WIRELESS LAPTOP CHARGER

By

Enrique Ramirez

Jason Kao

Onur Cam

Final Report for ECE 445, Senior Design, Spring 2018

TA: Zhen Qin

2 May 2018

Project No. 37

Abstract

We designed a system that allows a user to quickly connect and disconnect power to their laptop quickly. The core of the system is a medium power DC/DC converter with a separated transformer. The system transforms DC power into AC power to transfer through the transformer, then rectifies the waveform back to DC power and outputs it. The system operates in a stable state, albeit at a lower power rating than expected.

Contents

Abstract ii

Contents iii

1. Introduction 1

2 Design 2

2.1 Clamp Circuit 3

2.1.1 Minimum Breakdown Voltage 3

2.1.2 Power Dissipated 3

2.1.3 Simulation 3

2.2 MOSFET Circuit 4

2.2.1 MOSFET 4

2.2.2 MOSFET Driver 5

2.3 PWM Generator 5

2.4 Transformer 5

2.4.1 Number of Windings 5

2.4.2 Copper Wire Gauge 6

2.4.3 Simulation 7

2.5 Rectification Circuit 8

2.5.1 Diode Stress Calculations and LC Values 8

2.5.2 Simulation 9

3. Design Verification 11

3.1 Clamp Circuit Verification 11

3.2 PWM Generator Verification 11

3.3 MOSFET Circuit Verification 12

3.4 Transformer Verification 12

3.5 Rectifier Circuit Verification 14

4. Costs 15

4.1 Parts 15

4.2 Labor 15

4.3 Schedule 16

5. Conclusion 18

5.1 Accomplishments 18

5.2 Uncertainties 18

5.3 Ethical considerations 18

5.4 Future work 19

References 20

Appendix A: Requirement and Verification Table 21

1. Introduction

Classrooms have seen a notable increase in the usage of laptops for notetaking and research. Many laptops do not have a long battery life and are reliant on their charging adapters. These chargers are fully wired, contributing to the cable traffic involved with multiple charging adapters strewn across tables and floors to reach the outlets. This project aims to develop a solution that allows the user to deploy and retrieve their adapter with minimal effort, decreasing frustration and confusion related to charging adapters.

The project consists of three major blocks: the switching circuit(MOSFET, PWM, Clamp), the transformer, and the rectifying circuit. The switching circuit converts DC power to AC power. The transformer transfers AC power over a metallic core. The rectifying circuit converts AC power back into DC power.

Ultimately, the project is mostly success. We were able to transfer most of power over the transformer, albeit at a lower power than our set goals. Future work would be greatly beneficial to our project, as there is much room for improvement.

A top-level block diagram of our project can be seen in figure 1 with descriptions of the main blocks given in the design section of this report as well as very brief descriptions in the introduction.

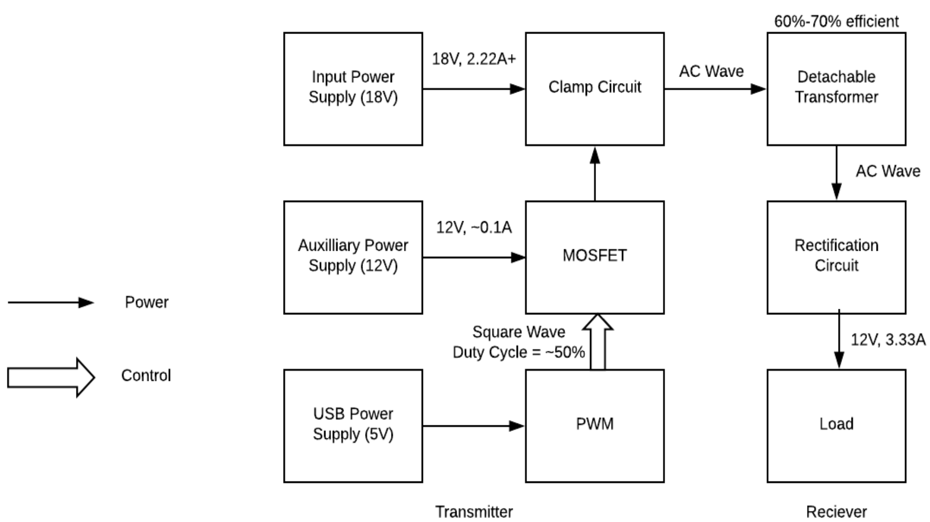

Figure 1. Block Diagram of Laptop Charger.

2 Design

Our design is composed of 5 blocks: The transformer, the clamp circuit, the MOSFET circuit, the PWM generator, and the rectifying circuit. The transformer conveys electrical power using magnetic fields through the ferrite core, allowing for wireless transfer of electrical power. The clamp circuit allows the transformer's ferrite core to dissipate magnetic flux, allowing it to continuously operate. The MOSFET circuit modifies the DC input, turning it into a wave according to the forward switching DC converter topology, which the transformer can use. The rectifying circuit inputs the waveform on the secondary side of the transformer and converts the wave back into a usable DC signal.

We used LTSPICE to simulate our design which is broken down into two parts which are ultimately connected to provide wireless power. The two parts can be seen in figure 2 and 3.

