Inductive Charging Case

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Design Review - ECE 445 Spring 2017

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1. Introduction

1.1 Objective

As USB type C is becoming more common in phones, many companies are removing the headphone jack on phones [1]. This creates a big problem for those who want to transfer data or listen to music while charging their phone. 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.

1.2 Background

Nowadays there are some phone cases that allow you to charge your phone without plugging it into the socket [2]. 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.

1.3 High level requirements

- The system has to be able to delivering 1000 mAh to the phone.
- The system has to deliver 5 W to the receiving coil.
- The system efficiency has to be greater than 70%.

2. Design

2.1 Block diagram

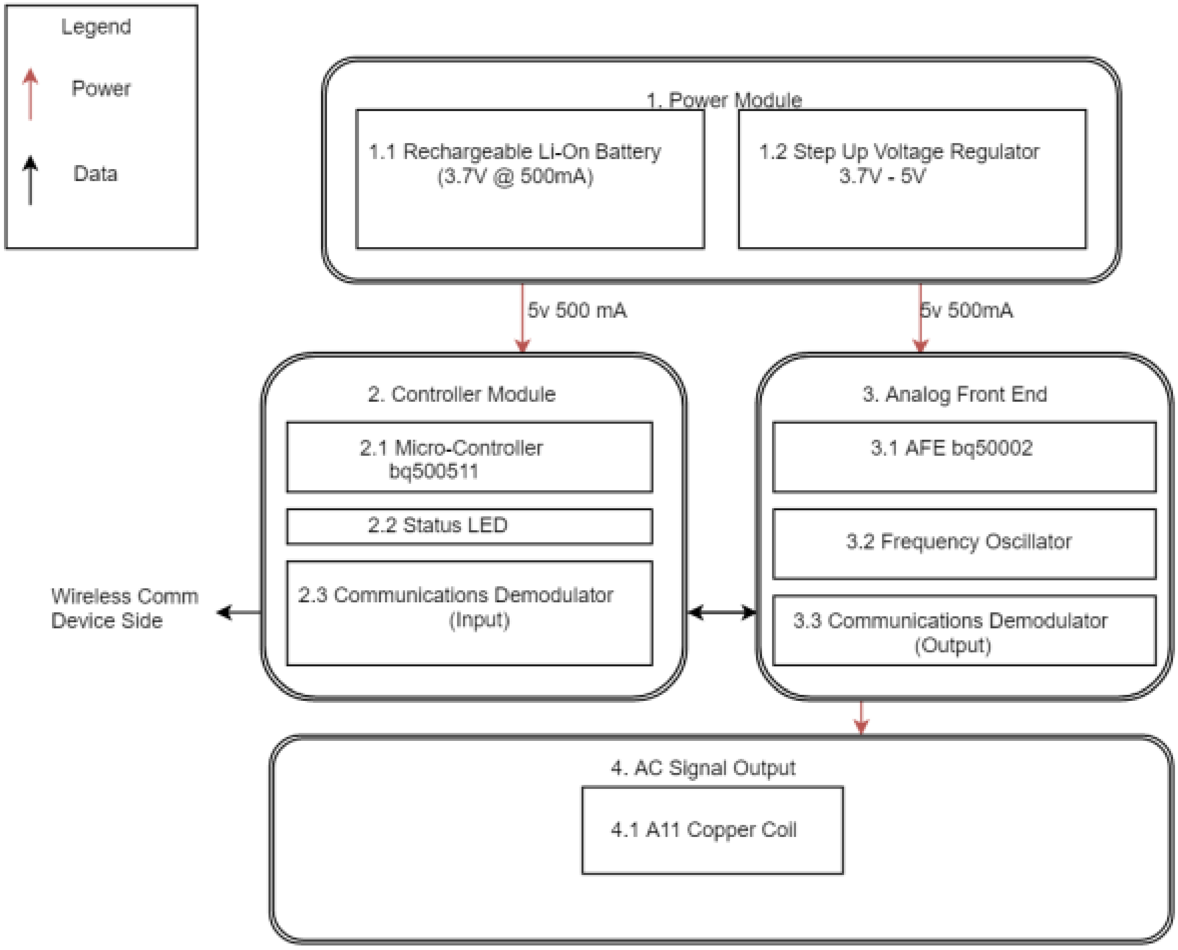

Figure 1: Block diagram

2.2 Power module

2.2.1 Description

2.2.1.1 Battery

We are using a lithium ion polymer battery to power our circuit. These units are rechargeable and have undergone penetration as well as extreme heat testing. Capacity ranges from 200 mAh to 2000 mAh changing battery thickness from 1mm to 3.6mm. [3]

Nominal Voltage	3.7V	
Charging Cut-off Voltage	4.20V	
Discharge Cut-off Voltage	3.0V	
Max. Charging Current	1C	
Max. Discharging Current	2C	
Operating Temperature	Charge 0～45℃ Discharge –20～60℃	
Storage Temperature	-20～45℃ for 1Month -20～35℃ for 6Months	
Impedance	180mΩ	Maximum value
Weight	6g	Approximate value

Table 1: Battery specifications

2.2.1.2 Step up voltage regulator

We are using the LM2621 as a high efficiency, step up DC-DC switch regulator for low voltage input systems. It can accept an input voltage between 1.2V and 14V, and can output a regulated voltage in the range [1.24V, 14V]. We want to output a voltage of 5V from an input of 2-3V.

