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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December 9, 2019

1. Abstract

The Power Modules sub-team has worked on designing a module to power the SPARTAN Superway project and the housing for it. The sub-team was split away from the Wayside Power sub-team, but still works in conjunction and consults with the team regularly to meet design specifications. 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, 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.

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 were made. 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 was used to design the PCB schematic and PCB itself. The team worked with the Wayside Power Team closely to determine how much power would be necessary to be picked up from their system, and at what amperage.

The team was able to complete calculations, which allowed for simulations to be conducted determining the charging time of the supercapacitors. Designs for the housing of the module have been made, and the team expects to begin obtaining material and parts to construct it. The circuit design has been completed, and can now be assembled. Design for the PCB is still underway, though the schematic for it has been completed. A proper cooling system is yet to be designed.

2. Acknowledgments

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

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

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

[4] To Husain Bootwala from San Jose 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 powering a 100kg bogie through a 10 meter track at 0.25g up to a cruise speed of 1m/s. 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 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 background 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 an increasing number of vehicles on the street, not only would greenhouse emission increase, but transportation would become more time consuming for those from less fortunate backgrounds. In hope to mend for these problems, SPARTAN Superway has proposed an overhead transportation system that will run entirely on solar energy.

6.2 Solution 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 bank 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 contain the capacity to power a 100kg bogie through a 10 meter track. Contrary to the design from 2019 Power Module team's battery pack, the 2020 Power Module team has decided to incorporate both supercapacitors and lithium-ion batteries into the system. The 2020 power module consists of 16 supercapacitors in series along with 2 parallels of 3 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 cruise speed.

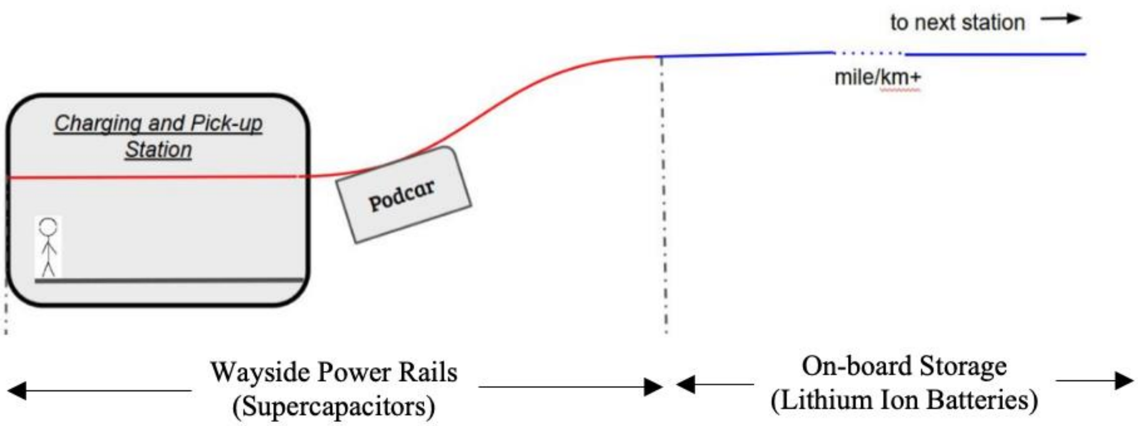

Figure 1: Proposed use of On-board Energy Storage

6.3 Actions that have been taken

Energy calculation has been done to estimate the capacity of energy storage devices. A system of supercapacitor was simulated in order to predict charging time. Lithium-Ion battery pack has been design to provide power during cruise. The overall circuit design has been finalized to include current sensor and relays. The power module has been designed on SolidWorks and simulated using Finite Element Analysis under appropriate loads.

7. *Introduction and Project Description*

7.1 Background

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 adds 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 and finite resource, so using it effectively is important for the quality of life of residents, productivity and activity in local industries.

Various solutions have been proposed to address these issues. An automated Transit Networks (ATNs) 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.

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 the productivity. Reduction in greenhouse gas emissions will also occur, because of the sustainability and environmental impact of the system.

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 its full development, the transportation system would be implemented in urban and population-dense environments to reduce traffic congestion and reduce greenhouse gas emissions.

7.2 Goals and Objectives

The Power Modules sub team is responsible for providing power to the motors of the SPARTAN Superway bogie that houses supercapacitors and batteries and all electrical components with a neat wiring configuration for easy maintenance. The power module will interface with the wayside power pickup system, charging, BMS, an applied load, and provide power monitoring for the system. The power module system should accurately deliver power to dual motors that are attached to the system in the bogie. Deliverables that are to be given are a PCB (Printed Circuit Board) for charging other electronics, an appropriate cooling system for the components of the power module, a portable and robust supercapacitor and battery housing with appropriate integrated connectors and wiring that can easily be serviced, and to demonstrate power delivery as supplied by the Wayside Power Team.

8. 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, Eric Near
3. Capacitor charging FEA Analysis, Joe Lau

Other tasks, such as researching about 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.

9. ***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 tradition forms of transportation cannot reach (Transweb.sjsu.edu).

Figure 2: An example of an ATN network in an urban residential area.

In hopes to reduce traffic congestion, reduce greenhouse gas emission, 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 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 be able to 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 3: 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. In order 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).

10. Design Requirements and Specifications

Design Specifications		
Mass of Power Module	100	kg
Total track length	10	m
Maximum Bogie Velocity	1	m/s
Acceleration of Bogie	2.45	m/s^2
Estimated Power required to move bogie	110	W
Voltage of Supercapacitor Pack	43.2	Volts
Capacitance of Pack	17.5	Farads
Energy Capacity of Supercapacitor Pack	11.1	kJ
Voltage of Lithium-Ion Battery Pack	12	Volts
Energy Capacity of Lithium-Ion Battery Pack	5000	mAh
Estimated Charging time of Pack using 1200 W	120	seconds

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

10.1 Power Calculation

The power module will receive electricity from the wayside power pickup mechanism. It will combine supercapacitors and lithium-ion (li-on) battery as energy storage. Supercapacitors were chosen due its huge power density, while lithium ion for its energy density. Power density is defined as how much energy we can deliver. Energy density is defined as how much energy we can store. Combining these two devices, a system can be created for a system that can deliver huge power while not comprising energy density. Specifically, the team will use supercapacitors to accelerate the bogie up to speed, and the lithium ion batteries will maintain bogie speed during cruise. With a few assumptions, a power calculation to move the bogie to its desired specifications has been completed. This calculation can be used in small scale applications, as well as real-word applications. It is obtained from last year's team.

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

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.

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

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

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

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

For the scope of this project, the team used the following assumptions listed below. Kinematics calculations was done to calculate the time needed for each process. The complete datasheet for the power calculation is listed in Appendix B. The estimated power curve for this project is shown in Figure 2.

Parameters	Values
Wheel Radius (R)	0.254 m
Mass of Bogie (m)	100 kg
Total Track Length (s)	10 m
Desired Acceleration (a_{max})	2.45 m/s^2
Density of Air (ρ)	1.125 kg/m^3
Drag Coefficient (C_D)	0.51
Frontal Area (A_f)	4 m^2
Wind Speed (v_w)	3.576 m/s

