UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

INDUCTIVE CHARGING CASE

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Abstract

Our project aims to bring a cost-efficient, wireless charging solution to the consumer. It solves the problem of having a single USB port (USB type C), and having that port occupied when charging. A wireless charging solution will leave that port open for other uses such as listening to music and transferring data.

Our product will also have a mobile application to accompany it, so that the user can view important battery statistics, and get informed in the case of overheating. Our entire system, along with a portable rechargeable battery, is enclosed in a slim, lightweight phone case that can fit in your pocket with ease.

Contents

1. Introduction

As USB type C is becoming more common in phones, many companies are removing the headphone jack on phones. This creates a big problem for those who want to transfer data or listen to music while charging their phone [1]. This problem increases as phones become more powerful and their battery life do not grow at the same rate. It is very common to run out of battery at the end of the day after having used your phone during the whole day.

Our idea to solve this problem is to develop a rechargeable wireless battery that can give your phone an extra amount of power without taking up the only jack the phone has. We will implement a Qi transmitter circuit into a case along with the rechargeable battery. Power will flow from the battery to the transmitter circuit and will be received by the circuit integrated in our phone.

Nowadays there are some phone cases that allow you to charge your phone without plugging it into the socket. Our device is different because we are going to use a system that transmits the power wirelessly. In the already existing cases, the rechargeable battery is directly connected to the charging port. These cases partially solve our problem as you do not need the phone to be connected to the wall, but we want to completely solve it by charging the phone wirelessly so we can use the port for other purposes.

In this report, the context of the project will be discussed followed by the objectives, design, and design verification.

1.1 Objectives

The main objective of this project is to develop a product that charges your cellular device wirelessly without using your USB port. More specifically, the features provided are listed below.

1. Charge a phone without using the USB port.
2. Create a device that fits in a pocket.
3. Incorporate Foreign Object Detection to save power.
4. Design a software application around the device.

2 Design

The system is divided into two general blocks: Power Module and Transmitting Circuit. We have a power module that consists of a 3 V Li-On battery which sources a DC-DC step up voltage regulator. The regulator gives us constant 5 V which we need for the next module. The main block of the design is the transmitting circuit which converts the 5 VDC to an AC signal that the coil sends to the receiving circuit built in the cellular device. The transmitting circuit is composed of two modules: The Analog Front End (BQ50002A) and the microcontroller (BQ500511) by Texas Instruments [2] [3]. The main goal of this module is to set the charging frequency that varies for each device. The microcontroller communicates with the receiving circuit built in the device and sends data to the Analog Front End which adjusts the charging frequency. The AC signal is sent to the copper coil which in turn induces a magnetic field. That magnetic field is used to inductively charge Qi enabled devices. This block also has a LED system to indicate when the circuit is charging the cellular device. Our software application will pull data from the phone in order to analyze charging efficiencies along with other useful user end data.

While the core of our design remained intact, we decided to change the 3.7 V rechargeable battery of our original design to the 3 V Li-On battery mentioned before.