2.2.2 Circuit schematic

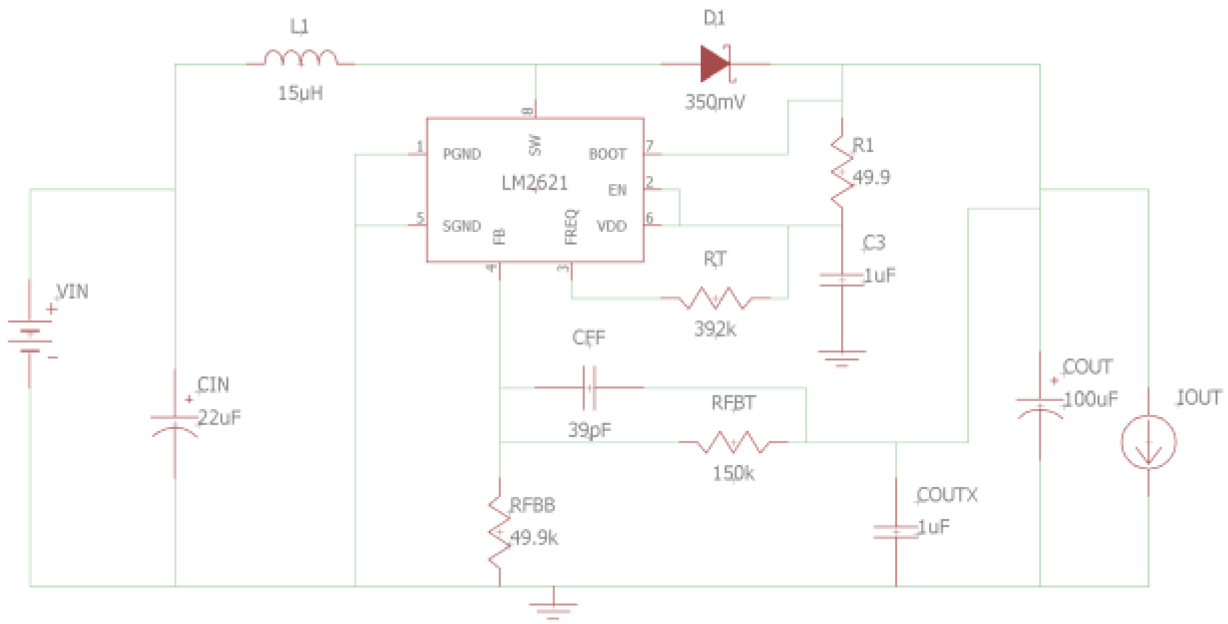

Figure 2: Power module schematic

2.2.3 Calculations

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

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

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

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

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

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

As the frequency ranges from 110 kHz to 205 kHz, we choose Lp = 6.3μH and Cm = 22μF.

