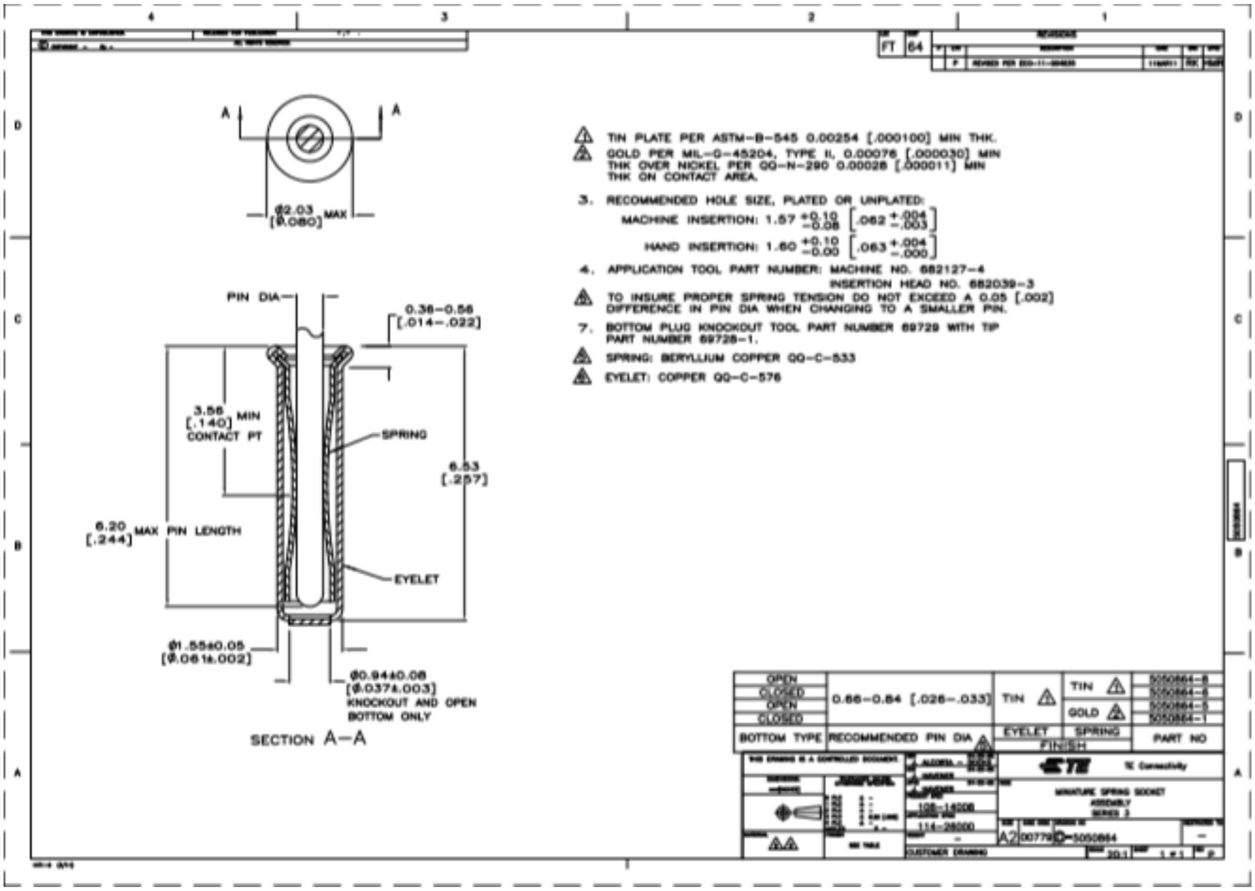
Appendix K: 1939K930 DC Equipment Cooling Fan



Appendix L: 1658621 TE Connectivity Connector



Appendix M: 5050864-1 TE Connectivity PCB Pin



Appendix N: DOI-9923246 Harwin, Inc. Header

PC Board Sockets

SOCKETS

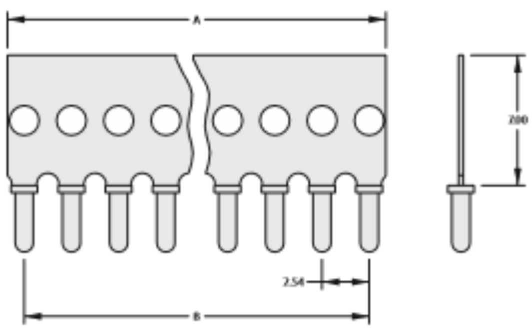
Strips of Sub-Miniature Sockets

- Sub-miniature sockets using the four finger Beryllium Copper contact, mounted on carrier strips for ease of production use.
- See previous page for information on the individual sockets.

SINGLE-IN-LINE SOCKET CARRIERS

CALCULATION	
A	B + 1.8
B	2.54 x (No. of sockets - 1)

- Brass carriers are supplied fitted with the sub-miniature socket shown in the tables below.
- Supplied in standard lengths.



HOW TO ORDER

D01 - 9XX XX 01

SERIES CODE

TYPE	
979	Single-in-line Socket Carrier with H3192-01
982	Single-in-line Socket Carrier with H3191-01
984	Single-in-line Socket Carrier with H3155-01
990	Single-in-line Socket Carrier with H3153-01

FINISH	
01	Gold contact, Tin shell

NO. OF CONTACTS PER STRIP
04, 06 to 10, 12, 14, 16, 20, 32

All dimensions in mm.

www.harwin.com 235 HARWIN