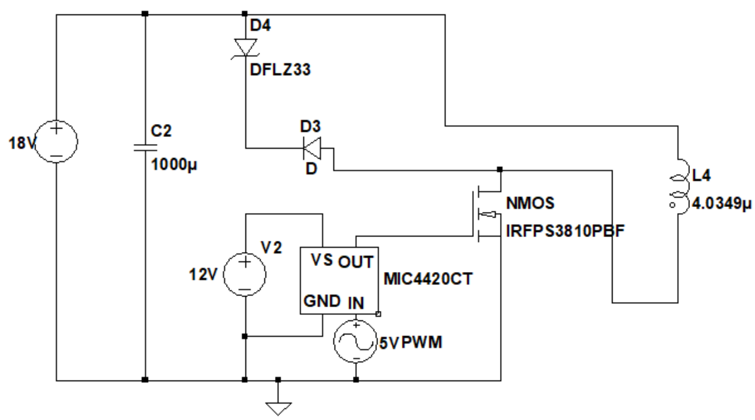

Figure 2. Transmitter side which includes MOSFET, Clamp Circuit, Primary Transformer

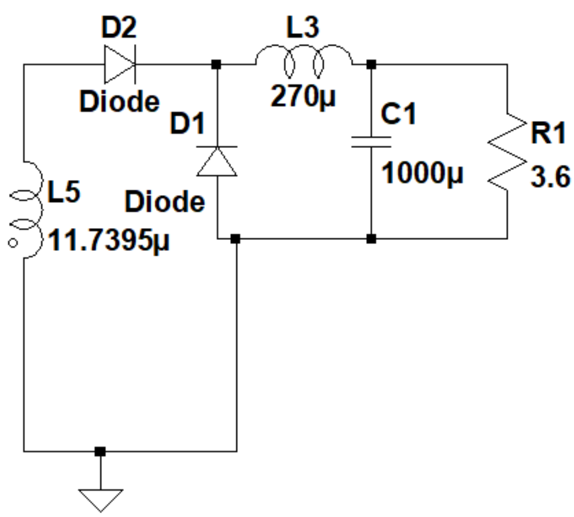

Figure 3. Receiver side which includes Rectifying Circuit, LC Filter, and Load.

2.1 Clamp Circuit

The clamp circuit resets the core to prevent saturation due to spikes in current and voltage. Without this part in the circuit there would be less efficient switching as the clamp circuit helps reduce the ringing effect of a switch. Which in turn create a more reliable system as components are not dealing with spikes in voltage or current. The circuit consisted of a Zener and a Schottky diode. Parameters like V_c (breakdown voltage) had to be calculated and power losses of this system as it should not be a lossy part of the system.

2.1.1 Minimum Breakdown Voltage

The minimum breakdown voltage V_c was calculated using equation 1:

$$DT + \Delta + reset \leq T \tag{1}$$

With some manipulation, equation 1 is changed to equation 2:

$$\left(D + \frac{V_{in} D}{|V_{in} - V_c|}\right) \leq 1 \tag{2}$$

With D(Duty Ratio) = 49% and Vin = 18V, we were able to obtain a minimum V_c of 30V.

2.1.2 Power Dissipated

The power dissipated from the clamp circuit was calculated using equation 3:

$$P_{diss} = \frac{1}{2}(L_m + L_{1k})\, I_M^2 \approx 45\ \mu W \tag{3}$$

With the very small losses, we could see that this would help our overall efficiency of the circuit.

2.1.3 Simulation

Using LTSPICE we were able to probe the clamp circuit voltage which is very close to primary side transformer voltage as the two are connected in parallel. The clamp voltage can be seen in figure 4:

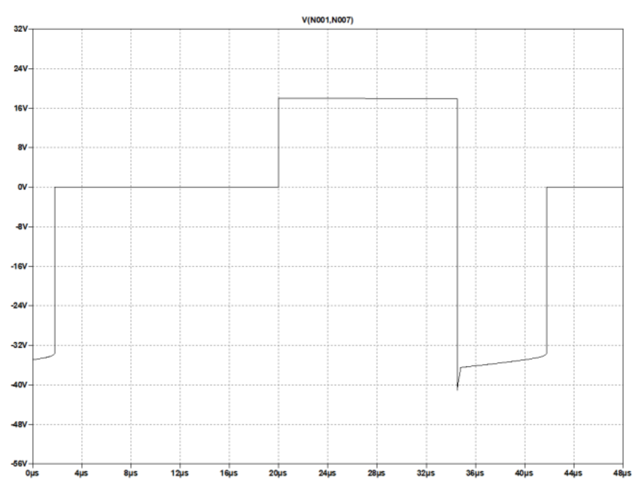

Figure 4. Clamp circuit voltage from simulation.

As seen from the waveform the waveform the Vc calculation was very close to the simulation and so we opted to go with a 1W Zener with a breakdown voltage of 36V but later in the project we switched to a 5W Zener with 100V breakdown because of the unexpected ringing which needed a higher voltage.

2.2 MOSFET Circuit

2.2.1 MOSFET

Transmitter unit includes a n-channel power MOSFET that is used as the switching device that passes the energy to the transformer during conduction phase. When the MOSFET switches off, this will reverse and the transformer voltage toward the clamp circuit while resetting, until MOSFET turns back on.

IRFPS3810PBF is the MOSFET that we have used in our testing unit. It receives signal in its gate from the gate driver that controls the direction of the power going into the transformer. As seen in figure 5 the voltage shoots to a high value and then settles to the expected value of 18V. We concluded that our representation of a MOSFET in LTSPICE of using a switch and a voltage source as the switching component was not a 100% accurate representation of the MOSFET which explains the increased value.

We chose the MOSFET according to the results of the clamp circuit calculations to meet its specs.