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

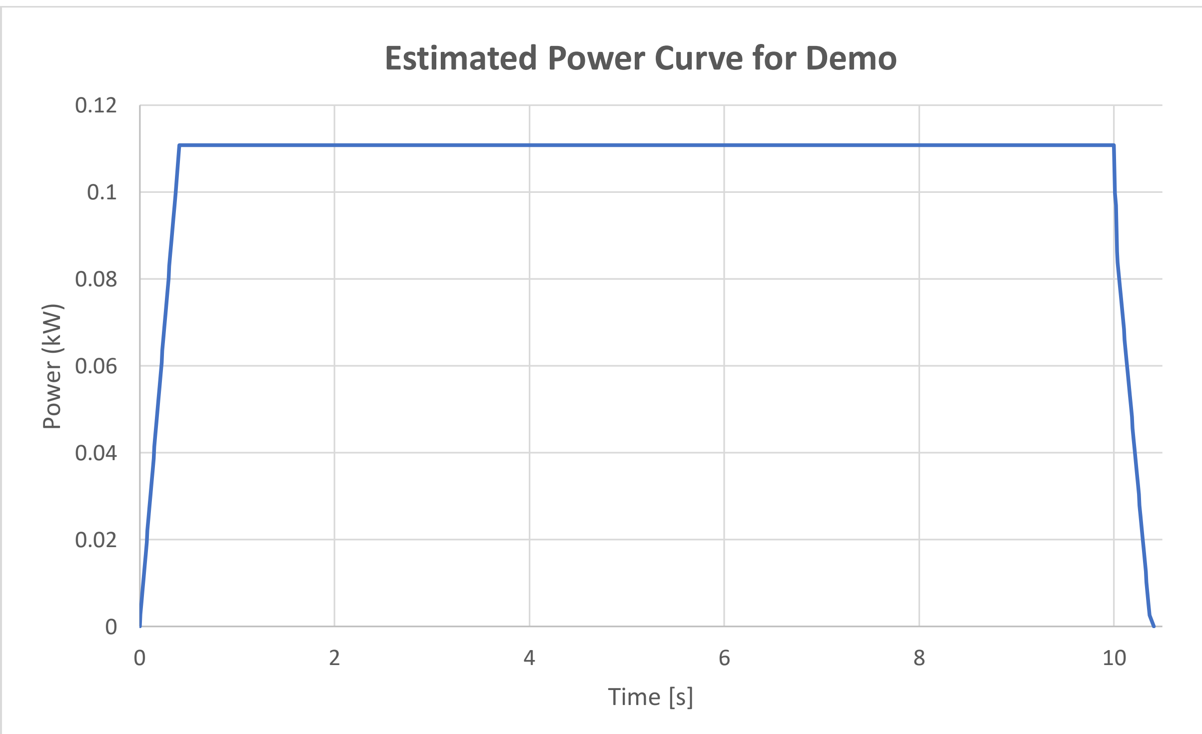

Figure 4: Estimated Power Curve for SPARTAN Superway Demo

10.2 Energy Storage Design Specifications

10.2.1 Supercapacitor Calculation

As previously mentioned, supercapacitors have a large power density. Compared to batteries, supercapacitors can deliver power 10 times faster. This can be achieved, as it stores energy in a magnetic field. Also, because no chemical reactions take place, the charge and discharge cycles are higher compared to batteries, meaning it will last longer than batteries.

This year, the Power Modules team will be using Maxwell BCAP0350 Supercapacitors. Each capacitor has a rated voltage of 2.7V with capacitance of 350 Farads. To achieve larger energy density, a string of capacitors needed to be connected in series.

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

In contrast, the capacitance is reduced as we connect them in series:

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

Capacitance linearly corelate to energy stored in a capacitors.

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

Ideally, the value of the capacitance is desired to be increased by connecting strings of it in parallel to achieve higher energy density. Yet, when considering the constraint of the demonstration, a bigger energy density is not needed. Each electrical component has some form of resistance. While supercapacitors have low ESR (Equivalent Series Resistance), it will be useful to consider them in simulations.

10.2.2 Supercapacitor Charging Curve

The charging model of the supercapacitor pack is modelled as below.

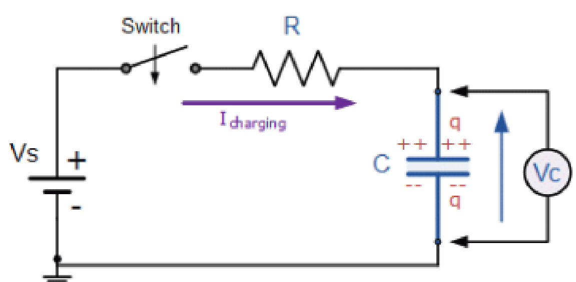

Figure 5: Supercapacitor RC Charging Circuit

Using these formulas, the team was able simulate the time needed to charge the pack. The voltage source is modelled as the charger we are going to used. The charger was provided in the previous year by Howland Technologies. Since the charger functioned well last year, no reason to research and acquire a new one was deemed necessary. It is a 1200 W charger with AC input and has 3 charging profile: 24V, 36V, and 48V. It was decided that using a charging profile from 36V and 33.3 Amps was appropriate. With this configuration, the team is confident that the pack can be charged in less than 120 seconds.

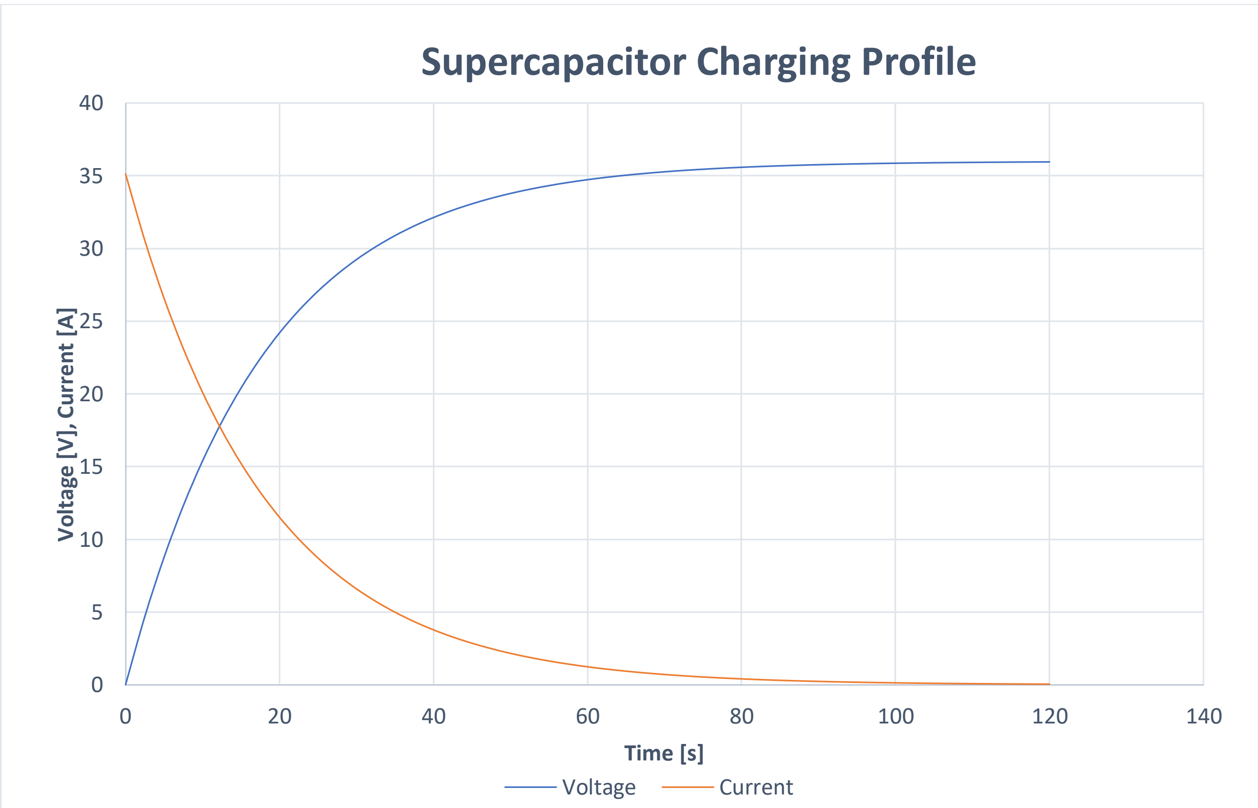

*Figure 6: Supercapacitor Charging Profile. (***Full Data set can be seen on Appendix A)**

10.2.3 Lithium-Ion Battery Calculation

While supercapacitors can deliver a significant amount of power in a short amount time, its energy density is too small for real world application. In real world applications, the system must be able deliver constant power for a long period of time. For this reason, the team incorporated a lithium ion battery into the system. This year, a Samsung IDE 18650-25R lithium-ion battery will be used. Each cell has a rated voltage of 3.7V and capacity of 2500 mAh. The universal unit for capacity of battery is in mAh. This term represents how much current (Amps) the system can supply in an hour. To create a pack with bigger voltage bank, 3 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.