2.2.4 Plots

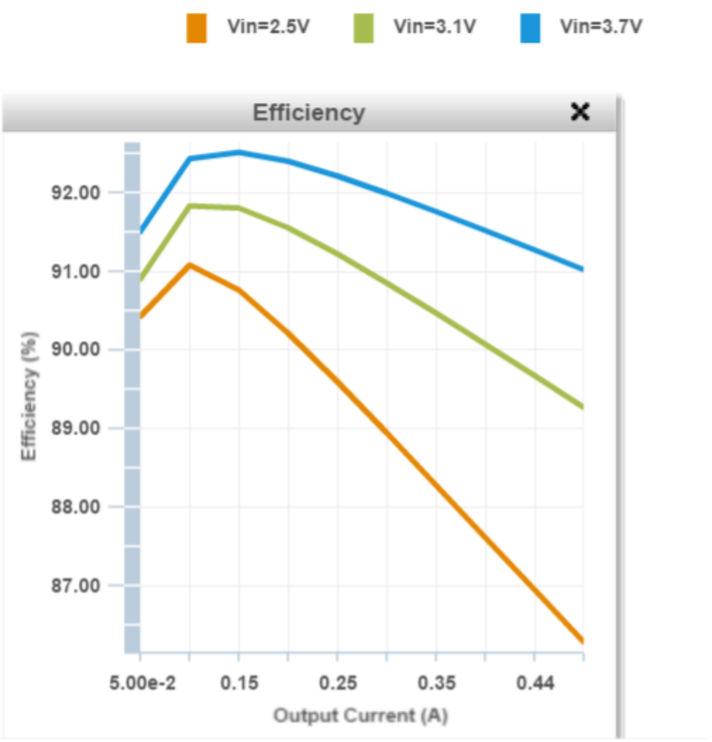

Figure 3: Power module. Efficiency vs. Output current

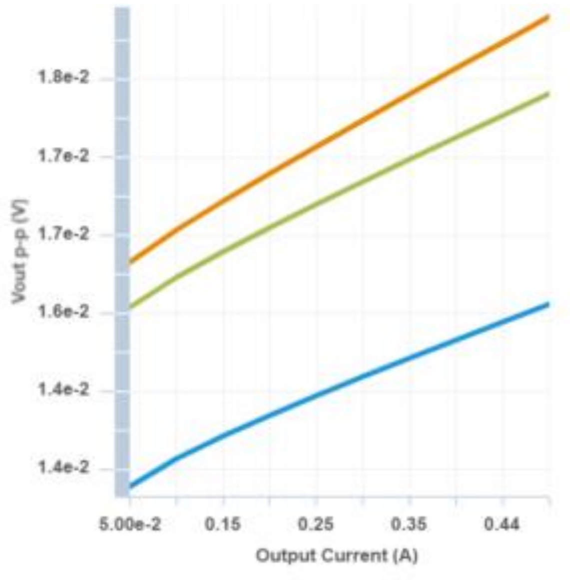

Figure 4: Power module. Output voltage ripple vs. Output current

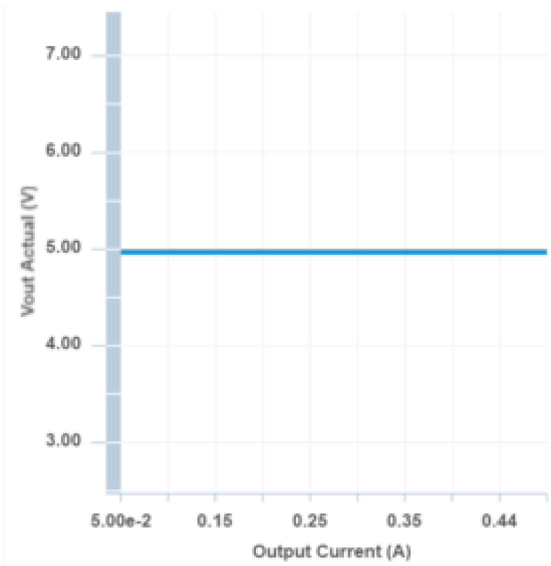

Figure 5: Power module. Mean output voltage vs. Output current

2.3 DC-AC module

2.3.1 Description

2.3.1.1 Analog Front End bq50002

The bq50002 [4] device is a highly integrated wireless power transmitter analog front end (AFE) that contains all of the analog components required to implement a Wireless Power Consortium (WPC) compliant 5-V transmitter. The bq50002 device integrates a full-bridge power driver with MOSFETs, variable-frequency oscillator, two-channel communication demodulator, linear regulator, and protection circuits. The bq50002 device must be used together with the digital controller bq500511 to realize a compact two chip wireless power transmitter solution.

2.3.1.2 Micro-controller bq500511

The bq500511 [5] is a wireless power transmitter controller that, when combined with the bq50002 analog front end device, integrates all functions required to create a Qi-compliant or proprietary 5-V transmitter. The bq500511 pings the surrounding environment for the receiver devices to be powered, safely engages the device, receives packet communication from the powered device and manages the power transfer according to WPC v1.2 specifications.

2.3.1.3 Transmitting coil

We are using an A11 type copper coil. It is compliant with Qi and WPC standards.