MOSFET minimum stresses:

V = Vc = -100V (Zener breakdown voltage)

|I| = 10.3A (experimentally found)

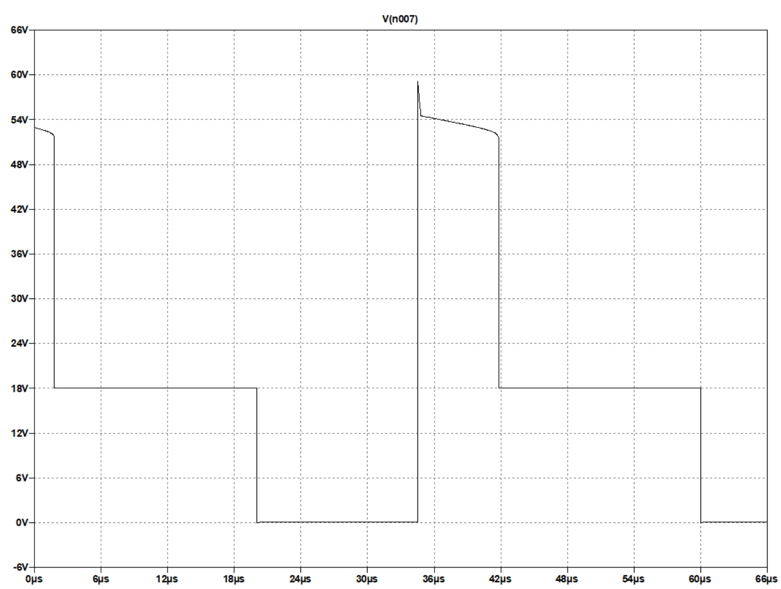

Figure 5. Simulation of V_{ds} of MOSFET.

2.2.2 MOSFET Driver

The Power MOSFET requires a gate driver that amplifies the signal from PWM generator to the gate of the power MOSFET. Gate driver is powered with 12V from a power source, isolated from the 18V input voltage of the transmitter unit. MIC4420CT in figure 6 was the recommended low side gate driver for our chosen power MOSFET.

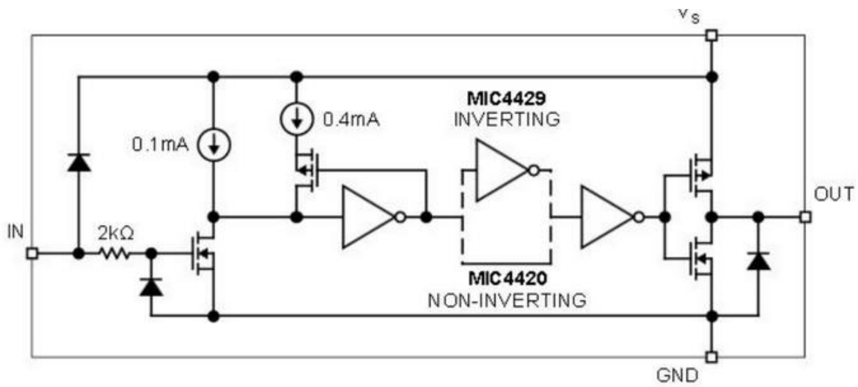

Figure 6. Low side gate driver schematic.

2.3 PWM Generator

Pulse Width Modulation is used to control the MOSFET by generating a square wave with set frequency and duty cycle. After completing transformer calculations(Equation #5), with limitation of ferrite core and copper wire considered, a frequency of 50kHz and duty cycle of 50% was used to drive the power MOSFET. It is important to note that any duty cycle value higher than 50% would prevent the transformer core from resetting which would cause critical failure of the system. In addition, a higher frequency could cause suboptimal skin depth in the 14 AWG copper wire and a lower frequency could cause more noise in the system.

2.4 Transformer

Before beginning with the calculations of the transformer, we picked out a usable core (described in its datasheet [1]), and set our operating frequency to 50 kHz. We chose this number because the operating frequency of ferrite cores are 10 kHz to 50 MHz [4]. This frequency was also convenient for our PWM, which could operate at that frequency. 50 kHz is a good medium between high and low frequency since a higher frequency could lead to suboptimal copper skin depth and lower frequencies may be heard, as well as require too many windings for our bobbin size.

2.4.1 Number of Windings

Primary winding calculations are described by equation 4 [6]:

$$Bsat > \frac{Vin \cdot D}{4 \cdot f \cdot Np \cdot Ac} \tag{4}$$

Where:

- B_{sat} = maximum magnetic flux density [1] = 320 mT
- A_c = effective cross-sectional area of the magnetic core [1] = 535 mm^2
- V_{in} = pk-pk input voltage = 18V
- D = duty ratio of the input voltage = 0.35 (35%)
- f = frequency of the input voltage = 50 kHz
- N_p = number of turns on primary side of the transformer

When solving for N_p: **N_p > 0.736**

We decide to maximize the number of windings on the transformer, given the space: **N_p = 7**

More windings lead to stronger coupling between coils, and thus, greater efficiency. If we increase duty ratio, the minimum number of windings required on the primary side increases, so we want more windings to be able to increase duty ratio.

To find the number of windings on the secondary side, we use equation 5 for the overall voltage change of the topology:

$$V_{out} = D * \frac{Ns}{Np} * V_{in} \tag{5}$$

Given that V_{in} = 18V, D = 0.35, and V_{out} = 12V,

We find that $\frac{\text{Ns}}{\text{Np}}$ = 1.9 => ~2.

Considering that N_p = 7, that means that **N_s = 14**

2.4.2 Copper Wire Gauge

Even though we know the number of windings required on each side of the transformer, we have to size the wire according to the current.

First, we find the projected current through the transformer, using equation 6:

$$I = \frac{VA}{efficiency \cdot Vp} \tag{6}$$

The complex power, VA, is found by the equation 7:

$$\text{VA} = \frac{\text{Voltage} * \text{Current}}{\text{PF}} \tag{7}$$

Power Factor is estimated to be around 0.6 for a typical transformer, so **VA = 67 VA**

We find the efficiency using equation 8:

$$n = \frac{Ps}{Pp} \tag{8}$$

The powers are found at the secondary and primary sides of the coil: **P_s = 42.7W, and P_p = 45.18W**. The efficiency is **94.5%**.

Since we have VA, efficiency, and V_p = 18V, we can solve for I (A): **I = 3.93886A**

We estimate that copper wire has a current density of 2.3A/mm^2 [6], and use equation 9 to solve for A:

$$A = \frac{I}{2.3} \tag{9}$$

A = area of wire = 1.7125 mm^2

Using the area of a circle equation, we can derive the diameter of the wire: **D = 1.477 mm**

Using the AWG table from [7], this corresponds to 15 AWG wire. However, we decided to use **14 AWG** wire due to availability. A smaller AWG number allows for a higher amperage in power transmission, at the cost of being bulkier and having decreased skin depth at higher frequencies.

