Wireless Laptop Charging System

ECE 445 Mock Design Review

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1.1 Diagrams

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

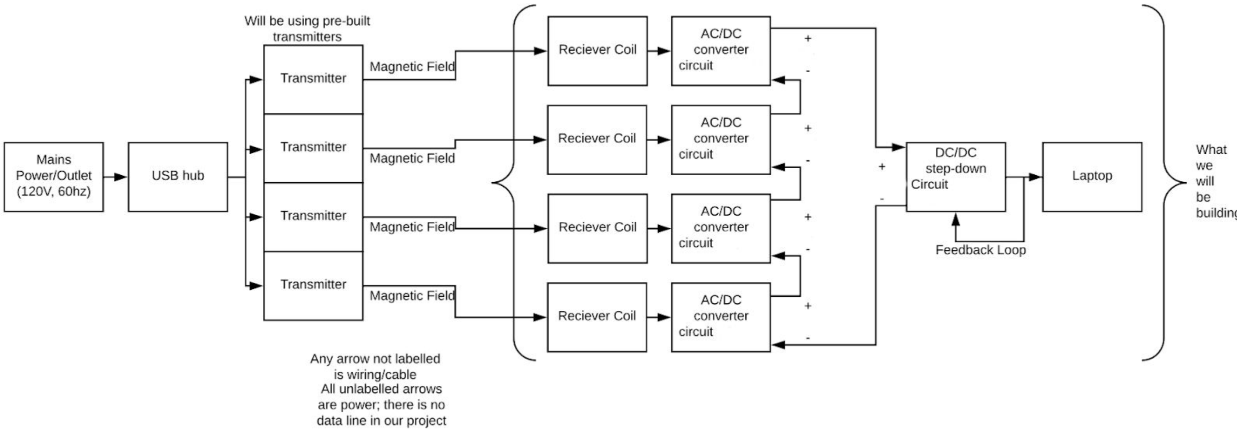


Diagram 1: Initial diagram

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

2.1 Requirements and Validation Plans

Requirement	Verification	Verification Status
Coil Circuit 1. V_{out} = 9V +- 0.3V 2. Coil receives power from at least 10 mm away 3. Be able to run for 12 hours	**Coil Circuit** **Verification Process for 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. Run for 12 hours, monitoring the circuit every two hours (req 3)	
AC/DC Converter 1. Rectify $V_{rms} = 9\sqrt{2}$ with Full-wave rectifier 2. Filter with Capacitor 3. Be able to run for 12 hours	**Verification Process for Item 1, 2 , and 3** 1. Ensure that the rectifier circuit works by measuring its output 2. Measure capacitor output for DC output with acceptable noise. 3. Run for 12 hours, monitoring the circuit every two hours (req 3)	
DC/DC Buck Converter 1. V_{out} = 12V +- 0.2V, I_{out} = 3.33A +- 0.06A 2. Be able to run for 12 hours	**Verification Process for Items 1 and 2:** 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. Run for 12 hours, monitoring the circuit every two hours (req 3)	

