Wireless Laptop Charging System

ECE 445 Design Document

Onur Cam, Jason Kao, Enrique Ramirez
Group 37
TA: Zhen Qin
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1. Introduction

1.1 Objective

Laptops are everywhere in classrooms. Many laptops do not boast a long-lasting battery, making them reliant on their chargers. Despite efforts to make outlets closer and more available in order to clean up cable traffic, long cables and tedious clean-up remain a problem in the student ecosystem. We know that wireless charging solutions enable integration of charging transmitters in discreet locations, which minimizes cable chaos with multiple people. However, in its current state, this technology has only been applied to phones. Our solution is to create an adapter that allows laptops to harness the same wireless charging technology, cutting down on cables in a classroom setting.

1.2 Background

There is currently almost nothing on the market that serves the purpose of our product. Every wireless receiver is designed to be installed to a small device, such as a smart phone, and some tablets. All of these loads have a smaller power requirement, so in order to power larger electronic devices such as laptops, we have to build our own. There is one exception: Dell Wireless Charging Mat for the Latitude 7285. However, the high price ($200 MSRP)[2] and limited compatibility prohibits it from being a classroom integrated product.

1.3 High-Level Requirements

- The receiver output reads 12V, 3.33A. This is the power requirement for our test laptop.
- The coils allow for power transfer up to 10 mm.
- The receiver adapter can operate with an overall efficiency of no less than 66%.

2. Design

The design has two main blocks, transmitter block and receiver block. Within the transmitter block, we start with mains power from a standard US outlet and this powers a USB hub. The USB hub supplies power to four pre-made transmitters. The AC current goes into the transmitter coil and induces a magnetic field that creates a current in the receiver coil. This AC power in the four receiver coils is then turned into DC power by using a AC/DC converter with voltage regulator. The voltage outputs of the AC/DC are then added together and inputted to a buck DC/DC converter that outputs the required power to the laptop. A feedback loop is also incorporated to regulate the output of the DC/DC converter.

2.1 Block Diagram

The block diagram below shows how the modules will connect to each other and the general layout of the circuit.

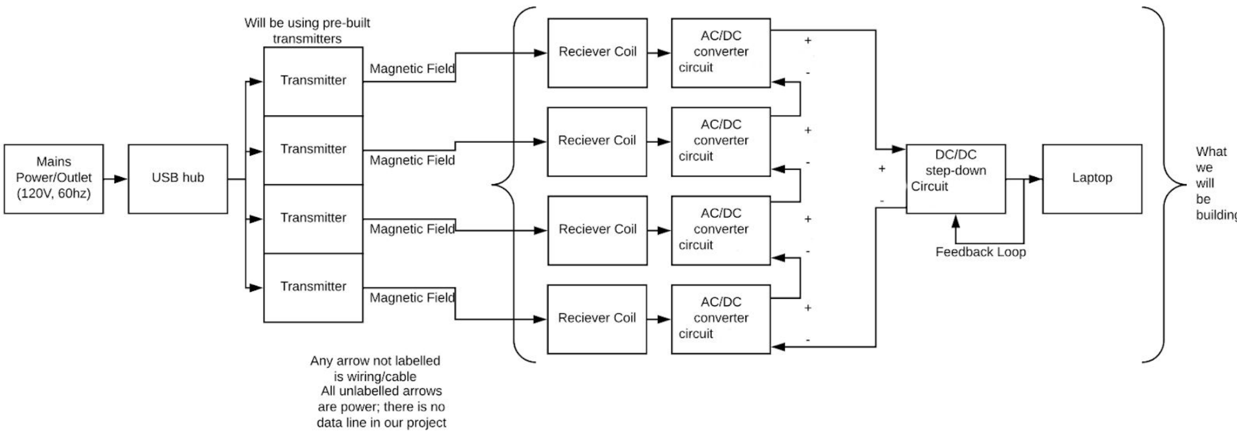


Diagram 1: Initial diagram

*Number of modules may vary; will depend on the power output we get out of the coils.

2.2 Block Design

2.2.1 Functional Overview

<u>Receiver Coil</u>

Input: Magnetic fields and detection signal sent by the transmitter.

Output: AC voltage and current, experimentally found.

The receiver coil takes the transmitters magnetic field and it induces its own AC current, which is then outputted to the AC/DC converter. The transmitter contains an object detection circuit, so we configure a series and parallel capacitor to tune the operating frequency of the receiver coil to match the frequency of the transmitter. We have found that the operating series frequency of the coil is 127.8 kHz, while the detection frequency is about 1000 kHz (with ~10% tolerance). The block diagram specifies 4 coils and AC/DC modules, but in reality this number may vary. The actual number of coils and modules will depend on the experimental coil data found in the lab, as the DC/DC converter has certain voltage and current requirements.

Requirement	Verification	Verification Status
Coil Circuit 1. V_{out} = 9V +- 0.3V	**Coil Circuit Verification Process for**	

2. Coil receives power from at least 10 mm away 3. Be able to contribute to 66% efficiency.	**Items 1, 2, and 3:** 1. Connect a coil to breadboard 2. Connect an equivalent capacitance of 0.18656 uF in series with the coil 3. Connect an equivalent capacitance of 3.149 nF in parallel with the coil and series capacitor bank. 4. Connect a 1MΩ as load to simulate an open circuit. 5. Connect the oscilloscope terminals to the load 6. Hold coil 10mm away from the transmitter 7. Read voltage across the load on the oscilloscope 8. Ensure that there exists a voltage (req 2) 9. Ensure that the output voltage is 9V with a deviation of less than 0.3V (req 1) 10. Be able to contribute to 66% efficiency. (req 3)	

Measurements and Calculations:

f_s = 127.8 kHz (found experimentally using an oscilloscope. Put the coil in between the transmitter and a phone in order to find the output power frequency of the coil).

