Final Design Report
ECE 362
5/24/2022
Team 08: Burnt Hotdog
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Executive Summary:

The purpose of this design project is to demonstrate engineering techniques like programming and circuit design on a car that will inspire high school students to pursue an education in STEM. In our car, we will use a microcontroller to handle the control signals and computations required to steer the car along a line, and this microcontroller will be able to communicate information about the current state of the car to the user during operation. To provide power to the vehicle, we will use an energy storage system capable of quickly recharging, internally balancing the energy stored within each of its constituent stages, and providing a consistent output of power to the motor controller on the vehicle. All features to be implemented to achieve these design goals will be created with both safety and creativity in mind, and special importance will be put on the overall system's usability and reliability so that the vehicle can promote learning for people with various backgrounds of engineering.

Stakeholders/Features/Metrics:

Feature	ID	Attribute/Metric	Stakeholders	Justification (Validation)
Functional - Power Supply	FP1.0	The power supply will power the vehicle for 1.5 minutes while it is maneuvering around either course.	Competition, Audience, Instructor, Future Students, Our Future Employers, Rose Marketing and Admissions	The ninety-second limit provides for a reasonably sized power supply but also creates an interesting amount of time for a race.
	FP1.1	The power supply will be able to provide at least a 1A continuous current draw to the vehicle for the duration in FP1.0.	Competition, Audience, Instructor, Future Students, Our Future Employers	The car consistently draws 0.8-1.0 A when connected to a power supply

	FP1.2	The power supply will provide a voltage between 12V max and 6V min to the vehicle for the duration in FP1.0.	Competition, Audience, Instructor, Future Students, Our Future Employers	The motor controller used on the vehicle requires an input voltage between 5.5V and 12.6V
	FP1.3	The power supply will be able to source peak currents up to 2A for 5s without damage.	Competition, Audience, Instructor, Future Students, Technicians, Our Future Employers, Life infrastructure	When the car is first connected to power, a surge current of about 1.7 A is drawn. Therefore being able to provide up to 2 A for a short period of time is necessary.
	FP2.0	The power supply will recharge rapidly.	Competition, Audience, Instructor, Future Students, Our Future Employers	To make pit stops practical, the power supply must recharge in much less time than the battery. This is one of the key benefits of the use of a supercapacitor supply rather than a battery.
	FP2.1	The power supply will charge from 0V to 12V in 6 minutes or less using the wireless charger.	Competition, Audience, Instructor, Future Students, Our Future Employers	Wireless charging is more power limited than wired, so it needs more time to charge.
	FP2.2	The power supply will charge from 0V to 12V in 2.5 minutes or less using the wired charger.	Competition, Audience, Instructor, Future Students, Our Future Employers	The three-minute limit is a compromise that keeps charging currents from being too large while at the same time making it a bit challenging to meet this limit

	FP2.3	The power supply will be charged from a wireless transmitter and receiver that adhere to the Qi standard [https://www.wirelesspowerconsortium.com].	Competition, Instructor, Future Students, Our Future Employers	The Qi standard is nearly ubiquitous for wireless charging so it is possible for schools to obtain inexpensive transmitters and receivers
	FP2.4	The power supply will be charged by a 120V AC to 12V DC power supply from the parts room	Instructor, Future Students, Technicians, Our Budgets	These are what we have available so it saves money. Also the max safe voltage is 12V.
	FP3.0	The power supply will change from wired to wireless charging and vice versa with a simple user interaction	Instructor, Future Students	This needs to be a simple thing that high school students can understand and use. Also, because the wired charging occurs before a run and the wireless charging occurs during a run, this user interaction must be short enough to meet FC1.4.
Functional - Controller	FC1.0	The controller will drive the vehicle autonomously around both tracks for the duration specified in FP1.0	Competition, Audience, Instructor, Future Students, Rose Marketing and Admissions	This is the basic tenet of the competition. Students learn to program and can see the immediate effects of their program as they make changes. Also Autonomous vehicles are coming and this exposes students to some of the challenges.
	FC1.1	The vehicle will stop automatically after [the time duration specified in FP1.0] of going around the track.	Competition, Audience, Instructor, Future Students	Driving the vehicle uses more power than letting it sit idle, so not driving more than necessary avoids the use of unnecessary amounts of power, which could lead to the vehicle drawing more energy out of the supercapacitor storage system than it was designed for according to FP1.1.

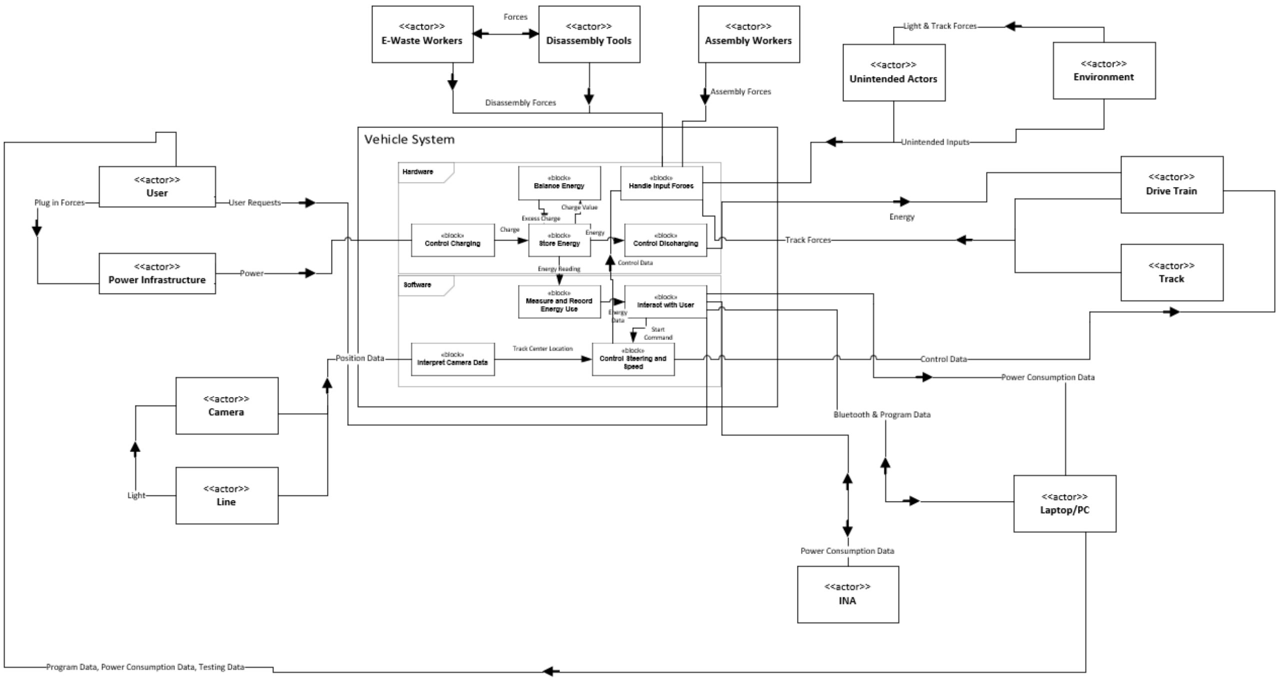
	FC1.2	The controller will produce less than a three lap difference between the battery and designed power supply.	Instructor, Our Future Employers	Encourages the teams to design for hardware/software interactions.
	FC1.3	The controller will compensate for different lighting and background conditions.	Instructor, Our Future Employers	The vehicle will not perform in the same room in which the team practices.
	FC1.4	The vehicle will begin the race through a simple human interaction	Future Students, Audience	The primary intent of autonomous vehicles and systems is to limit or remove the need for human input.
	FC2.0	The controller will log power data at intervals of 0.5 second while the vehicle is maneuvering around the track.	Instructor, Our Future Employers	The vehicle will not change state significantly within 0.5s and this is necessary to determine control efficiency.
	FC3.0	The system will display energy use data with respect to time for a given run around either track.	Instructor, Our Future Employers	This is necessary to show total energy use during a run. Seeing energy use over time can help to tune the controller.
Safety	S1	The power supply will prevent reverse polarization of capacitors as long as they are within specified capacitance tolerance (do not assume all capacitors have the same capacitance)	Instructor, Future Students, Technicians, Our Budgets, Waste Disposal, Parts manufacturers, Life infrastructure	Supercapacitors will explode if reverse biased. Large capacitance tolerances create conditions where reverse polarization can occur.
	S2	The power supply must fit on the vehicle without changing any other function of the vehicle.	Technicians, Audience, Life Infrastructure	If the power supply is too large it may interfere with the vehicle's wheels or add too much weight to the vehicle.

	S3	The power supply must securely attach to the vehicle chassis without any permanent modifications to the chassis (i.e. no glue, new holes, etc.)	Technicians, Life Infrastructure	We must reuse the vehicles each year, and they need to begin in the same state. Don't want the power supply to move around and damage the vehicle.
	S4	The power supply and/or controller must contain one additional safety feature as designed by the student team.	Instructor, Parts manufacturers, Waste Disposal	This is to teach students the process of defining features and then designing for them. Safety is of paramount importance to engineers.
Affordable	A1	The power supply and wireless charger will cost less than $120 of circuit components to develop.	Future Students, Our budgets, Our Future Employers	High schools could afford one kit at $200 as validated by VCSC officials. The cost of $20-$30 per college student on a 5-6 person team is much less than a textbook.
Valuable	V1.0	The power supply and/or controller will contain at least one additional Feature or metric as determined and designed by the team that adds value to at least one stakeholder.	Instructor	This is to teach students the process of defining features and then designing for them.

