Formula SAE Power Distribution Controller

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Abstract:

The Power Distribution Controller senior project aims to replace the current Power Distribution Module (PDM) on Cal Poly's Formula SAE internal combustion vehicle with a more advanced, configurable, and reliable system. The Power Distribution Controller will be a MOSFET based system that can be controlled through either controller area network or a parallel interface to distribute and control power from the vehicle's battery to the several electrical devices on the car. The Power Distribution Controller will also feature data collection capabilities on output voltage and current, and communicate this data to the vehicle's data logger. This will allow engineers troubleshoot electrical problems on the car by looking through log files, and also detect possible sources of electrical failure before the devices fail. Finally, the Power Distribution Controller will be highly configurable and adaptable to any surrounding electrical system by being updatable through firmware rather than hardware.

The Power Distribution Controller is in large contrast the PDM on the car currently. The PDM uses a network of relays and fuses, which is the traditional method of distributing power in production vehicles, however, not ideal for a prototype race car that has frequent changes to the electrical system. In order to adapt the current PDM to new electrical system improvements, the outputs of the PDM must be used in ways otherwise intended by the original design. In some cases, the PDM requires hardware upgrades to be used in new surrounding electrical systems. The Power Distribution Controller solves this issue by using firmware updates to reconfigure the behavior of the outputs. Furthermore, the PDM uses heaving and power inefficient relays to switch the outputs. The Power Distribution Controller aims to solve this issue through the use of power efficient and light weight MOSFETs. Additionally, the PDM contains no data collection capability. This directly affects the significant amount of time engineers spend finding and troubleshooting electrical failures on the car.

Overall, the Power Distribution Controller will be smarter, more configurable, lighter, and more power efficient than the existing solution on the Formula SAE car.

1. Background and Introduction

Background:

Formula SAE is an engineering competition in which "teams are to assume that they work for a design firm that is designing, fabricating, testing and demonstrating a prototype vehicle for the nonprofessional, weekend, competition market [1]". As an engineering project, Formula SAE teams have extensive electronics systems to control the engine, as well as collect kinematic data to tune and improve designs. At the center of the electronics systems is a power distribution circuitry to deliver power to several electronic devices.

Figure 1.1: Cal Poly Racing 2016 Formula SAE car

Historically, Cal Poly Racing has used relays and fuses to distribute power and protect circuits as seen in figure 2. While this is the typical method of power distribution for production vehicles due to simplicity and cost, this is an atypical solution for racecars. Racecars generally use power distribution controllers which have digital inputs as well as digital outputs in order to control, distribute, and protect circuits as seen in figure 3.

Figure 1.2: Typical Production Vehicle power distribution circuitry

Figure 1.3: Typical racecar power distribution controller

Racecars use digitally controlled, solid state, power controllers as depicted in figure 3 for several reasons. First, the digital input and output controller allows for a much more controllable, and versatile system than its analog counterpart as seen in figure 2. Secondly, when circuits fail and draw too much current with a traditional relay and fuse style power distribution system, the fuse blows, and the circuit is unusable until the fuse is replaced. This could be detrimental to a racecar's operation and performance in the middle of a race. A digital power distribution controller is able to attempt to restart the circuit after the overcurrent condition, and can determine if a circuit should be left on or shut down after analyzing the failing circuit's impact to the car's operation, safety, and potential electrical system damages. Thirdly, and finally, racecars utilize digital power distribution controllers because racecar electrical systems undergo several modifications throughout a racing season, and major modifications between seasons. With analog power distribution circuity, when modifications are made to the surrounding electrical system architecture, hardware such as relays and fuses are required to be added to the power distribution circuity to support the new system architecture. With a digital power distribution controller, when a change is made to the surrounding electrical system architecture, a wire may need to be added going to the power controller, but toggling and controlling the output(s) can be modified in firmware, leading to a much faster and more reliable implementation.

Product Description:

The Formula SAE Power Distribution Controller (PDC) is a solid-state power controller for prototype racecars. Racecars aim for lightweight, small, reliable, and efficient products. This power controller takes advantage of lightweight solid state electronics to replace power inefficient, large, and heavy relays and fuses. The CAN interface of this product also contributes to a very clean device implementation. The primary customer of the product, Cal Poly Racing Formula SAE, sees the greatest improvement in lap times with more testing time for the car. When electrical devices fail on the vehicle, engineers have a painstaking process of continuity testing, checking fuses, and testing relays to determine the source of the problem, all of which takes away time from testing. The PDC solves this issue by logging output currents and voltages to detect problems before devices fail, and locate the source of the electrical problem quickly when devices do fail. This will decrease the amount of time troubleshooting, and more time on the track.

Racecar electrical systems can best be described as prototypes that undergo several modifications and revisions within a season. Because power distribution circuity sits at the center point of this architecture to deliver power to all electrical devices, it needs to be changed frequently to work with the modifications and revisions of the surrounding system. Traditional fuses and relays require hardware changes in order to support changes in the vehicle's electrical system. This also requires revalidation of hardware reliability, and often compromises in reliability. The PDC solves this issue by being able to change input and output relationships through firmware updates, making this product highly configurable. Finally, formula SAE teams cannot afford programmable solid state power controllers from well-known suppliers such as Motec. These products have a significant amount of development cost and are highly priced in the market due to the convenient user interface they have for configuring inputs and outputs. The Formula SAE power controller lowers cost by acknowledging that our customers have technical knowledge to program firmware into the power controller. This removes development cost of the user interface, and decreases the price of the product in the market, ultimately saving customers thousands of dollars.

