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January 30, 2017

Steve Whitmore
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 405W Project Proposal for PowerPad

Dear Mr. Whitmore:

The attached document, *Disconnect Electronics PowerPad Proposal,* provides an overview for our ENSC 405W/ENSC 440 project. We are developing a wireless charging prototype specifically to be implemented for golf carts. This will be done in conjunction with Delta-Q Technologies in order to interface with their existing technology, allowing for more intelligent battery management and charging convenience.

This proposal will provide an outline of our proposed project, including a high level overview, the project scope and plan, the potential risks and benefits, the current market and competition, our company details, and cost considerations.

We are Disconnect Electronics and our team consists of six dedicated upper year engineering students: Connor Floyd, Amar Masalmeh, Paul Vu, Michael Hsiao, Thomas Prettejohn, and Valery Ushakov. If there are any further questions about this document, I can be reached by email at cfloyd@sfu.ca.

Sincerely,

Connor Floyd

Enclosure: *Disconnect Electronics PowerPad Proposal*

School of Engineering Science
Simon Fraser University
ENSC 405W

Disconnect Electronics
PowerPad Proposal

Team 2
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Contributions

Each member of the group has put in equal amount of effort in the design of this proposal.

Executive Summary

Wireless charging via current induction has emerged as convenient and effective form of power transfer in recent years. However, current implementations are geared towards small-scale devices such as mobile phones, or large-scale machines such as automobiles; this has resulted in a rapidly growing market gap in the range of hundreds of watts to one kilowatt. In this power range, the combination of a need for high efficiency and challenges concerning heat dissipation have stunted development. Due to the high volume of devices that fall into this range, which consist of anything from golf carts to electrics scooters to boom lifts, the market opportunity for a wireless charging solution is evident. In this proposal, ***Disconnect Electronics*** will outline the need for, benefits of, and efficacy of a wireless power transfer solution that we have coined: the ***PowerPad***.

The need for a wireless charging system largely stems from convenience, since the user does not have to interact with cables or adverse external conditions such as mud or snow. A wireless solution with some degree of automatic terminal alignment would allow the user of a golf cart to simply park at a station to automatically begin charging. More tangible benefits, however, are related to safety, reliability, and efficiency. A wireless implementation allows the battery and charger to be completely insulated, allow charging in any weather condition, and is more resistant to physical degradation than traditional systems. Further, more convenient charging and common charging terminals (termed ***opportunity charging***) allows for reduced battery size, weight, cost, and increased efficiency. This is significant because batteries account for a large proportion of the cost and weight of golf carts, for example.

Disconnect Electronics intends to fill this market gap with a seamless, efficient, and easy-to-use wireless power transfer solution. The final device will have the ability to wirelessly charge at a distance of 10-20cm, and will have the ability to detect, verify, and possibly automatically adjust terminal alignment. Further, an obstacle detection mechanism will be implemented for safety. Delta-Q Technologies Corp., which works in with 300-1200W wired battery chargers for OEM applications, has expressed a strong desire for such a system and is prepared to provide resources and support towards development. The ***PowerPad*** will initially be designed for golf carts as a proof of concept because they account for a large portion of the global electric vehicle market and are a significant focus for Delta-Q's development team. However, a fully ready-for-market ***PowerPad*** could be applied to any electronic device in the power range of roughly 500-1200W.

This proposal will outline the market gap in more detail, as well as introduce preliminary design specification and a project timeline, which will include a proof-of-concept demonstration in early April and a demonstration of a prototype in early August.

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1. Introduction

Studies have shown a high demand for wireless charging of low scale and large scale devices, however there is a market gap between these two solutions. On one hand, mobile devices can be wirelessly charged at low power levels through qi charging pads. On the other hand, Plugless Power, an American manufacturer, developed a modular product to charge electric vehicles wirelessly in 2014 [1]. From here, our team, ***Disconnect Electronic***s, has drawn a conclusion that wireless charging solutions have a large demand in the market, and although there are existing solutions for low scale and large scale products, we will target a medium scale solution for our capstone project.

In partnership with Delta-Q Technologies, ***Disconnect Electronic***s has targeted an inductive charging solution for the middle-scale market. There are currently no publicized products of charging low-speed vehicles and middle range electronic products. Forecasting the growth in demand for wireless charging it is only a matter of time before this market gap is filled with demand, and our capstone team will devise a product to fulfill this gap.