2.4.3 Simulation

After building the transformer physically, we found the experimental inductance of the primary side of the transformer and secondary side of the transformer: **$L_{primary}$ = 4.0349 µH, $L_{secondary}$ = 11.7395 µH**
As well as the second side of the transformer:

We decided to run some simulations with these values along with the rest of the circuit, to get a general idea of the waveform we would be getting in practice.

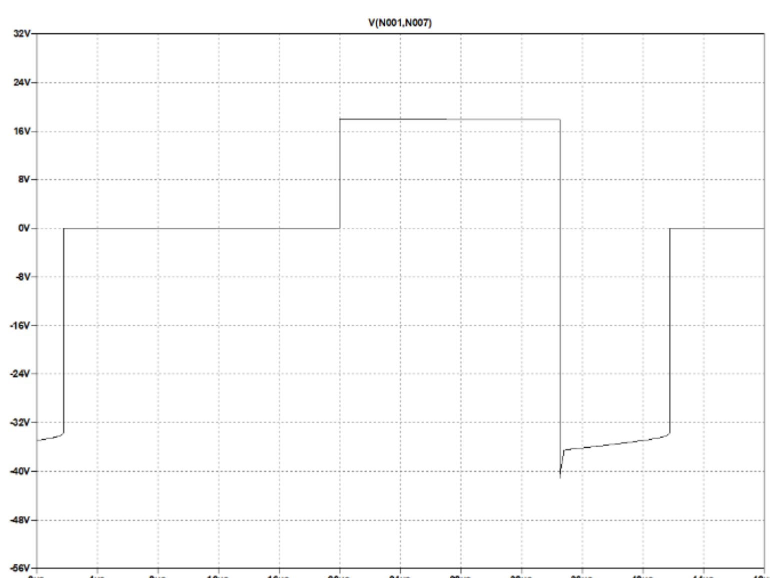

Figure 7. Primary-Side Voltage Simulation Result

We should see something like figure 7 in practice.

Table 1: Transformer Summary

N_p	N_s	Wire Size (AWG)
7	14	14

2.5 Rectification Circuit

The rectification circuit consisted of two Schottky diodes and the LC filter was included in this module as well. The primary role of the circuit was to rectify the signal coming from the transformer and then the LC filter would smooth the signal out into a DC voltage and DC current for the load to use. The stress calculations for the diodes had to be completed so we could safely operate with the high voltage and current coming from the transformer. The LC values also had to be found to produce a clean output.

2.5.1 Diode Stress Calculations and LC Values

The first diode that was connected to the secondary side coil and the inductor was the first diode that was calculated. The values for D1 are easier to find as the transformer values are used as well as the output voltage which lead to V = -97V and I = 4A.

The second, free-wheeling diode's voltage and current values were calculated using equations 10 and 11:

$$V = 18 * (n) = 94V \tag{10}$$

$$I = 4.3A \tag{11}$$

Now that we had the stress values for both the diodes, the LC values had to be found. The LC values were found using LTSPICE after we calculated the values of everything else in the system. The values that were worked out for our system that provided low ripple for current and voltage were L = 270.9uH and C = 1000uF.

2.5.2 Simulation

From simulation we were able to verify the diode stress levels were within the max levels calculated values from the following simulation waveforms in figure 8, 9:

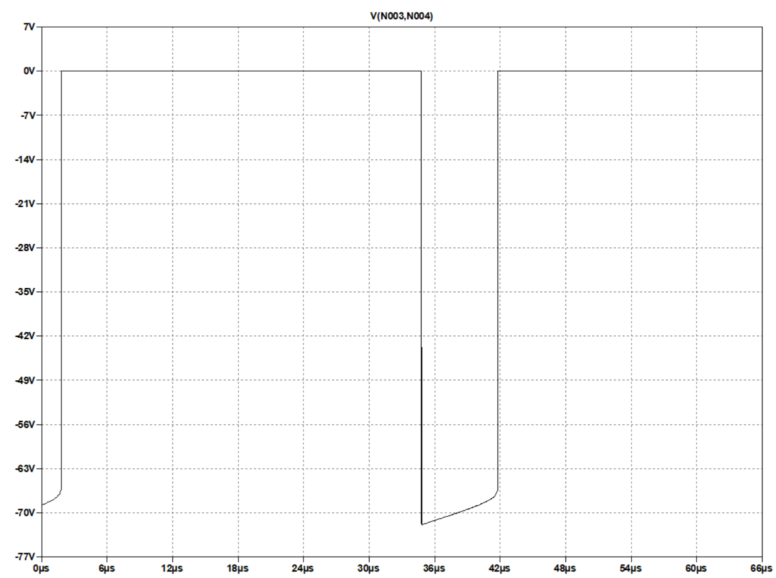

Figure 8. Voltage waveform of first diode.

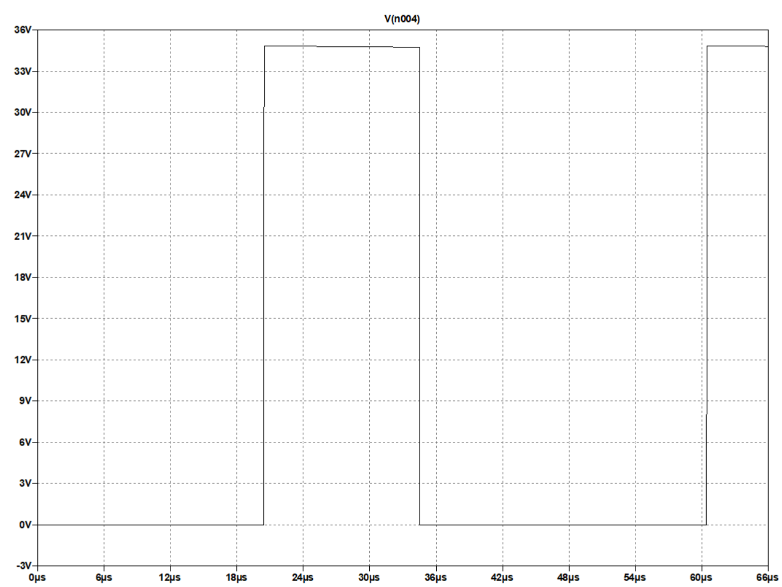

Figure 9. Voltage waveform of second diode.