Table 1.1: Market research and competing products [2] [3] [4]

Picture	Product Name	Price	Pros	Cons
	Motec PDM15	$1636.53	• Small • Light weight • Developed User interface for modifying settings	• Expensive • Limited configurations based on user interface
	Motec PDM16	$2463.55	• Small and light weight • Durable • High quality components • Developed user interface	• Expensive • Expensive mating connectors (~$150 per connector) • Limited Configurations based on user interface
	Cartek Power Distribution Module	$272.74	• Inexpensive and affordable • Very small and light weight	• Too few outputs (may require purchase of 2 modules) • Outputs too low of current rating • Not configurable

2. Customer Archetype

The customers for the Formula SAE Power Distribution Controller are Formula SAE teams. These teams consist of full time students, mostly engineers, who also build Formula SAE cars in their spare time. The users and influencers on the team are typically electrical or computer engineering students who are in charge of designing the electrical systems for the teams' vehicle. These students typically have technical aptitude and programming knowledge. However, the short timeline to design, manufacture, and test the Formula SAE car, in combination with the limited amount of spare time an engineering student has, often leads to the users and influencers looking for suitable off-the-shelf solutions that can be implemented quickly. The buyer on the team is typically a student and the team manager. This individual controls a very tight budget, as Formula SAE teams are often reliant on donations and sponsorships. The predesigned hardware and open source firmware of the Power Distribution Controller is an excellent solution for the users and influencers because the product is incredibly adaptable and offers the user full control over the inputs and outputs, while also saving time on the design and implementation. This product appeals to the buyer on the teams because it is reasonably priced. When the influencer asks the buyer to purchase a product, the more expensive the product is, the more the influencer must convince the buyer that the money spent will improve the overall performance of the vehicle at competition. Teams that will be seeking to purchase this power distribution controller will generally be newer teams, small teams, and teams just starting out in developing electronics. Teams that are well established in the Formula SAE competition series often have a custom designed power controller already.

Pain relievers and gains:

The Formula SAE power distribution module solves both technical and management pains for Formula SAE teams. From a technical standpoint, because the Power Controller utilizes solid state electronics, it is more robust and more reliable than traditional fuse and relay systems. Additionally, because of microcontroller on the power controller, electrical circuits will only be turned off in competition if the circuit is a risk to safety, or any other criteria set by the team, not just a simple overcurrent criteria set by traditional fuses. The microcontroller will also allow for analysis of the electrical system and enable faster troubleshooting when problems do arise. The more time spent testing the vehicle and less time troubleshooting problems, directly translates to a better performing car at competition. From a management standpoint, this product solves the problem of teams having to choose to spend a significant amount of time designing a power distribution system, or spending a significant amount of money purchasing one. This product offers a nice compromise to the two solutions by providing low cost hardware, but also requiring a small amount of time configuring the open source firmware so that the hardware integrates nicely with each team's car.

For teams that have previously used relays and fuses for power distribution, teams will see significant gains in electrical system control, and see gains in optimizing electrical systems by collecting data from the power distribution controller. These teams will also have gains by obtaining more reliable system while having a faster design and implementation than designing their own fuse and relay system or custom power controller.

Market Leaders:

Motec created the market for aftermarket digital power distribution modules. They are the market leader for intelligent power distribution modules for motorsports. They mostly serve professional and Semiprofessional markets

Littelfuse is the market leader for relay and fuse based power distribution modules. Littelfuse sells modular systems in which different configurations of relays and fuses can be used to distribute power. They mostly serve the aftermarket truck, commercial, and industrial markets.

Market Size:

There are currently 521 SAE collegiate chapter clubs and branches worldwide [5] [6]. Of these teams, the top 30 teams most likely have well developed electrical systems and power distribution systems. Additionally, the 100 least competitive teams most likely have underdeveloped electrical systems, and will not be in the market for a new power distribution controller as of now. This leaves 381 teams that may be interested in purchasing a power controller. Initially, we can target the 275 North American teams that are not in the top 30 or bottom 100 teams.

3. Market Description

Detailed Product Description:

The Formula SAE Power Distribution provides four 12 volt 20 Amp maximum switchable outputs, and eight 12 volt 5 Amp maximum switchable outputs. The controller also has six digital inputs, and a CAN interface that can be used as an input to the system, and a data output which sends data about output currents, voltages, and warnings to the car's data logger. Most importantly, this product will be low cost due to significant development into hardware, and then creating a minimally developed software platform that can be improved by individual teams by making it open source.

The power controller will use solid state electronics, such as MOSFETs, and a microcontroller in order to turn circuits on and off based on user inputs, and configurable current limits. The power controller will also use a high quality and low cost automotive connector to ensure a reliable interface between the power controller and surrounding electrical system. The power controller will also be water resistant and have a durable build in order to be reliable in the harsh environment of an open wheel autocross car.

Limitations of Competitors

The two key competitors for this product are Littelfuse and Motec. Motec does not have limitations on their product that would be problematic to a Formula SAE team. Their systems are designed to power electrical systems for professional and semiprofessional racecars that are much more extensive than a Formula SAE car's electrical system. These features come at a price that is far too expensive for the vast majority of Formula SAE teams. Littelfuse is the leader in providing analog power distribution modules. While these systems are affordable, they often lack the feature set desired by Formula SAE teams. The limitations of Littelfuse systems is that once a fuse blows, the electrical circuit cannot be reset immediately, which could lead to a poorly performing racecar. Additionally, multiple criteria cannot toggle an output on the Littlefuse system without the addition of external controllers.

Key Areas of Strength

The Formula SAE Power Controller has two key areas of leverage. First, the system is affordable for most Formula SAE teams and other amateur race teams. This is in contrast to the overpriced Motec system. The second area of leverage is that the Formula SAE Power Controller is versatile, configurable, and adaptable through open source firmware. This is in contrast to the Littelfuse system. Overall, the combination of these two strengths offers leverage over Motec and Littelfuse in the target market.

Market Area Not Well Served and Window of Opportunity:

The window of opportunity in this market is to create a low cost solution for power distribution that provides a set of features sufficient to amateur and semi-professional racecar drivers, but that also is low cost. The current solutions are either low cost and do not have a sufficient set of features, or the systems are too expensive and are priced out of a large sector of the market.

Effort to Enter Market

Table 3.1 shows a cost breakdown of the effort to enter the market. Two prototype boards must first be made. Then once the beta prototype is finalized, five Power Controllers must be made for manufacturing validation and testing. Due to the harsh environment of the racecar, including heat, vibration, and impact, testing costs are very high in order to have a piece of hardware that is professionally tested. The most expensive cost of bringing the product to market is tooling for the plastic enclosure because molds are expensive. Tooling costs for PCBs will be minimal due to tooling costs already associated with the prototypes and pre-market builds. Finally, marketing will primarily be done through strategic partnerships, public forums for Formula SAE teams, and social media, however, a small website will be setup and maintained for those looking for further information on the product. Overall, the cost of entering the market is $11,700.00.