2.3.2 Schematic

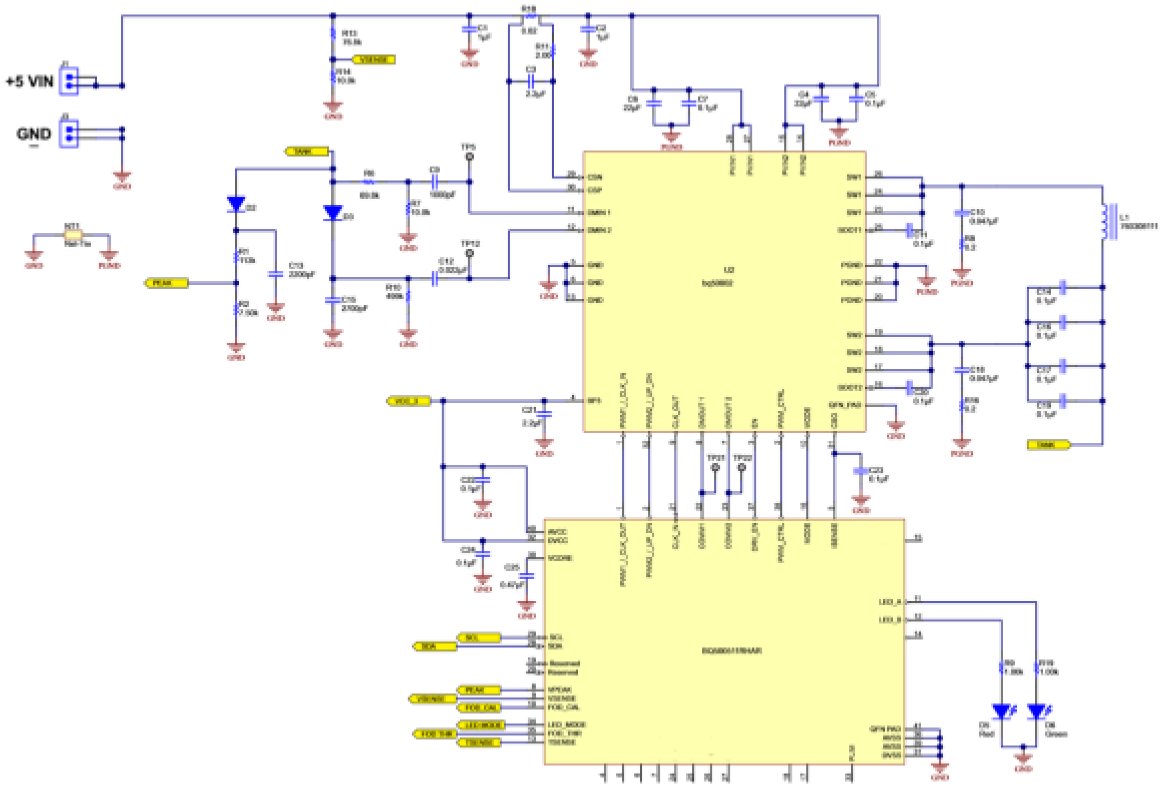

Figure 6: DC-AC module schematic

2.3.3 Calculations

Corresponds to LED control option 8. Standby correlates to both LEDs being off. The red LED turns on when charging occurs. Once the phone is fully charged, the red LED will turn off and the green LED will turn on. Both LEDs will blink if a fault has occurred. [6]

$R_{LED} = 200k\ \Omega$

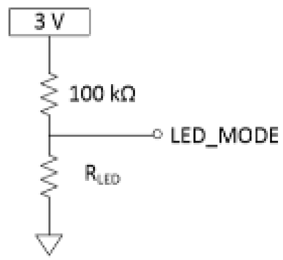

Figure 7: LED control

For the FOD (Foreign Object Detection) system, it is based off of input voltage.

FOD threshold = input voltage * 400 = maximum allowed loss in mW.

2.3.4 Plots

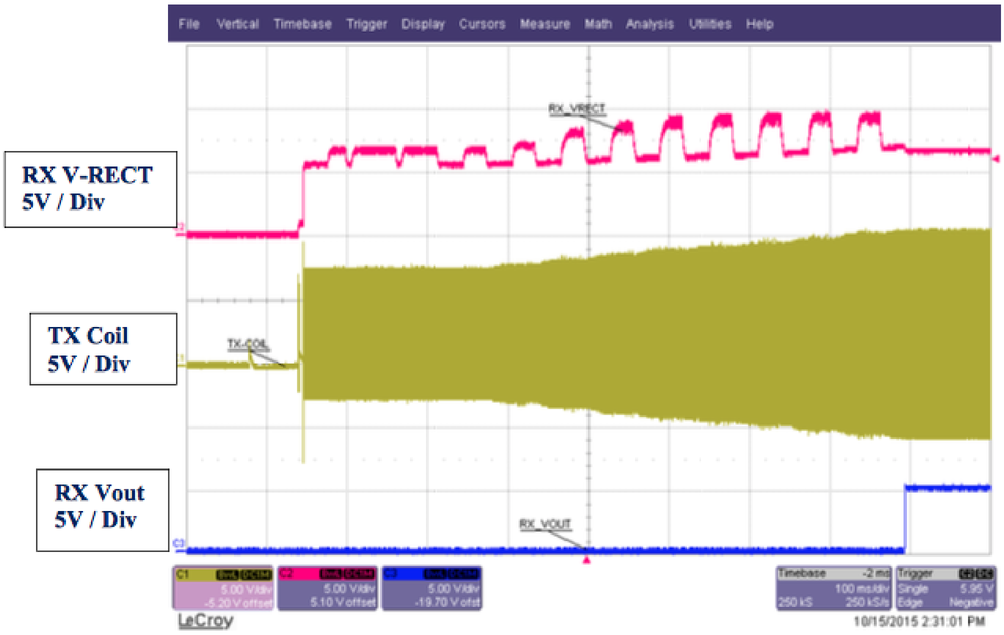

Figure 8: DC-AC module. Transition from standby

It shows a typical start up behavior for the TX and RX as the RX is placed on a TX in standby. The RX and TX can be seen transitioning from standby. (TX transmitter, RX receiver).