L_{coil} = 8 uH (from datasheet)
L_{series} = 8.18 uH @ 0 Hz (Coil can be modeled as an inductor and resistor in series. This is the inductive part. Found using the precision RCL meter)
R_{series} = 0.06388 Ω @ 0 Hz (The resistive part of the aforementioned circuit. Found using the precision RCL meter)
$L_{parallel}$ = 20.73 uH @ 0 Hz (Coil can also be modeled as a inductor and resistor in parallel. This is the inductive part. Found using the precision RCL meter)
$R_{parallel}$ = 0.1053 Ω @ 0 Hz (This is the resistive part. Found using the precision RCL meter)
L'_{series} = 8.313 uH @ 125 kHz (this is the inductance with an operating frequency of 125 kHz. Use this value when calculating C_s later.)
R'_{series} = 0.2010 Ω @ 125 kHz
$L'_{parallel}$ = 8.320 uH @ 125 kHz
$R'_{parallel}$ = 212.3 Ω @ 125 kHz
f_d = 1000 kHz (+- 10% tolerance, taken from Qi spec)

Using
f_s = $1/(2\Pi\sqrt{L's * Cs})$
and
f_d = $1/(2\Pi\sqrt{Ls * (1/Cs + 1/Cd)^{-1}})$
Solve for C_s and C_d
C_s = 0.18656 uF @ 127.8 kHz
C_d = 3.149 nF @ 1000 kHz

We after combining capacitors, we measured the capacitance and effective resistance of each one:
$C_{s,exp}$ = 190 uF
R_s = 210.9 Ω
$C_{d,exp}$ = 2.99 nF
R_d = 51.6 kΩ

This is the circuit we built using our found values:

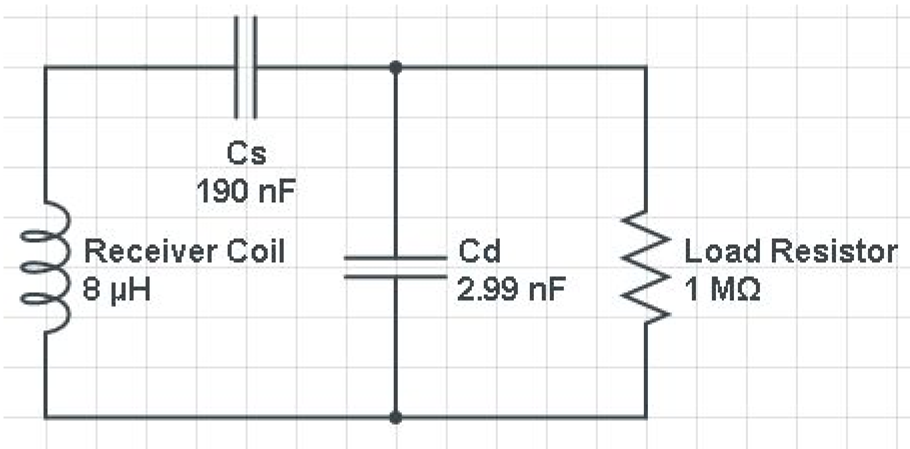
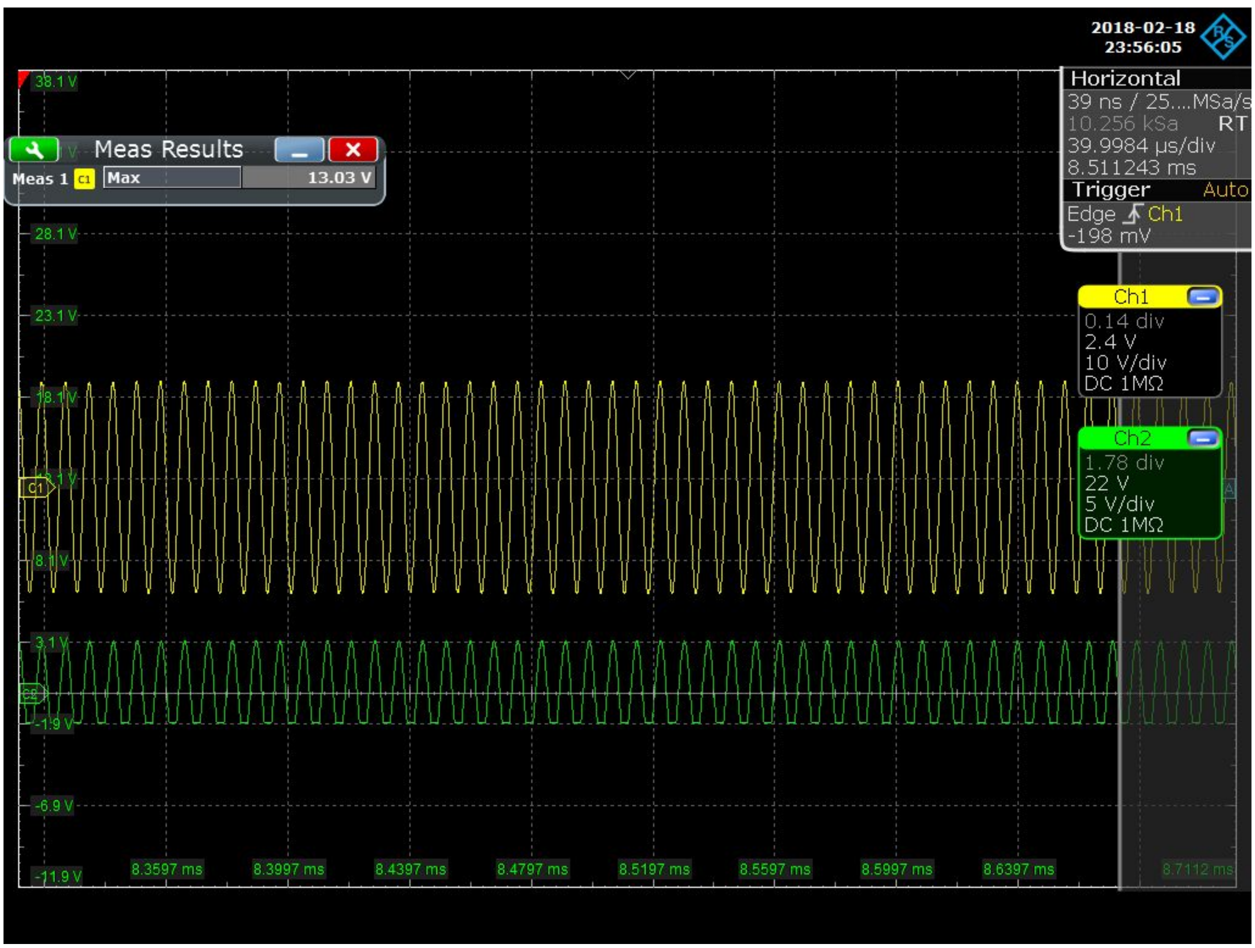