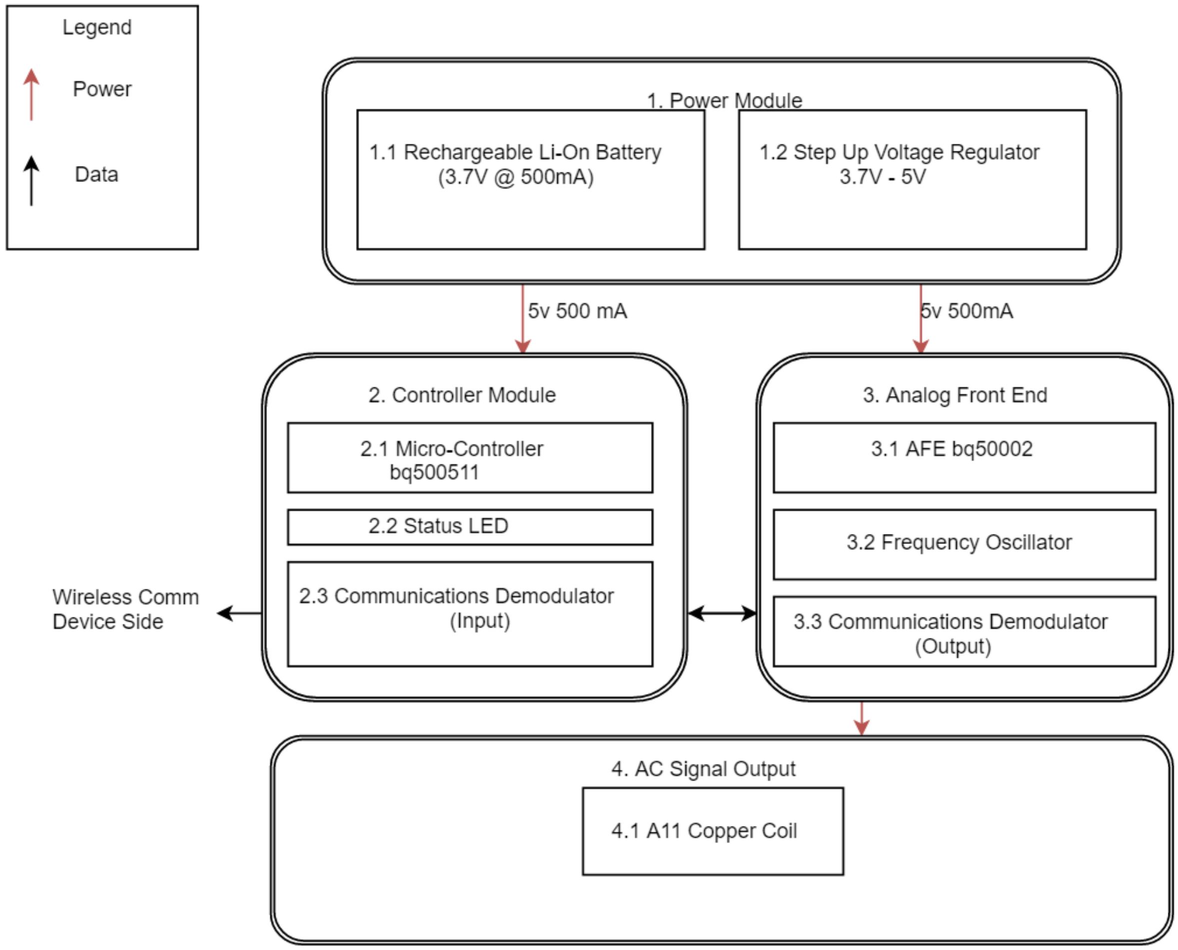

Figure 1: Block Diagram

2.1 Power module

The battery would provide our dc-dc converter with a variable voltage from 3 V up to 4 V. The converter must be able to step up that voltage to 5 +/- .2 V at load currents of 0.5 A. The output would be used to power the dc-ac converter. We used Texas Instruments LM2621 which has an input range from 1.2 to 14 V up to 1 A load current [4].

2.1.1 DC-DC converter

Figure 2 shows the schematic for the step up voltage regulator.

From LM2621 datasheet, the feedback resistors are set using equation (1).

$$RFBB = \frac{RFBT}{\frac{Vout}{Vmin} - 1} = \frac{150k}{\frac{5}{1.24} - 1} = 49.9k \approx 50k \quad (1)$$

In order to set the frequency in the desired range for Qi standard, we use equation (2).

$$Z(\omega) = j\omega Lm + \frac{\frac{j\omega Lp}{jwCm}}{j\omega Lp + \frac{1}{j\omega Cm}} = \frac{j(\omega^3 LmLpCm - \omega(Lm + Lp))}{\omega^2 LpCm - 1} \quad (2)$$