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

10.3 Supercapacitor and Lithium-Ion Batteries Circuit Design

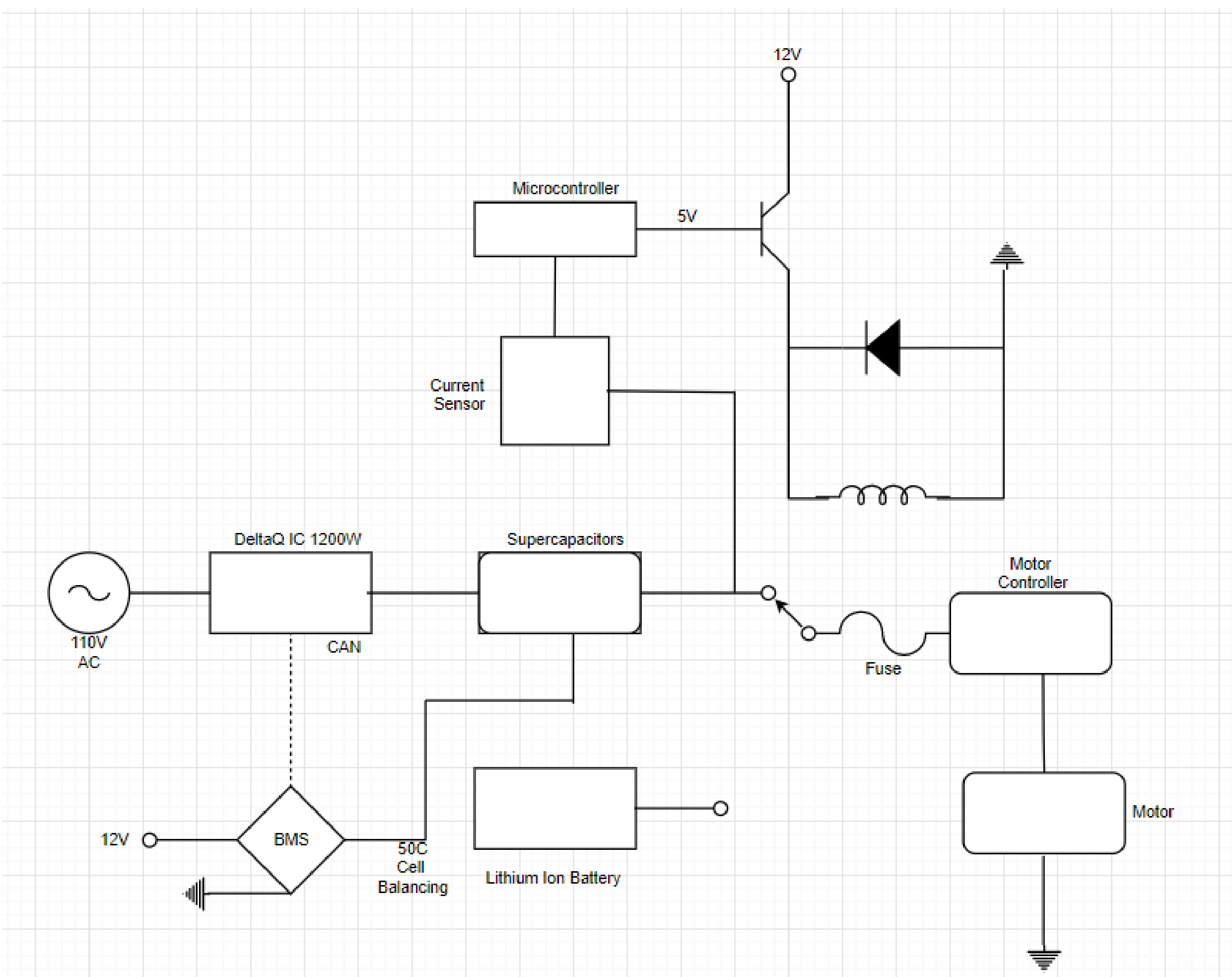

Figure 7: Circuit Design for Power Modules system.

Starting from 110-220V AC Outlet, the DeltaQ Charger can only work with AC source. The charger will the convert it to a DC signal at 1200W and 25A max. The DC output will be hooked up to the positive and negative third rail. A current pickup mechanism will then transfer power to the supercapacitors via pickup mechanism designed by SPARTAN Superway Wayside Power Team. As the capacitors are charged, a current balancing method will be completed to avoid overcharging of each cell. Also, a Battery Management System (BMS) will be connected to the supercapacitors to monitor the state-of-charge (SOC) of each cell. As the capacitors are fully charged, its energy will be transferred to power a motor controller. In between these two systems, a current sensor will be used to monitor the current output of the capacitor pack. As mentioned earlier, supercapacitors will only be used to accelerate the bogie up to speed, while the lithium-ion batteries will maintain the cruising speed. In order to switch between supercapacitors and batteries, a 12V industrial grade relay will be used. The current sensor will send its data to an Arduino which will control the relays. Since the Arduino can only output low level signal (5V), a transistor and 12 V power supply are connected to energize the coils inside the relays. Unlike the supercapacitors, the lithium-ion batteries will be pre-charged since charging the batteries on-board aren't possible. Since the motor has not been determined, the team decided to add a DC-DC Converter to control motor input.

10.4 Current Housing Design Description

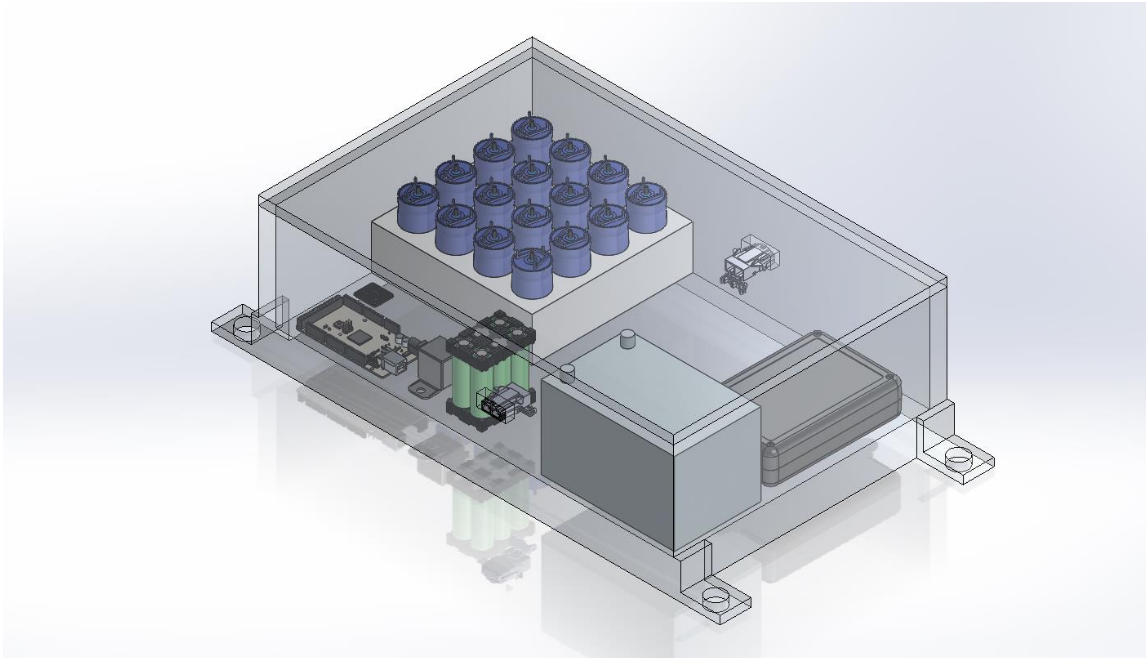

Figure 8: Power Module Rendering which includes Supercapacitors, Lithium-Ion Batteries, Battery Management System (BMS), 12V Lead-Acid Battery, Arduino, Industrial Grade Relays, Current Sensor, and Molex Connectors.

10.5 Power Module Finite Element Analysis

Since the beginning of this project, it has been decided to have a minimum factor of safety of 10. The power module is constructed using 6061-T6 Aluminum Alloy to ensure rigidity. The estimate load for this analysis is 10kg, which account for all storage devices and safety components. The power module is fixed at all corner using bolts and nuts.