Figure 1: Detection circuit

Using an oscilloscope, we measured the receiver coil output(yellow) and load resistor voltage output(green):



<u>Plot 1: CH1(Yellow) is voltage at the coil and CH2(Green) is the voltage after Cs and Cd.</u>

AC/DC Converter
Input: AC voltage and current.
Output: DC voltage and current with less than 2% voltage ripple. Single unit V = ~6-7V, I > 1.54A

The AC/DC converter takes the receivers AC power from the receiver coil and outputs DC power by rectifying the AC signal, filtering, and regulating the signal. This DC signal from the AC/DC converter is then connected in series with the other three AC/DC converters, which sums the voltages. This increased voltage is then fed into the buck DC/DC converter.

Requirements	Verification	Verification Status
AC/DC Converter 1. V_{out} = 8V $\rightarrow$ 26V +- 1V 2. I_{out} = 5A $\rightarrow$ 1.54 +- 0.01A	**Verification Process for Item 1** 1. Assemble a full-wave bridge rectifier. 2. Connect a 80 μF capacitor parallel to act as a filter. 3. Connect a multimeter to the terminals of the circuit. 4. Measure the voltage at the load. Make sure it matches the requirement 1. 5. Be able to contribute to 66% efficiency. (req 3)	

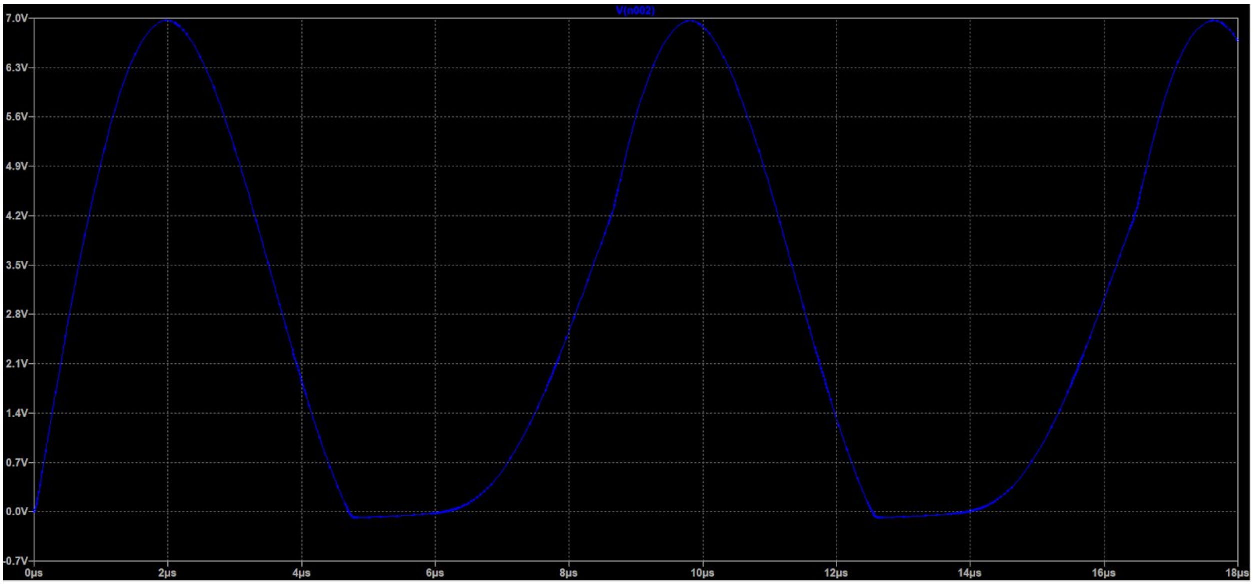
In our design we will be using a full wave bridge rectifier. In order to have the capability to test this part of our circuit, we made our simulations using the 1N5819 Schottky diode that was easily available to purchase at the UIUC ECE Store. Due to the price and available quantity, we might consider other diode options.

To determine a correct capacitance for filter, the following formula should be applied
$V_{Ripple,\,C} = \frac{Iload}{fC}$

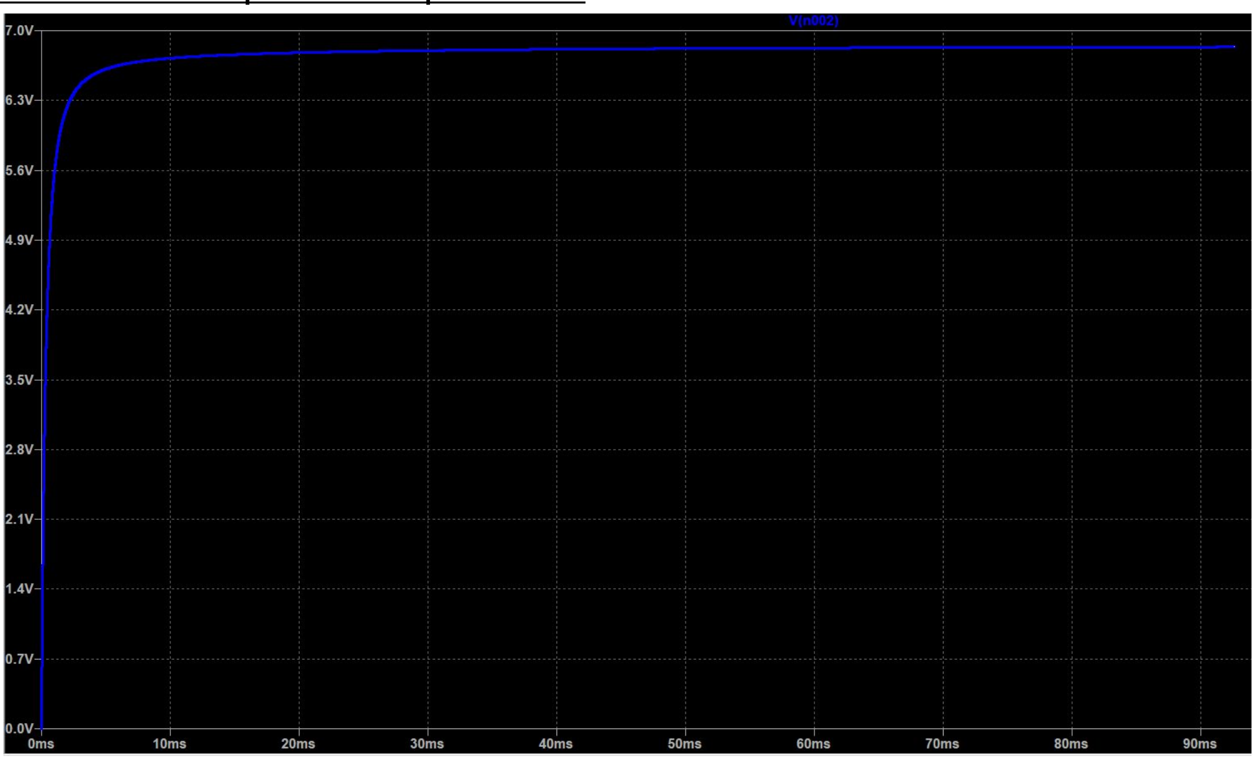
Since we are using a full-wave rectifier our frequency is going to double from 127.8kHz to 255.6kHz.