Interactions Model:

Interaction	Description	Actor(s)	System I/O(s)	Feature(s)
Driving and reading sensor data	The vehicle's sensors will read data from the actors and the vehicle will move accordingly. The system I/Os may play a role in the performance of the interaction.	Line, Track, Environment, Camera, Drivetrain	Light, Track Forces, Position Data, Bluetooth Data, Control Data	Functional Controller
Programming the system	The vehicle will be able to be reprogrammed by the user to change its behavior and ability to use the physical systems implemented.	User, Laptop/PC	Program Data	Functional Controller
Mishap	Unintended actors may affect the system via physical or electrical damage, like in cases of dropping, spills, electrical or mechanical faults, or unintended environmental impacts.	Unintended Actors, Environment	Unintended Interactions, Light, Track Forces	Safety
Wired charging of the power supply	The car will charge via AC power through the wall outlet.	Power Infrastructure	Plug In Forces, Power, User Requests	Functional Power Supply
Wireless charging of the power supply	The car will charge via a wireless charger and the charging data will be transmitted to the system in order to track the status of wireless charging.	Power Infrastructure	Plug In Forces, Power, Program Data, User Requests	Functional Power Supply
Display voltage/current/ power data (extra feature)	Electrical data from the vehicle during operation will need to be displayed on the side of the car as an extra feature.	User, INA, Laptop/PC	Voltage, Current and Power Consumption Data, Bluetooth Data, Light	Valuable
System Testing	During testing, information regarding the power supply or controller may need to meet specified functionality or safety benchmarks.	User, Laptop/PC	Testing Data, Program Data, User Requests, Voltage, Current, and Power Consumption Data, Control Data	Functional Power supply, Safety, Functional controller
Vehicle Assembly	The car will be manufactured out of purchased components.	Assembly Workers	Assembly/Disassembly Forces	Affordable

Functional Architecture Model:



Physical Design Solution Models:

<u>Software Flow Diagram:</u>

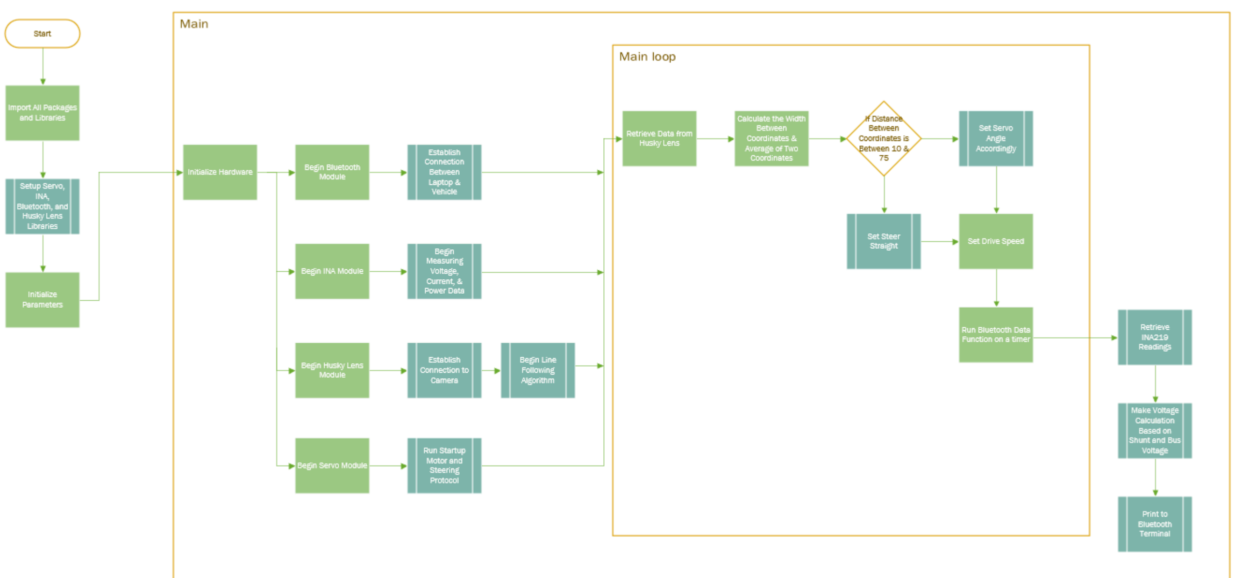


Figure 1: Software Flowchart Diagram. This code establishes/begins various modules (bluetooth, INA219, servo, and huskylens) to collect and interpret data to then execute various decisions to both track and follow the line on the track.

<u>Energy input system</u>:

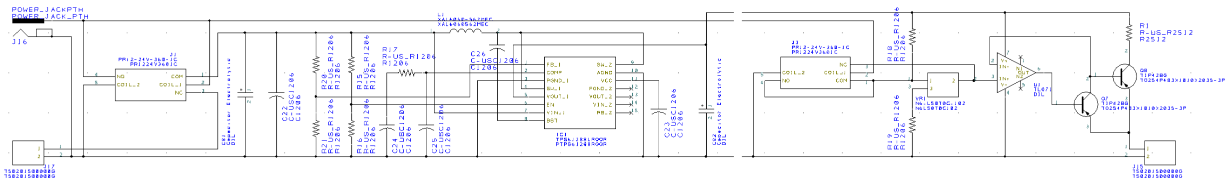


Figure 2: Initial energy input circuit design schematic (Note that the boost converter and all supporting components shown in the center of this image were replaced by the boost converter module shown in Fig. 3 in the final design implementation)

The energy input circuit schematic found in Figure 2 can be mapped to the control charging block of the functional architecture model and is composed of a power source selection circuit, a boost converter, and a current limiting circuit. The energy input circuit schematic is designed such that the power selection circuit automatically toggles between wired and wireless charging depending on if the wired charger is plugged into the power supply.

<u>Subsystems</u>:

- Wired charger (not pictured):
  The wired charger will use a 120V AC to 12V DC wall power supply capable of supplying up to 5A.

- Wireless charger (not pictured):
  The wireless charger will use a USB-C power input and will be capable of providing 12V DC at the receiver coil at currents up to 2A.

- Power source selector:

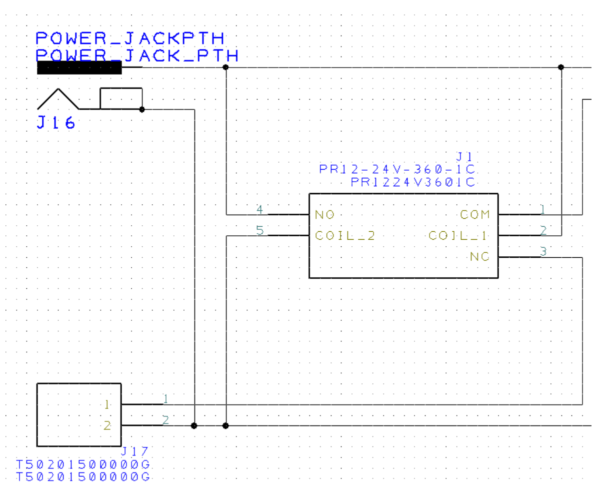


Figure 3: Power source selection circuit schematic

To switch between the wired and wireless power, the PR12-24V-360 relay is used to toggle between the respective sources when its coil is energized by the connection of the 12 wired charger. The schematic for the power source selection circuit can be found in Figure 3. This effectively satisfies requirements FP2.3, FP2.4 and FP3.0.

- Boost converter:

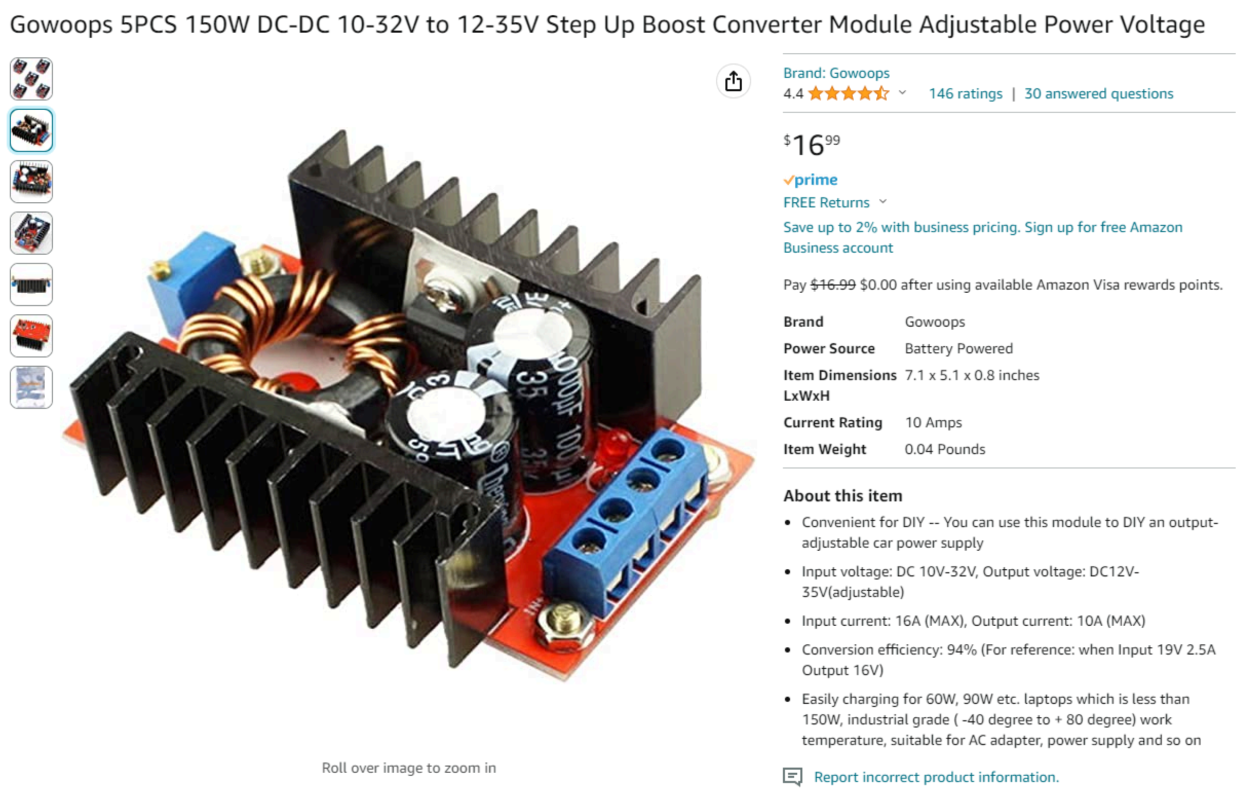


Figure 4: Boost converter module (Note that because this module came in a pack of 5, the cost added to the bill of materials only reflects one fifth of the ordering cost)

The boost converter module is used in the energy input circuit to increase the charge voltage of the charge storage module, allowing for higher overall energy storage. From the specifications provided by the product page for the selected boost converter module shown in Fig. 4 above and from our tests of the module we received, the module is capable of delivering an output voltage of approximately 16V to the current limiter circuit at currents of at least 3.2A, as shown in the test conducted in Fig. 5 below. The boost converter module did increase the overall current draw above the approximately 3A used to charge the energy storage module, but as is shown below, the total current draw did not exceed the wired charger limit of 5A. When used for wireless charging however, the overall system did experience inrush current issues which were not accounted for in the initial design and were not able to be fixed by the time of the competition, as is discussed later in the Reflections and Conclusions section.

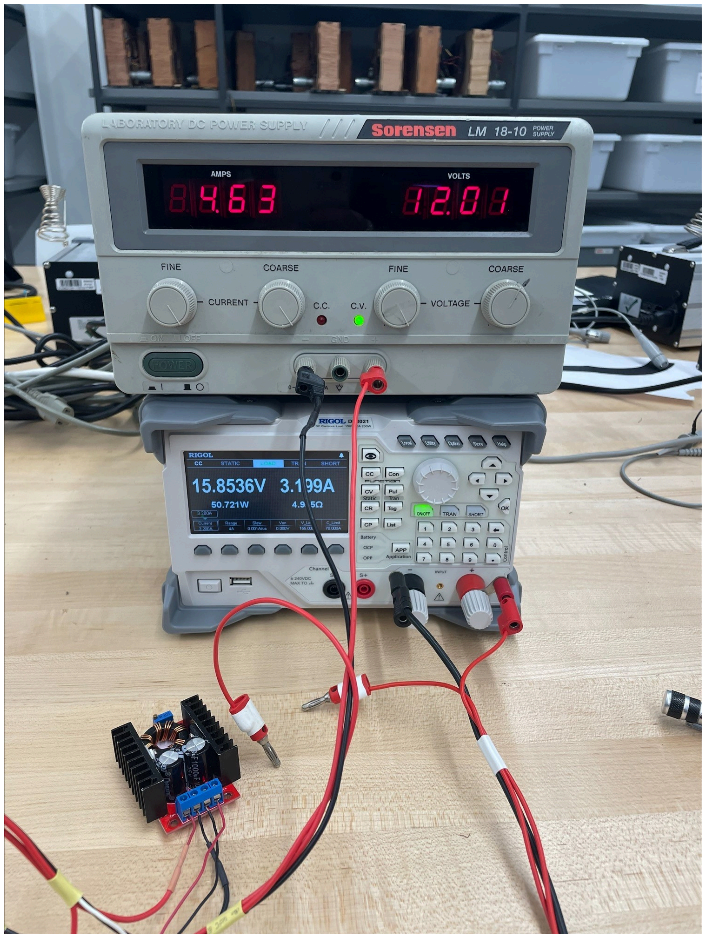


Figure 5: Boost converter module measurements at 16V output, 12V input, and an output current of 3.2A, demonstrating an input current draw below the rated 5A limit of the provided 12V chargers

- Current limiter with mode toggling:

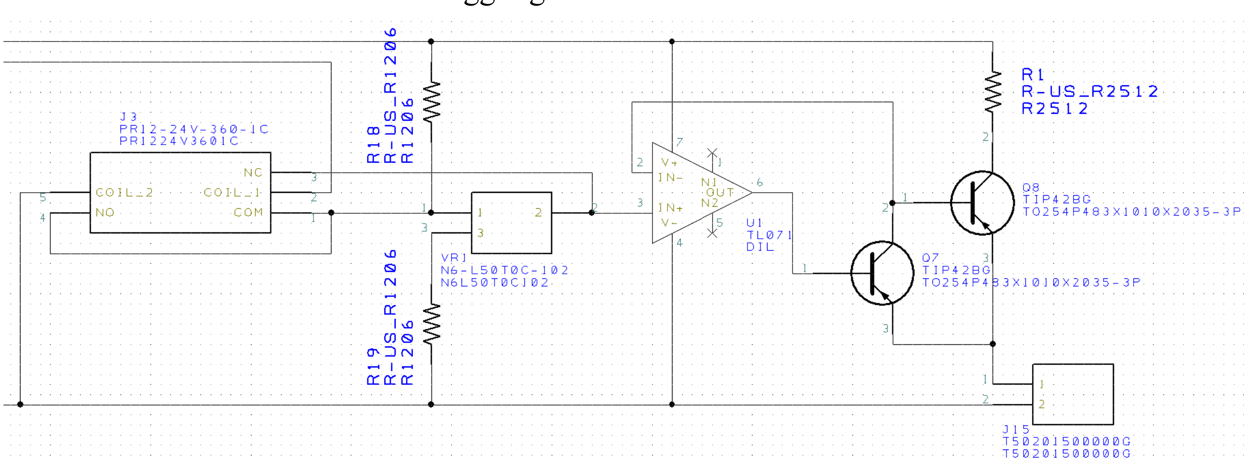


Figure 6: Current limiter circuit schematic showing mode-toggling relay

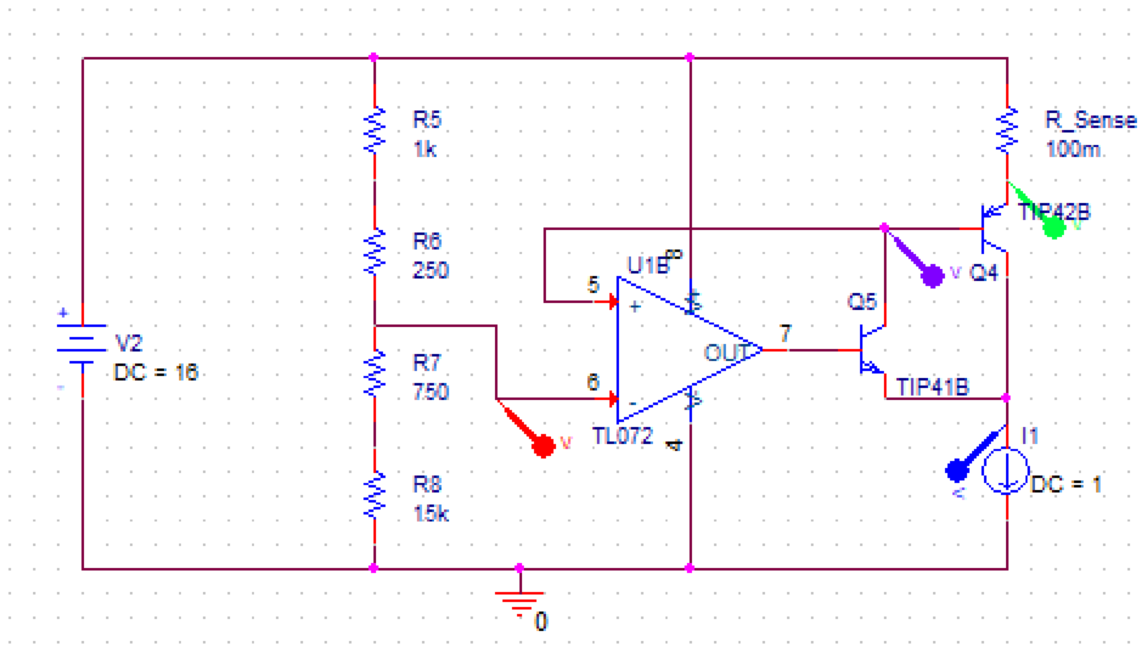


Figure 7: Pspice Schematic for 3A current limiter

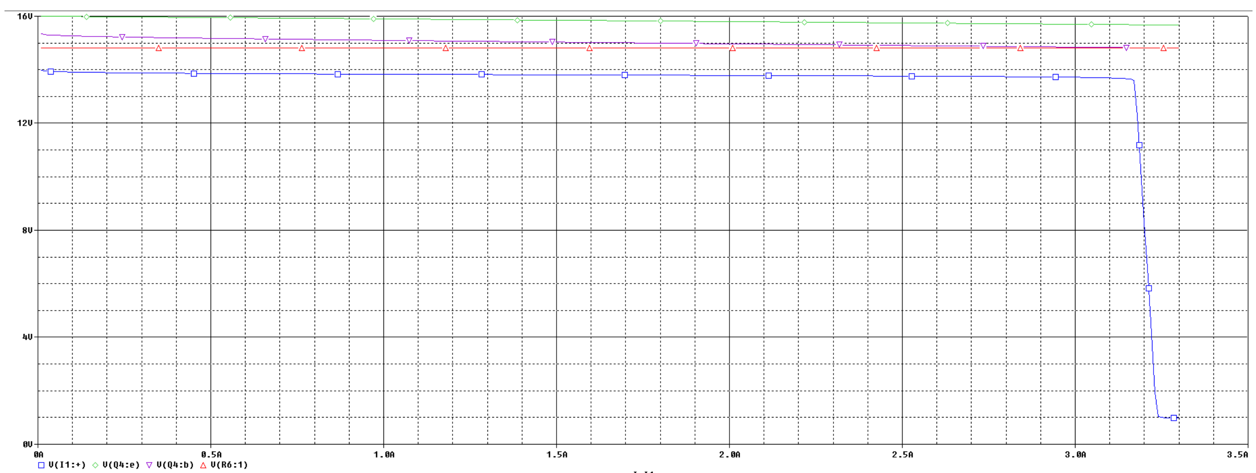


Figure 8: PSpice simulation results for 3A current limiter, created by sweeping load current I1 and observing the voltage shutoff that occurs at approximately 3.2A, which fits our design requirements

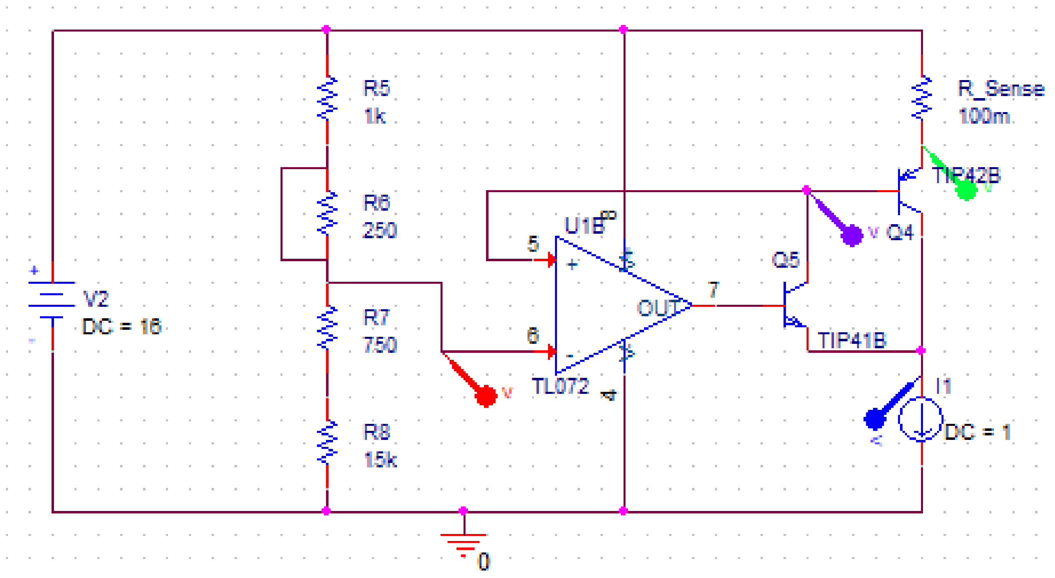


Figure 9: PSpice schematic for 1.5A current limiter (All parts of the schematic are kept the same except for the short across R6 to simulate the behavior of the mode-switching relay when the wired charger is unplugged)

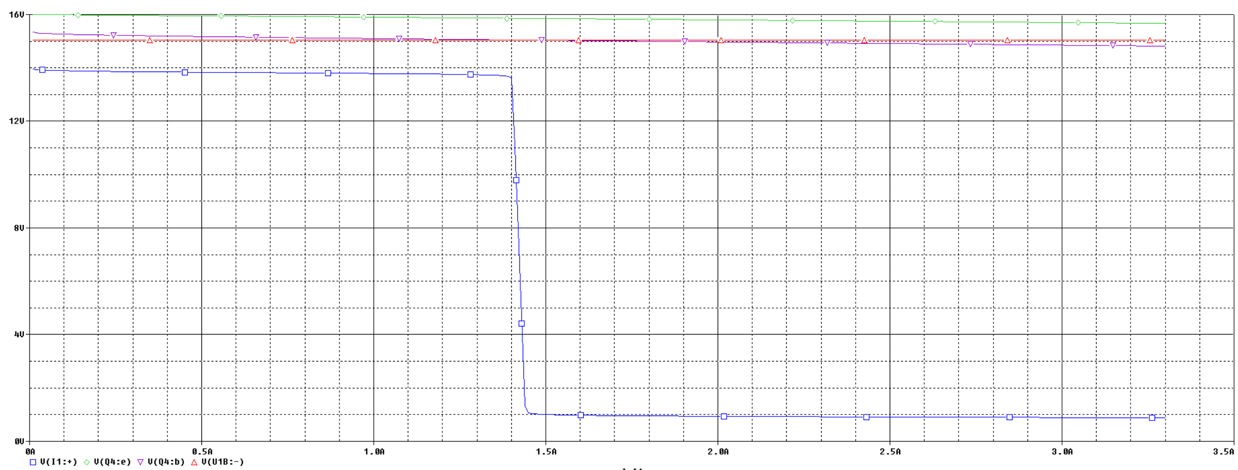


Figure 10: PSpice simulation results for 1.5A current limiter, created by sweeping load current I1 and observing the voltage shutoff that occurs at approximately 1.4A, which fits our design requirements

Charge balance and energy storage

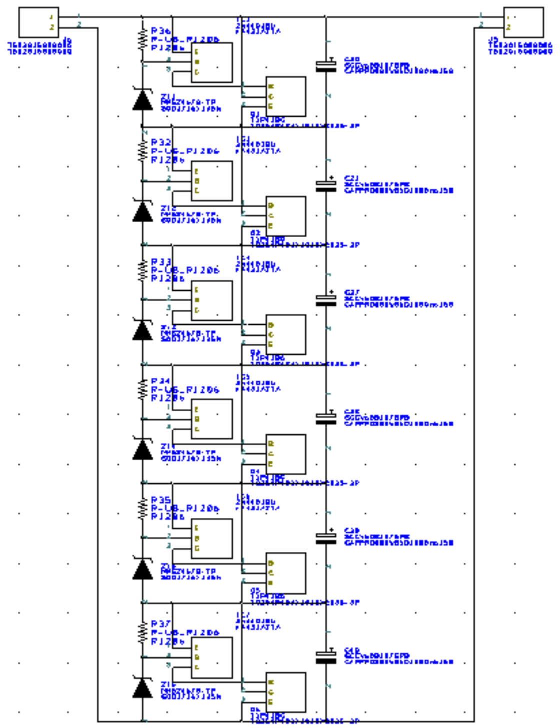


Figure 11: Energy storage and balancing circuit schematic

The energy storage and balancing circuit can be mapped to the store energy and balance energy blocks of the functional architecture. The energy storage design allows for six 100F capacitors to be charged in series to supply a voltage of 15V as found in Figure 11. In order to meet safety requirements S1, the charge balancing circuit prevents leakage current from damaging the supercapacitors, a charge balancing circuit is necessary. The charge balancing design uses a 1N4678 zener diode and darlington pair combination of a TIP41B which is rated for 6A and a 2N4403 transistor. The supercapacitors to be used are portrayed in Figure 12. This design was chosen as opposed to a singular zener diode, as the available diodes on the market rated for a high enough current provided by the current limiting circuit were too expensive. When the zener diode reaches 1.8V, it shunts the capacitor and prevents it from overcharging.