Our product, the ***PowerPad***, will be a modular solution for wireless power transfer of a primary transmitter to a secondary receiver mounted to a single middle scale electronic device such as a golf-cart or other low speed vehicle. To do this we will implement a primary transmitter which will draw power from an AC outlet and charge our secondary receiver which will be mounted to the on-board charger on an electric golf-cart vehicle. We will also develop a feedback system for users to determine primary and secondary device alignment, charge efficiency, and foreign object detection. As a result, we will need several sensors to measure power transfer and charge efficiency. For funding, our group will receive funds from the SFU ESSS and Delta-Q Technologies, while any outstanding budgets will be covered internally by ***Disconnect Electronic***s**.** A rough schematic for the architecture of ***PowerPad*** is provided in figure 1. Ultimately, the goal is to prove that a medium scale inductive charging solution can be developed to fill a known market gap.

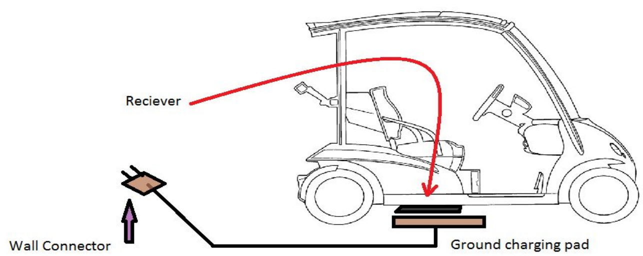


Figure 1: PowerPad Concept

2. Background

Wireless charging has proven to generate revenue and profits in the low-scale markets such as cellular devices, while large scale markets have only recently been exposed to cableless charging in electric vehicles as of Fall 2016. Following market trends and demand, it is only a matter of time before medium scale wireless chargers hit the market, specifically in the low-speed vehicles such as electric golf carts. These vehicles have short battery life and slow charging times, thus they would benefit from a wireless charging solution that can be fixated around golf courses.

2.1 Growing Demand & Revenue

Inductive wireless charging has grown in popularity in the electronic device market over the last few years and has been forecasted as a growing demand in the next 4 years. In a 2016 research survey conducted in the UK, it was reported that wireless charging was the most requested feature for smartphones[2]. In addition, Pike Research, forecasts inductive charging revenue will eclipse $11.8 billion by 2020 [3]. Figure 2 depicts Pike Research's study on the growth in revenue of wireless charging. This comes as no surprise as wireless charging is a convenient cable free alternative which is also more durable than a USB charging connection.

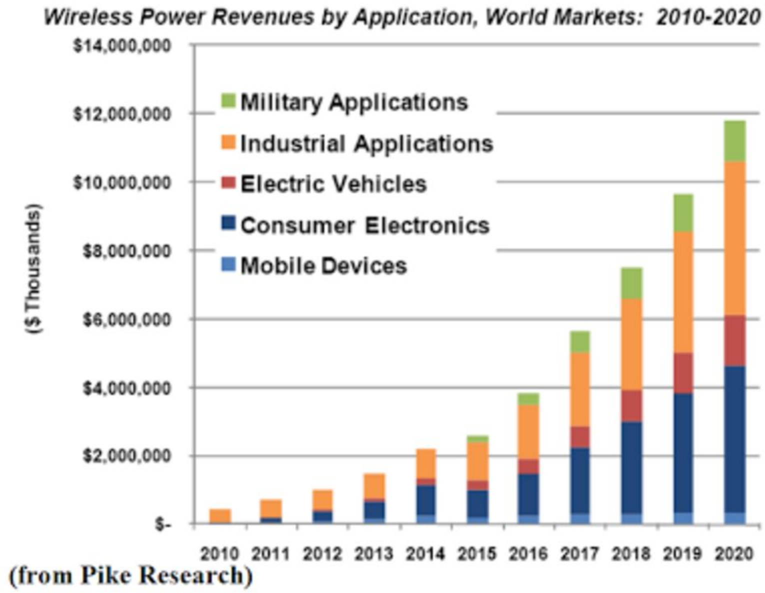


Figure 2: Wireless Power Revenues for 2020

2.2 Current State of Need: Electric Golf Carts

Electric golf carts with a healthy full battery typically have a range of 15 and 30 miles [4]. In practical use, this can cover upto 2-3 rounds of 18 hole golf depending on how much weight in people and golf bags are loaded. As a result, these golf carts struggle to keep up with demand during tournaments and are charged within half a day. Unfortunately, charge time for these vehicles range from 2-8+ hours depending on the battery [4]. As a result, golf course owners compensate by purchasing extra electric golf carts and cycle charges in while tournaments are ongoing. Additionally, in an interview with Chris Botting, Manager of Research at Delta-Q, it was noted that batteries account for approximately ⅓ the weight and cost of electric golf carts [5]. Therefore, a solution which reduces the costs and weight of golf carts will allow golf course owners to invest more into our product which allows for opportunity charging at every golf hole. In addition to this, having the ability to charge golf carts while playing could reduce the total amount of golf carts needed to maintain each course which further reduces costs.