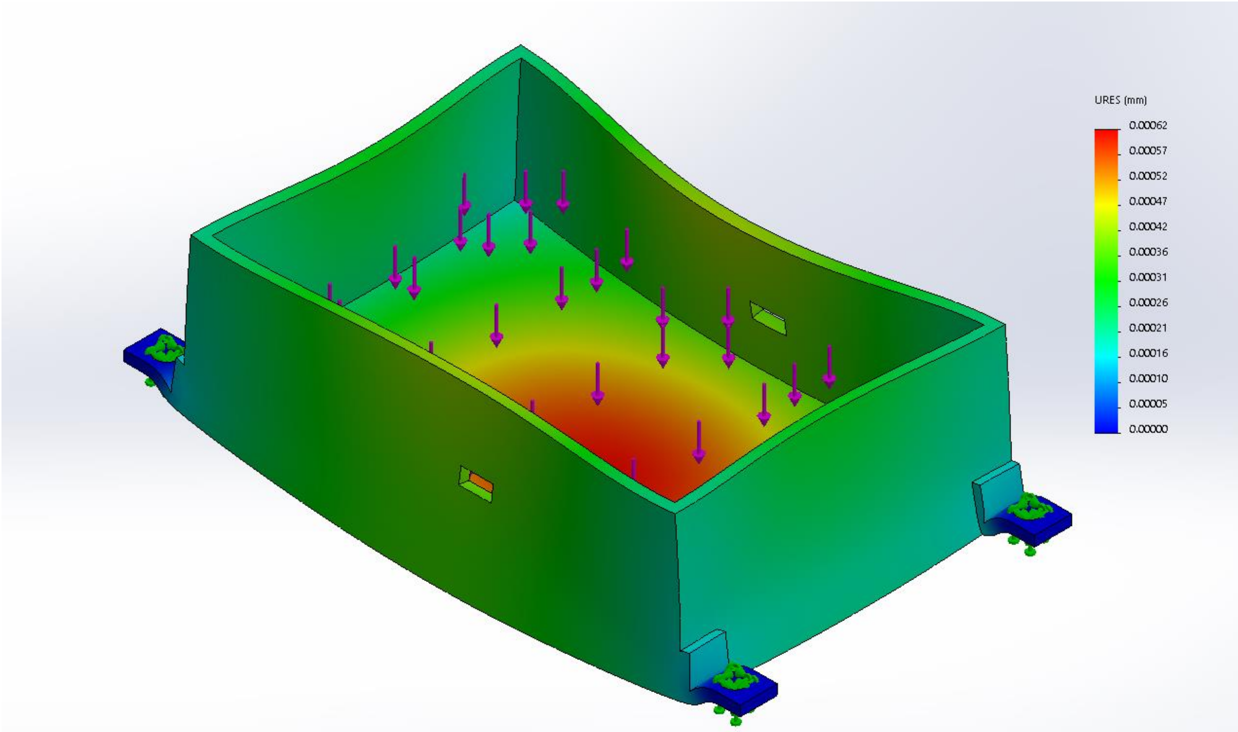

Figure 9: Finite Element Analysis that describes the deflection of each point.

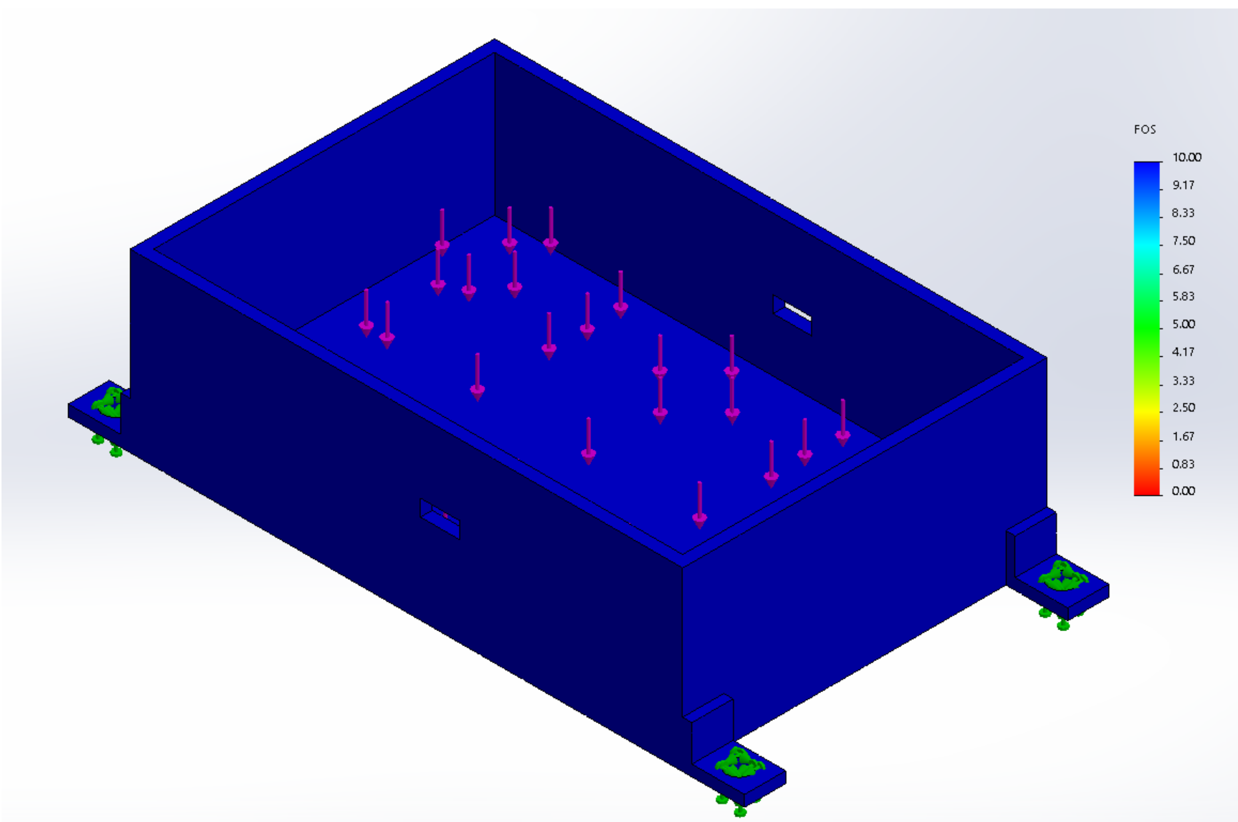

Figure 10: Finite Element Analysis that describes the factor-of-safety (FOS) of each point.

10.6 Printed Circuit Board (PCB) Design

Last year's Power Modules/Wayside Power Team used a complex system of wiring to connect the different electrical components in their design. This includes wiring for the BMS, the battery, the supercapacitor cells, and other components. For this year's design, a printed circuit board (PCB) was decided to be used to reduce the amount of wiring required, and to make serviceability easier.

The first step for designing the PCB is to design the schematic for the board, and decide which and what components will be present on the board, along with appropriate connectors and pad connections. A series of 16 supercapacitors will be used for the design, which are connected to a power source, and wired to a BMS for monitoring. The schematic is not indicative of where the components for the PCB will be placed physically, but shows how the components are wired and connected, as shown below in Figure 9.

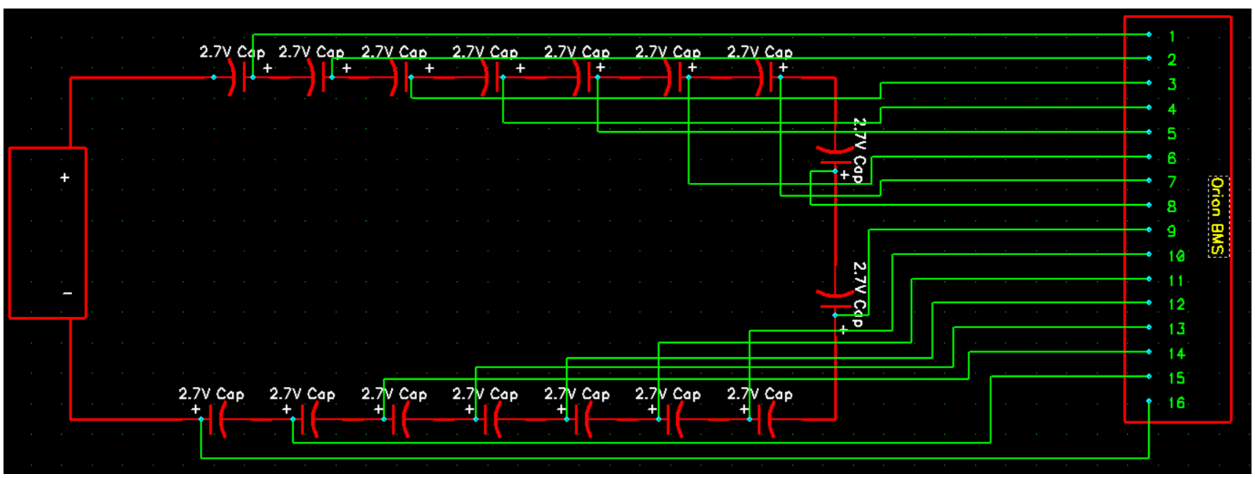

Figure 11: PCB schematic, with 16 supercapacitors wired in series to a power source, and connected to an Orion BMS.