Now the simulation of the output with 2% ripple for current and voltage are shown in figure 10:

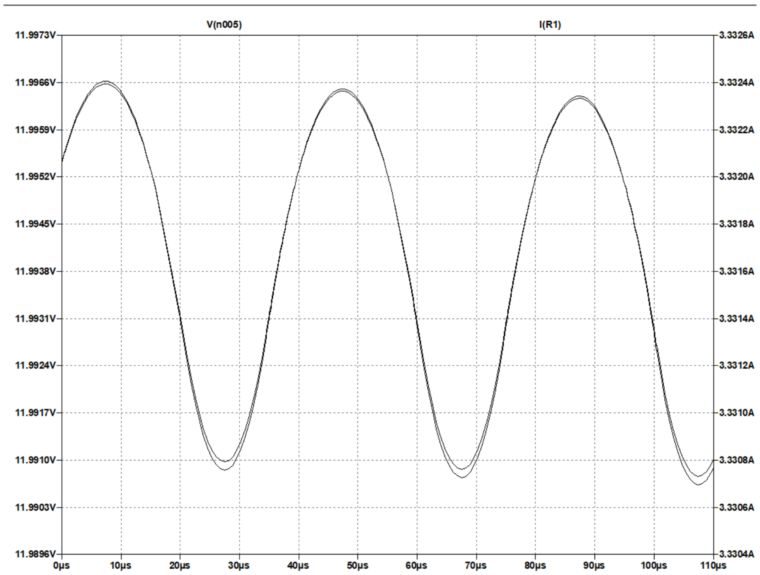

Figure 10. Output Voltage and Current waveforms from simulation.

3. Design Verification

For verification of the design, it was based on the requirements for our modules which can be seen in Appendix A of this report. With the defined modules we tested each module to verify that they were meeting our requirements by taking measurements and having a set procedure.

3.1 Clamp Circuit Verification

The clamp circuit was verified to have a V_c or breakdown voltage greater than 30V and resetting the core with the waveforms of figures 11 and 13. The figures show the voltage and current going back to zero with minimal ringing during switching which indicates a successful switch with less power dissipated. The 1W Zener with breakdown voltage of 36V produced an unwanted transient during reversed voltage as seen in figure 13 and so we tried a 5W Zener with breakdown of 100V and got figure 11, which got rid of the transient but lost most of the square wave. We concluded that we needed a Zener that was between 1W-5W and had a breakdown voltage closer to the voltage waveform.

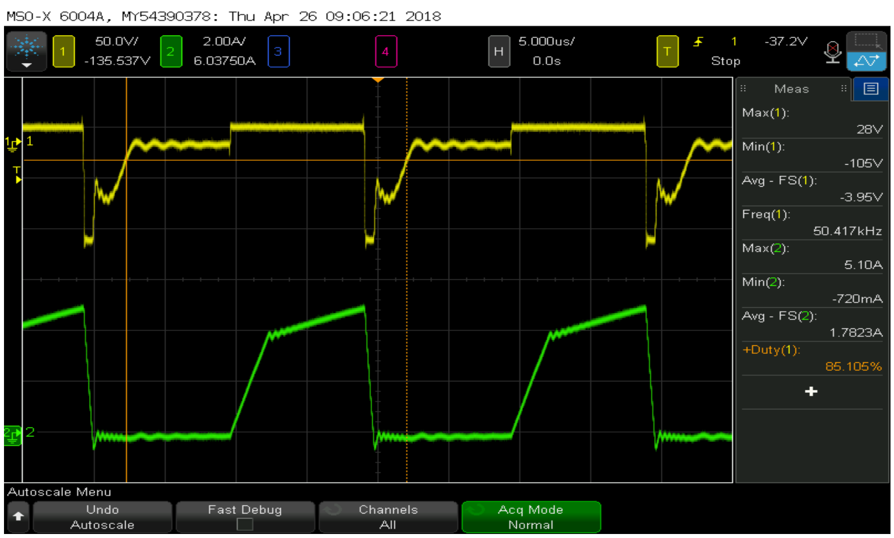

Figure 11. Primary side coil voltage and current with 5W Zener.

3.2 PWM Generator Verification

Three PWM generators have been tested before going forward with the ICStation Digital PWM square wave generator. Two other PWM generators that were tested failed to output constant and clean signal also, they couldn't generate a signal with less than 50% duty cycle. During testing, PWM generator was powered using USB power. Output of the PWM generator has been recorded in Figure 12. The output is actually ~4V which is lower than planned voltage which was 5V. However, this does not cause a problem for the system since the output is amplified by the gate driver before being fed into gate of the power MOSFET.