$V_{Ripple,C} = 7 * \%2 = 0.14V$

$0.14V = \frac{1.7A}{C*255.6kHz} = 47.5073\,x10^{-6}$ F≈ 48 μF



Plot 1: Rectifier output without capacitor filter.



Plot 2: After Capacitor filter, AC/DC circuit voltage output.

Our choice of full-wave bridge rectifier design was decided upon the low ripple voltage it brings compared to the half-wave design however, more simulations will be conducted with half-wave when we gather more data for input from our coil.

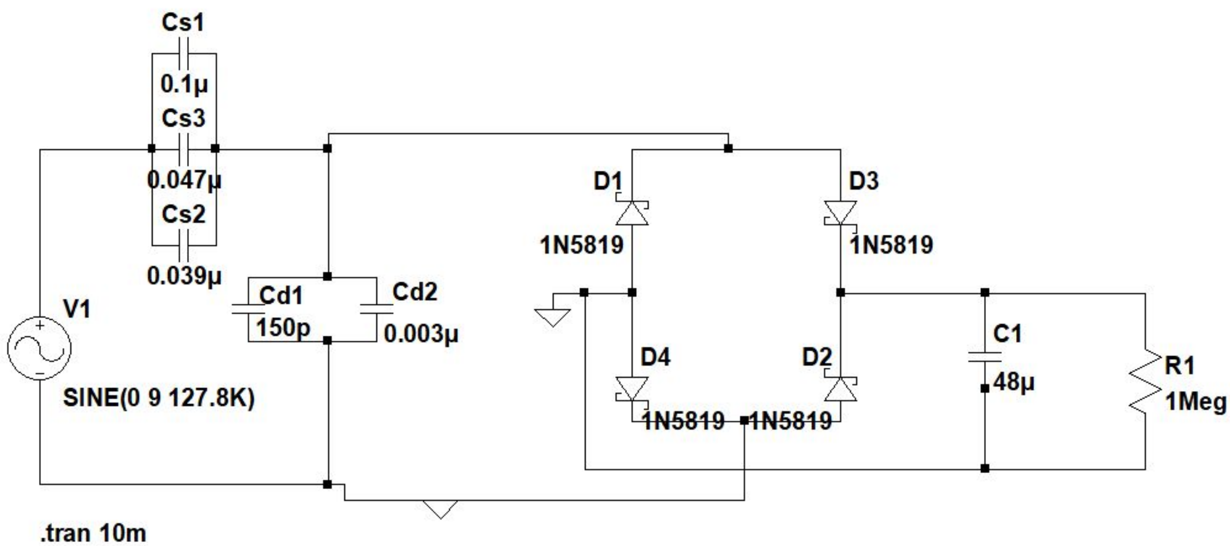


Figure 4: Receiver circuit with detection capacitors, full wave rectifier and capacitor filter.

DC/DC Converter

Input: DC voltage and current from the AC/DC converter. V = ~25-26V, I > 1.54A
Output: Stepped down DC voltage and current. V = 12V, I = 3.33A. 5% tolerance.

The DC/DC converter takes the DC output from the AC/DC converter and steps the voltage down using a buck converter. The output is then fed to the laptop, while also being regulated by a feedback loop to keep a constant voltage with very small ripple. Ideally this module should output 12V, 3.33A; this is the same voltage and current parameters as the charger of the test laptop we will be charging with our circuit. We found that the buck converter fails to operate properly with currents below 1.54A, and has a maximum current specification of 5A. Thus, we expect the voltage out of the AC/DC converter module to be maximum of about 26V and a hard minimum of 8V, to adhere to the law of conservation of power. The amount of coils and AC/DC modules that we will use will depend on the experimental data found.

Requirements	Verification	Verification Status
DC/DC Buck Converter 1. V_{out} = 12V +- 0.2V,	**Verification Process for Items 1 and 2:**	

I_{out} = 3.33A +- 0.06A 2. Be able to run for 12 hours	1. Attach a DC power source input equal to the output of the AC/DC converter. 2. Attach a 3.6 Ω resistor to load. 3. Measure voltage across load using a multimeter. 4. Measure current through load using a multimeter 5. Ensure that the voltage found is 12V +- 0.2V and the current is 3.33A +- 0.06A. (req 1) 6. Be able to contribute to 66% efficiency. (req 3)	

<u>Measurements and Calculations:</u>

V_{out} = 12V (taken from the charger specifications)

I_{out} = 3.33A (taken from charger specifications)

$I_{max, buck}$ = 5A (hard rated limit of the coil. Found in the coil datasheet. Current should not go anywhere near this number)

$V_{min, buck}$ = 8V (minimum voltage output of the coil. Found by dividing power by maximum current)