The PCB design will follow the schematic strictly for wiring of components to their appropriate connections. The design is still under development, but once the schematic has been completed to satisfaction, proper wiring of the components will begin on the PCB before being checked for shorts. A short refers to a short circuit, or when there is a low resistance connection between two conductors, which then causes an excess of voltage and flow of current. The PCB design file will then be sent to a PCB fabricator for fabrication once approved.

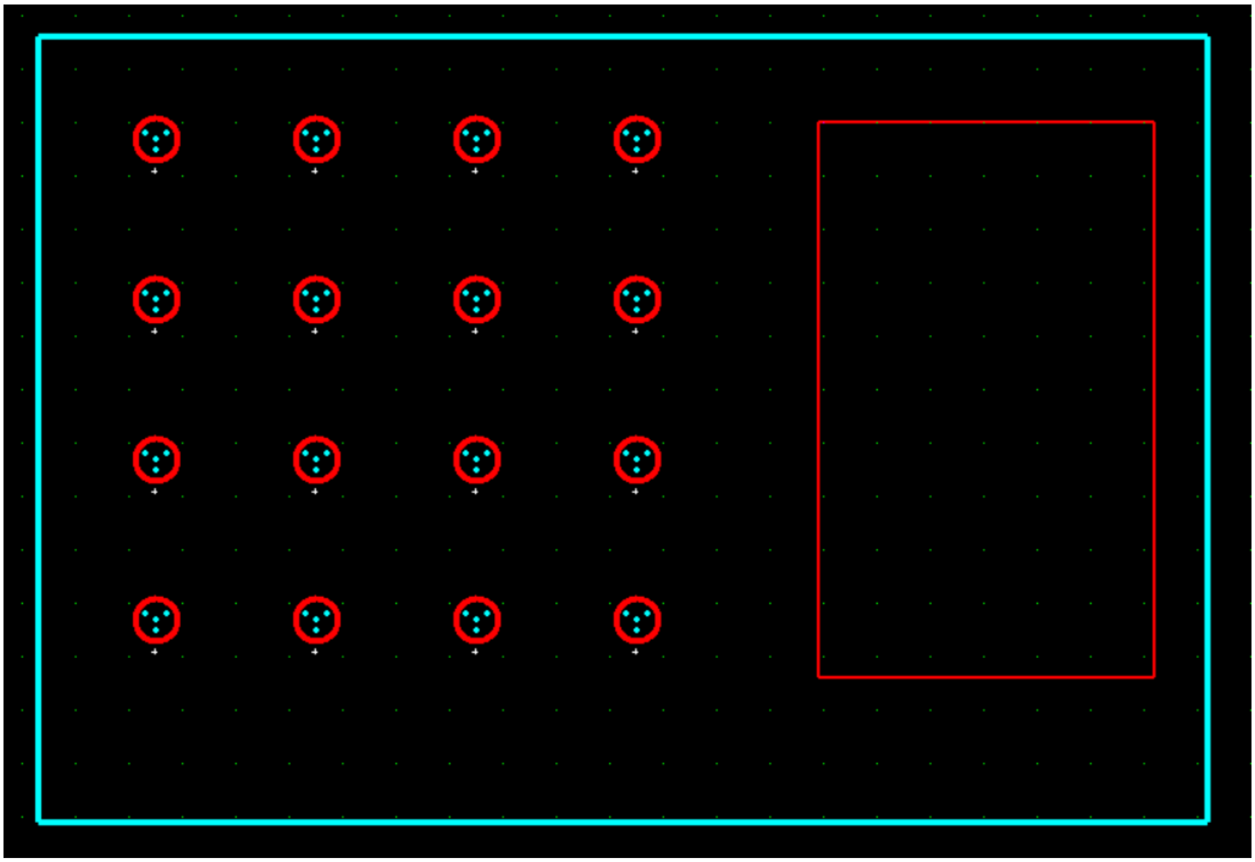

Figure 12: PCB design with 16 supercapacitors placed on the board. Appropriate wiring and connections are not present.

11. ***Conclusion and Recommendations***

The SPARTAN Superway project aims to reduce the amount of greenhouse gas emission from the transportation industry, and reduce the amount of traffic congestion on city roads. During the course of the semester, research of supercapacitor technology was conducted to better become familiarized with the topic, and how the technology is being developed and implemented in other areas of the world and how to apply them to benefit our needs. CAD designs were made for the housing of the supercapacitors, battery and any other necessary components needed for the power module were made. Simulations of the supercapacitors were conducted, along with tests for lithium-ion batteries to determine the proper amount of supercapacitors and batteries. Design of the PCB began with the design of the schematic for the board.

For the next semester, the focus will be on the fabrication and construction of the power module housing based on the CAD drawings will begin. The PCB will also be fabricated and the supercapacitors installed. Parts will be bought to construct the housing and connect the supercapacitors and various other components that will be contained inside the housing. However, learning to use the charger and BMS will prove to be the most difficult, since they come with their own software that we are not familiar with using.

12. References

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13. ***Appendices***

Appendix A: Supercapacitor Charging Data

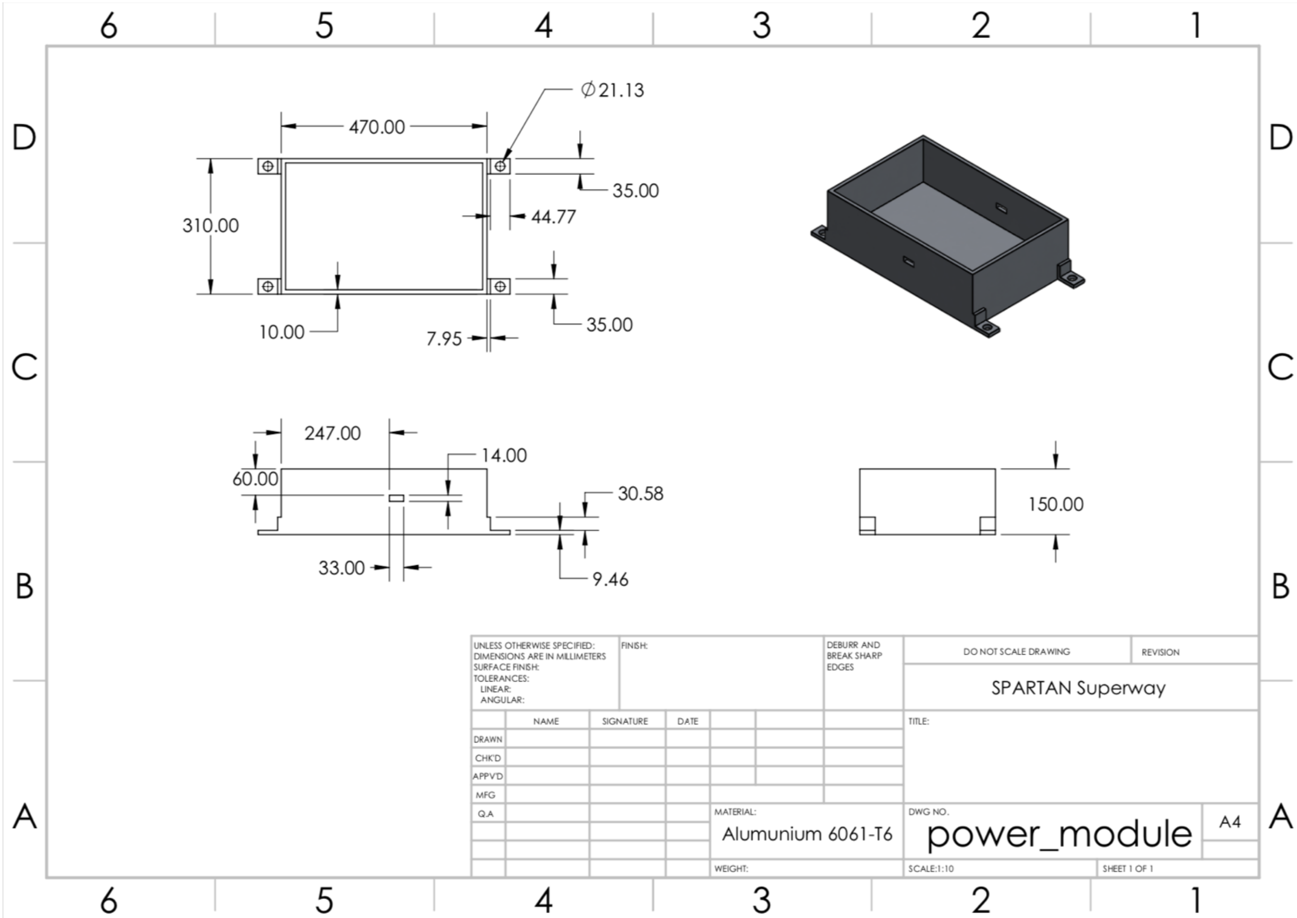
RESULTS		
Time [s]	*Bogie Voltage [V]*	Current [A]
0	0	35.1305196
2.5	4.68453345	30.5591281
5	8.75948763	26.5825932
7.5	12.3041846	23.1235085
10	15.3876246	20.1145405
12.5	18.0698291	17.4971172
15	20.4030093	15.2202886
17.5	22.4325822	13.2397344
20	24.198055	11.5169017
22.5	25.7337941	10.0182541
25	27.0696937	8.71461951
27.5	28.2317581	7.58062155
30	29.2426078	6.59418612
32.5	30.1219197	5.73611153
35	30.8868104	4.98969469
37.5	31.5521689	4.34040603
40	32.1309471	3.77560666
42.5	32.6344112	3.28430234
45	33.0723616	2.85692944
47.5	33.4533232	2.48516884
50	33.7847119	2.16178394
52.5	34.0729783	1.8804798
55	34.3237338	1.63578062