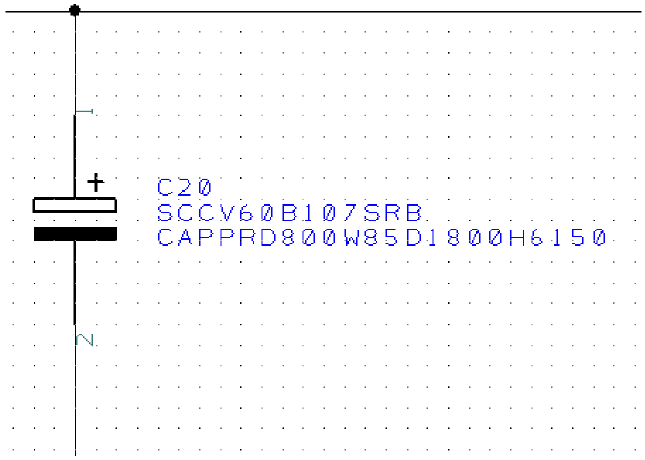


Figure 12: Supercapacitor used in the power supply schematics

Balancing circuit

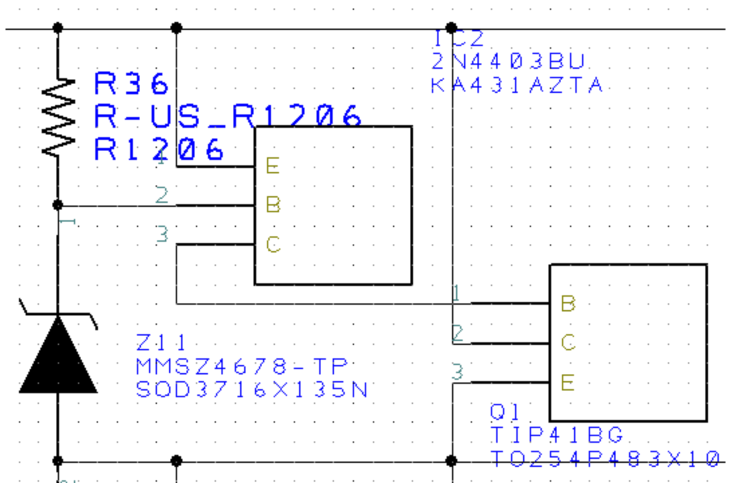


Figure 13: charge balancing circuit stage

The individual charge balancing circuit for a single supercapacitor can be found in Figure 13. The PSpice schematic for the wired and wireless chargers can be found below in Figure 14 and Figure 16. The wired charger is shown to charge within 2.5 minutes, and the wireless charger similarly charges within 6 minutes as found in Figure 16 and Figure 18.

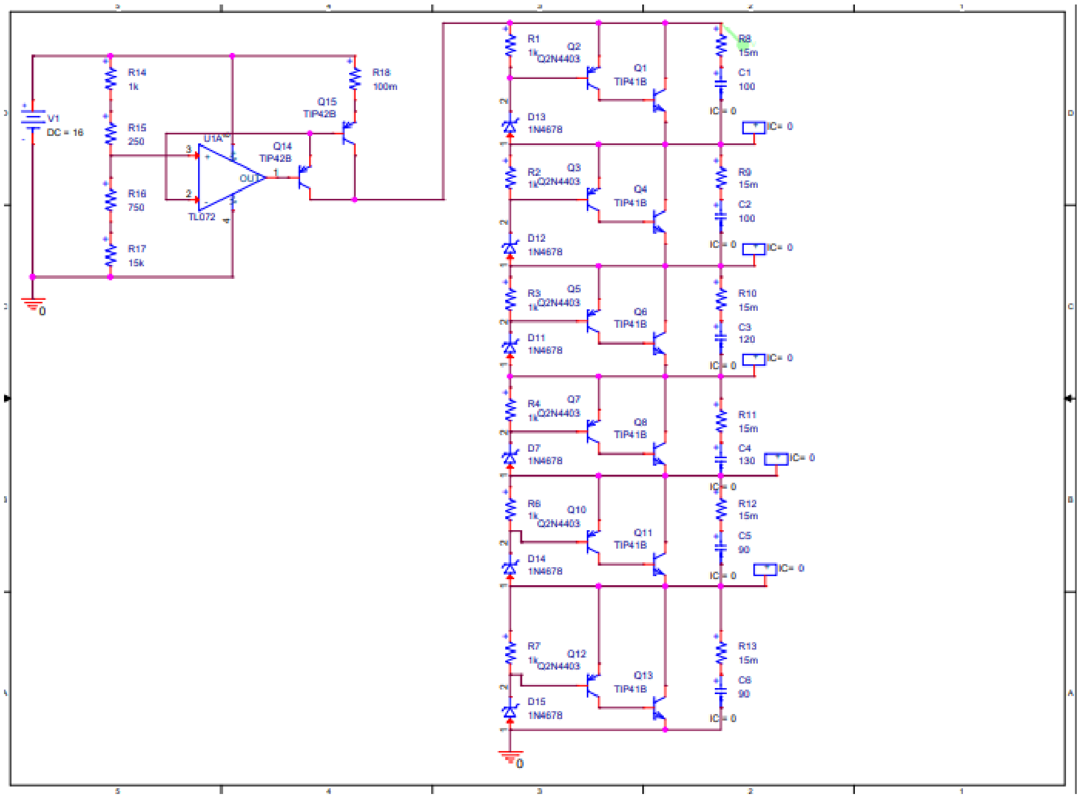


Figure 14: Pspice circuit model for capacitor charging using the wired charger

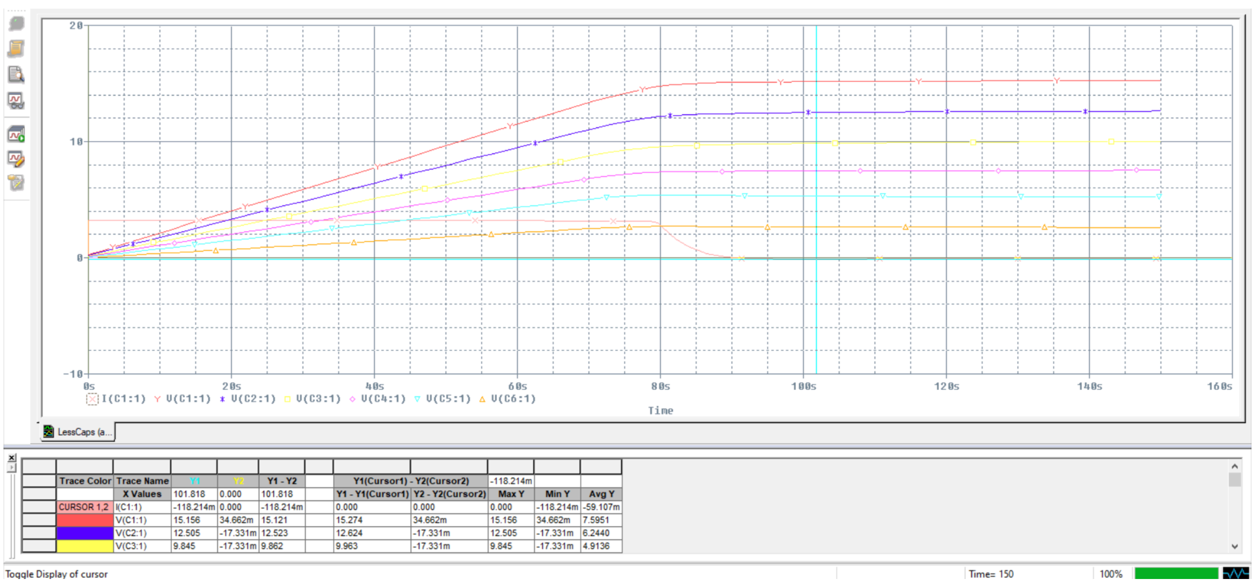


Figure 15: Simulation of wired-current charging of the energy storage system demonstrating that no capacitor reaches a potential difference greater than their rated 2.7V maximum