2.3 Wireless Power Transfer

To wirelessly charge electronic devices, a primary transmitter and secondary receiver is required. These two devices will each have an inductive coil inside them. The primary device will be connected to an AC plug outlet and draw in voltage which will be converted to high frequency

AC and transmitted through the primary coil to the receiver coil through electromagnetic induction which is passed to the secondary receiver device. Within the secondary receiver, the current induced by the coils will need to be converted to DC. Figure 3 illustrates a typical wireless power transfer.

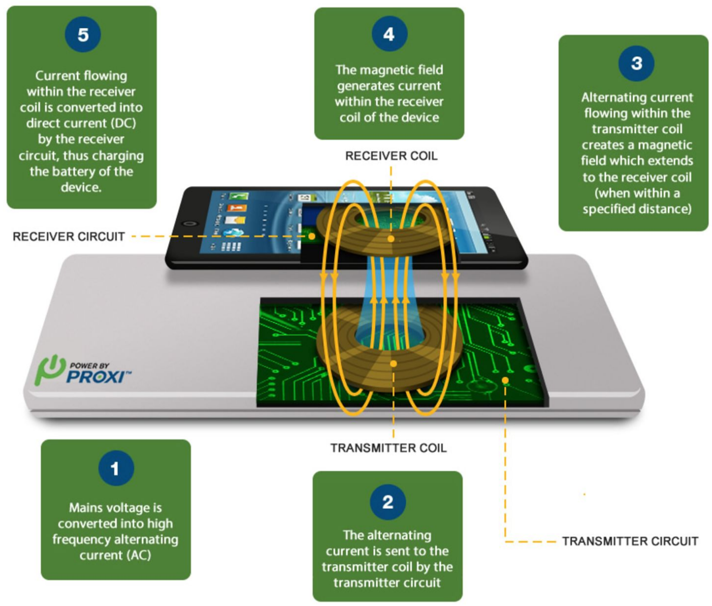


Figure 3: Wireless Power Transfer in Cellular Devices

3. Market & Competition

Current wireless charging solutions only exists below 50W, for cell phones and small electronics, or above about 3kW, for full electric vehicles. This leaves a market gap that we aim to fill. With our product, we are targeting a power level of about 1kW. This is ideal for charging golf carts, but may also be used for a range of middle-scale consumer electronics.

Looking at golf as our primary market, a recent study from 2014, "***Golf Around the World***", identified 34,011 golf courses around the world [6]. Depending on the size of the course, these courses can operate upwards of 200 carts on a daily basis. "The global golf cart market is estimated to be valued at US$ 1,115.0 M by 2016 end and is expected to reach US$ 2,080.0 M by the end of 2026" [7]. This is a very large market to implement our wireless charging solution. We believe that the convenience of our system will be an attractive alternative to conventional wired charging, especially when offered at a comparable price. Additionally, Delta-Q already has many partners as a current supplier of charging solutions and working with them will make our entry into the market smoother.

Currently, golf carts and forklifts are charged overnight in charging stations, and they do not normally last the entire day on the charge of a single battery. Therefore, multiple batteries are used. These batteries are mounted onboard the vehicle, and they account for most of the weight of the vehicle. This itself drains the battery, in addition to the cost of buying multiple large batteries for each vehicle.

Our product will solve these issues by employing “Opportunity Charging”. That is, charge the vehicle at multiple opportunities throughout the day depending on location. Our wireless charger can be implemented anywhere there is an AC outlet, one may place numerous charging pads around the premises, preferably where these vehicles stop for extended periods of time during operation. For example, a charging pad could be integrated into the turf near every second or third hole in a golf course. Compare this to the inconvenience of having a single charging location far away from the main operation location of the vehicle.

One of the main benefits of wireless power transfer is to reduce the number of system failures due to connector malfunction. In the field of power electronics, connector deformities or breakages are the leading cause of overall charging system failure. This could be due to a number of factors, such as carelessness, accidents, or simple wear and tear. This issue is non-existent when connectors are not used.