$$\omega_2{}^2 LmLpCm - \omega_2(Lm + Lp) = 0$$

$$\omega_2 = \sqrt{\frac{Lm + Lp}{LmLpCm}}$$

$$\omega_1^2 LpCm - 1 = 0$$

$$\omega_1 = \sqrt{\frac{1}{LpCm}}$$

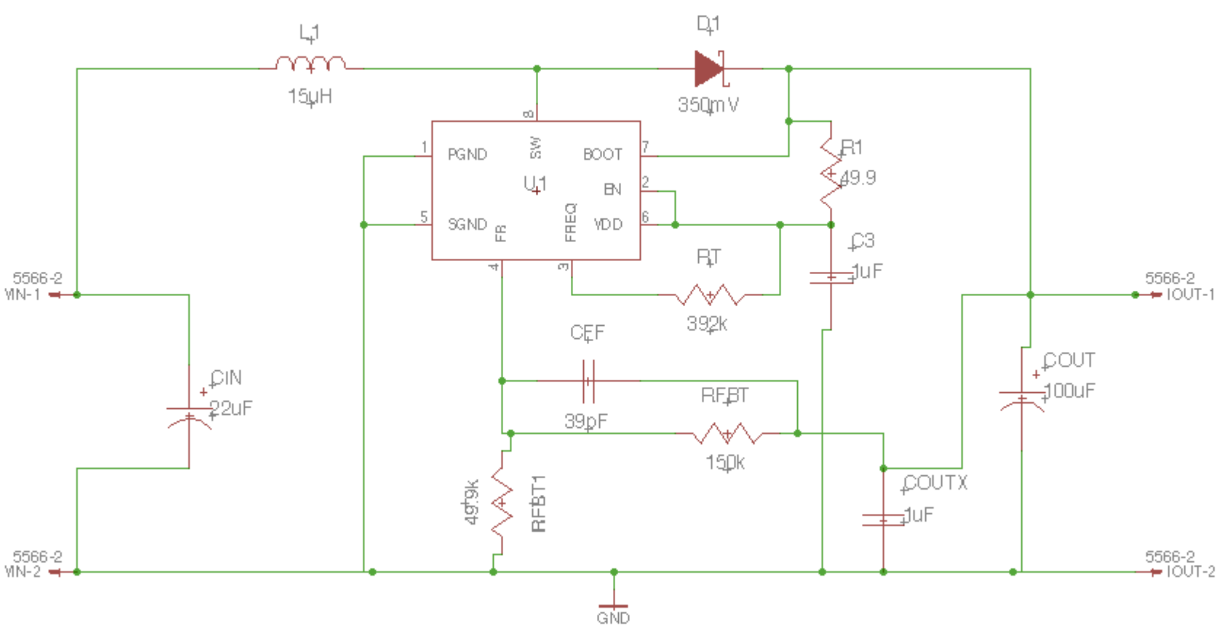

Figure 2: Schematic DC-DC converter

Figure 3 shows the ideal operation of the dc-dc converter. In this graph we can see how the efficiency of the converter increases as the input voltage increases. This is the reason why we wanted to use a 3.7 V rechargeable battery but unfortunately we had to change it for a 3 V battery.

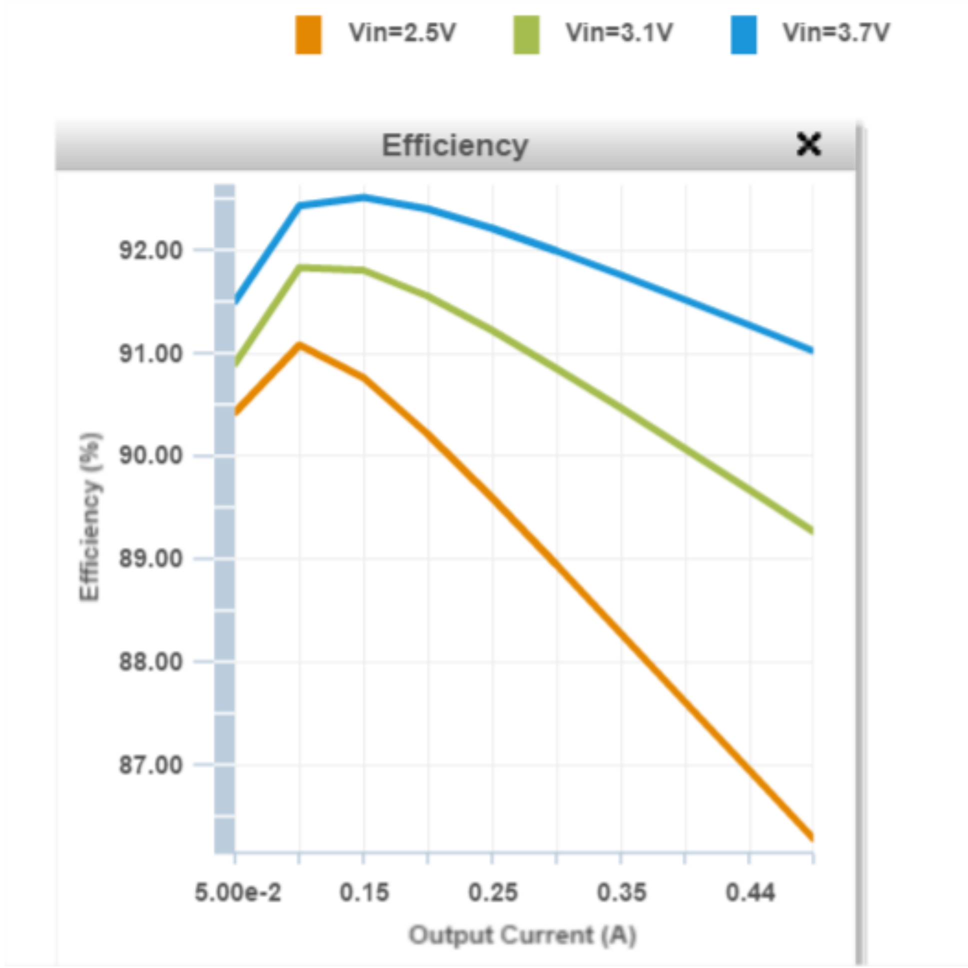

Figure 3: DC-DC converter. Theoretical efficiency

2.2 Transmitting circuit

The transmitting circuit is composed of two main chips: the analog front end chip (BQ50002A) and the micro-controller chip (BQ500511). These two ICs from Texas Instruments must be used together to realize a compact power transmitter.

The micro-controller receives data communication from a receiving circuit and demodulates this data in order to send it over to the analog front end chip. This data includes but is not limited to the foreign object detection system where the entire DC-AC circuit only draws a minimal amount of power to maintain the object detection. Once a receiving circuit sends a signal back initiating charging, the full 5V will be transmitted to the entire circuit. The receiving circuit will send feedback data to the micro-controller designating what frequency the output current should be maintained at in order to have maximum charging efficiency at resonant frequency. Once the microcontroller gets this data, it sends it to the analog front end chip where it uses a built in frequency oscillator to modify the signal. The transmitting circuit and receiving circuit are in constant communication and the transmitting signal will be modified as needed throughout the charging process.