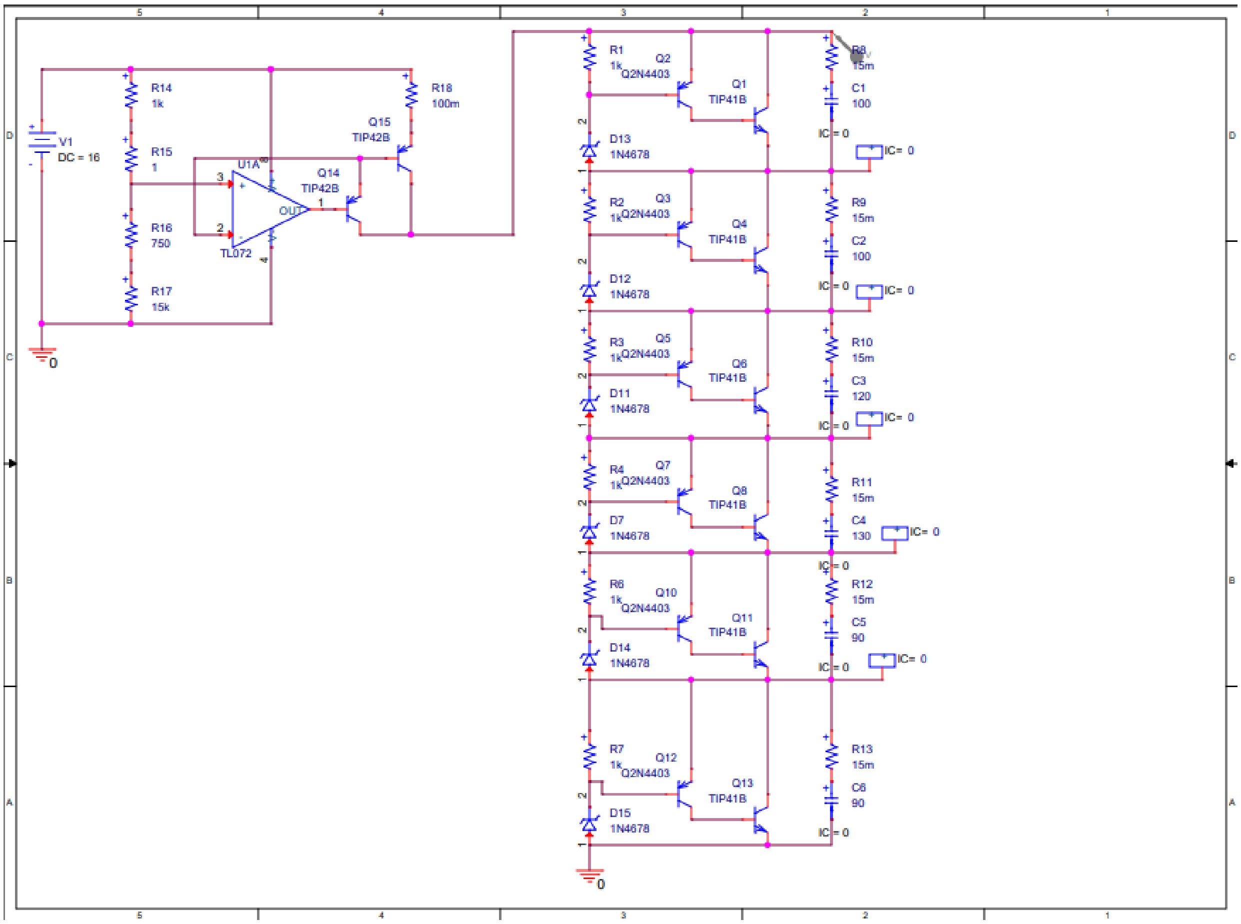


Figure 16: Pspice circuit model for capacitor charging using the wireless charger

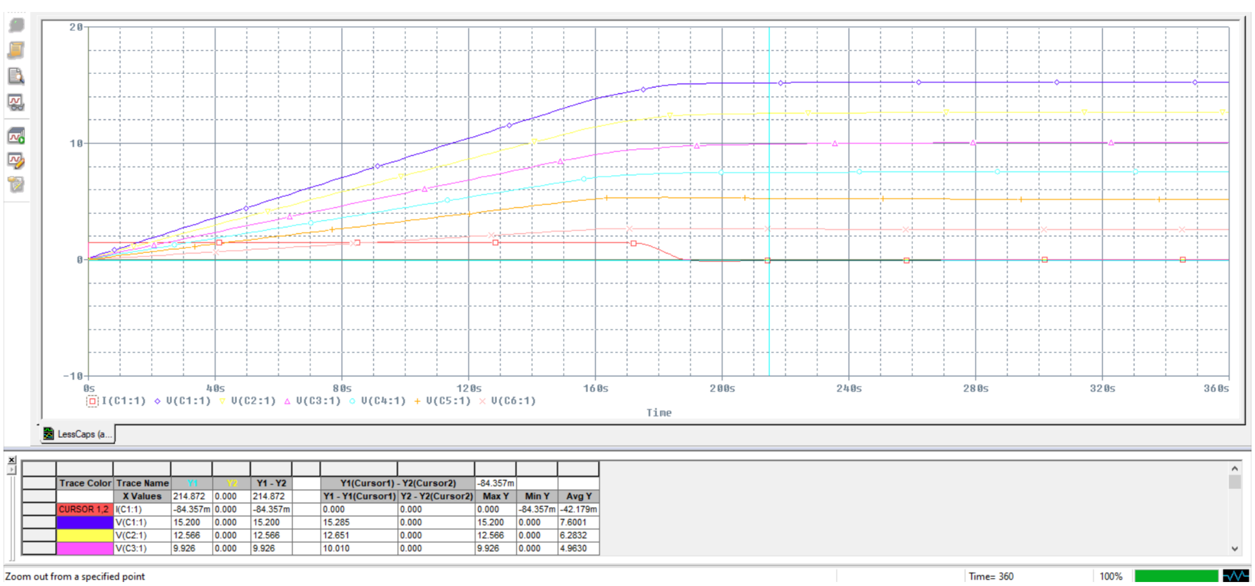


Figure 17: Simulation of wireless-current charging of the energy storage system demonstrating that no capacitor reaches a potential difference greater than their rated 2.7V maximum

Energy Output System

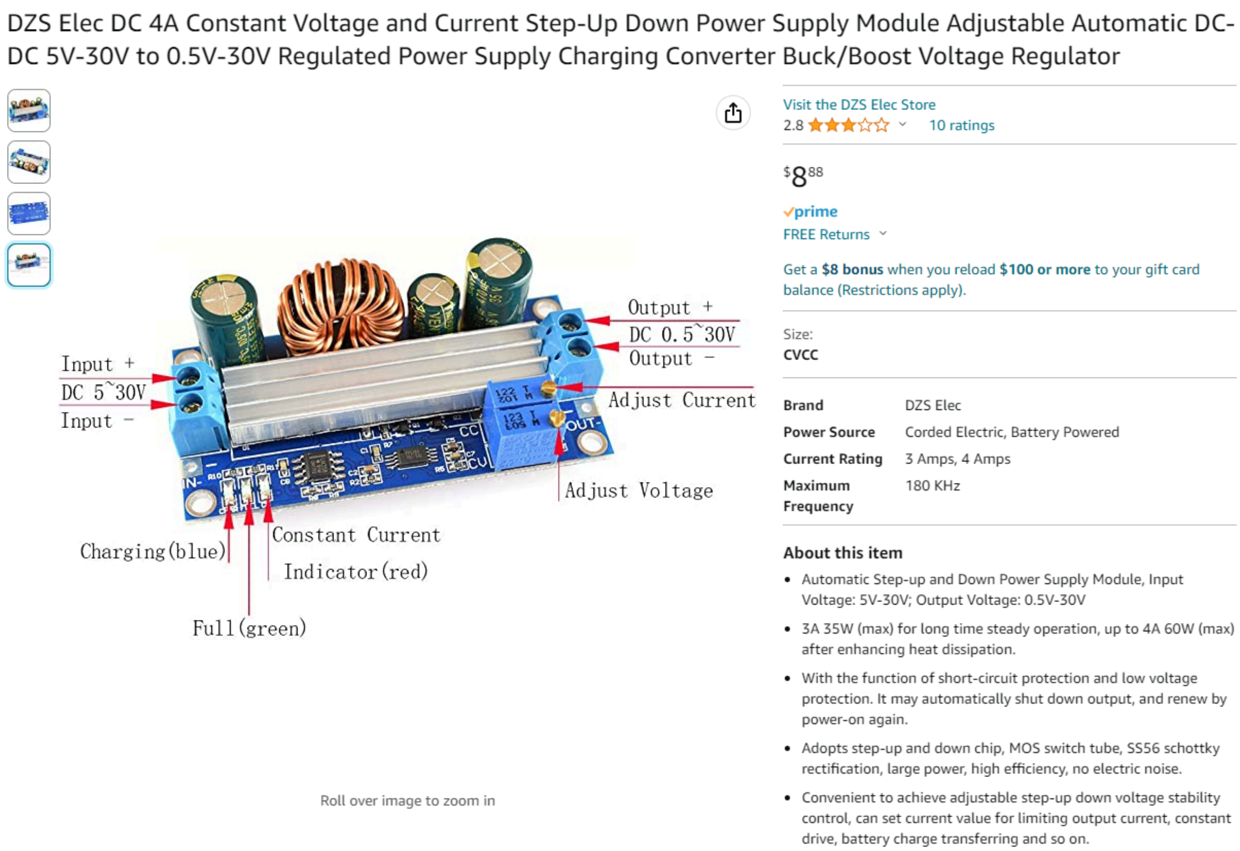


Figure 18: Energy output buck-boost module

The energy output circuit can be mapped to the control discharging block of the functional architecture. By using a buck-boost converter rated for our expected input voltages of 5V-15V at least 2A, it is possible to regulate the voltage provided to the controller. From the specifications provided by the product page for our selected buck-boost converter module shown in Fig. 18 above and from our tests of the module we received, the module is capable of meeting these input voltage and current expectations while delivering a steady 7.6V supply to the motor controller at currents greater than 2A. When the capacitors discharge below approximately 5V, the buck-boost converter cuts off, deactivating the output current and dropping the output voltage to 0V, but by this point the car should have completed the race, therefore meeting the 90s requirement.