The nature of our product enables us to expand its domain to the household user level. This could include the regular use of the wireless charging pad indoors and simply powering appliances directly off of it. Examples of this would include vacuum cleaner charging, or portable heaters, refrigerators, humidifiers, dehumidifiers, televisions, gaming systems, and many more.

Another household application of our product would be simply ease of installation of additional power outlets as desired. This would be accomplished by installing the receiving coil in the wall connected to the new outlet, with the transmission coil connected to AC power on the other side of the wall. This vastly reduces the normal work of running a new set of wires through a hard wall all the way to your service box.

As stated above, currently no competition exists in this power range. This will allow us to corner the market in this segment, giving us an advantage over any technology that may be developed after our product is released. The closest alternative is PLUGLESS POWER 3.3kW charging solution for full scale electric vehicles [1]. With over 850,000 wireless charging hours [1], their success proves that the market for wireless charging does exist and we intend to exploit it at our targeted lower power level.

4. Project Outline

In this section we will be talking about the overall framework of the project; we will establish the risks and benefits associated with the design. The scope will be clearly defined here to highlight future drawbacks and to identify the risks and benefits of our product.

4.1 Scope

For this project, our goal will be to replace the AC cord with a wireless power transfer solution in order to increase the durability of the chargers. Power electronics has become increasingly reliable, however one of the most common points of failure in a charger is the AC cord. Our solution, depicted in Figure 1, will use a ground charging pad to supply power to the receiver that will be connected to the on-board charger. The ground charging pad will serve as a source resonator and then transfer the power to the device resonator as in Figure 4.

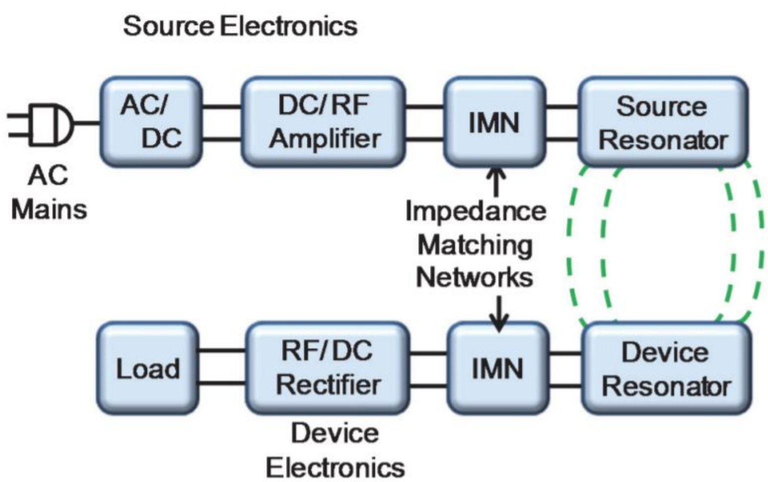


Figure 4: Basic Diagram of Wireless Battery Charging

We will be powering the PowerPad using AC voltage. A system of power MOSFETs and filtering capacitors, briefly mentioned in the cost section, will be used for rapid switching and amplification. In conjunction with a PWM signal from a microcontroller, this will convert the 50/60 Hz mains sine wave into a radio frequency (RF; 20 kHz - 1 MHz) sine wave. This is fed into the source coil through a network of inductors and capacitors (tuned to resonate at the chosen RF frequency). This LC network adjusts the impedance of the primary network to match the impedance of the secondary network to ensure maximum power transfer. It also helps negate the effect of stray magnetic and leakage inductances seen by the source. At the receiver, the output waveform is rectified and stabilized, ready to power the load.

In general, this layout will eliminate the need for an AC cord to be connected directly to the golf cart, effectively increasing the durability and product lifetime of the charger it is used with. The added benefit of easily accessible opportunity charging will also provide customers with the ability to outfit their vehicles with smaller battery packs.

We will have many options for approaching the feedback mechanism for the PowerPad. The most basic approach for UI would be to simply use LEDs to indicate when there is proper alignment between the vehicle and the charging pad. The user interface will most likely be implemented through a combination of audio and visual feedback, using speakers to announce proper alignment as well as LEDs to indicate that power is being supplied to the vehicle. The LEDs could also be used to provide directions for the vehicle, and to provide feedback on detection of foreign objects.