Vin = 25V

Vripple = 0.24V

Duty Ratio = V_{out}/V_{in}

= 48%

$L_{out} = V_{out}/2I_{out}F$

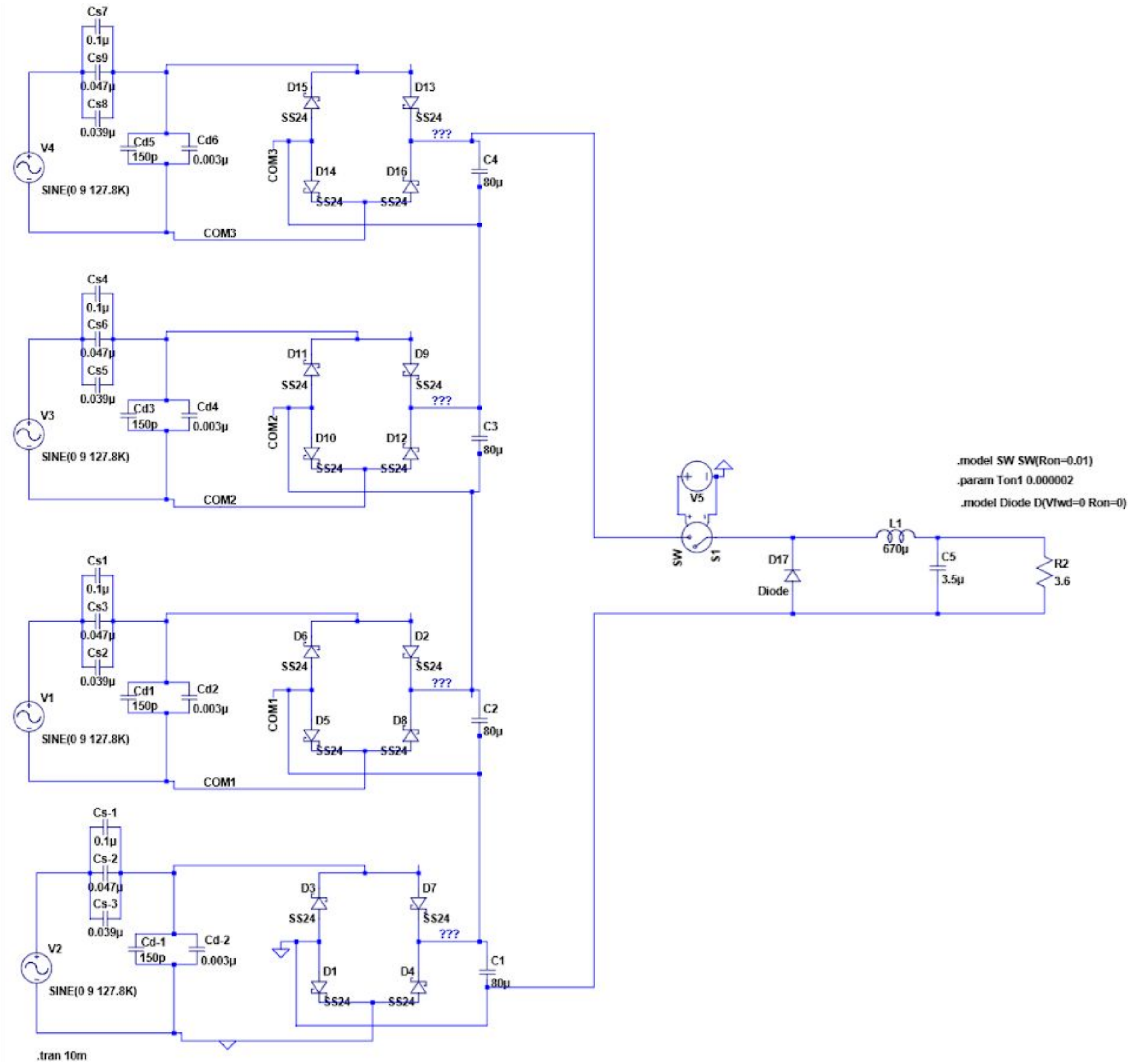
= 14.1uH

$C_{out} = I_{out}/4F*V_{ripple}$

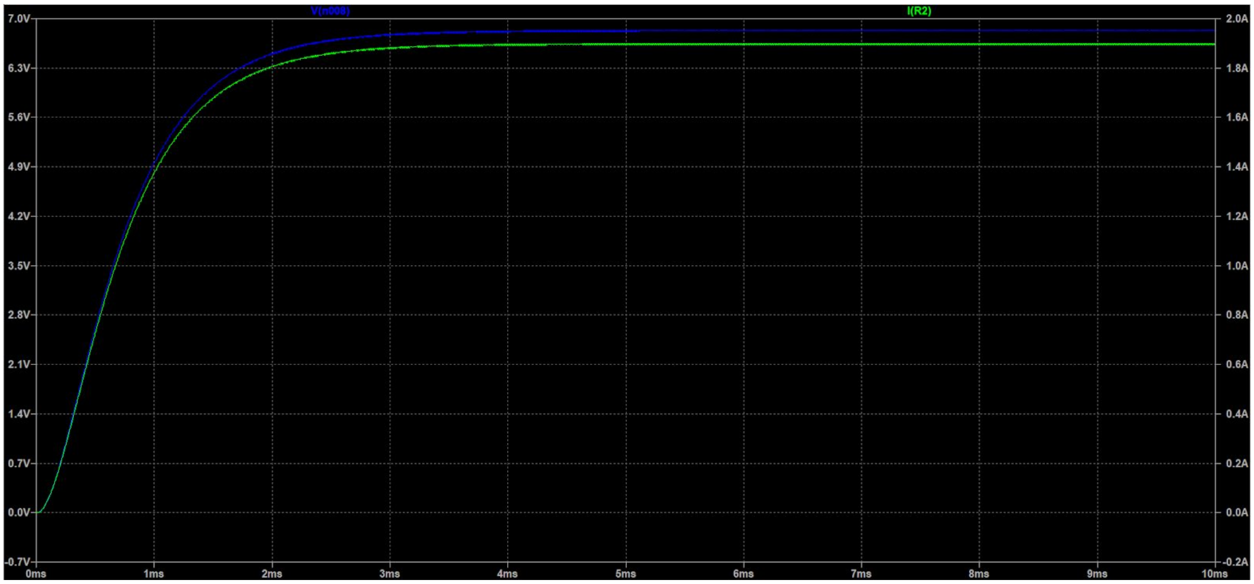
= 27.14 uF

R_{load} = V/I = 12/3.33

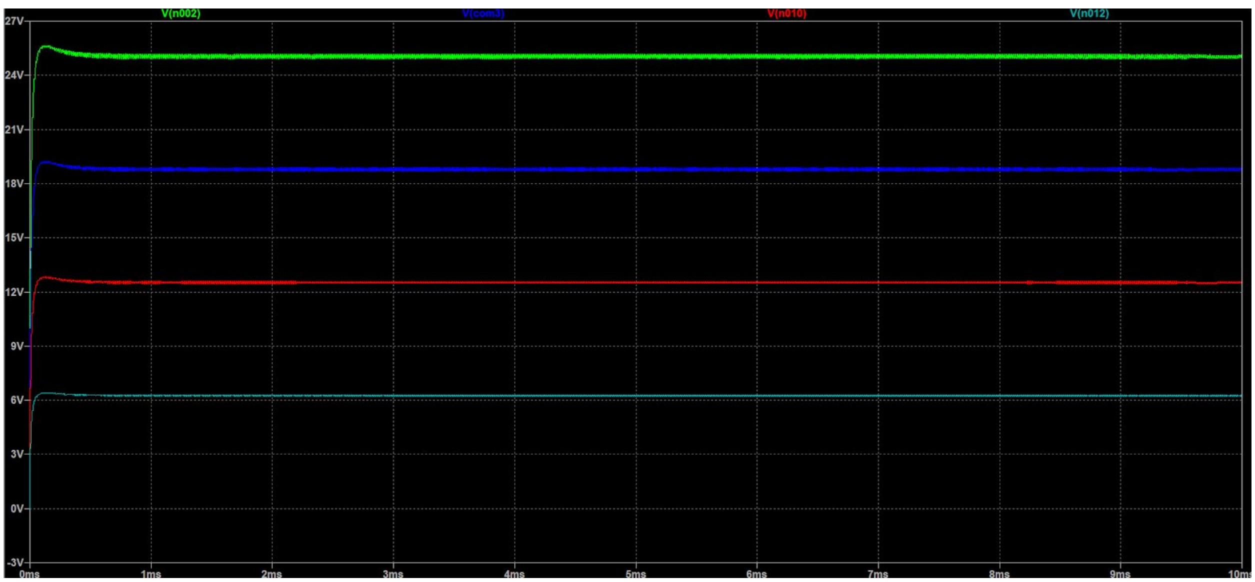
= 3.6 Ω



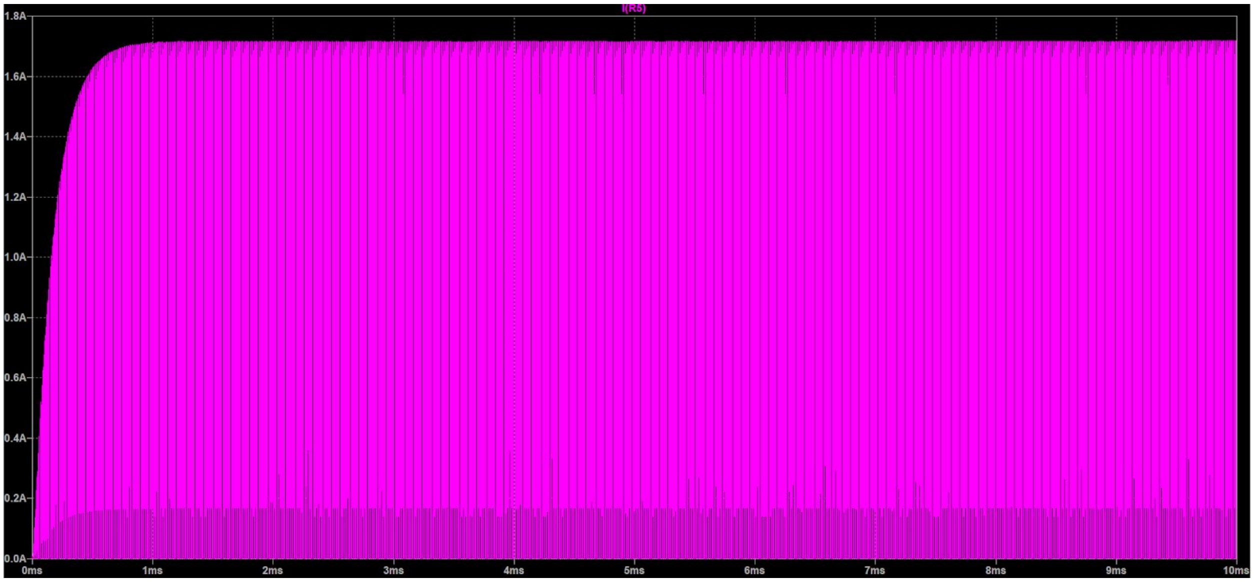
<u>Figure 2: 4 receiver circuits serially connected to the bulk converter.</u>



Plot 2: From the two converter combo the load current is about 1.9A(green) and load voltage is about 7V(blue)



Plot 3: Cyan, red, blue and green are the voltage outputs from Receiver #1,#2,#3 and #4 respectively.



Plot 4: Current that goes in to the bulk converter at 1.7A.

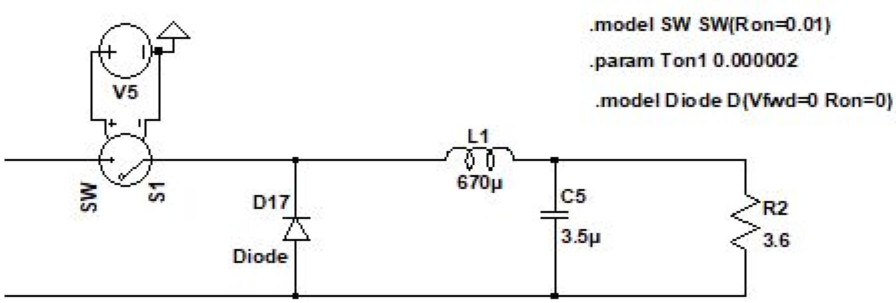


Figure 3: Buck converter

2.2.3 Requirement Summary

Module Name	High-Level Requirement	Points
Coil Circuit	This module should successfully output an AC voltage that our AC/DC circuit can handle.	10
AC/DC Converter	This module should be able to take an AC input and output a DC voltage	20

	and current.	
DC/DC Converter	This module should be able to step down a larger voltage to a smaller one for the test laptop to use.	20
	Total	50

2.3 Risk Analysis

There are two major obstacles that we face in making the project work. The first one is the coil coupling. We will have to make sure that our coils will be able to properly receive the magnetic fields and get an AC voltage out of them. Frequency analysis will not be easy, and the entire project hinges on this block working. The second, more subtle obstacle will be interfacing the blocks together. There may be unforeseen consequences when connecting the modules, and we will have to put in effort to solve it. If we cannot get the modules to work together, our project will be rendered useless.