The transmitting circuit receives constant 5 V from the Power Module and maintains a frequency within the Qi designated standard frequency range (105 kHz - 210 kHz).

2.2.1 DC-AC

Figure 4 shows the schematic of the DC-AC converter.

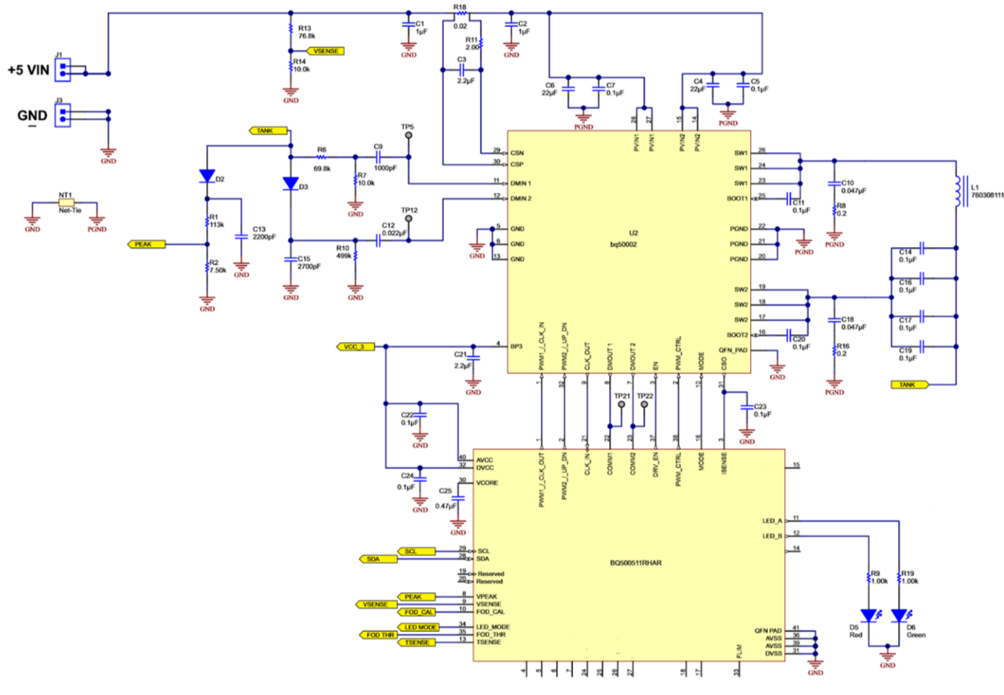

Figure 4: Schematic DC-AC converter.

Figure 5 shows the theoretical output of the transmitting circuit while charging a receiving circuit.

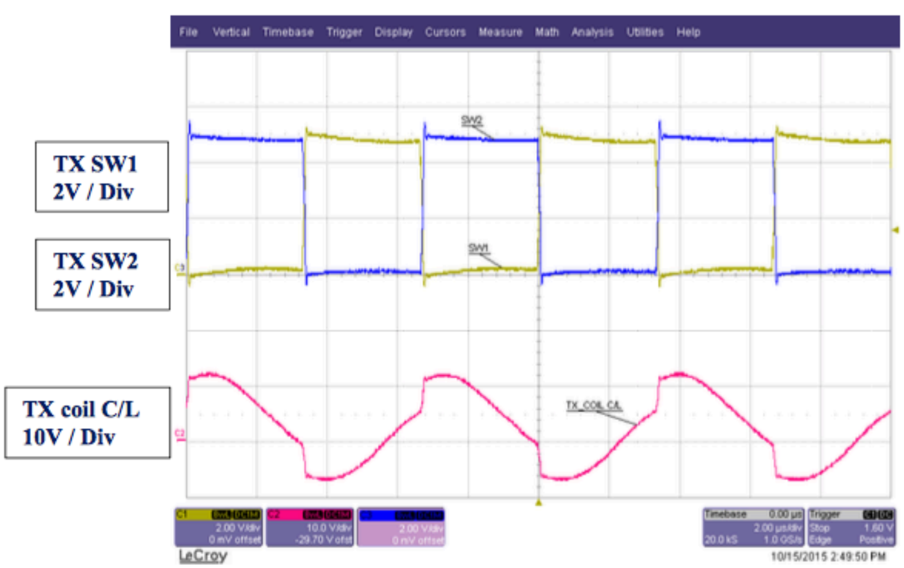

Figure 5: DC-AC converter. Output voltage

2.2 Software design

For the software application, we used Android Studio as the Integrated Development Environment. This is the most widely used IDE for developing Android applications, hence it was an appropriate choice. While developing the application, we realized we needed to add more components such as the *model* (that is central to the application). The different components and their functions are as follows:

1. **Android Manifest** - This is the configuration file which sets up the required intents, and launches the application from the Main Activity.