4.2 Proposed Solution

Our proposed solution will involve the primary transmitter (ground charging pad) as well as the secondary receiver that will be powering the on-board charger. The ground charging pad will utilize sensors in order to detect the positioning of the vehicle and the receiver, and will provide the user with feedback on their current position and whether or not they will need to reposition the vehicle. The receiver will be connected to the on-board charger as the replacement for the AC cord. The receiver is intended to be left on the charger to the effect of reducing wear on the connections, which are prone to failure. We plan to use a Delta-Q Technologies charger, and to build the electronics for the ground charging pad and the receiver. For the alignment of the vehicle, we will use a microcontroller to communicate with the location sensors to control the user interface. The microcontroller will also be used to detect foreign objects, and to detect the receiver when it is in range, to prevent charging in the case where an object may be blocking the way. The description of the overall system is shown below in Figure 5. The user interface (UI) will also closely rely on the system block diagram.

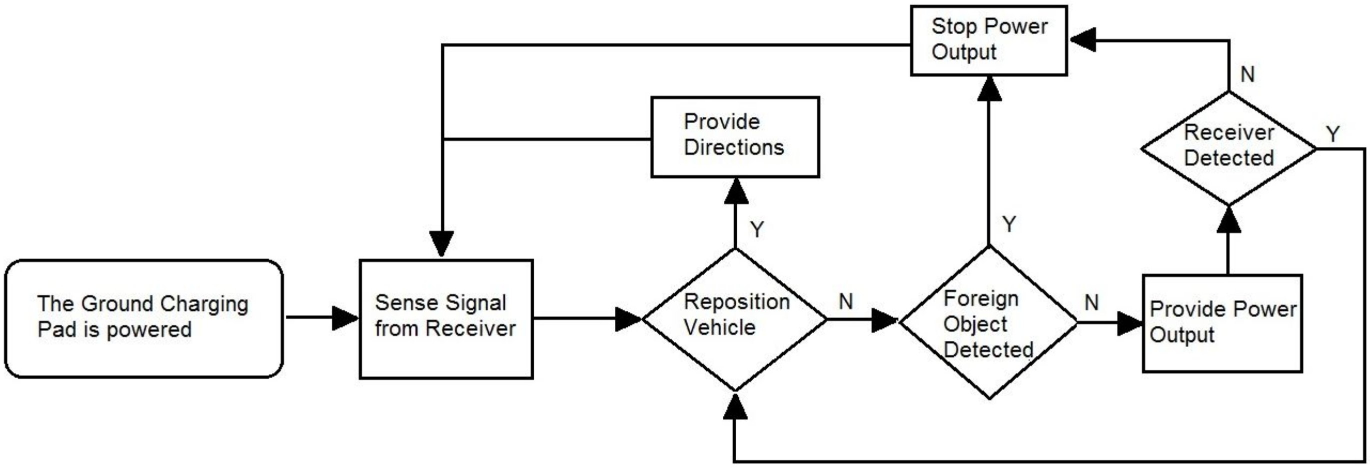


Figure 5: System Block Diagram

4.3 Alternative Solution

In terms of alternate solutions, we will have a freedom in terms of the implementation of the foreign object detection and misalignment of the primary transmitter and secondary receiver, as well as with the communications between the ground charging pad and the receiver. At minimum, our project will be able to wirelessly transfer power between the transmitter and receiver as well as having foreign object detection that can prevent power output. The alignment portion of this product could be implemented in a mechanical method, using some form of guide rails to ensure good alignment of the ground charging pad and the receiver. This would be an alternative to our current solution which will use an electronic solution to provide feedback to the end user about their positioning of the vehicle.

4.4 Benefits

4.4.1 Safety and Reliability:

• Completely insulated charging system, reduced risk of shocks and fires.
• Charging under conditions such as snow, rain, or ice will not compromise the power connection.
• Corrosion, wear and tear will not be an issue.
• Charging system cannot be damaged or easily vandalized.

• Will allow for chargers to track battery statistics since they will be paired with a certain battery. This battery tracking ability will allow for an increase in battery life

4.4.2 Opportunity Charging

• The driver no longer has to get out of the car and plug in the cord. They will never have to check for a bad connection or a faulty AC cord.

• Placing the chargers on the road, near a cafeteria, or near a lunch room will allow for ***opportunity charging***. This means that the EV can be charged at any convenient time.

4.4.3 Lighter, "Greener" , More Efficient:

• Opportunity charging will lead to reducing the battery size for all EVs effectively making them cheaper, lighter, and more environmentally friendly. Smaller batteries mean a safer and lighter vehicle, less raw materials (rare earth metals), and increased efficiency.

4.5 Risks

4.5.1 Trivial Risks:

The trivial risks of this project focus on safety and include electric shocks and potential explosion of the battery. Such risks would be present in any project that involves high voltage circuitry and are important to take into consideration as they could potentially harm people. The ground charging pad will also pose a tripping hazard since it will be sitting on the ground and if placed on the golf course it may not be easily seen by customers and staff.