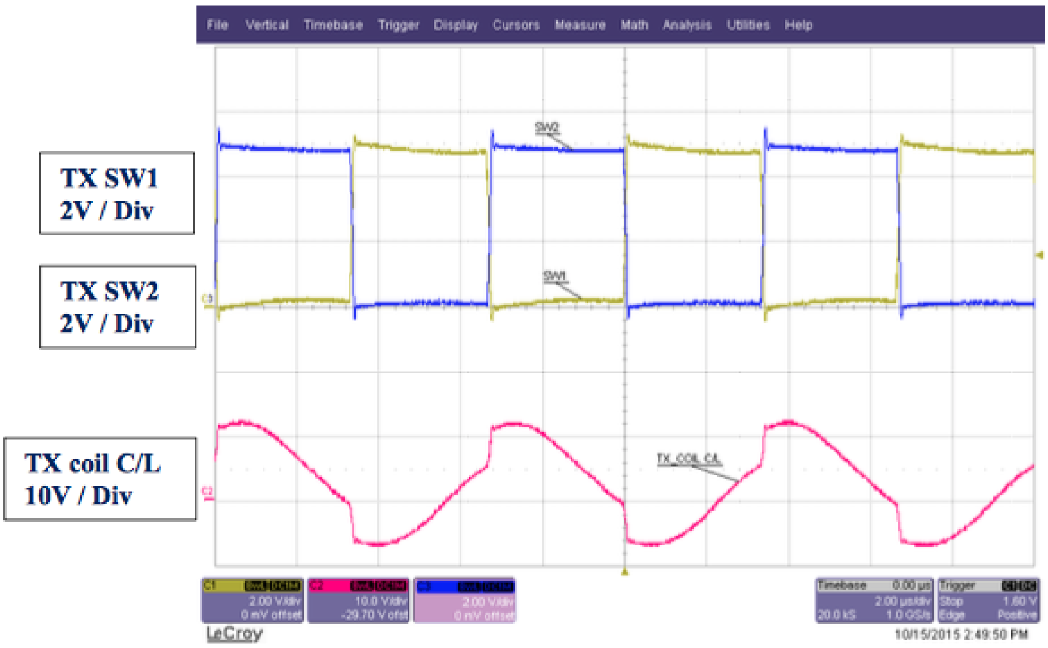

Figure 9: DC-AC module. Power transfer mode

It shows the transmitter operating in power transfer mode with a load of about 5-W. The coil drive signal is a 50% duty cycle signal 180 degrees out of phase. Operating frequency will change with load between 110 kHz and 205 kHz, at this point frequency is about 150 kHz.

2.4 Software module

2.4.1 Description

For our software module, we will develop a mobile app (Android), to enable user control, and present battery statistics, and other useful information. The application will communicate with the controller module, specifically with the bq500511 and bq50002a wireless power transmitter chips, that integrate all functions of a Qi-compliant wireless charger pad. These chips have communication ports that will transfer data to/from the cellular device. The app will read in data from the chips, and also send signals to the circuit to switch on/off the charging. We will continue to brainstorm features to add to the application to make the user experience better. To detect signals, I will use the *BatteryManager* class, which is in the Android SDK. [7]
If it is not possible to communicate with the chips, then we plan to build a Wi-Fi module in the circuit to communicate with the application.

Technology stack:

- Android Studio as IDE (Integrated Development Environment)
- Java for controller and data logic
- XML for view
- Android emulator for basic testing
- Actual Android device for thorough testing.

2.4.2 Schematics

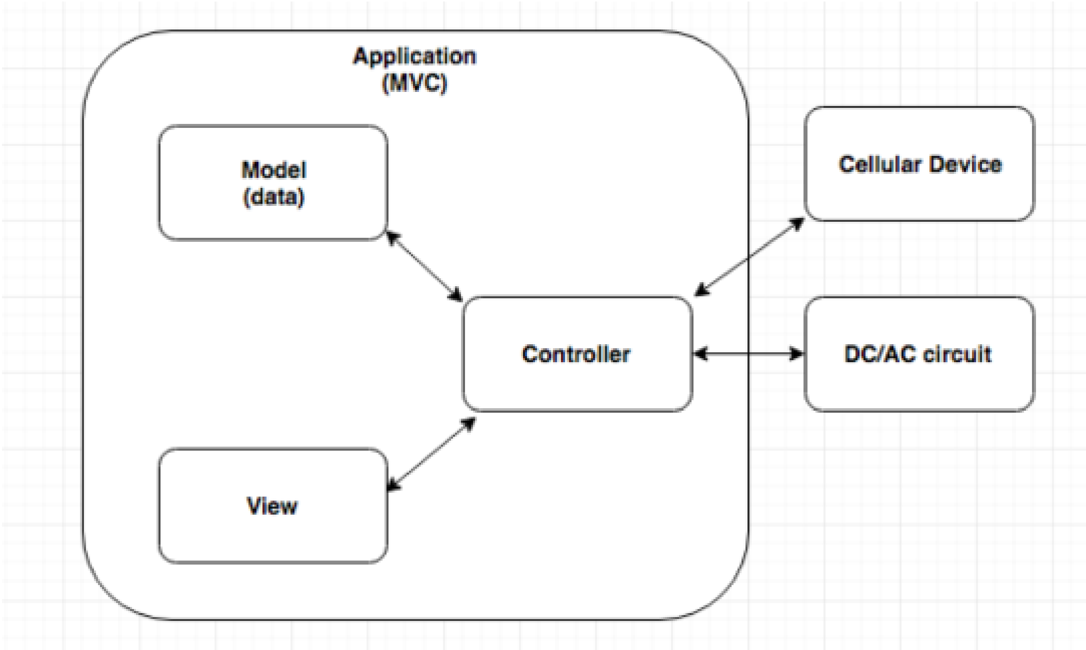

Figure 10: Software module schematic

2.5 Requirements and verifications

Module	Requirements	Verification procedures
Power	The fluctuation of output voltage from the DC-DC circuit must not be more than .1V (i.e. the voltage should only range from 4.9V to 5.1V).	This will be tested using only the power module. We will hook up a multimeter to the output of the step up circuit and take voltage values using a constant DC input as a source and then the lithium ion battery as a source.
	The voltage from the battery should always be in the rated voltage range for the IC (1.2V - 14V).	We will test this by again using a multimeter to measure battery output voltage. This will be done until the battery is completely drained.
	The output current cannot exceed the IC's peak current of 2.85A.	We will perform the same test as the voltage test, instead measuring current. Again, we will use a constant DC source as well as a battery source in order to gauge how different inputs affect our output current.
DC-AC	The DC input voltage into AFE should not exceed 7V.	We will test it with a multimeter.
	The AC signal frequency has to be in range (110 kHz – 205 kHz) for the right operation of the charging receiving circuit.	We will check the frequency of the AC signal with the help of an oscilloscope.
	The LED system works.	We will check the phone battery charge when the green LED turns on.