2. **Main Activity** - This is the controller for the main view (6 buttons). It initializes and connects all the components from the view with the objects in Java. It also initializes the Power Connection Receiver component, and registers it with the Android OS to receive data.

3. **Power Connection Receiver** - This component receives battery data from the Android OS when the battery level changes. It is a class that we implemented which extends the BroadcastReceiver class, and overrides the onReceive() function, where it receives data such as the battery level, the health of the battery, the status, the efficiency, and the type of charging. All this data is parsed, formatted, and stored in the Model. An important aspect of this component is that it adds the battery level periodically to the Queue data structure, which is defined in the model.

4. **Model** - This is a class holds all the data it receives from the Power Connection Receiver, and defines and implements the API to send the data to the PopUpBox.

5. **PopUpBox** - This is the controller for the pop up views. Instead of making 6 different views for the 6 buttons, this class dynamically changes the data in the single pop up view, based on which button is pressed. It queries data from the Model, and loads it into the view.

6. **View** - This is the container xml file that holds the views. Here the buttons and their ids are defined.

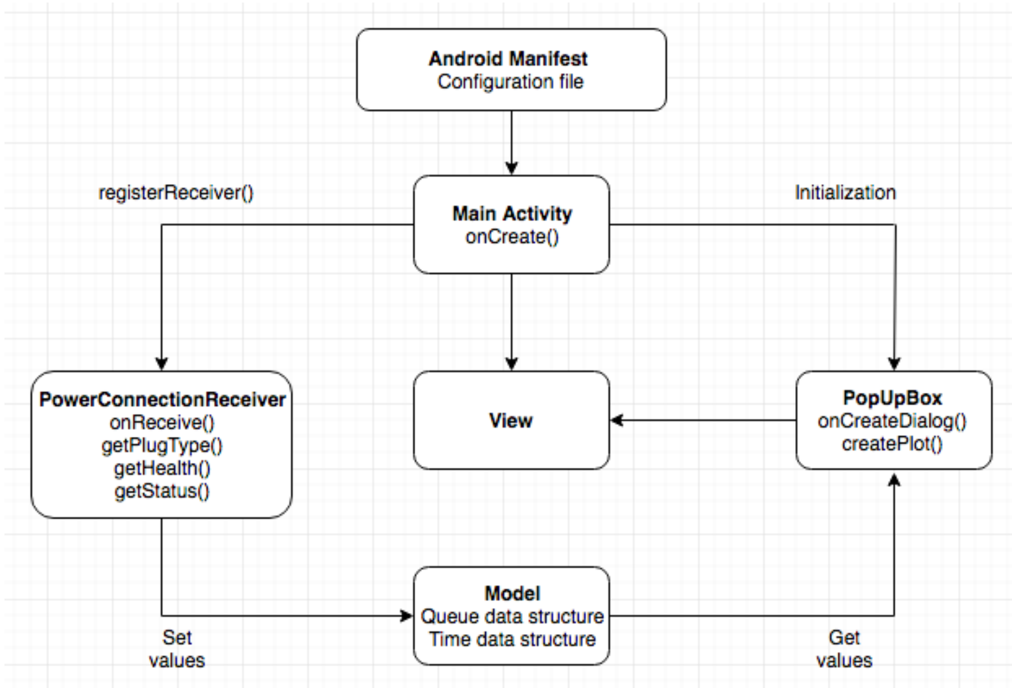

Figure 6: Software Block Diagram

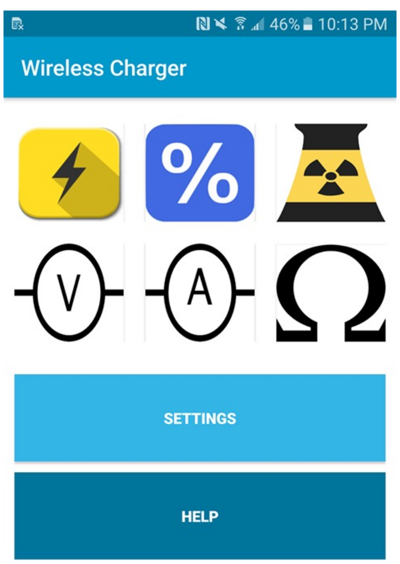

Figure 7: App. Main view

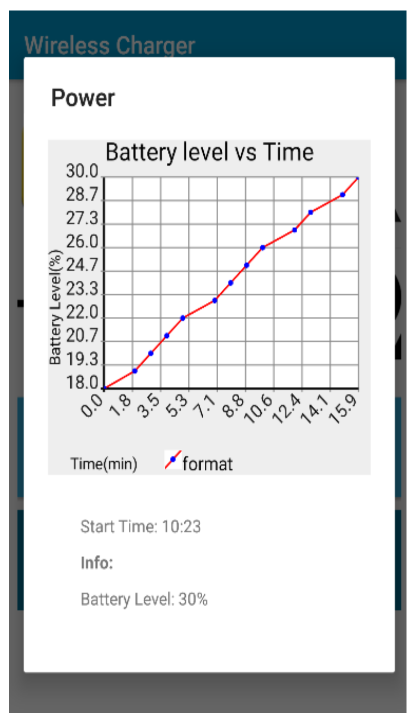

Figure 8: App. Pop up view for battery level

3. Design Verification

Our RVs table can be found in Appendix A. We were able to successfully satisfy the requirements for the transmitting circuit but we failed with the requirement for the power module.