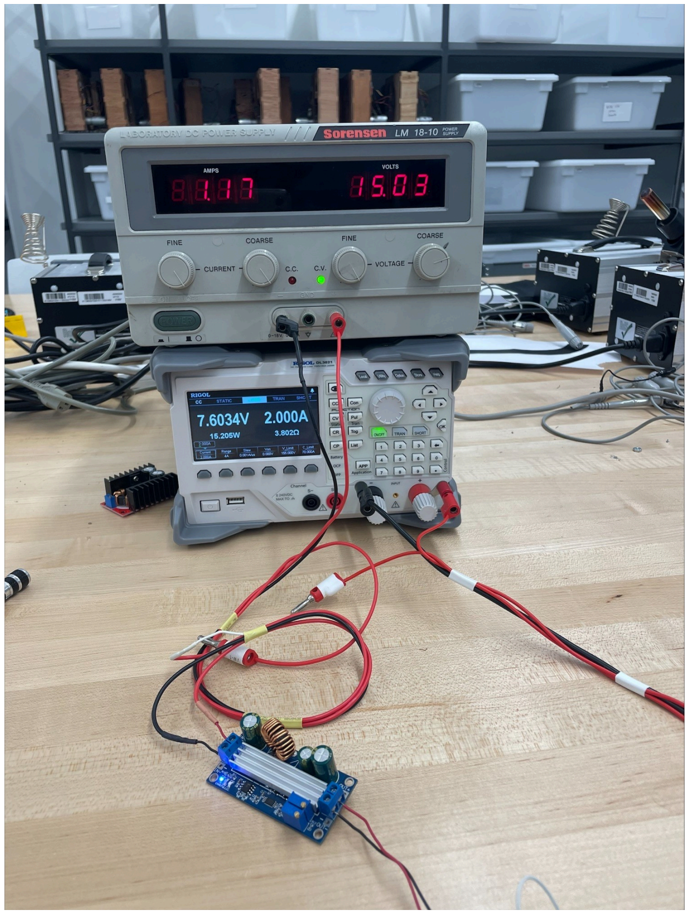


Figure 19: Buck-Boost converter module measurements at 15V input, 7.6V output, and an output current of 2A

Value Feature

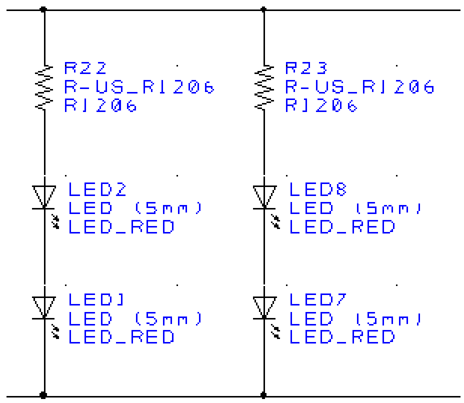


Figure 20: LED headlight circuit schematic

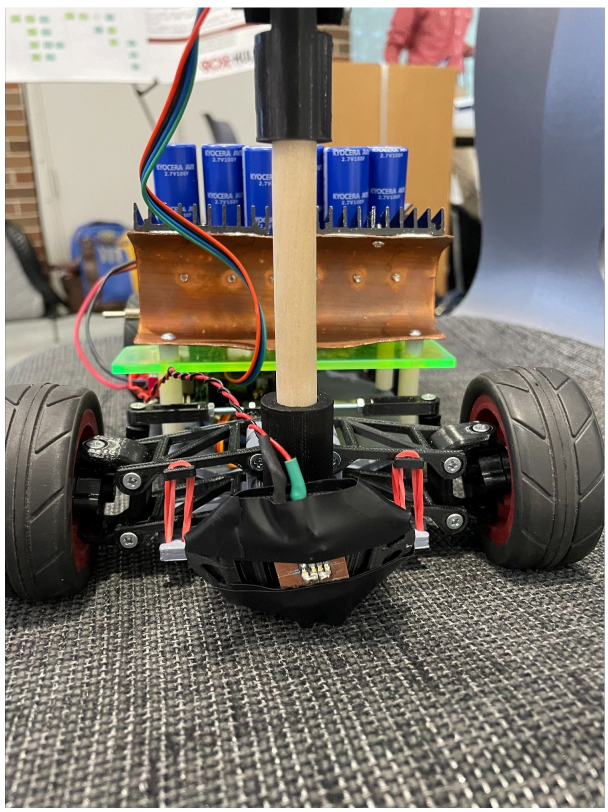


Figure 21: LED Headlight implementation on the vehicle

The additional value feature added to the system is a headlight feature as depicted in Fig. 21 and Fig. 22 which has been placed at the front of the car to improve the visibility of the line, which will in turn increase the reliability of our line following algorithm, thereby satisfying requirement V1.0.

Safety Feature

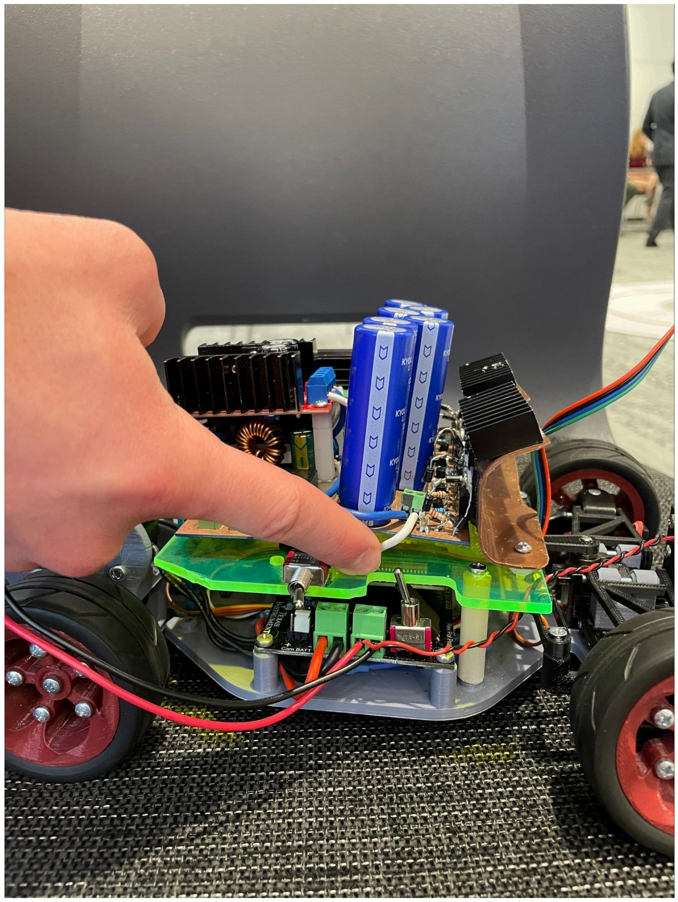


Figure 22: Final implementation of the power supply safety shield

The additional safety feature for the system is a safety shield designed to prohibit unintentional access to the terminals of the supercapacitors or to any other dangerous exposed terminals present on the final physical design implementation. This system completes our previously defined safety requirement as defined in requirement S4, and was provided to us for free thanks to Gary Meyer and Mark Crosby.

Final Charge and Discharge Results

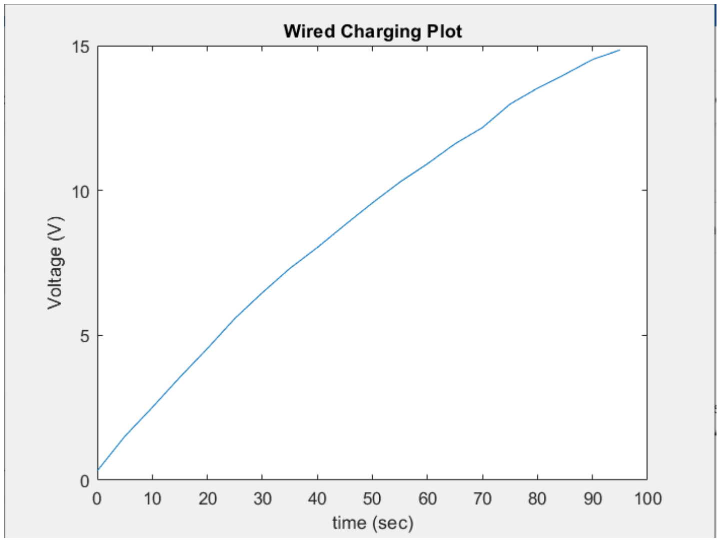


Figure 23: Plot of final power supply charging from the wired charger

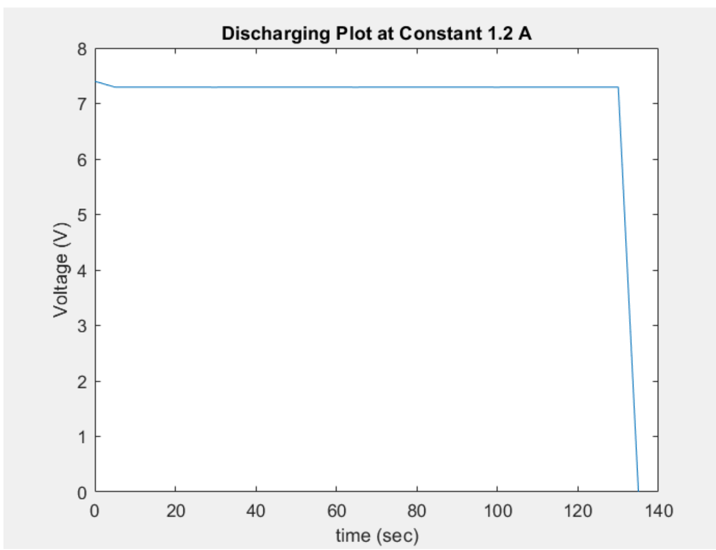


Figure 24: Plot of final power supply discharging at a constant 1.2A current draw

Assembling all of the components discussed above, we were able to produce a supercapacitor power supply that was capable of charging up to its maximum voltage well within the required time and discharging to provide more than the current required by the vehicle for well above the time requirements of the competition, as shown in Fig. 23 and Fig. 24 above.