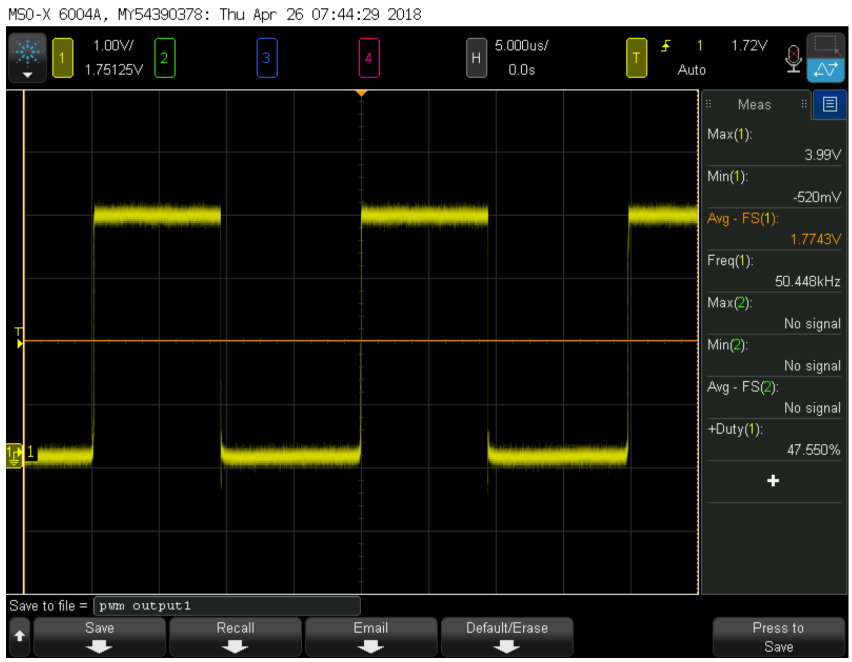

Figure 12. Pulse Width Modulation IC output.

3.3 MOSFET Circuit Verification

MOSFET verification can be done by analyzing the transformer primary side waveforms. Figure 13 clearly shows that the voltage in primary side of the transformer is able to change levels and successfully returning back to 0V therefore verifying that signal received in gate is able to control the power going in the transformer.

3.4 Transformer Verification

The transformer is one of the few components in the project that can be tested separately. The key thing to look for is whether the voltage level doubles from primary to secondary side. An equally important, requirement is that the transformer maintains the operating frequency of the input wave. In this case, we are shooting for 50 kHz.

The main test that can be applied to the transformer is the basic voltage shift test using a low-power function generator. Setting the function generator to a low voltage value provides a basic picture for the transformer's functionality. The function generator also allows for varying frequencies, so the operating frequency can be simulated.

For the most part, the transformer passed most of the preliminary requirements, as shown in table 4 in appendix A.

In the context of the entire project, the transformer should operate similarly to the function generator test, except at a higher power.

The results are described in figures 13 and 14.

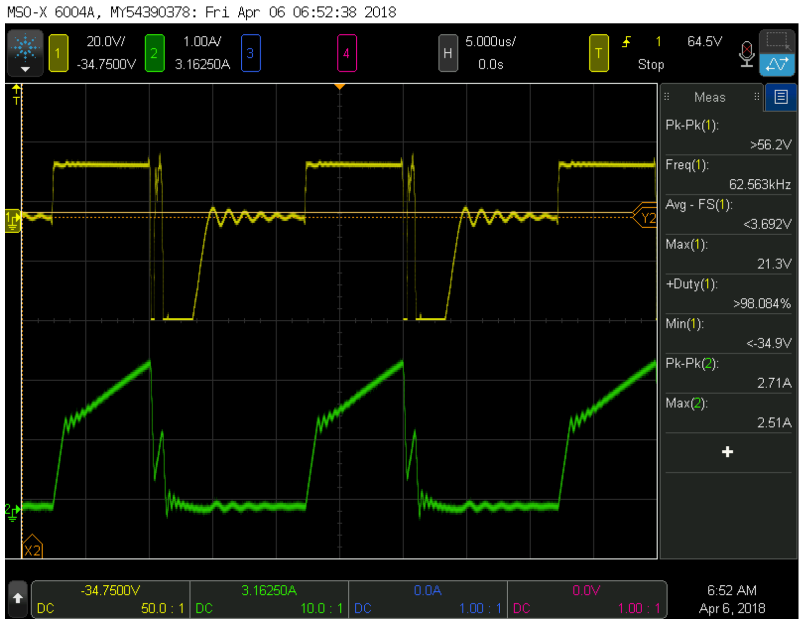

Figure 13. Actual Primary Side Transformer Voltage and Current with 1W Zener

In figure 13, the yellow waveform is the voltage, while the green waveform is the current. The maximum voltage is very close to 18V, which makes sense, considering that is the voltage we are inputting into the circuit. The general voltage shape is approximately the same, note the strange behavior before minimum of the wave. There aren't that many things to go wrong in the transformer, as the cores were purchased and none of the coils were damaged during winding. A suboptimal winding would simply result in less voltage and current, so the most likely possibility is that there is a design flaw somewhere else in the circuit.