3.1 Power module

The dc-dc converter failed to work while testing its maximum current load but it worked as expected for nominal load currents. The problem we encountered was that our original design was insufficient. In addition, the current limit for the LM2621 was lower as given in the datasheet. This component failed to work the day before the Demonstration, if we have had time we would have fixed it by limiting the maximum current drawn by the circuit.

3.2 Transmitting circuit

The transmitting circuit has worked as expected reaching a charging rate of 16% in 45 minutes as we can see in Figure 9. The output voltage and frequency are within the range for Qi standard charging. Furthermore, the AFE has been able to detect the receiving circuit built in our phone within a range of 5 mm.

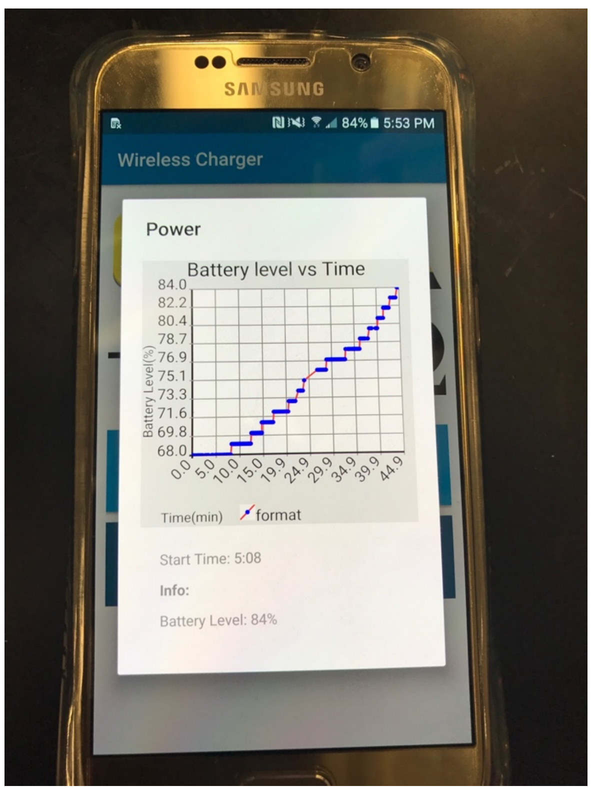

Figure 9: App. Battery level

As we can see in Figure 10, the frequency (153 kHz) is within Qi standard frequency range (110 - 205 kHz).

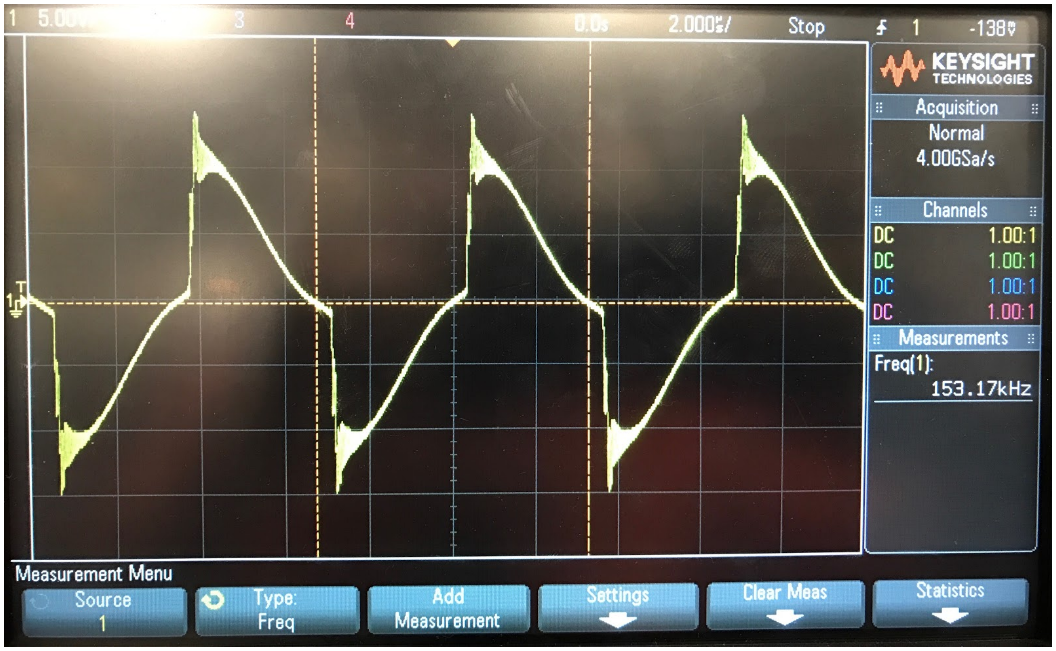

Figure 10: Transmitting circuit. Real output voltage

3.3 Physical design

Due to the unexpected failure of the dc-dc converter, we had to design a physical enclosure for the transmitting circuit since it was very fragile. Figure 11 shows the transmitting circuit and the coil with the case we designed.