Table 3.1: Cost to enter the market

Category	Cost	Description
Prototype	$400	Total cost of alpha and beta prototypes
Pre Market Builds	$1000	Cost to build five Power Distribution Controllers (with possible revisions based on testing)
Testing	$3000	Professional testing and certification requirements for harsh conditions of racecars
Tooling	$7000	Tooling for packaging and PCB
Marketing	$300	Building and hosting a website for marketing

Key Partners

The Society of Automotive Engineers is the professional organization that hosts and sponsors the Formula SAE competition series. All students who attend the Formula SAE competition must be a member of this professional organization, so this partner is strategic in meeting reaching the customer.

The Sports Car Club of America is an organization that organizes several racing events for amateur and semi-professional racecar drivers. This organization is responsible for the dynamic events of the Formula SAE competition (events that require driving). SCCA is a key partner to reaching customers beyond the Formula SAE race series.

Key Potential Costumers

Formula Seven is a company that designs and sells car parts specifically for the Formula SAE series. They already have an excellent channel of distribution to the identified customer, and selling Power Controllers to Formula Seven at wholesale to then use their channels of distribution would result in a faster return of investment.

4. Business Model Canvas

Key Partners

-SAE for marketing to potential customers

-SCCA for marketing to potential customers

-Formula Seven for distribution channels

-Advanced Circuits for manufacturing circuit boards

-Digikey for components

-Cal Poly Racing Formula SAE Team for test vehicle

Key Activities

-Create a functioning product

-Technical support for customers

-Warranties and Repairs

-Develop firmware and to improve user experience

Key Resources

-Manufacturing facility

-Warehouse and Shipping

-Tech support team

Value Propositions

-A Power Distribution Controller that is in the ~$400 price range

-A Power Distribution Controller that utilizes digital logic to make decisions

-An adaptable controller that uses open source firmware to enable the motorsports community to work together to improve the product

Customer Relationships

-Social Media

-Professional Organization forums
  a. SAE
  b. SCCA

-Website

Channels

-Website

-Select Distributors (ie. Formula 7)

Customer Segments

-Formula SAE Teams
  a. Teams developing electrical systems
  b. Teams that are not in the top 30 or lower 100 teams in ranking
  c. North American Teams and oversees teams

-SCCA Amateur drivers:
  a. Individuals looking to improve their racecars while on a tight budget.

Cost Structure

-Materials/Prototyping/Tooling

-Warehouse Shipping and Distribution

-Marketing

-Testing

Revenue Streams

-Hardware sales

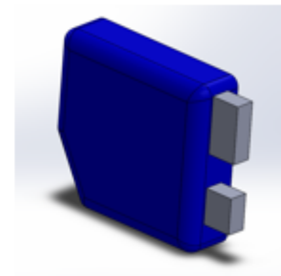
-Technical support for setting up custom firmware

-Advanced firmware upgrades

5. Marketing Specification

Marketing Datasheet

Product/Project Name: Formula SAE Power Distribution Controller



Unmet Customer Need: Amateur racecar drivers currently do not have a solution to have complete control over power distribution in racecars at an affordable price.

Unique Value Proposition: This product provides complete control over power distribution and circuit protection at an affordable price for amateur racecar drivers

Target Customer: Formula SAE Teams in North America

Positioning: The Power Distribution Controller is the most affordable and versatile power distribution solution

Pricing and Availability:
- Sells for $400
- Senior Project Expo
- Spring 2017

Product Objectives:
Provide a technologically advanced, versatile and affordable power distribution controller for formula SAE teams.

Customer Benefits:
- Affordable (sells for $400 instead of competitors $2000)
- Open source firmware to make product versatile, configurable, and adaptable
- Multiple interface/integration options

Sustainable Differentiation:
- Limit feature set to reduce price but include enough features for Formula SAE
- Open source firmware for improved integration into racecars

Disruptive Go-to-Market:
- FSAE Racing forums
- Social Media
- Website
- Select specialty racecar electronics distributors

Marketing Requirements

Table 5.1: Marketing requirements

Marketing Requirement	Rationale
Product sold for $400	This price point is low enough where Formula SAE teams would buy the product and low enough to significantly disrupt the market when the product arrives at the market. This price is also high enough to make a profit
4 High Current Outputs	The Formula SAE car currently uses three high current outputs. The 4th high current output would be to add another high current device if necessary.
8 Low Current Outputs	Low current outputs are the most common output on the car, and the Formula SAE car currently uses two of these outputs. This is being expanded to eight to more properly protect various electronic devices from overcurrent conditions.
6 Digital Inputs	6 digital inputs are needed because if CAN fails, three inputs would be enough to control the fuel pump, cooling fan, and ignition, and then the other three inputs could be used for various inputs such as a pressure sensor for a brake light.
Capable of delivering 420 Watts of power steady state for extended periods of time	The Formula SAE car currently draws 396 Watts. Requiring the device to supply 420 Watts allows for a small safety factor, and leaves room to improve the electrical system by adding more electronics.
All Outputs can individually have current limits set in firmware	Different outputs require different current limits. Users need to be able to choose any current limit they desire for a particular output.
Product must interface easily with surrounding electrical system	The customer must not be frustrated with the implementation or use of this product, in order for the business model to be sustainable.
Build must be durable and resistant to impact, pressure, and heat	The device is being used in a high vibration and hot environment. Furthermore, people may hit the device by accident while working on the car.
Product must be user friendly, adaptable, and easily configurable through firmware	The device must be easy to use for the customer to be satisfied. The system must also be adaptable to give the race car’s electrical systems designer to be flexible in his or her design.