3.1 Schematics with plots

3.1.1 Receiver Coil Output

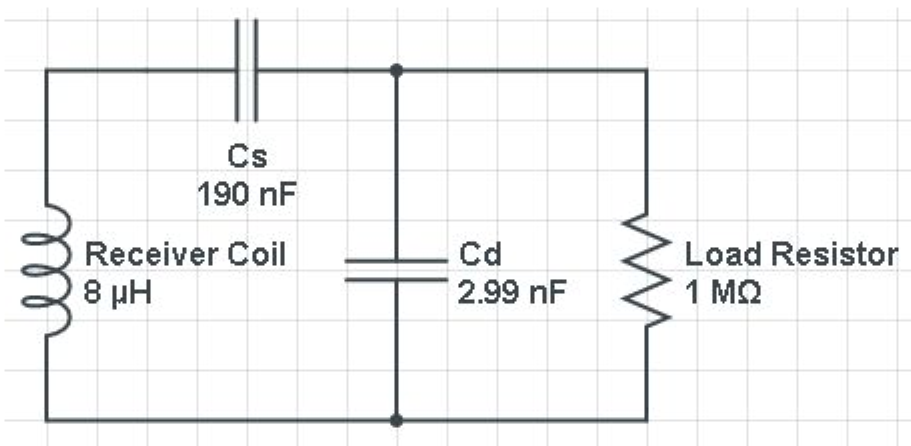
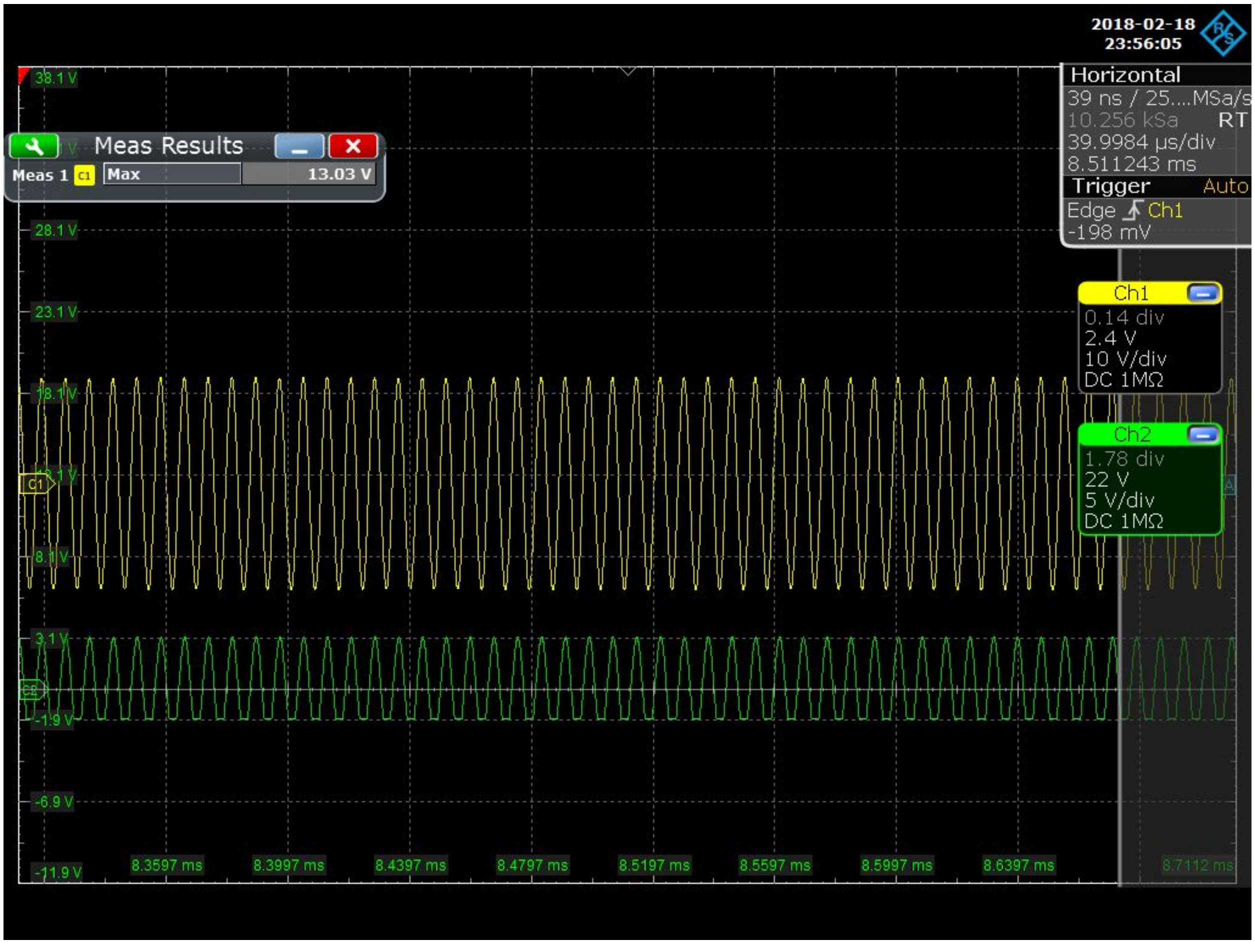