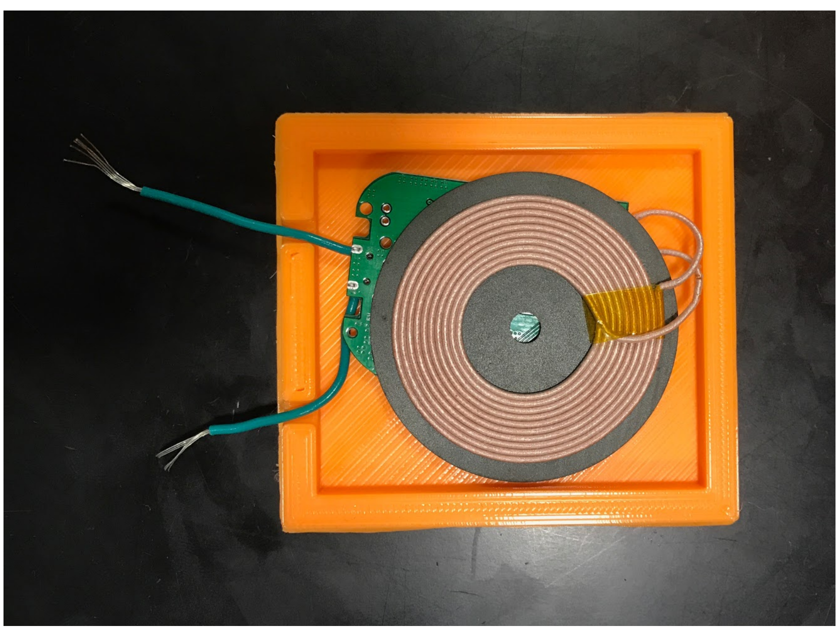

Figure 11: Physical design

4. Costs

4.1 Parts

Table 1 shows the total cost of the parts of our product.

Table 1 Parts Costs

Part	Manufacturer	Price (1 unit) ($)	Price (10,000 units) ($)	Actual Cost ($)
LM2621	Texas Instruments	2.13	1.26	6.39
BQ500511A	Texas Instruments	3.69	1.96	3.69
BQ50002A	Texas Instruments	4.26	2.25	4.26
392k	Vishay Dale	0.035	0.0046	0.35
150k	Vishay Dale	0.035	0.0046	0.35
49.9k	Vishay Dale	0.035	0.0046	0.35
49.9 ohms	Vishay Dale	0.035	0.0046	0.35
Inductor 15 uH	Bourns Inc.	0.77	0.397	2.31
Diode Schottky	ON Semiconductors	0.55	0.21	1.65
1 uF	KEMET	0.1	0.013	1
100 uF	Vishay Sprague	0.82	0.40	2.46
22 uF	Vishay Sprague	0.57	0.168	1.71
1 uF	Taiyo Yuden	0.13	0.024	0.39
39 pF	Yageo	0.1	0.019	0.3
Total				**25.56**

The total cost for parts of our product is $25.56. However, if we build the components in industrial quantities, the cost of our products reduces itself to approximately $12. The most expensive components are the Texas Instruments chips for the DC-DC as well as for the DC-AC circuit. We cannot reduce the cost of this product because these components are vital for the correct functioning of the product.

4.2 Labor

Table 2 shows the breakdown of labor costs for this project. At an hourly rate of $16 for each group member and a total of 200 hours invested each, the total labor cost would be $24,000.

Table 2 Labor Costs

Name	Hours Invested	Hourly Rate	Salary
Anshil Bhansali	200	$16.00	$8,000
Brian Slavin	200	$16.00	$8,000
Jose Javier Rueda	200	$16.00	$8,000

4.3 Grand Total

Table 3 shows the total for labor cost and for one unit.

Table 3 Grand Total

Section	Cost
Labor Cost	$25.56
Parts Cost	$24,000
Total Cost	**$24,025.56**

The labor cost greatly exceeds the parts cost.

5. Conclusion

5.1 Future Work

Our project’s scope was limited to building the Power Module, Transmitting Circuit, and the Android Application. We have the complete functional circuit that charges the phone wirelessly, and a software application to accompany it.