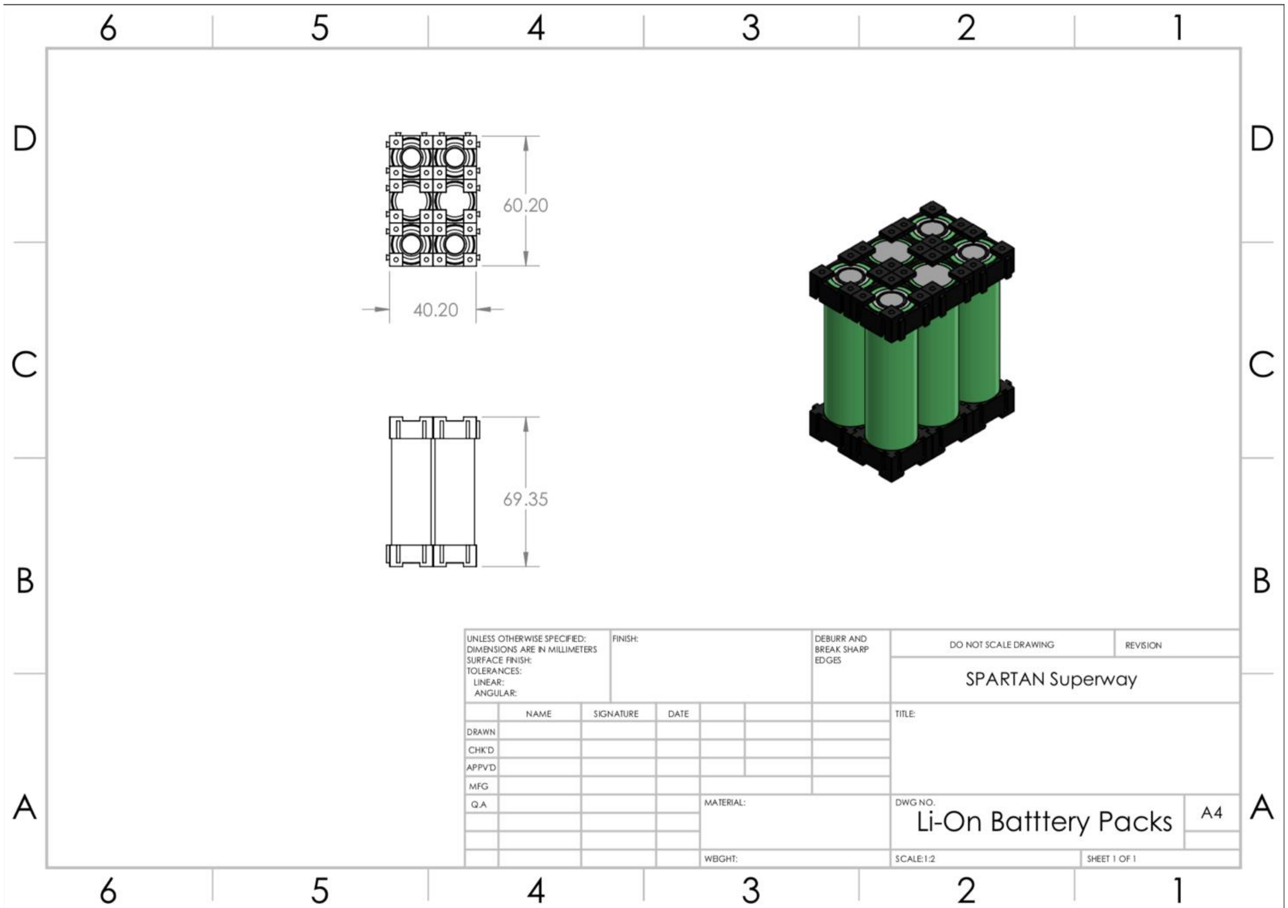
57.5	34.5418595	1.42292314
60	34.7316014	1.23776395
62.5	34.8966529	1.07669876
65	35.040227	0.93659234
67.5	35.1651184	0.81471739
70	35.2737581	0.70870153
72.5	35.368261	0.61648109
75	35.4504666	0.53626091
77.5	35.5219752	0.46647946
80	35.5841786	0.40577839
82.5	35.6382877	0.3529761
85	35.6853559	0.30704476
87.5	35.7262992	0.26709027
90	35.7619148	0.2323349
92.5	35.7928959	0.20210211
95	35.8198455	0.17580338
97.5	35.8432883	0.1529268
100	35.8636805	0.13302706
102.5	35.8814192	0.11571679
105	35.8968497	0.10065904
107.5	35.9102722	0.08756069
110	35.9219481	0.07616677
112.5	35.9321047	0.0662555
115	35.9409396	0.05763394
117.5	35.9486249	0.05013427
120	35.9553101	0.0436105