The biggest struggle we are currently facing is being able to attain high enough power output for use to use in the AC/DC converter. If we are not able to convert enough power, the charger will not charge the battery fast enough to overcome the power consumption of the laptop. This will render our project impractical and pointless.

2.4 Tolerance Analysis

For tolerance analysis the module that is most important for us is the coil requirement. Since the coils interact with each other with a magnetic field, the distance between them plays a major role. As we have seen, power transfer decreases as the coils are farther apart and as they become unaligned. From our observations a distance of around 10mm gives us enough power transfer with 1 to 1 sized coils. What makes or breaks our project is that in real life our product could be moved around and so we need to keep the transmitter and receiver fixed and so to remedy the situation we will design a circuit with the max power transfer we get from the coils so no one will get hurt from the circuit overheating. Where max power occurs when the coils are closer together or less than 5mm.

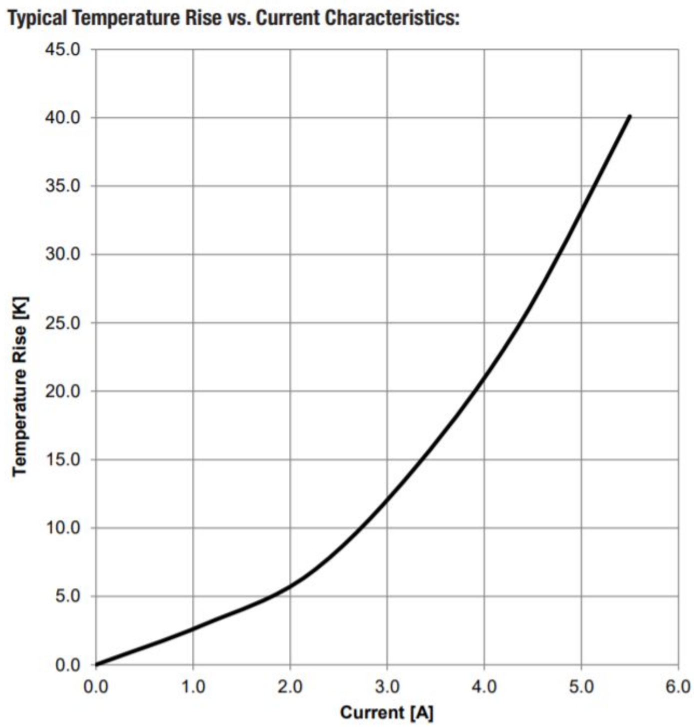


Figure: Receiver coil Temperature Vs. Current characteristics[6]

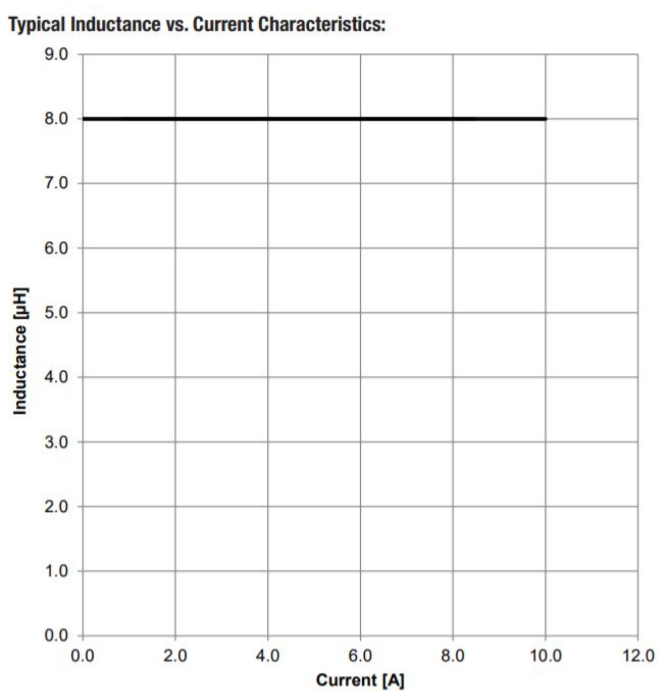


Figure: Inductance Vs. Current characteristics[6]

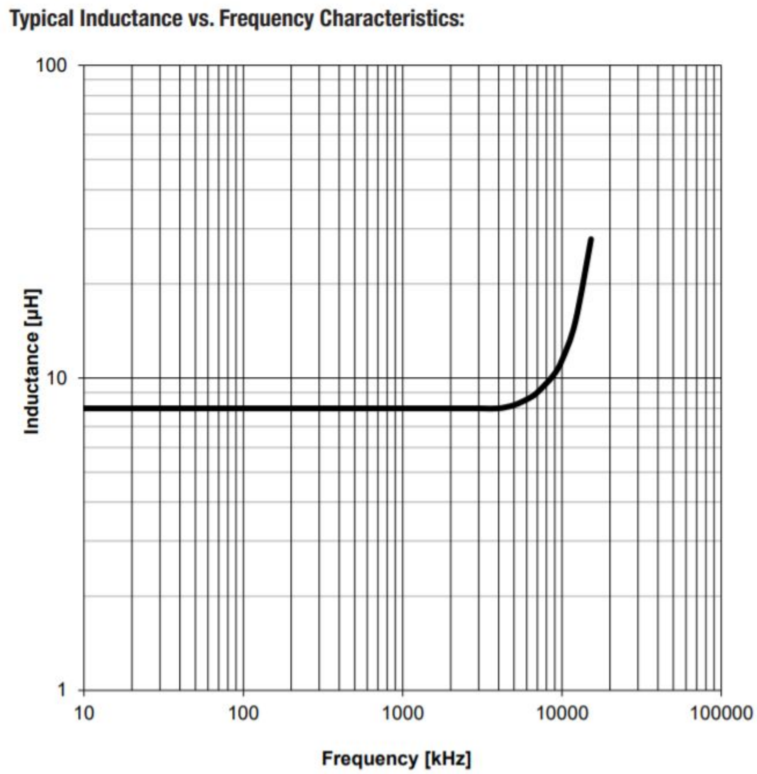


Figure: Inductance Vs. Frequency characteristics[6]