For future plans we plan to design a slim phone case to incorporate a lightweight rechargeable battery. In addition, we also plan to improve the functionality of the software application such that it can communicate with the circuit directly, and not limited through the Android OS. This can add more functionality such as user control for charging. Furthermore, we would like to develop a similar application for iOS. We would like be very happy if we could gain user feedback and market our product as well.

5.2 Safety Statement

When working with electricity it is vital to follow five key safety rules to avoid any injury or harm. First of all, disconnect all voltage sources with the help of fuses or switches. Then, prevent any reconnection by locking out elements and avoiding feedback loops. After this, verify absence of voltage in the installation with voltage detectors. Then, carry out grounding and short-circuiting the active elements of our installation. Finally, provide protection against adjacent live parts by signaling these elements and securing the work zone [5].

We will follow these rules to make sure that we do not suffer any harm although we will be working with low voltage circuits. We will be especially careful with our capacitors so that they will not discharge instantaneously.

We must be aware that lithium ion batteries are potentially dangerous to the user as well as the environment and should seek out a stable, rechargeable battery solution. By avoiding a lithium metal battery setup, we can produce a more environmentally friendly product since it will be reusable. It’s also important to implement safety features into the output portion of the device so we don’t run the risk of breaking the consumer’s phone.

5.3 Ethical considerations

Lithium-ion batteries are difficult to recycle and can be dangerous to the environment if not disposed of properly. Another major concern is the production of the batteries. The mining of lithium contributes to the greenhouse effect, so we must maximize the usage of our battery to avoid endangering our environment as stated in #1 of the IEEE Code of Ethics [6]. Testing battery lifetime and stability will be a major component of our project.

In accordance with #3, we will be honest in stating claims based on data. This implies showing the user the proper data and efficiency of our product. Our system user interface has to be truly honest and show the data collected.

In accordance with #8 and #10 of the IEEE Code of Ethics, we will work all together as a team and we will support our colleagues whenever it is necessary. We reject any form of discrimination. Racism does not belong here at Illinois.

References

[1] J. Chamary, «Why Apple Was Right To Remove The iPhone 7 Headphone Jack?,» 2016. [En línea]. Available: http://www.forbes.com/sites/jvchamary/2016/09/16/apple-iphone-headphone-jack/#574247633019.

[2] T. Instruments, «BQ50002 DataSheet,» [En línea]. Available: http://www.ti.com/lit/ds/symlink/bq50002.pdf.

[3] T. Instruments, «BQ500511 DataSheet,» [En línea]. Available: http://www.ti.com/lit/ds/symlink/bq500511.pdf.

[4] T. Instruments, «LM2621 DataSheet,» [En línea]. Available: http://www.ti.com/lit/ds/symlink/lm2621.pdf.

[5] «Dehn,» [En línea]. Available: http://www.dehn-international.com/en/safe-working-5-safety-rules.

[6] IEEE, «IEEE Code of Ethics,» [En línea]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html.

Appendix A Requirement and Verification Table

Table 4 System Requirements and Verifications

Requirement	Verification
The output must be 5V ± 0.25V for load currents of 0.5A - 2.85A and Vin: 3.0V - 4.0V. **Points: /10**	1. Connect voltage source (Vin = 3.0V) 2. Attach DC load and set DC load to 0.5A. 3. Sweep from 0.5A to 2.85A
The coil temperature should not exceed 120ºC. **Points: /5**	1. Turn device on for five minutes. 2. Take temperature reading of the coil using an infrared thermometer.
The AC signal frequency has to be in the range between 110 and 205 kHz for the right operation of the charging receiving circuit. **Points: /10**	1. Connect voltage source (Vin = 5V) 2. Connect Oscilloscope to coil leads. 3. Measure frequency using Oscilloscope.
LED goes green when it charges and goes red when it stops charging. **Points: /5**	1. Connect voltage source (Vin = 5V). 2. Take note of LED color during standby. 3. Put receiving coil in contact with transmitting coil. 4. Take note of LED color during charging.
Output to the coil must be between 4.5V ± 0.5V **Points: /5**	1. Connect voltage source (Vin = 5v) 2. Use multimeter to measure voltage going into tx coil.

Microcontroller can detect qi receiver circuit within a range of 5mm. **Points: /5**	1. Connect voltage source (Vin=5V) 2. Measure coil current 3. Place receiving circuit within 5mm of coil 4. Measure new coil current and compare
Software can differentiate between wireless charging and direct charging. **Points: /3**	1. Connect phone to regular charger 2. Check if pop up alerts user that phone is connected. 3. Disconnect and set phone on TX coil. 4. Check if pop up alerts user that phone is wirelessly charging.
Software can accurately display the temperature of the battery within a 5% margin of error. **Points: /5**	1. Use app to note current battery temperature 2. Use infrared temperature sensor to get the actual battery temperature
Software accurately displays current of the battery **Points: /2**	1. Use app to note battery current. It should be negative when the battery is discharging. 2. Commence wireless charging. Use app to note whether battery current is now positive.