Table 2: Requirements and verifications

2.6 Tolerance analysis

For our tolerance analysis, we are examining the Wurth Electronics A11 TX coil [8]. It's crucial to understand the limiters of the coil as a fault in the coil will prove catastrophic to the entire circuit. As seen in figure 11, the inductance value of the coil does not change with the current, so we don't have to be too concerned with small variations in current affecting our transmitter. What we must be careful of is the frequency values as they have a major effect on the system (shown in figure 12). Our microcontroller will keep us under 205khz, but as we get to higher frequencies, the inductance values will shoot up, thus rendering our coil connections useless. Once we hit 250khz, our inductance value will change enough to render charging too inefficient based on our requirements.

Moving on to figure 13, we have a wide range of current as the coil is rated for operating temperatures between -20 degrees celsius and 120 degrees celsius.

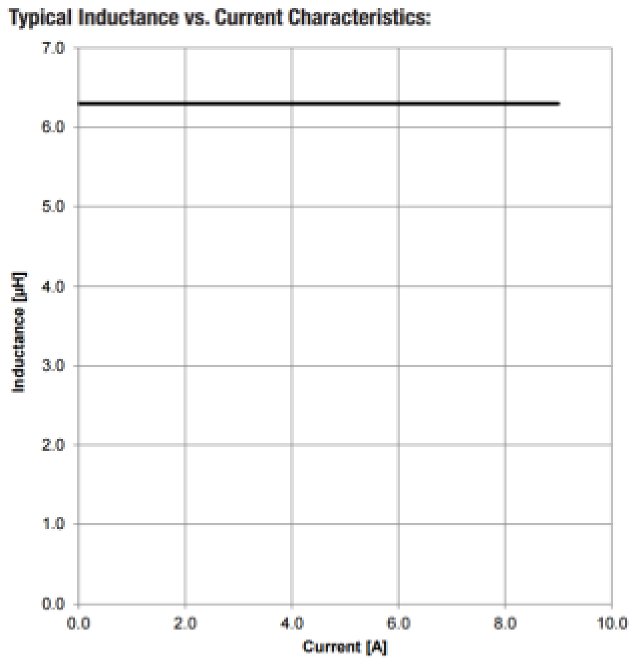

Figure 11: Inductance value according to current

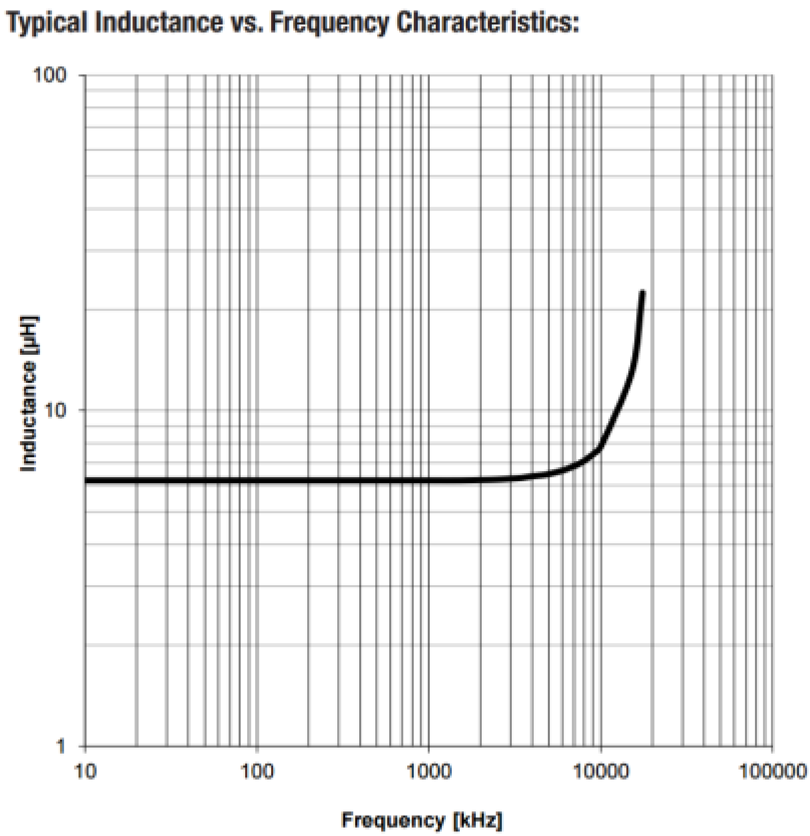

Figure 12: Inductance value according to frequency

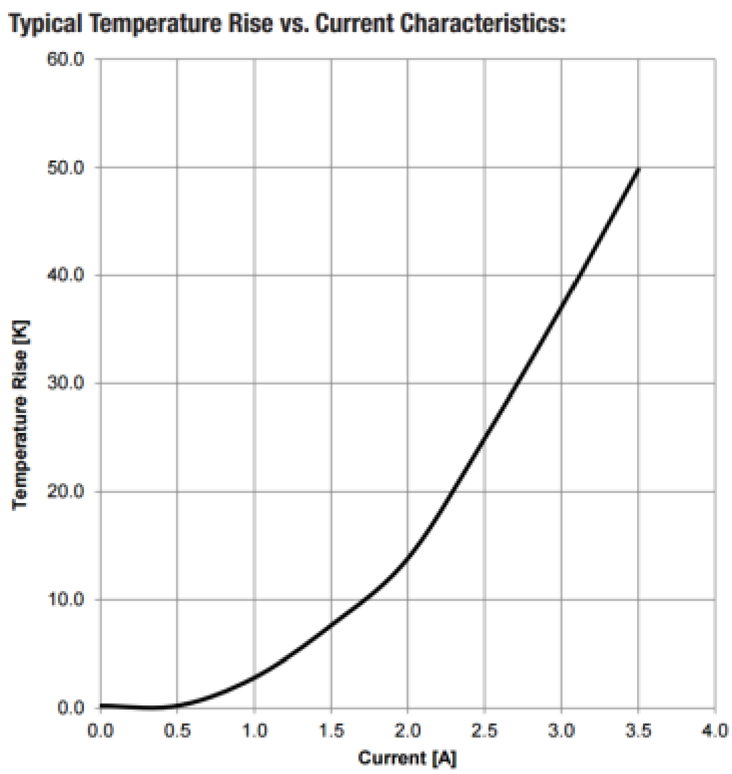

Figure 13: Temperature according to current

3. Cost and Schedule

3.1 Cost analysis

3.1.1 Labor

We estimated a total of 20 hours of work per week.

Name	**Hours invested (hrs)**	**Hourly rate ($/hrs)** [9]	**Salary = hourly rate x hours x 2.5 ($)**
Anshil Bhansali	200	16	$8,000
Brian Slavin	200	16	$8,000
Jose Javier Rueda	200	16	$8,000
Total			$24,000

Table 3: Labor costs

3.1.2 Parts

3.1.2.1 DC-DC circuit

Part	**Manufacturer**	**Part #**	**Description**	**Attributes**	**Quantity**	**Cost($)**
C3	Taiyo Yuden	EMK212B7105KG-T	Capacitor	Cap=1uF	1	0.02
Cff	Yageo America	CC0805JRNPO9BN3	Capacitor	Cap=39uF	1	0.01
Cin	Vishay-Sprague	293D226X9016B2TE	Capacitor	Cap=22uF, ESR=1.9 Ohm	1	0.14