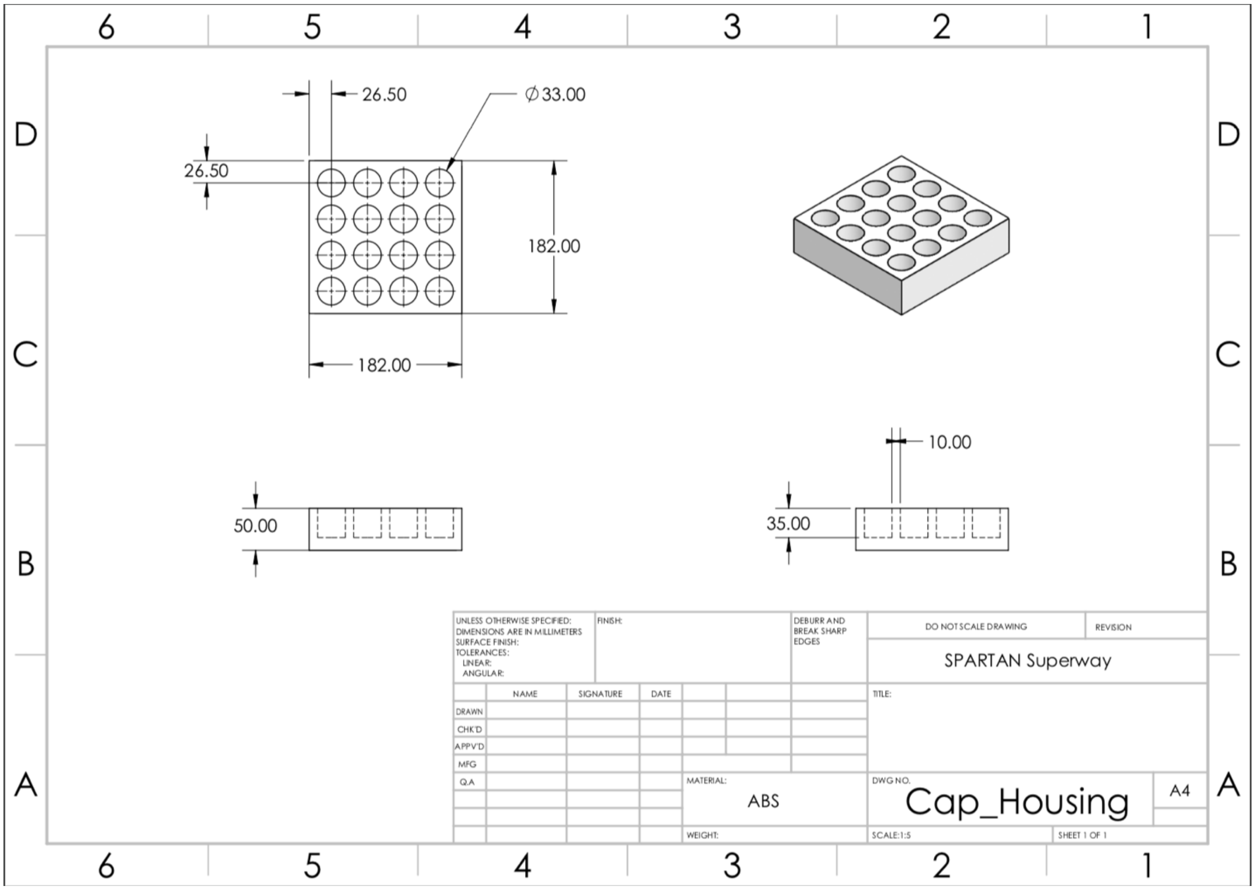
Appendix B: Bill-of-Materials

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)	1	$7.64	$7.64
17-Nov-19	Bestol 200pcs 18650 Battery Cell Holder Safety Spacer	1	$21.84	$21.84
	Samsung SDI 18650-25R Li-on Battery	6	$2.89	$2.89
	Terminal Blocks	1	$3.47	$3.47
	Fuse 50/100A	1	$2.04	$2.04
	12 V Automotive grade Relay (OMRON #G8JN-1C7)	2	$4.48	$4.48
	npn Transistor	1		
	Diode	1		
	Molex - 428160212	1		
	Current Sensor (CJMCU - 219 INA 219)	1		
	Molex - 428180212	1		
	Arduino	1		
	Li-On battery Smart Charger	1	$58.99	$58.99
	Total Expenses			$175.63

Appendix C: Part Drawings

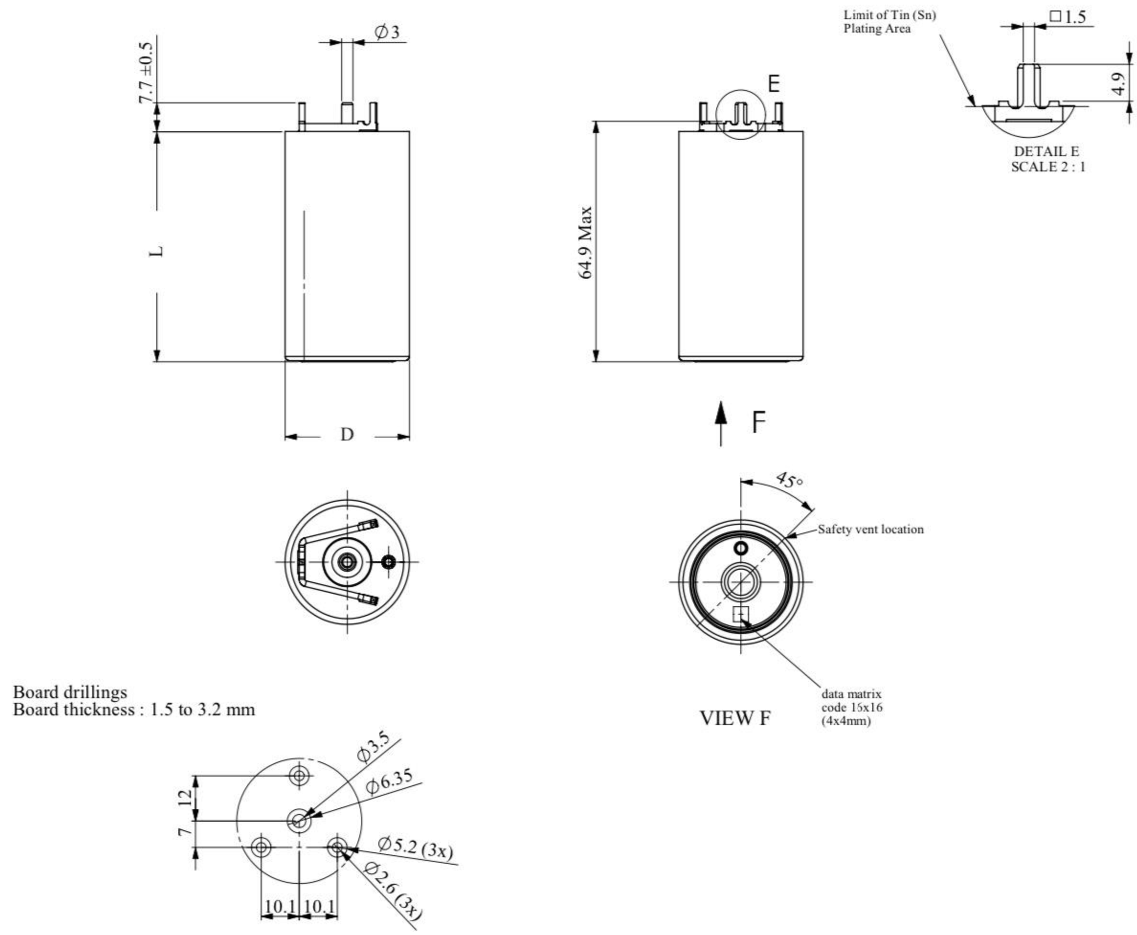



60.20
40.20
69.35
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
SPARTAN Superway
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Li-On Batttery Packs
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1


6
5
4
3
2
1
D
C
B
A
26.50
Ø33.00
26.50
182.00
182.00
10.00
50.00
35.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
SPARTAN Superway
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
ABS
DWG NO.
Cap_Housing
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1

Appendix D: Maxwell Supercapacitor BCAP0350

BCAP0350 E270 T11



Appendix E: Power Sonic PS-12120 Lead Acid Battery

POWER PS SONIC
TRUSTED BATTERY SOLUTIONS

PS SERIES

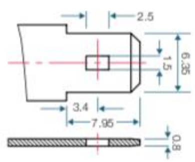
General Purpose | Emergency Lighting | Medical | Fire & Security

PS-12120 12V 12.0 AH @ 20-hr. 12V 11.0 AH @ 10-hr.