Table 5.2: Customer Needs

Feature	Importance	Customer Need
High Current Outputs	High	Customers need to be able to drive and control Fuel pumps, fans, and ignition systems that draw a lot of current
Low Current Outputs	High	Costumers need to control power to low current control systems such as shifting and engine control
Digital Inputs	Medium	Customers without CAN communication on their vehicles need to interface with product through digital inputs
CAN Receiver	High	Costumers with CAN must be able to control Power Controller through CAN communication
CAN Transmitter	Low	Communicate output current and voltage data to external data logger
Digital “Fuses”	High	Customers must be able to set current limits on outputs through firmware to protect electronics
Water resistant/Durable Build	High	Power Distribution Controller must be able to operate in rain, wet road conditions, and dusty/dirty conditions

6. Block Diagram, Engineering Requirements and Specifications

Level 0 Block Diagram Input/Output Descriptions

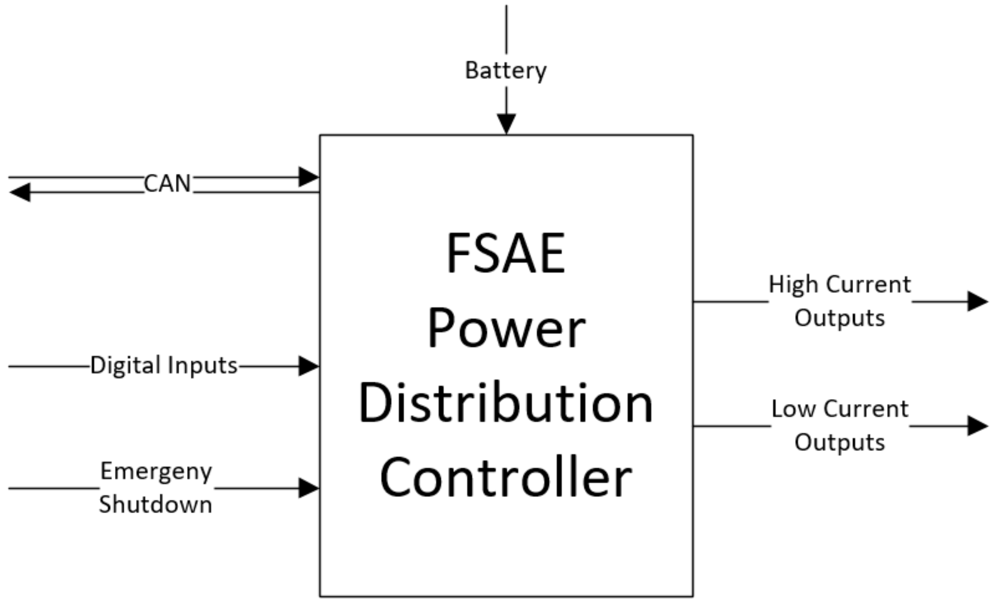


Figure 6.1: Level 0 Block Diagram of the FSAE Power Distribution Controller

High Current Outputs: Four high current outputs that are current limited at 15 amps provide the FSAE vehicle power for high current loads such as ignition coils, cooling fans, and fuel pumps.

Low Current Outputs: Eight low current outputs that are current limited at 5 amps each, provide power for low current draw loads such as data loggers and sensors.

Digital Inputs: Eight digital inputs can be configured to control and toggle the high current outputs and/or the low current outputs.

Controller Area Network (CAN): CAN will be used for the communication between the Power Distribution Controller, and other controllers in the FSAE car. Channels received over CAN will be able to toggle the high current and low current outputs. CAN data will also be transmitted from the power controller so that information on current draws and output voltages can be logged in the car's data logger.

Emergency Shutdown: In accordance with FSAE competition rules, power must be turned off to critical engine components through two switches in the case of an emergency. Additionally, these switches are required to act through analog means (ie. not software dependent). Due to these switches requiring analog circuitry, they are distinctly different from the digital inputs.

Level 1 Functional Block Description

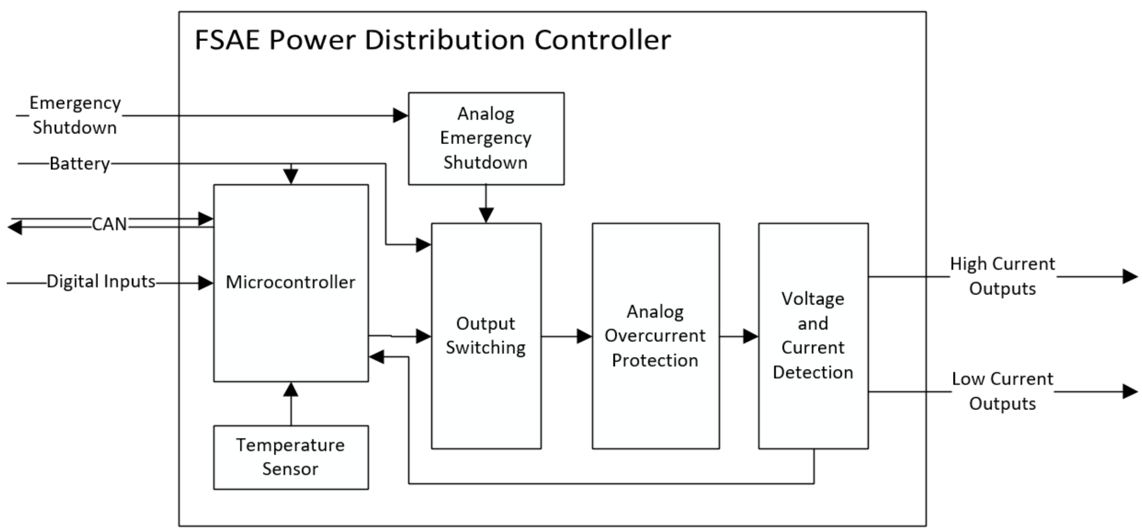


Figure 6.2: Level 1 Block Diagram of the FSAE Power Distribution Controller

Microcontroller: The microcontroller is at the center of the power controller and analyzes information from the digital inputs, CAN communication, and voltage and current information from the outputs, and controls the high current and low current outputs accordingly.

Output Switching: The microcontroller is unable to provide the outputs with sufficient voltage and current at the outputs, so the output switching block receives signals from the microcontroller, and then amplifies these signals to the appropriate levels for the output. The switching block must make the output signal the same as the battery voltage, and source current up to 20 amps for the high current outputs, and 5 amps for the low current outputs

Analog Emergency Shutdown: The analog emergency shutdown circuit is required by FSAE rules. This circuit accepts input from an external switch, and if activated, the circuit disables power to the high current outputs. The circuit is required to bypass the microcontroller so that it still operates in the case that the code in the microcontroller fails.