Cout	Vishay-Sprague	593D107X0010D2TE	Capacitor	Cap=100uF, ESR=0.1 Ohm	1	0.27
Coutx	Kemet	C0603C105Z8VACTU	Capacitor	Cap=1uF	1	0.01
D1	ON Semiconductor	MBRA210LT3G	Power Rectifier	VFatIo=0.35V, Io=2A, VRRM=10V	1	0.16
L1	Bourns	SRU8043-150Y	Inductor	L=15uH, DCR=0.046 Ohm, IDC = 2A	1	0.33
R1	Vishay-Dale	CRCW040249R9FKE	Resistor	R=49.9 Ohm	1	0.01
Rfbb	Vishay-Dale	CRC040249K9FKE	Resistor	R=49.9k Ohm	1	0.01
Rfbt	Vishay-Dale	CRC0402150KFKE	Resistor	R=150k Ohm	1	0.01
Rt	Vishay-Dale	CRC0402392KFKE	Resistor	R=392k Ohm	1	0.01
U1	Texas Instruments	LM2621MM/NOPB	Switching Regulator		1	0.78

Table 4: DC-DC circuit costs

3.1.2.2 DC-AC circuit

Part	Manufacturer	Part #	Description	Attributes	Quantity	Cost($)
U1	Texas Instruments	BQ500511ARHAR	Low Cost 5V Wireless Power Transmitter Controller		1	2.30
U2	Texas Instruments	BQ50002ARHBR	Low Cost 5V Wireless Power Transmitter AFE		1	1.64
L1	Wurth Elektronik	760308111	Inductor	6.3uH	1	0.05
BUZ1	TDK	PS1240P02CT3	Buzzer, Piezo, 4kHz		1	0.3
C1, C2	Murata	GRM188R71E105KA12D	Capacitor	1uF	2	0.15
C3	Murata	GRM188R71A225KE15D	Capacitor	2.2uF	1	0.19
C4, C6	Murata	GRM21BR61E226ME44	Capacitor	22uF	2	0.26
C5, C7, C11, C20, C22, C23, C24, C27	TDK	C1608X7R1E104K	Capacitor	0.1uF	8	2.2
C8	Murata	GRM32ER71E226KE15L	Capacitor	22uF	1	0.12
C9, C26	TDK	C1608C0G1H102J	Capacitor	1000pF	2	0.23
C10, C18	TDK	C1608X7R1H473K	Capacitor	0.047uF	2	0.26
C12	TDK	C1608X7R1H223K	Capacitor	0.022uF	1	0.08
C13	Murata	GRM188R71H222KA01D	Capacitor	2200pF	1	0.08
C14, C16, C17, C19	TDK	C3216C0G1E104J	Capacitor	0.1uF	4	0.17
C15	TDK	C1608C0G1H272J	Capacitor	2700pF	1	0.26
C21	Murata	GRM188R61C225KE15D	Capacitor	2.2uF	1	0.13
C25	Murata	GRM188R71A474KA61D	Capacitor	0.47uF	1	0.03
D1, D6	Lite-On	LTST-C190KGKT	LED	Green	2	0.05
D2, D3	Micro Commercial Components	MMDL914-TP	Diode, Switching	100V	2	0.1
D4	Lite-On	LTST-C190KFKT	LED	Orange	1	0.05
D5	Lite-On	LTST-C190CKT	LED	Red	1	0.05
NTC1	TDK	NTCG163JF103F	Thermistor NTC	10k Ohm	1	0.45
R1	Susumu Co Ltd	RG1608P-1133-B-T5	Resistor	113k Ohm	1	0.05