4.5.2 Non-trivial Risks:

The overall system would have to be cheap and in the same price range as the existing plug in chargers in order for people to buy them. The system has to have good obstacle detection mechanism in order to detect objects other than golf carts being over the ground charging pad. Such objects could be animals finding their way to a warm place in the middle of the night. Since the operating power will be in the range of 600 to 1500 watts, the radiation from the ground charging pad could be damaging to the skin [5]. This issue will be addressed through foreign object detection. Finally the power efficiency level will need to be as high as possible to meet all the necessary requirements imposed on battery charging systems in other countries. Regulations such as those set by the California Energy Commission dictate the standards for efficiency and power usage in battery charging systems [8].
Future regulations that are going to be set by the United States Department of Energy will also need to be considered. In 2018, all 50 states in the United States will follow the standards for

energy outlined in their Energy Conservation Program [9]. These strict regulations, which significantly affect Delta-Q Technologies and any similar companies, will require us to design our product in such a way that the charging systems will still be able to pass regulations while using our product. One of the challenges with meeting these requirements, is that the battery used in the testing procedure has a significant impact on the results [10]. As we will be using a Delta-Q Technologies charger, which currently meet the standards and regulations, we will have to be mindful of our product to ensure that the charger can retain its current specifications when integrated with our product. One of the more non-trivial risks to our team, would be a lack of expertise with respect to wireless power transfer. It will be challenging to learn about this topic enough to be able to create our product with our desired efficiency rates.

5. Cost Considerations

A preliminary costs list is included in the table below. All prices are in CAD. Note: as the scope of this project is very scalable, a 30% contingency "cost" has been added. This includes shipping costs and possible discrepancies in currency conversion. Also, the Development kit items (totalling $530) are not additional costs, as Delta-Q already possesses these items. See the "Funding" section below.

Table 1: Preliminary cost breakdown

Item	Vendor	Cost	Quantity	Total
Development Kit - Transmitter	Texas Instruments	$200	1	$200
Development Kit - Receiver	Texas Instruments	$330	1	$330
Arduino Uno	Amazon	$30	1	$30
Passive Components (RLC)	Digikey	Lot of ~100 for $20	1	$20
Variable (Tuning) Capacitors	DigiKey	$10	4	$40
Power MOSFETs	DigiKey	$4	5	$20

Full Wave Rectifier (LM74670-Q1)	DigiKey	$5	2	$10
Magnetic Wire/Coils	SparkFun	$20	2	$40
Ferrite Core	DigiKey	$10	2	$20
Quartz Oscillators	SparkFun	$25/20	20	$25
Microcontroller (ATMega328P)	DigiKey	$5	1	$5
MkII Programmer	Atmel	$53	1	$53
PCB Manufacturing		$30/2	2	$30
				$823
Contingency		30%	N/A	$247
				$1070

For our final product, we are expecting a mere cost of $100-$200. This is due to the one-time cost of buying items, and circuit optimization. The development kit is also a one-time cost.

5.1 Funding

We are designing and implementing this product in conjunction with Delta-Q Technologies. Delta-Q has agreed to provide most of the materials and services we will be needing for this project, or the funds to purchase them. This includes: A wireless power transfer development kit, circuit components, transmit and receive coils, ferrite cores, PCB manufacturing, and possibly licensing for power electronics simulation software.

Our team will be applying for the ESSEF (Engineering Science Student Endowment Fund) for the Summer 2017 semester (beginning May).

We are not expecting any shortage in funds (beyond even the 30% contingency). However, if any additional funds are needed for parts/services, the team has agreed to split the cost amongst the six of us.

6. Project Timeline

The developmental timeline of this project is largely dependent on the deliverables defined in the course schedule. Added to this are other milestones and timelines specific to the project. These include training with the the development kit, which is supplied by Delta-Q Technologies and is meant for power engineering projects. We will receive this kit early in the week of January 29, and expect to get up to speed within a week. Following this, development of a simulation in PSIM will be necessary before acquisition of parts. Upon a successful simulation and procurement of hardware, full development can begin and will last until close to the date of the poster presentation. This presentation must include a demonstration of wireless power transfer at a projected distance of roughly 15cm. The proof of concept will not implement any automatic alignment or obstacle detection features.