Appendix

Bill of materials

Component:	Value:	Quantity:	Link:	Cost (per):	Cost (net):
Output Circuit					
Output Buck-Boost Converter Module	DZS Elec DC 4A Constant Voltage and Current Step-Up Down Power Supply Module	1	https://www.amazon.com/DZS-Elec-Adjustable-Automatic-Regulated/dp/B07BPY315D/?_encoding=UTF8&pd_rd_w=oEZMp&content-id=amzn1.sym.bc5f3394-3b4c-4031-8ac0-18107ac75816&pf_rd_p=bc5f3394-3b4c-4031-8ac0-18107ac75816&pf_rd_r=EFD6C3TWCCDCM3QNDKMS&pd_rd_wg=tfFDl&pd_rd_r=f24acf1c-3698-4f2f-af86-4d6d7227fe57&ref_=pd_gw_ci_mcx_mr_hp_atf_m&th=1	8.88	8.88
Storage Circuit					
Supercapacitors	100F	6	https://www.mouser.com/ProductDetail/KYOCERA-AVX/SCCV60B107SRB?qs=qSfuJ%252Bfl%2Fd7u%2FjAgEAlO4Q%3D%3D	6.85	41.1
Balancing Zener Diodes	1N4678	6	https://www.mouser.com/ProductDetail/Central-Semiconductor/1N4678-BK-TIN-LEAD?qs=l7cgNqFNU1i1fDmzLOfw9w%3D%3D	0.65	3.9
Balancing Resistors	1k	6	https://www.mouser.com/ProductDetail/Bourns/CR	0.1	0.6

			1206-JW-102ELF?qs=sGAEpiMZZMvdGkrng054ty0Ltb6w4qYv7A71gbUhRcA%3D		
Balancing PNP	2N4403BU	6	https://www.mouser.com/ProductDetail/onsemi-Fairchild/2N4403BU?qs=hXzPkG2nhVb8OEuSUeGhQw%3D%3D	0.37	2.22
Balancing NPN (High Power)	TIP41BG	6	https://www.mouser.com/ProductDetail/863-TIP41BG	0.96	5.76
Input Circuit					
PNP Current Limit Transistor	TIP42BG	1	https://www.mouser.com/ProductDetail/onsemi/TIP42BG?qs=xZq1yRCsb1dlvjLThgpzCA%3D%3D	1.07	1.07
NPN Current Limit Transistor	TIP41BG	1	https://www.mouser.com/ProductDetail/863-TIP41BG	0.96	0.96
Current Limit Op Amp	TA75S558F,LF	1	https://www.mouser.com/ProductDetail/Toshiba/TA75S558FLF?qs=lX6dEUlT%252BgcRNUil8WoaRA%3D%3D	0.51	0.51
Current Limit Sense Resistor	100mOhm, 3W	1	https://www.mouser.com/ProductDetail/Bussmann-Eaton/MSMA2512R1000FGN?qs=sGAEpiMZZMtlubZbdhIBINZaoL9yqB51SBzad2zMvQI%3D	0.35	0.35
Current Limit Bias Resistor, Top	1k	1	https://www.mouser.com/ProductDetail/YAGEO/RC1206FR-0784K5L?qs=sGAEpiMZZMvdGkrng054t8Tx25L%252BvTaRWXr7%2Fl8TcSM%3D	0.1	0.1

Current Limit Bias Resistor, Bottom	15k	1	https://www.mouser.com/ProductDetail/YAGEO/RC1206FR-0784K5L?qs=sGAEpiMZZMvdGkrng054t8Tx25L%252BvTaRWXr7%2Fl8TcSM%3D	0.1	0.1
Current Limit Bias Potentiometer	1k	1	https://www.mouser.com/ProductDetail/Amphenol-Piher/N6-L50T0C-102?qs=yLGXVRudD3phqf7g1%2F88Ag%3D%3D	0.35	0.35
Input Boost Converter Module	Gowoops 150W DC-DC 10-32V to 12-35V Step Up Boost Converter Module	1	https://www.amazon.com/gp/product/B01GRIQBRY/ref=ppx_yo_dt_b_asin_image_o00_s00?ie=UTF8&psc=1	3.40	3.40
Input Circuit Relays	PR12-12V-360-1C	2	https://www.mouser.com/ProductDetail/CUI-Devices/PR12-12V-360-1C?qs=T%252BzbugeAwjg6aK6r1ZXrpA%3D%3D	1.08	2.16
Connectors					
2.1mm Power Jack	CON-SOCJ-2155	1	https://www.mouser.com/ProductDetail/Gravitech/CON-SOCJ-2155?qs=fkzBJ5HM%252BdCcpvFQyQZHtA%3D%3D	1	1
Battery/Dean Connector	PRT-11864	1	https://www.mouser.com/ProductDetail/SparkFun/PRT-11864?qs=WyAARYrbSnbtPvKJK8JtAA%3D%3D	0.95	0.95
2-Input Screw Terminal	T50201500000G	6	https://www.mouser.com/ProductDetail/649-T502015000J0G	0.64	3.84

Value Feature: LED Headlights					
White Headlight LEDs	KW DELSS2.CC-BXCY-4J8K-46A8	4	https://www.mouser.com/ProductDetail/ams-OSRAM/KW-DELSS2.CC-BXCY-4J8K-46A8?qs=81r%252BiQLm7BT%252BEznX4a3zvA%3D%3D	0.48	1.92
LED current-limiting resistors	47R	2	https://www.mouser.com/ProductDetail/Bourns/CR1206-FX-47R0ELF?qs=sGAEpiMZZMvdGkrng054t%252BRNGJdg958RWuOSuYLEeg4%3D	0.1	0.2
				Total Component Cost:	79.54

Reflections and Conclusions

Feature	ID	Attribute/Metric	Verified
Functional - Power Supply	FP1.0	The power supply will power the vehicle for 1.5 minutes while it is maneuvering around either course.	Yes
	FP1.1	The power supply will be able to provide at least a 1A continuous current draw to the vehicle for the duration in FP1.0.	Yes
	FP1.2	The power supply will provide a voltage between 12V max and 6V min to the vehicle for the duration in FP1.0.	Yes
	FP1.3	The power supply will be able to source peak currents up to 2A for 5s without damage.	Yes
	FP2.0	The power supply will recharge rapidly.	Yes
	FP2.1	The power supply will charge from 0V to 12V in 6 minutes or less using the wireless charger.	No
	FP2.2	The power supply will charge from 0V to 12V in 2.5 minutes or less using the wired charger.	Yes
	FP2.3	The power supply will be charged from a wireless transmitter and receiver that adhere to the Qi standard [https://www.wirelesspowerconsortium.com].	No
	FP2.4	The power supply will be charged by a 120V AC to 12V DC power supply from the parts room	Yes
	FP3.0	The power supply will change from wired to wireless charging and vice versa with a simple user interaction	Yes

Functional - Controller	FC1.0	The controller will drive the vehicle autonomously around both tracks for the duration specified in FP1.0	Yes
	FC1.1	The vehicle will stop automatically after [the time duration specified in FP1.0] of going around the track.	No
	FC1.2	The controller will produce less than a three lap difference between the battery and designed power supply.	No
	FC1.3	The controller will compensate for different lighting and background conditions.	Yes
	FC1.4	The vehicle will begin the race through a simple human interaction	Yes
	FC2.0	The controller will log power data at intervals of 0.5 second while the vehicle is maneuvering around the track.	Yes
	FC3.0	The system will display energy use data with respect to time for a given run around either track.	Yes
Safety	S1	The power supply will prevent reverse polarization of capacitors as long as they are within specified capacitance tolerance (do not assume all capacitors have the same capacitance)	Yes
	S2	The power supply must fit on the vehicle without changing any other function of the vehicle.	Yes
	S3	The power supply must securely attach to the vehicle chassis without any permanent modifications to the chassis (i.e. no glue, new holes, etc.)	Yes
	S4	The power supply and/or controller must contain one additional safety feature as designed by the student team.	Yes

Affordable	A1	The power supply and wireless charger will cost less than $120 of circuit components to develop.	Yes
Valuable	V1.0	The power supply and/or controller will contain at least one additional Feature or metric as determined and designed by the team that adds value to at least one stakeholder.	Yes

We were capable of constructing a functional wired power supply, however looking back on the project, there were a few obstacles in our design process that prevented us from meeting a few specifications. Our initial design for the current limiter used inverted comparator logic, causing the op amp we had used to burn out from needing to constantly supply large amounts of current in order to keep the Darlington pair conductive. To fix this issue, we remade the current limiter circuit as an independent module using perfboard and parts from the parts room and then mounted it on top of the section of our old PCB where the original current limiter circuit was. While our design was modular, we did not optimize the means by which we dealt with heat dissipation and in doing so used more heat sinks than necessary. This significantly increased the weight of the car which prevented it from driving up the hill on the oval track. Furthermore, during the day of the competition, there were mechanical issues with our car's power-delivery belt that worsened the car's ability to climb inclined surfaces. Additionally, the chassis of our car was broken for a majority of this design project – we had implemented our own suspension system. When we went to get our belt tightened, the suspension we had been using was also fixed and without adequate time in between the fix and the competition to optimize the controller with the final power supply combined with the difference in Kahn room lighting meant that our vehicle suffered from instability issues during the final competition that had not been taken into account during the initial design of the controller in the laboratory in the NAB. Had we had enough time to tune our controller to accommodate for the changing environmental factors we would have likely seen better results regardless of our headlight value feature that was meant to eliminate that variable.