Analog Overcurrent Protection: The analog overcurrent protection consists of PTC resettable fuses that will “blow” if the current detection and/or microcontroller fail and the output current exceeds the rated output current. Under normal operation, the user will set a current limit, and this value will be lower than the value of the PTC fuse in this block.

Voltage and Current Detection: This block detects the voltage and current of the output and feeds this information back to the microcontroller. If the current exceeds the user set current limit, the microcontroller will turn the output off. If the output voltage is lower than expected, the microcontroller will send error messages over CAN in order to notify the driver.

Temperature Sensing: The power controller will have an internal temperature sensor because the significant amount of power passing through the circuit board will result in a significant amount of heat. If the heat exceeds a particular temperature, the microcontroller will turn off all outputs that do not stop the car from driving.

Table 6.1: Marketing requirements translated to engineering requirements

Marketing Requirement	Engineering Requirement

Product Sold for $400	• Prototype Costs $200 (max)
	  o Microcontroller: $10
	  o Printed Circuit Board: ~ $60
	  o Discrete Components and ICs: $70
	  o Connectors, Enclosure, and Hardware: $60

4 High Current Outputs	• Outputs must source 20A max at 12 Volts • Selected PMOS must source 20A at 120°F ambient temperature
8 Low Current Outputs	• Outputs must source 5A max at 12 Volts • Selected PMOS must source 5A at 120°F ambient temperature
6 Digital Inputs	• Inputs must accept up to 12 volts • Inputs must be over voltage protected
Capable of delivering 420 Watts of power steady state for extended periods of time	• Size PCB traces to reduce heat generation • Use light weight and small heat sinks if necessary
All Outputs can individually have current limits set in firmware	• Current limits must have 0.1A accuracy • Turning off circuit in reaction to current limit must be faster than a fuse
Product must interface easily with surrounding electrical system	• Use inexpensive connectors to interface with the rest of the electrical system <$10 per connector • Low current outputs must connect to 22AWG wire, and high current outputs must connect to 14AWG wire
Build must be durable and resistant to impact, pressure, and heat	• Connectors must be automotive rated and water resistant • Enclosure must be dust and water resistant • Product must operate between 40°F and 120°F
Product must be user friendly, adaptable, and easily configurable through firmware	• Sends data regarding output voltages and currents over CAN • Current limits for outputs set in firmware • All outputs can be toggled based on code • Outputs can be toggled from data received over CAN • Electrical system warnings can be sent over CAN

Testing and Verification:

Table 6.2: Tests for requirement verification and descriptions

Test	Description
Functional test	Run code that toggles outputs based on CAN data and digital inputs. Test the emergency shutdown circuit under multiple input conditions.
High current output test	Test that each output is capable of delivering 20 amps at 12 volts
Low current output test	Test that each output is capable of delivering 5 amps at 12 volts
Durability test	Spray the enclosure with water, dry it off, and inspect the internals for signs of water seeping in. Drop the product from 1 meter. Ensure that no damage other than aesthetic damage occurs.
Power and temperature test	Load the product so that it delivers the maximum load (420 Watts). Perform this test at 40°F and 120°F to confirm the operating temperature range. Run the test for 1 hour to confirm the product can run twice as long as the longest race.