R2	Yageo America	RT0603BRD077K5L	Resistor	7.5k Ohm	1	0.07
R3, R5	Vishay-Dale	CRCW12060000Z0EA	Resistor	0	2	0.05
R4, R9, R17, R19	Vishay-Dale	CRCW06031K00FKEA	Resistor	1k Ohm	4	0.31
R6	Yageo America	RC0603FR-0769K8L	Resistor	69.8k Ohm	1	0.09
R7, R12, R20, R24, R28	Yageo America	RC0603FR-0710KL	Resistor	10k Ohm	5	0.36
R8, R16	Panasonic	ERJ-S6SJR20V	Resistor	0.2 Ohm	2	0.24
R10	Yageo America	RC0603FR-07249KL	Resistor	249k Ohm	1	0.14
R11	Vishay-Dale	CRCW06032R00FKEA	Resistor	2 Ohm	1	0.12
R13	Susumu Co Ltd	RG1608P-7682-B-T5	Resistor	76.8k Ohm	1	0.04
R14	Yageo America	RT0603BRD0710KL	Resistor	10.0k Ohm	1	0.03
R15	Yageo America	RC0603JR-0747KL	Resistor	47k Ohm	1	0.07
R18	Ohmite	LVK12R020DER	Resistor	0.02 Ohm	1	0.06
R21, R22, R27	Yageo America	RC0603FR-07100KL	Resistor	100k Ohm	3	0.27
R23	Yageo America	RC0603FR-07200KL	Resistor	200k Ohm	1	0.1
R25	Yageo America	RC0603FR-0724K9L	Resistor	24.9k Ohm	1	0.1
R26	Yageo America	RC0603FR-0793K1L	Resistor	93.1k Ohm	1	0.1
C28	TDK	C1608X7R1E104K	Capacitor	0.1uF	0	0.12
L2	Murata	DLW5BTM102TQ2K	Coupled Inductor		0	2.15

Table 5: DC-AC circuit costs

Total parts cost = $15.38.

3.1.3 Grand Total

Section	Total
Labor	$24,000
Parts	$15.38
Total	$24,015.38

Table 6: Grand Total costs

3.2 Schedule

Week	Task	Responsibility
Feb 6	Write Proposal	ALL
	Research options for DC-AC microcontroller	Brian
	Research options for DC-DC microcontroller	Javier
	Prototype, defining the scope of the application	Anshil
Feb 13	Design DC-DC converter	Brian
	Design DC-AC converter	Javier & Anshil
Feb 20	Write Design Review	ALL
Feb 27	Research options for battery and TX coil	Brian
	Purchase DC-AC and DC-DC components	Javier
	Build user interface with dummy data	Anshil
March 6	Build DC-DC converter	Brian & Javier
	Purchase battery and TX coil	Anshil
March 13	Begin building around DC-AC converter	Brian
	Test DC-DC converter to match requirements	Javier
	Understand communication between the chips and the phone device	Anshil
March 20	Spring Break: Research	ALL
March 27	Test battery separately from other modules	Brian
	Build DC-AC converter	Javier
	Test communication chip	Anshil
April 3	Test DC-AC converter	Brian & Javier
	Develop application	Anshil
April 10	Make hardware modifications if necessary	Brian
	Ensure individual module functionality	Javier
	Test app and update if necessary	Anshil
April 17	Prepare Demo	ALL
April 24	Write Final Paper	ALL
May 1	Finish Final Paper	Brian
	Check out lab equipment	Javier
	Research market possibilities	Anshil

Table 7: Schedule

4. Ethics and safety

4.1 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. [10]
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.

4.2 Ethics statement

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 [11]. 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. [Online]. Available: http://www.forbes.com/sites/jvchamary/2016/09/16/apple-iphone-headphone-jack/#574247633019.

[2] "Amazon," [Online]. Available: https://www.amazon.com/cell-phone-battery-charge-cases/b?ie=UTF8&node=7073958011.

[3] "PowerStream," [Online]. Available: http://www.powerstream.com/p/PGEB014461.pdf.

[4] "Texas Instruments," [Online]. Available: http://www.ti.com/product/BQ50002.

[5] "Texas Instruments," [Online]. Available: http://www.ti.com/product/BQ500511/description.

[6] "Texas Instruments," [Online]. Available: http://www.ti.com/tool/bq50002aevm-607.

[7] "Android Developer," [Online]. Available: https://developer.android.com/reference/android/os/BatteryManager.html.

[8] "Mouser Electronics," [Online]. Available: http://www.mouser.com/ds/2/445/760308101103-357306.pdf.

[9] University of Illinois at Urbana-Champaign, "Office of student. Financial Aid," [Online]. Available: http://osfa.illinois.edu/types-of-aid/wages.

[10] "Dehn," [Online]. Available: http://www.dehn-international.com/en/safe-working-5-safety-rules.

[11] IEEE, "IEEE Code of Ethics," [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html.