The following Gantt chart displays this proposed timeline, which extends beyond the April 10 poster demonstration to the completion of the prototype. This phase of the project will culminate in a full-fledged prototype that combines optimal efficiency, automatic terminal alignment, and an obstacle detection safety mechanism.

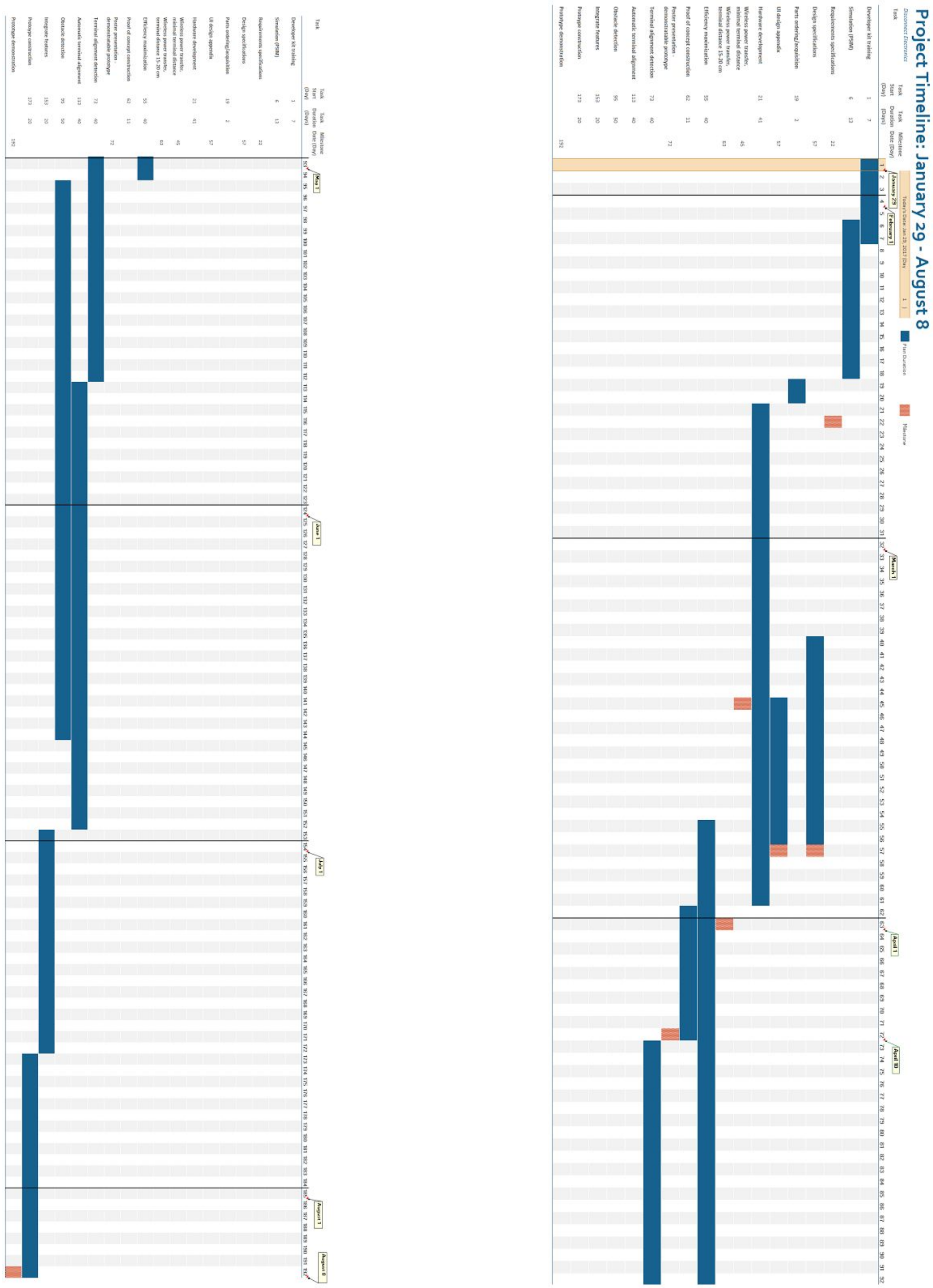


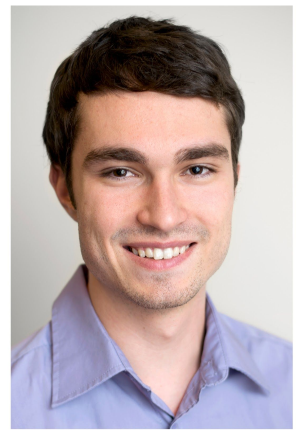
Figure 6: Gantt chart spanning from January 29th to August 8

7. Company Details

Founded in January 2017, ***Disconnect Electronics*** was formed by 6 senior engineering students from Simon Fraser University. ***Disconnect Electronicsô*** first product, ***PowerPad***, a wireless charging solution for electric golf carts, is expected to be released in August 2017.