Figure 1: Detection circuit

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



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

3.1.2 AC\DC and DC\DC Converter

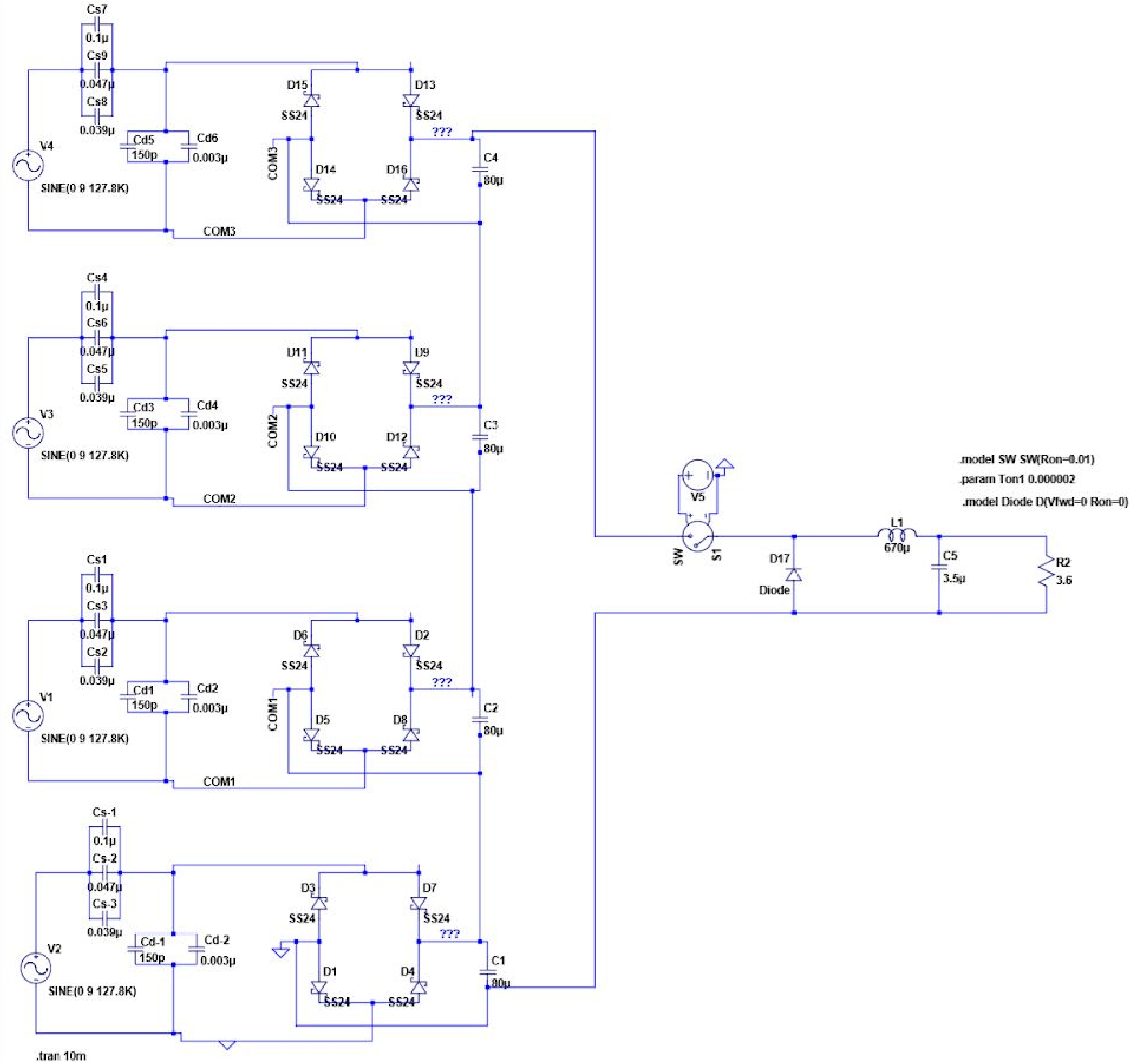
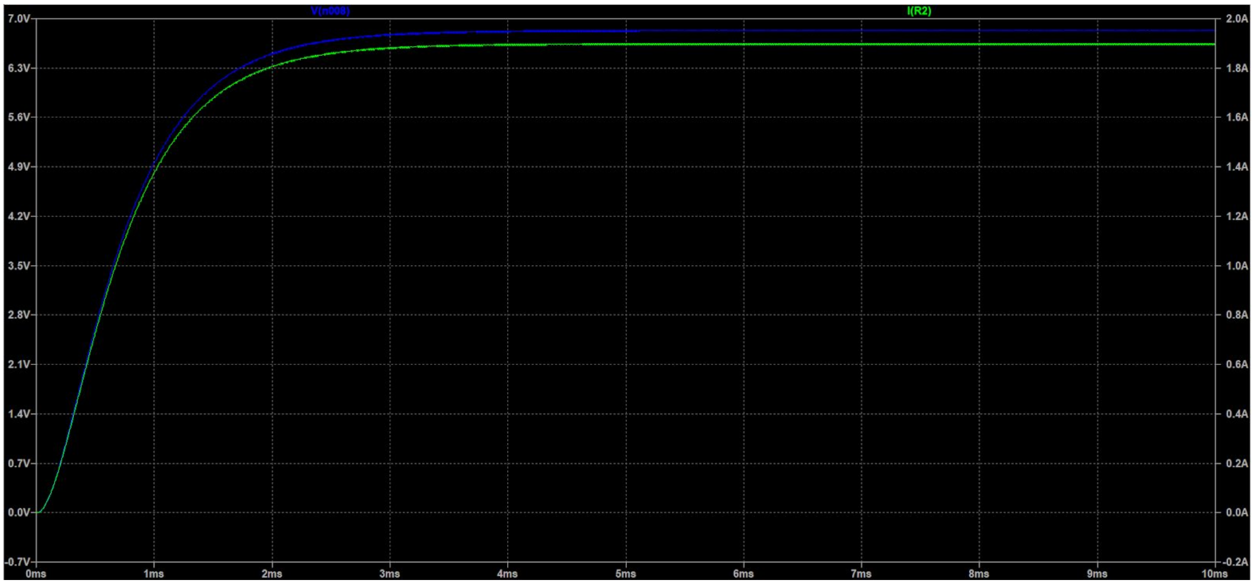
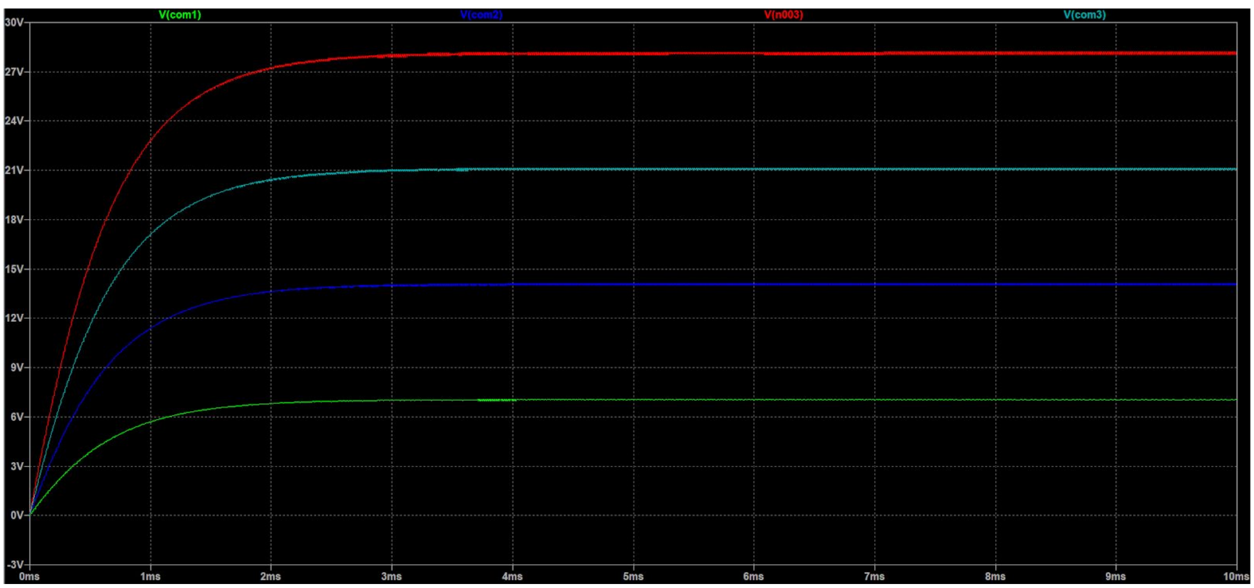