7. Project Management

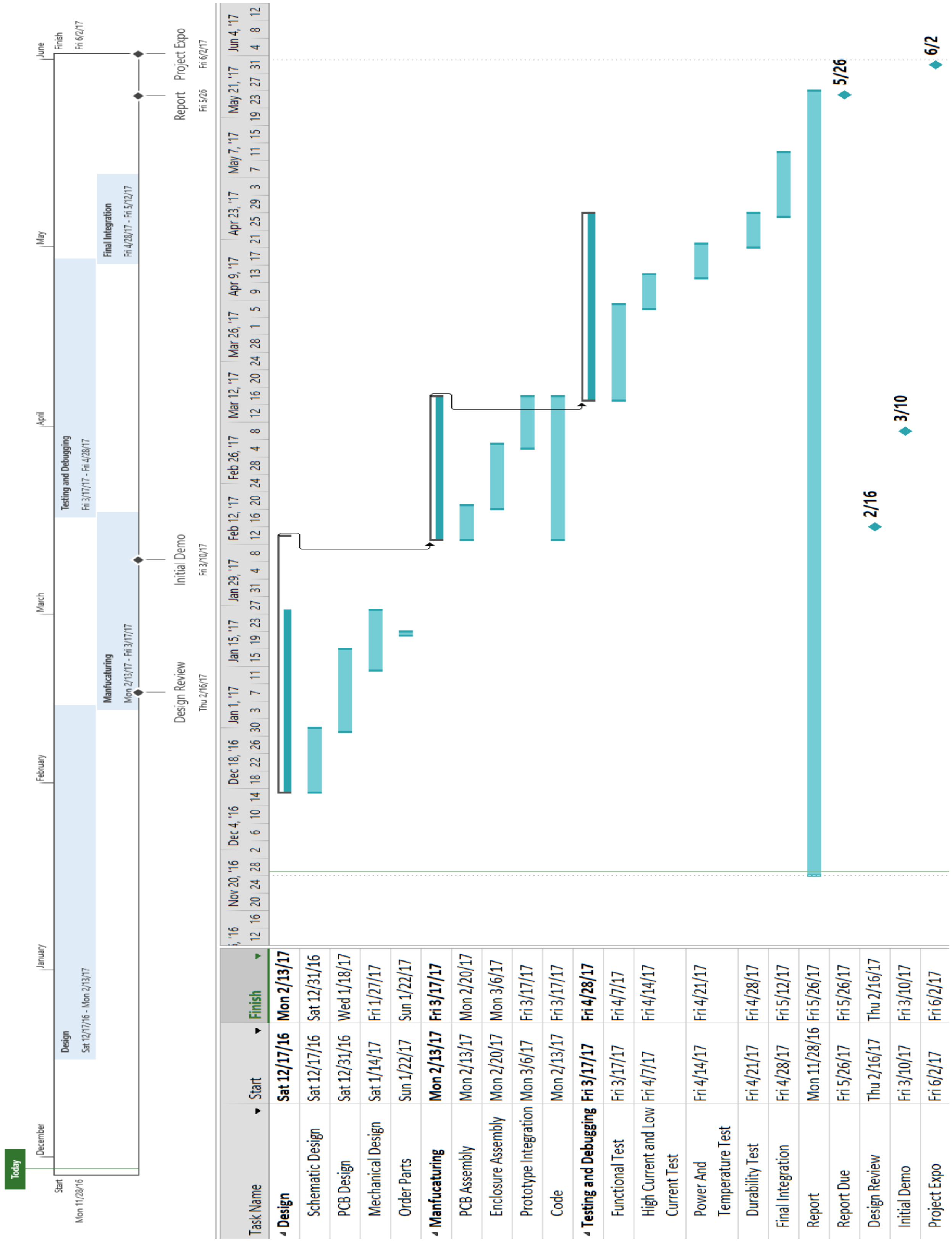


Figure 7.1: Gantt Chart for EE 461 and EE 462

High risk items that may affect schedule

Extensive research on lightweight thermal dissipation strategies is needed. Furthermore, an understanding of the thermal energy dissipated by the system is needed in order to properly choose components, design the PCB, and design the enclosure. A lack in understanding of the heat transfer of the system may result in redesigns of the circuit board and/or enclosure, and would result in a significant delay in the schedule.

Another high risk item is finding time to test this product with the Formula SAE car's electronics. When this product is complete, the Formula SAE car will frequently be testing for competition, and will be unavailable to test with this product. Off-car testing strategies must be used to stay on schedule with testing. Furthermore, the product must be tested with the Formula SAE car when the car is not in use.

Cost

Table 7.1: General Cost breakdown

Item	Quantity	Cost
Microcontroller	1	$10
Printed Circuit Board	1	$60
Discrete Components and ICs	-	$70
Connectors, Enclosure, and Hardware	-	$60

The cost breakdown of table 7.1 is very general because this project is not yet in the critical design phase, and components have not yet been selected. However, considering estimations based on other Formula SAE projects, table 7.1 shows a good estimation and budget strategy for this project. The "discrete components and ICs" item includes power MOSFETS, Darlington arrays, temperature sensors, as well as capacitors and resistors. While it is uncertain if all of these items will be used at the moment, they are included in this cost estimation.

Finance

This project will be primarily financed through the electrical engineering department's $200 grant per student. However, this project will also be financed through part donations from suppliers and Cal Poly Racing. While Cal Poly Racing will not contribute to the upfront costs of the prototype, the team will be responsible for the cost of maintaining the product as well as building more of these products for backups. This project will use Cal Poly Racing industry partners in order to obtain free and discounted parts.

Resources

People: Advisors will be very important to the success of this project. I will consult with Professor Benson, and Cal Poly graduate and former Formula Electric SAE team lead Thomas Wilson in order to review design decisions, schematics, circuit boards, and overall design. I will also be consulting with the current Cal Poly racing leadership and electronics subsystem lead in order to ensure that the end product will be compatible with next year's vehicle and vehicles for future years.

Campus Resources: This project will require access to the Senior Project Lab and the Electrochemistry lab. These two labs contain the equipment needed to construct and test this project. Furthermore, this project will require access to the Hangar and Mustang 60 shops in order to construct the enclosure for the project. Finally, this project will need access to the mechanical engineering vibrations lab in order to test the durability of the product on a shake table.

Skills: This project requires programming, analog circuit design, digital circuit design, mixed signal printed circuit board design, soldering, and debugging skills. Furthermore, in order to complete this project on time, this project will require superb organizational and time management skills.

8. Analysis of Senior Project

Project Title: Formula SAE Power Distribution Controller

Student Name: Daniel Baron

Advisor's Name: Professor Bridget Benson

Summary of Functional Requirements:

This project will accept a power input from the Formula SAE car's battery, and distribute the power to the various electronics on the vehicle. Current limits for each output will be set in firmware. If and when an over current condition as defined by the user occurs on an output, the device must immediately turn off the output on which the overcurrent condition occurs. Inputs into the system include CAN and digital inputs. Outputs will be able to toggle on and off based upon input values. Output current and voltage data will also be sampled and sent over CAN to the car's data logger.

Primary Constraints:

First and foremost, this project must abide by the Formula SAE rulebook. This especially affects the emergency shutdown circuitry that disables the high current outputs of the system. The system must also be designed to dissipate heat from the high currents flowing through PCB traces, and be able to operate in ambient temperatures up to 120°F. Finally, the entire system must be light weight, as low mass is important to a competitive racecar. Finally, the system must cost less than $200 to build.

Economic:

What economic impacts result?

Human Capital: This device will create jobs in engineering, software development, manufacturing, sales, and technical support. Additionally, customer support jobs will be created to teach race teams how to implement and use the product.

Financial Capital: This product will create minimal business for suppliers due to a limited market, however, this product will have a large financial impact for the customer. Customers currently pay $3000 to $5000 dollars for a similar product. Undercutting the market price significantly will create a large market for this product.

Manufactured or Real Capital: The manufactured capital will be the inventory of this product.

Natural Capital: The ICs used on this device require a significant amount of water while being manufactured. Additionally the raw materials that create the components, circuit boards, and enclosures come from natural resources.

When and where do costs and benefits accrue throughout the project lifecycle?

Costs to the project team occurs during the design and manufacturing stages of the project lifecycle through research and development, labor costs, and material costs. When the product is sold, the customer has an upfront purchase cost. The customer will then see the benefits through the rest of the life of the product before for the product is ultimately disposed of.

What inputs does the experiment require? How much does the project cost? Who pays?

Table 8.1: Original cost estimate

Item	Quantity	Cost
Microcontroller	1	$10
Printed Circuit Board	1	$60
Discrete Components and ICs		$70
Connectors, Enclosure, and Hardware		$60

While different parties will be assuming the costs at different points in the product lifecycle, ultimately, the cost of this project will come from the EE department through the $200 grant they give to senior projects. If manufactured commercially, the customer would be assuming all the costs when they buy the product.

How much does the product earn? Who profits?

This project is being funded through the EE department grants, and donations. Furthermore, this project is being given to Cal Poly Racing, a nonprofit organization. Therefore, this project does not profit, however, Cal Poly Racing profits from new equipment, and the parts suppliers profit from purchasing parts from them.