3. Cost and Schedule

3.1 Cost Analysis

Labor:

Partner	Hourly Rate	Hours to complete	Multiplier	Total per person
Jason Kao	$8	100	2.5	$2000
Onur Cam	$8	100	2.5	$2000
Enrique Ramirez	$8	100	2.5	$2000
			Total	$6000

Hourly rate was calculated from the 6-year average of the average salary per year, then dividing it by 365 and 24. Afterwards, the number is rounded up.
The amount of hours to complete is a rough estimate.

Parts:

Part	Manufacturer	Part #	Quantity	Cost(USD)
Heat Resistant Mat	Colortrak	N/A	1	$9.99
.1MFD 50VOLT MONOLYTHIC CAPACITOR	1C20Z5U104M05 0B	181201250	4	$0.64
.047MFD 50VOLT MONOLYTHIC CAPACITOR	1C25Z5U473M05 0B	181200750	4	$0.60
.039MFD GOLDEN MAX	CW20C393K	181001500	4	$0.92
150PF 1KV CERAMIC	75-562R5GAT15	180708500	4	$6.76
.003MFD 1KV CERAMIC	18F2721	180701250	4	$3.44
40V SCHOTTKY DIODE	1N5819	30157400	16	$6.08
8µH Wireless Charging Coil Receiver 60 mOhm	760308102207	Not in ECEshop	4	39.44
			Total	$57.88

3.2 Schedule

Week	**Task**	**Delegation**
2/19	Finish Design Document	All
	Debug detection circuit	All
2/26	Prepare for Design Review	All
	Start PCBs using Eagle(dc\dc with feedback, ac\dc with Rx coils)	All
	Purchase components for	All

	breadboard implementation	
3/5	Continue with PCBs	All
	Start breadboarding modules with test points(Coil circuit with ac\dc converter)	All
	Do soldering assignment	All
3/12	1st round of PCB orders	All
	Continue breadboard and debug(dc\dc converter and feedback)	All
3/19	Spring Break(Research or continue breadboard)	All
3/26	Start PCB implementation	All
	Final Group PCB orders if needed	All
4/2	Continue with final circuit and debug	All
4/9	Finish final circuit	All
4/16	Prepare for mock demo	All
4/23	Prepare for presentation	All
4/30	Work on final paper	All
	Check out lab	All
	Finalize lab notebook	All

4. Ethics and Safety

The following tenets of the IEEE Code of Ethics[1] are the ones relevant to our project:

1. to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;
3. to be honest and realistic in stating claims or estimates based on available data;
5. to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems;
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;

Tenets 1 and 9 go hand in hand. Considering we are designing a circuit that works with somewhat high power, it is possible that we could build something that could potentially harm the user. As such, we will implement checks and warnings in our design to prevent its misuse. This is to protect users of the product, as well as ourselves while we work on it.

Tenet 3 is very straightforward; we aim to record our data honestly and accurately, as well as not being too ambitious with what we think we can do with our project.

With tenet 5, we will create a brief documentation in the final report detailing how existing wireless charging technology works, as well as the specifics of our own project.

Tenet 6 will be followed by doing the necessary research in order to design a wireless receiver. While nobody in the group has previous knowledge in directly designing a wireless charging interface, but we will make sure that we have that knowledge by the time we finish designing the project.

We will seek to follow tenet 7 to the best of our ability; in fact, we will likely be seeking much guidance in this project, as none of us has done anything like it before. It ties closely with tenet 6, where we will be building our knowledge in order to create a competent product.

An additional safety concern that we encountered is the danger of capacitors exploding. In the event that the load does not draw enough power, too much power could build up in the capacitors, overloading them and causing them to break down.

http://projects-web.engr.colostate.edu/ece-sr-design/AY13/measurement/High_Voltage_Safety_Manual.pdf

The above link leads to a manual about working with high voltage. There is a small bullet point there about safely working with power capacitors, which we will be using in the project. While we will not be working with any voltages beyond 40-50V, it is better safe than sorry, since 60V w/ an impedance of less than 5000 Ω can be harmful.

The ethical considerations of our project may include the usage of third-party products like the transmitters, as well as the usage of a pre-built coil. We do not claim to use the transmitters as part of the self-made portion of our project; we use it to ensure that our adapter will work with a wide variety of transmitters, increasing the modularity of the product. The coil that we bought is useless without accompanying circuitry, so we believe the intention of the creator is that it is to be used in development and research.

4. References

[1] "IEEE IEEE Code of Ethics." *IEEE - IEEE Code of Ethics*. N.p., n.d. Web. 07 Feb. 2018. https://www.ieee.org/about/corporate/governance/p7-8.html

[2] "Dell Wireless Charging Mat - PM30W17." *Dell United States*. N.p., n.d. Web. 07 Feb. 2018.
http://www.dell.com/en-us/shop/dell-wireless-charging-mat-pm30w17/apd/580-agli/pc-accessories

[3] Services, E. I. T. S. ECE ILLINOIS Department of Electrical and Computer Engineering. *Salary Averages :: ECE ILLINOIS* Available at: https://ece.illinois.edu/admissions/why-ece/salary-averages.asp. (Accessed: 19th February 2018)

[4] High Voltage Safety Manual. Colorado State University, projects-web.engr.colostate.edu/ece-sr-design/AY13/measurement/High_Voltage_Safety_Manual.pdf.

[5] “The Qi Wireless Power Transfer System Power Class 0 Specification, Parts 1 and 2: Interface Definitions .” Qi Wireless Power Specification, Wireless Power Consortium, Feb. 2017, www.wirelesspowerconsortium.com/downloads/download-wireless-power-specification.html.
[6] “760308102207 Datasheet.” katalog.we-online.de/pbs/datasheet/760308102207.pdf.