Figure 2: 4 receiver circuits serially connected to the bulk converter.



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



__Plot 3: Green, blue, cyan and red are the voltage outputs from Receiver #1,#2,#3 and #4 respectively.__

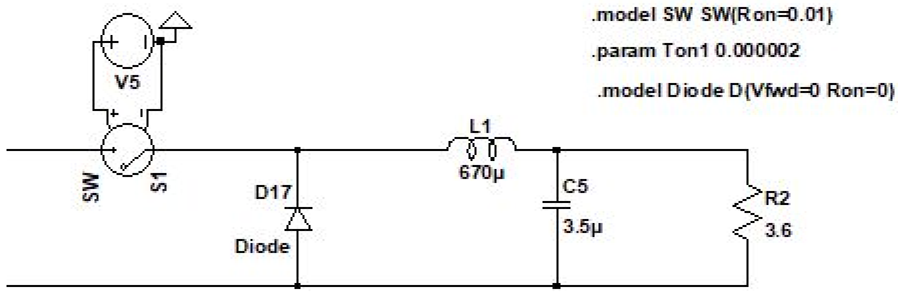


Figure 3: Bulk converter

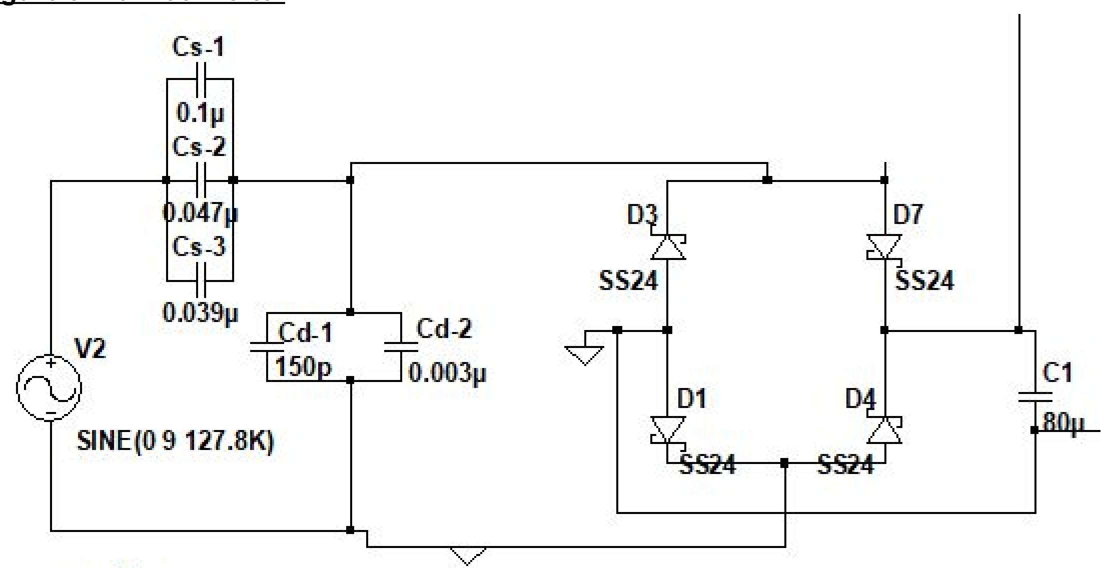


Figure 4: Receiver circuit with detection capacitors, full wave rectifier and capacitor filter.

4.1 Calculations

4.1.1 Coil Communication

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). Note how the block diagram specifies 4 coils and AC/DC modules; this is inaccurate. 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.

Some of the measurements and calculated parameters are found below:

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
$f_d = 1/(2\Pi\sqrt{Ls * (1/Cs + 1/Cd)^{-1}})$ *(Provided by WPC)*
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

4.1.2 AC\DC Converter
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.

In our design we will be using a full wave bridge rectifier
Some of the calculated parameters are found below:
Determining 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.
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.

4.1.3 DC\DC Converter
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.

Some of the calculated parameters are found below:

Duty Ratio = V_{out}/V_{in}
$L_{out} = V_{out}/2I_{out}F$
$C_{out} = I_{out}/4F*V_{ripple}$
$R_{load} = V/I = 12/3.33 = 3.6\ \Omega$

5.1 Safety Statements
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 its 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 concerns 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.

Citations

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

- **"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.**