Timing

Products would emerge after 20 weeks combined of design, manufacturing, and testing. The products are then expected to last 10 years at a minimum. In order for the product to last this long, some soldering and components may need to be repaired over time due to the amount of vibration and heat generated by the Formula SAE car. After the project is complete, the project will be given to Cal Poly Racing in order to implement on the 2018 vehicle. Product training for integration and use will occur after the 2017 Formula SAE competition.

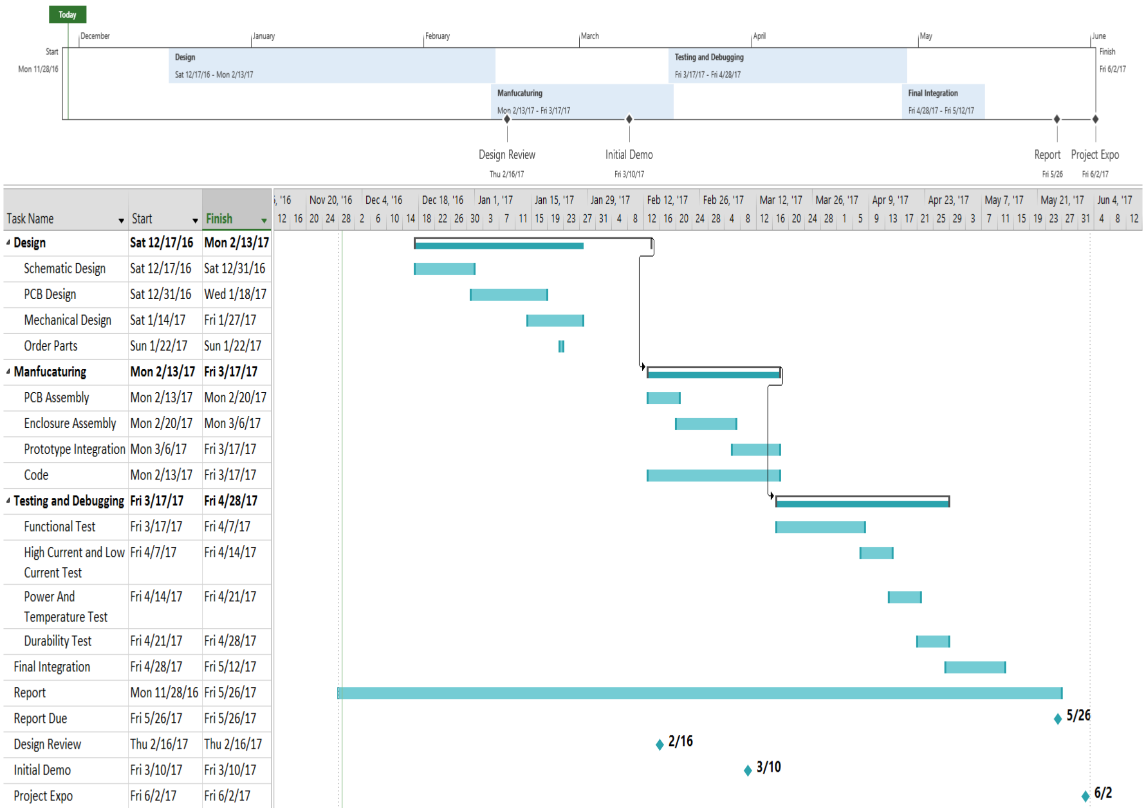


Figure 8.1: Original estimated development time

If Manufactured on a Commercial Basis:

Estimated number of devices sold per year: 200

Estimated manufacturing cost for each device: $110 (this considers economies of scale and labor)

Estimated Purchase price for each device: $400

Estimated profit per year: $29,000

Estimated cost for user to operate device: Operating the device for one hour will cost the user approximately $0.000072 per hour. This assumes $0.12 per Kilowatt-hour.

Environmental:

This product mostly affects the environment at the beginning and end of the product lifecycle, and has a minimal environmental impact during its use. At the beginning of the lifecycle, energy, raw materials, and consumable materials put into manufacturing the ICs, circuit boards, and enclosures for the product taxes upon the environment in water usage, waste, and emissions. During the use of the product, the product indirectly contributes to air pollution because its intended use is to help control internal combustion vehicles. At the end of the lifecycle, the product is disposed of, and affects the cleanliness of the environment because it would most likely end up in a landfill. While this product does cause some harm to the environment, it does also improve the environment. This product will be more effective at protecting electronics on the Formula SAE vehicles, so there will be less damage to the electronics. The electronics on the vehicles then will have extended lifecycles as a result, and less electronic waste will be in the landfills as a result. For the areas of the environment that this product negatively impacts, the species residing in those areas will see some impact in their habitat as the impact of this project combines with the impact of other projects on the environment.

Manufacturability:

Manufacturing will be difficult due to the environment the product will be used in. All solder joints must be of very high quality due to significant amount of vibration that the circuit board will be experiencing under normal conditions. Furthermore, the enclosure needs to be manufactured so that it is water and dust resistant which will be difficult due to the small tolerances this specification requires.

Sustainability

Describe any issues or challenges associated with maintaining the completed device or system.

The environment in which the device is operated will pose as a challenge to maintaining the device. This device must be designed to withstand vibration, heat, impact, water, and dust. Furthermore, due to the significant amount of power flowing through this device, this device must effectively dissipate the generated heat to ensure the longevity of the internal components, however, this device must also be lightweight due to it being used on racecars.

Describe how the project impacts the sustainable use of resources.

While this product taxes upon resources upfront through the manufacturing process, overall, this product improves the sustainable use of resources. This product not only distributes power to various electronics, but it also protects those electronics from overcurrent and overvoltage conditions. This will ultimately result in fewer damaged electronic devices that will then result in fewer electronic devices being disposed of, and fewer electronic devices being manufactured to replace the older devices.

Describe any upgrades that would improve the design of the project.

This project can be upgraded by making the internal circuit boards and components very accessible. This will allow the device to be serviceable, and would result in a longer product life cycle. Furthermore, reducing product weight and size would be advantageous because weight is a very big consideration when choosing devices to put on a racecar, and a smaller size will help with packaging the device in the racecar.