Rechargeable Sealed Lead Acid Battery
PS – General Purpose Series

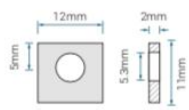
TERMINALS: (mm)

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

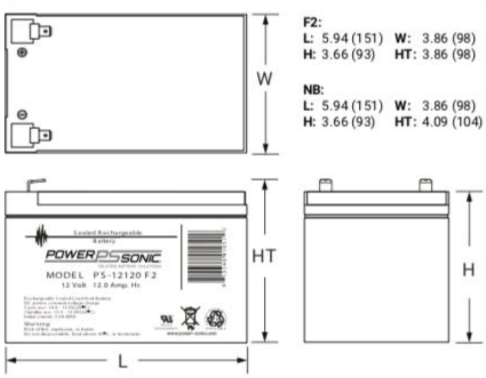
FEATURES

- 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

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F: +1 (619) 661 3650
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(EMEA – EUROPE, MIDDLE EAST AND AFRICA)
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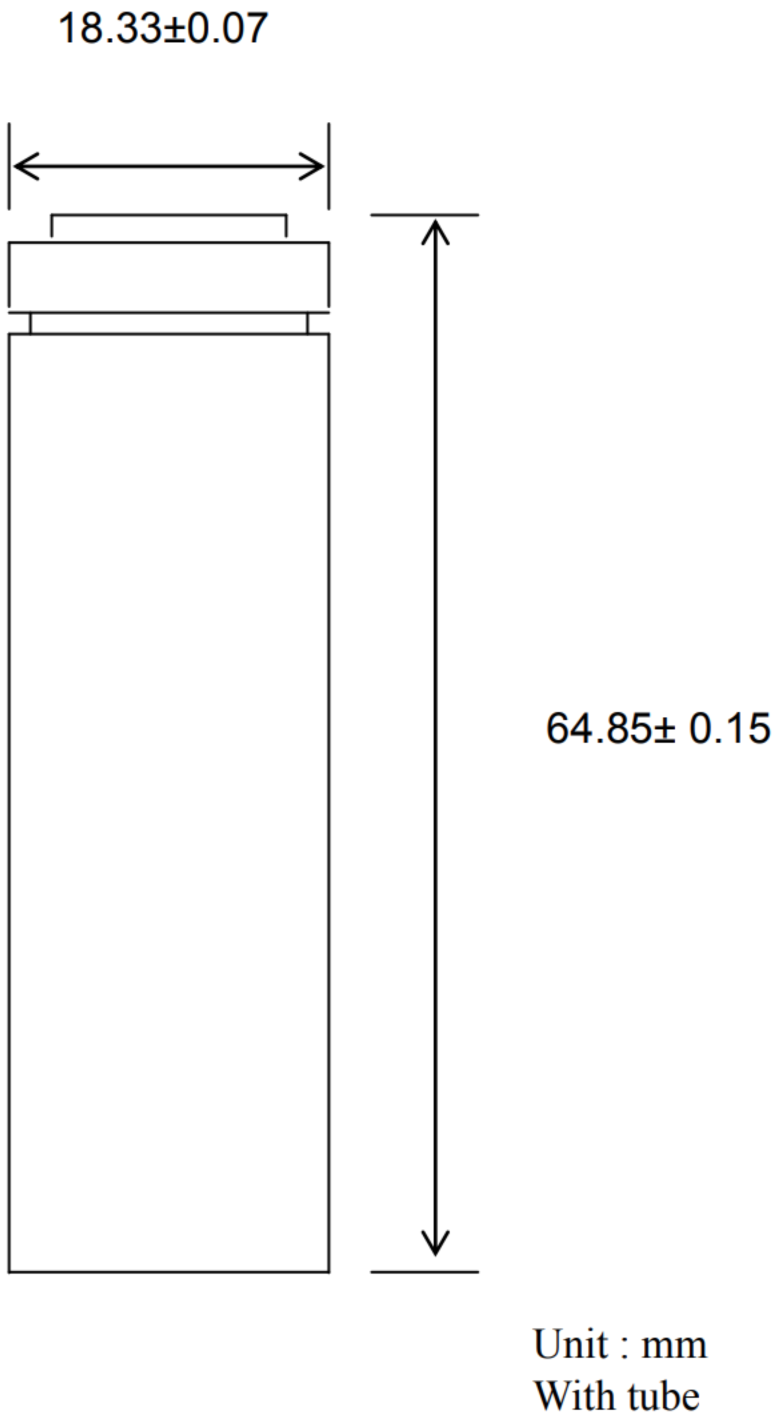
power-sonic.com

Appendix F: Samsung SDI INR18650-25R Lithium Ion Battery

Nominal Specifications:

Item	Specification
3.1 Nominal discharge capacity	2,500mAh Charge: 1.25A, 4.20V,CCCV 125mA cut-off, Discharge: 0.2C, 2.5V discharge cut-off
3.2 Nominal voltage	3.6V
3.3 Standard charge	CCCV, 1.25A, 4.20 ± 0.05 V, 125mA cut-off
3.4 Rapid charge	CCCV, 4A, 4.20 ± 0.05 V, 100mA cut-off
3.6 Charging time	Standard charge : 180min / 125mA cut-off Rapid charge: 60min (at 25℃) / 100mA cut-off
3.7 Max. continuous discharge (Continuous)	20A(at 25℃), 60% at 250 cycle
3.8 Discharge cut-off voltage End of discharge	2.5V
3.9 Cell weight	45.0g max
3.10 Cell dimension	Height : 64.85 ± 0.15mm Diameter : 18.33 ± 0.07mm
3.11 Operating temperature (surface temperature)	Charge : 0 to 50℃ (recommended recharge release < 45℃) Discharge: -20 to 75℃ (recommended re-discharge release < 60℃)
3.12 Storage temperature (Recovery 90% after storage)	1.5 year -30~25℃(1*) 3 months -30~45℃(1*) 1 month -30~60℃(1*)


18.33±0.07
64.85± 0.15
Unit : mm
With tube

Appendix G: 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.

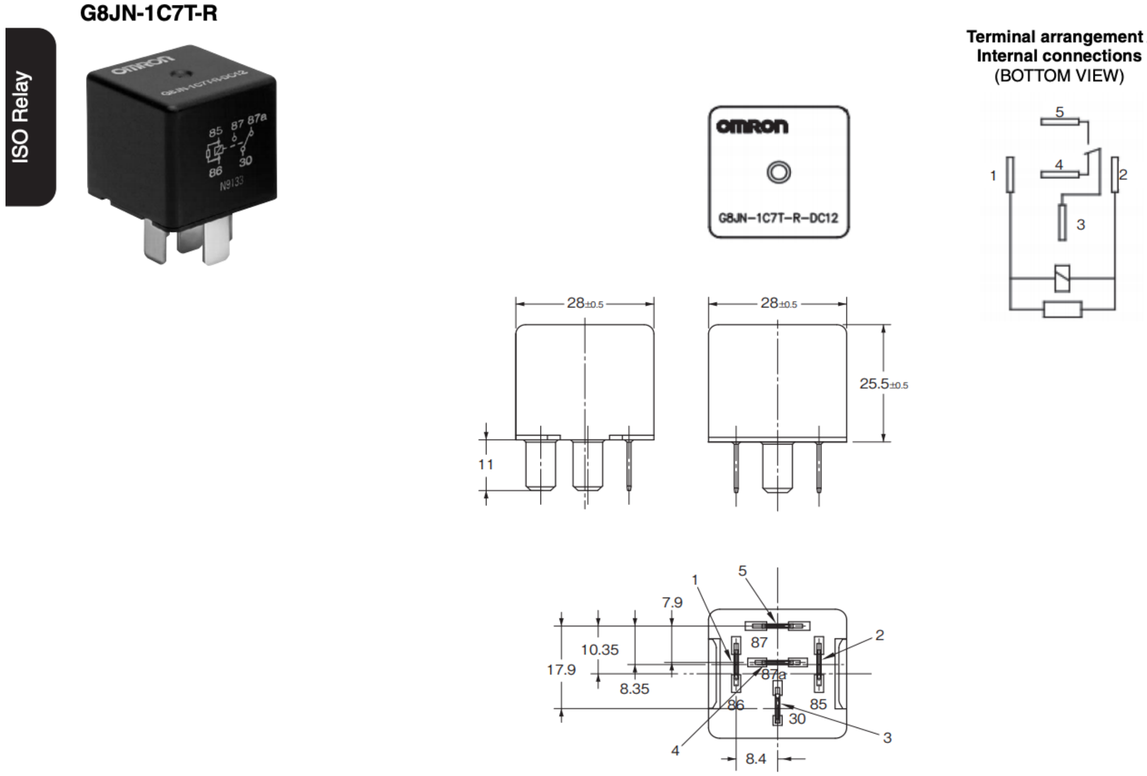
Ewert Energy Systems is a research and development company focused on developing solutions for plug-in hybrid and electric vehicles and other energy storage applications.

EWERT ENERGY SYSTEMS

Appendix H: Omron G8JN0-1C7T 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

G8JN-1C7T-R



* 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 I: Molex 428160212 Connector

molex
one company › a world of innovation

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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

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