7.1 Team Breakdown

Connor Floyd - *(B.A.Sc) Engineering Physics*



I have experience with power electronics, including failure and root cause analysis. In addition, I am skilled in circuit design and analysis. I have also worked with Delta-Q and am familiar with their charger designs and capabilities. I hope to contribute my hardware skills and knowledge of charging technology to this team.

Michael Hsiao - *(B.A.Sc) Electronics Engineering*

I have experience from the industry with software and mechanical engineering. This experience includes working with Delta-Q developing embedded software for their chargers. Through schooling, I have become accustomed to working with electronic circuits and hardware in general. My skill set will allow me to contribute to all of the technical aspects of the project.

Amar Masalmeh - *(B.A.Sc) Engineering Physics*

I am very enthusiastic about hardware design and problem solving in electronics. I have a year of experience working in the SFU laboratories, where I accomplished a number of goals related to low level circuit optimization, product design, and implementation. I am very interested in microcontrollers, and have a lot of knowledge and hands-on experience with electromechanical system development and troubleshooting from my extracurricular activities. I hope to make use of my experience in electronics and control in this project.

Thomas Prettejohn - ***(B.A.Sc) Biomedical Engineering***

In addition to hands-on electronics and computer engineering training at Simon Fraser University, I have industry experience in embedded development. I am particularly interested in applying electronics and other technological systems to the biomedical field, and I have completed a minor in biology. Noteworthy projects that I have worked on include developing an infrared spectroscopy system to monitor brain activity, and embedded work on industrial and mid-range battery chargers.

Valery Ushakov - ***(B.A.Sc) Electronics Engineering***

I am passionate about hardware development and electronics in general. I am also a BCIT diploma holder from Electrical and Computer Engineering (Power Option). I have over 2 years of experience in PLC programming as well as circuit design and troubleshooting. I have also worked at a medical company doing software testing for a short period of time. I hope to bring my knowledge of hardware design to this team and grow in other fields related to our project.

Paul Vu - ***(B.A.Sc) Computer Engineering***

I have 2+ years of experience in an industrial software development environment. Primarily focused in web and iOS development, I also specialize in digital system design and embedded development. Within our team, these skillsets will make me an ideal contributor to all components software related. Additionally, I have also worked as a project manager on several undergrad projects and will contribute as the lead role in bridging our team and client together.

8. Conclusion

The demand for wireless charging solutions has increased in the last few years, and the market for these solutions will soon expand to middle-large scale electric vehicles. ***Disconnect Electronics*** product, ***PowerPad***, will be released in August 2017, and will provide electric golf carts the ability to charge at opportune times throughout a golf course. Our solution will provide an alternative to conventional wired charging mechanisms, and aim to save park owner's costs in overall cart expenditure and charging maintenance. We will develop a primary charging pad which can be situated throughout a golf course to provide inductive wireless power transfer to secondary receivers mounted to each golf cart. Key features we will look at is maintaining a high power efficiency, foreign object detection as well as user feedback for alignment optimization. As we are developing our product, we understand we will be working with hazardous voltage levels and batteries and will keep our team and future product holder's safety in mind when we draw our design specifications. We will aim to keep costs at a maximum of ~$1100, and through the help of SFU's ESSS and Delta-Q we will have a majority of our costs covered. Finally, we at ***Disconnect Electronics*** expect a working alpha prototype demonstrating successful wireless power transfer by the end of April 2017, with a more developed Gamma prototype by the end of August 2017.

9. References

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Figure 1: http://stacalkas.deviantart.com/art/Golf-Cart-Side-93217090
Figure 2: https://www.chargespot.com/news/state-of-wireless-charging-2016-mobile-devices/
Figure 3: https://powerbyproxi.com/wireless-charging/
Figure 4: http://www.witricity.com/assets/highly-resonant-power-transfer-kesler-witricity-2013.pdf

10. Glossary

EV - Electric Vehicle
PWM - Pulse width modulation
OEM - Original equipment manufacturer
On-board charger - A charger that is mounted onto the vehicle or machine that it will charge
Opportunity charging - Recharging a battery whenever possible, in order to maintain the highest charge possible