Describe any issues or challenges associated with upgrading the design:

Upgrading the design to be modular would pose a challenge because even when the devices is designed to be easily taken apart, it must still be water resistant a durable. Upgrading the design to be smaller and lighter would pose issues because the circuit board would need to still fit all of the same components. Secondly, the circuit board must be large enough so that the trace width could be wide enough for the device to not generate too much heat. Finally, making the device lighter would prove to be difficult because the device must be cooled, and a significant amount of the weight of the system is designated to cooling the device.

Ethical

This project has several ethical implications. First, the device must be designed to follow the Formula SAE competition rules, even if simpler design choices could be made by not following the rules. Secondly, the device must be reliable and thoroughly tested. Not only is this device being used in a competition, and the customer expects a reliable product, this product also contains key safety shutdown circuitry that disables the engine of the vehicle in the case of an emergency, including, but not limited to a fire, crash, or loss of brake pressure. The current limiting circuitry must also work reliably because the customer is relying on this device to protect $10,000 to $15,000 worth of electronics from damage. Another important ethical consideration is that this product is documented properly. When the customer receives this product, the customer must have the documentation on how to implement the device into the vehicle and how to use it. Without that documentation and knowledge, the customer would invest time and money into this product, and then would be unable to use it. Finally, while this product is designed to be used in a motorsports application, the designers have no control over how the customer uses the devices. A customer could choose to misuse the product, and use it on a harmful system that causes damage to people and/or property.

Health and Safety

The safety concerns of this product revolve primarily around the design and use of the device. Specifically, the emergency shutdown circuitry must always work flawlessly as it is responsible for disabling the engine of the car in the case of an emergency. If this circuitry ever fails, it could put the driver and surrounding spectators in serious danger of injury.

Social and Political

This product has social implications associated with it because this product will seriously affect the motorsports electronics industry. This product impacts both motorsports electronics customers, and competing companies and the employees at these companies. This product significantly undercuts the price of competing products, and the customers will greatly benefit from the lower product cost. Likewise, competitors may lose business do to their products now being too expensive. This may affect the pay and livelihood of employees at the other companies. While all customers would pay equally for this product, this product does create inequities. This device requires programming knowledge in order to successfully implement this solution on a racecar. Therefore, individuals who have programming knowledge would be able to buy this low cost solutions, while individuals without programming knowledge would probably have to purchase the more expensive versions the competitors offer.

Development

This project will require development in knowledge of thermal dissipation of electronic components, thermal transfer and cooling, and how, quantitatively, heat affects the operation of various electronic components.

9. Preliminary Design Analysis

Several options exist for toggling outputs, detecting voltages and currents, and protecting outputs from overcurrent conditions.

Toggling outputs could be done through mechanical relays, solid state relays, or MOSFETs. Mechanical relays are inexpensive and easy to implement, however, they are large and power inefficient. Solid state relays are reliable in environments with vibration do to there being no moving parts, and they carry a significant amount of power without overheating. However, solid state relays are very expensive. MOSFETs are inexpensive and are reliable in environments with vibrations. They are also capable of carrying large amounts of current. However, at high drain currents, MOSFETs heat up significantly. Cooling and heat sinks would be required for a MOSFET to not overheat.

Detecting voltages and currents can be done in multiple ways. One way is to place a small resistor in line with the output of the devices, and then read the voltage across the resistor. With a known resistance and voltage, current through the output can be detected. The output voltage could then be measured separately to sample the output voltage value. While this solution is simple, the addition of the resistor for the sole purpose of measuring current makes this measurement technique invasive. Another solution for current measurement would be to measure the magnetic field of a trace and extrapolate current from that information. This system, however, would be expensive and susceptible to EMI.

Protecting outputs from overcurrent conditions could be done in two ways. One way is to have each output have several PTC resettable fuses assigned to it, and in software, the user could select which PCT fuse is enabled for each output. This would be expensive due to the price of PTC fuses. Additionally, there would be very few current limit options due to limited space on the PCB to fit PTC fuses and a limited budget to buy them. Another solution is to sample output currents and then send this data back to a microcontroller that then turns the particular output that has an overcurrent condition off. This solution relies heavily of software, however, it is a simple and inexpensive solution.

References

[1] "2016 Formula SAE Rules," in *Formula SAE*, SAE International, 2015. [Online]. Available: http://www.fsaeonline.com/content/2016_FSAE_Rules.pdf. Accessed: Oct. 24, 2016.

Description: The Formula SAE rulebook provides requirements for the Power Distribution Controller, as these are the rules that the customer must abide by while designing a racecar. This document also explains the competition which helps describe the customer architype.

[2] Tim, "prices_ecu_motec," in *Capa Performance*, 2016. [Online]. Available: http://www.capa.com.au/prices_ecu_motec.pdf. Accessed: Oct. 24, 2016.

Description: The pricelist of the top competitor's products describe the market and the unserved portion of the market. This source also creates the case of the value proposition

[3] "MoTeC," in *MoTeC Engine Management and Data Acquisition Systems*, 2008. [Online]. Available: http://www.motec.com/home. Accessed: Oct. 24, 2016.

Description: The website of the top competitor provides information on products already existing in the market, and therefore provides data on how this senior product can have a unique value proposition.

[4] "CARTEK Power Distribution Modules," in *CARTEK Motorsport electronics*, 2016. [Online]. Available: http://www.cartekmotorsport.com/pdm.html. Accessed: Oct. 24, 2016.

Description: This source provides information on a lower cost power distribution module to help describe products that are competitive with this senior project.

[5] "SAE Collegiate Chapters," in *SAE International*, 2016. [Online]. Available: http://www.sae.org/servlets/collegiate?PAGE=getCollegiateMainPage&OBJECT_TYPE=CollegiateChapInfo. Accessed: Oct. 24, 2016.

Description: This source describes the size of the market, based on the number of teams in North America.

[6] "Official Results," in *Formula Student*, Institution of Mechanical Engineers, 2016. [Online]. Available: http://formulastudent.imeche.org/docs/default-source/default-document-library/download-the-final-overall-class-1-results.pdf?sfvrsn=0. Accessed: Oct. 24, 2016.

Description: This website helps further describe the size of the market in Europe, Asia, Australia, and Africa through the listing of overall results for the international Formula competitions.