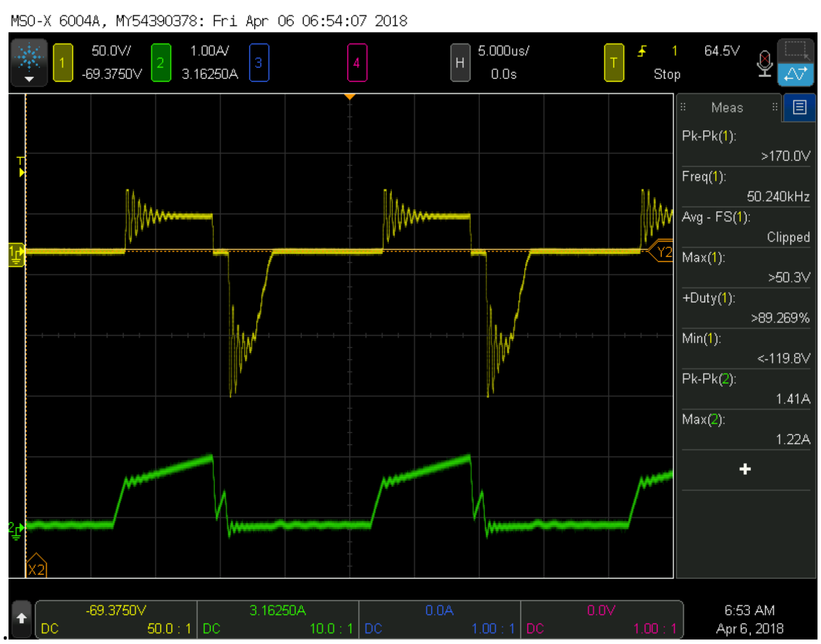

Figure 14. Actual Secondary Side Transformer Voltage and Current with 1W Zener

Figure 14 has the same color coding as figure 13. The wave has a similar shape, which is good. However, there is a lot of ringing at most of the discontinuities. This is likely due to the strange transience in figure 13, as well as the high frequency of the switching exacerbating the error. Upon closer observation, the maximum voltage of the waveform is about 36V, which meets the requirement that the secondary side voltage is twice of the primary side voltage.

3.5 Rectifier Circuit Verification

The rectifier circuit needed to output a clean output voltage and current waveform as well as handle the stresses associated with the boost transformer. As seen in figure 15 the output meets the ripple of 2 percent except for the parts where the circuit switches. This ripple is still in an acceptable range, but it was not so before. We added a 470pF capacitor to the MOSFET gate driver Vs to GND pins to reduce the ringing and in doing so reduced the ripple to acceptable levels. Next, as seen from figure 15 the voltage and current waveforms of the secondary side of the transformer are under the diode stress limits of 100V and 4A and so the system could safely operate in the required conditions.

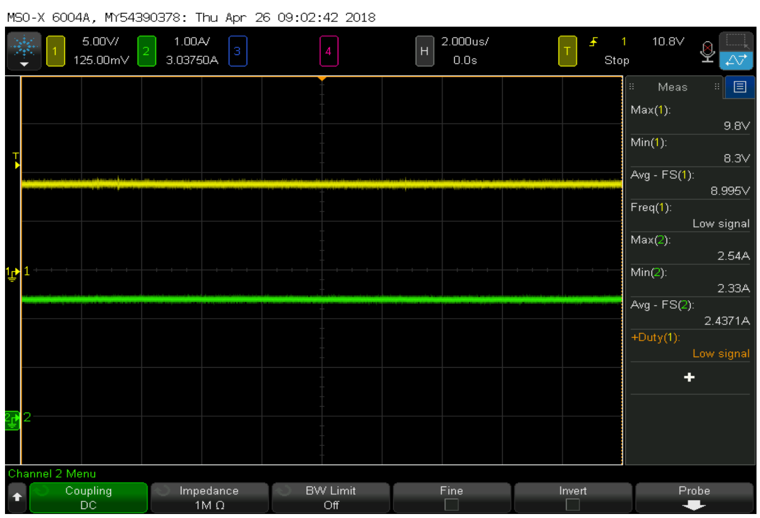

Figure 15. Load output Current and Voltage.

4. Costs

4.1 Parts

Table 2: Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Power Mosfet	Infineon	10.23	10.23	10.23
Gate Driver	Microchip Technology / Micrel	2.27	2.27	2.27
Zener Diode	Micro Commercial Co	0.68	0.68	0.68
Schottky Power Diode	SMC Diode Solutions	0.55	1.10	1.10
2x Ferrite E-core	EPCOS (TDK)	5.92	11.84	11.84
Bobbin	EPCOS (TDK)	4.44	8.88	8.88
PWM Square Wave Pulse Signal Generator	Icstation	6.99	6.99	6.99
14 AWG Magnet Wire	Remington Industries	8.51	8.51	8.51
1000 μF 63 VDC Input Capacitor	Nichicon	5.40	5.40	5.40
1000 μF 25 VDC Output Capacitor	Nichicon	1.57	1.57	1.57
Total				$57.47

4.2 Labor

Table 3: Labor Costs [5]

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

4.3 Schedule

Week	Task	Delegation
2/19	Finish Design Document	All
	Debug detection circuit Look into resonant charging C_s and C_p Calculations	All Onur Enrique and Jason
2/26	Prepare for Design Review	All
	Start PCBs using Eagle(dc\dc with feedback, ac\dc with Rx coils)	Jason
	Purchase components for breadboard implementation	Onur
3/5	Continue with PCBs	Jason
	Start breadboarding modules with test points(Coil circuit with ac\dc converter)	Enrique
	Do soldering assignment	All
3/12	1st round of PCB orders	All
	Continue breadboard and debug(dc\dc converter)	Enrique
3/19	Spring Break(Research new design for project) Transformer Calculations Clamp Calculations PWM MOSFET and Driver Rectifier and LC Filter Power Resistor	All Jason and Enrique Enrique Onur All Enrique

	Order new parts	Onur Onur
3/26	Debug breadboard(PWM) Order new PWMs New Transformer	All Onur Jason and Enrique
	Final Group PCB orders if needed	All

4/2	Continue with circuit and debug (PWM and Zener) Order new Zener Diode Redo clamp calculations	All Onur Enrique
4/9	Not enough time for PCB, switch to perf board implementation. Order perf boards Solder Primary side Solder Secondary Side Check for shorts on board	All Jason Enrique Jason All
4/16	Prepare for mock demo and final demonstration Capture final waveforms	All All
4/23	Prepare for presentation	All
4/30	Work on final paper	All
	Check out lab	All
	Finalize lab notebook	All

5. Conclusion

5.1 Accomplishments

We were able to successfully transfer most power across the transformer, which may have uses in charging electrical batteries and powering systems. With an overall efficiency of 71.6 percent from input to output, we accomplished a high efficiency. Our modules integrated well with each other and we managed to get 24.89W at the output. Our best accomplishment was being able to wirelessly transfer a considerable amount of power. Although our project lacks a PCB, we were able to integrate the systems on a perf board. The physical implementation can be seen in figure 16:

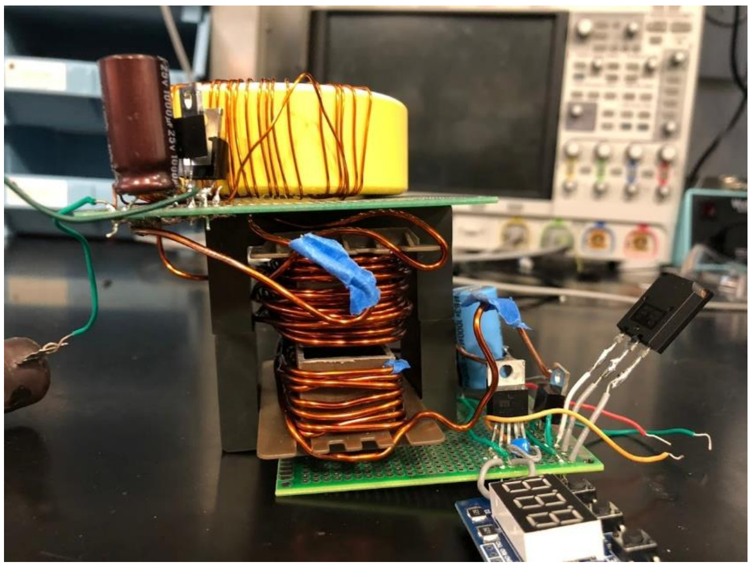

Figure 16. Both sides connected for wireless power transfer.

5.2 Uncertainties

As discussed throughout the report that although power transfer succeeded, we found that the output power was lower than expected. We are unsure if we can push this design further, as we have not run experiments with higher output voltage or a higher duty cycle. Large changes in the transformer windings and/or higher rated component replacement may be needed to increase the power.

As discussed quantitatively earlier in the design and verification sections the clamp circuit had some uncertainty in the Zener diode. During testing, it burned out several times due to the input power and possible spikes.

5.3 Ethical considerations

Our project is affected by tenets 1, 3, and 9 of the IEEE code of ethics [3].

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.

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.

In the "High Voltage Safety Manual" [2] 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 can be harmful.

At the time of the demo, we were unable to build a casing for the project. As such, many parts of the project have exposed, uninsulated wire. As such, the project is dangerous to touch when in operation, and is not suitable for consumer use.

5.4 Future work

Further developments of this project include further testing and simulation of higher input voltages to generate more power. Tighter windings and larger transformer cores will also be a consideration. Also purchasing more Zener diodes within the range of 1W-5W to fix our inverted square wave in the primary clamp circuit would further help with our efficiency. After achieving our power goals, efforts can be made to make the project safer, such as an insulating case, more covering of bare wire, and a PCB.

References

[1] *Ferrites and Accessories E 65/32/27* [PDF]. (2018, April). EPCOS AG.

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

[3] "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

[4] Learn More about Ferrite Cores. *Magnetics - Learn More about Ferrite Cores* Available at: https://www.mag-inc.com/Products/Ferrite-Cores/Learn-More-about-Ferrite-Cores. (Accessed: 2nd May 2018)

[5] 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)

[6] Ullah, A. Calculations for Design Parameters of Transformer. *Engineer Experiences* (2017). Available at: http://engineerexperiences.com/design-calculations.html. (Accessed: 30th April 2018)

[7] Wire Gauge and Current Limits Including Skin Depth and Strength. *American Wire Gauge Chart and AWG Electrical Current Load Limits table with skin depth frequencies and wire breaking strength* (2017). Available at: https://www.powerstream.com/Wire_Size.htm. (Accessed: 30th April 2018)

Appendix A: Requirement and Verification Table

Table 4: System Requirements and Verifications

Requirement	Verification	Verification status
Rectification Output a. 12V +- 0.5V b. 3.33A +-0.14A c. Diodes handle stresses from transformer d. Operate for 10 seconds	a, b, c, d 1. Connect power to primary side. 2. Connect 3.6Ω power resistor to output terminals 3. Connect measurement terminals of oscilloscope to power resistor 4. Connect ammeter to wire going into resistor 5. See if voltage and current waveforms maintain shape for 10 seconds 6. Connect voltage and current probes to secondary side transformer	a. 9.8V b. 2.54A c. Secondary side coil IV waveform was below 100V and 4A d. Passed (operated for 10 seconds)
PWM Output a. A square wave b. 5V Pk-Pk c. Duty Ratio = 49%	a, b, c 1. Connect an oscilloscope to the terminals of the PWM 2. Check shape of the wave 3. Set measurements on the oscilloscope (average) 4. Read off voltage and duty ratio values	a. Passed (wave is a square) b. 3.99V Pk-Pk (likely due to parasitics) c. 49% duty ratio
Transformer a. Output voltage is twice of input voltage (from turns equation) b. Maintains 50 +- 1 kHz from input to output	a, b 1. Attach oscilloscope probes to input and output terminals 2. Connect function generator to input terminals 3. Set function generator to 5V, 50 kHz and turn on waveform 4. Observe the waveforms on the oscilloscope	a. V_{in} pk-pk = 5V, V_{out} pk-pk = 10V, V_{out}/V_{in} = 2 (Passed) b. f = 49.89 kHz
MOSFET a. Has a voltage level equal to input voltage b. Has a voltage level equal to 0V c. MOSFET specifications can handle stress of circuit ($V_{c,min}$ = 30V)	a, b 1. Attach oscilloscope probes to D and S terminals of the MOSFET 2. Observe waveforms, check for a 18V and 0V level c 1. Check datasheet for values	a. Passed b. Passed c. V_{min} = -94V (Passed)
Clamp Circuit a. Resets core with minimal ringing during switch b. Has a Vc > 30V	a, b 1. Connect an oscilloscope to the terminals of the clamp circuit to read voltage Vc. 2. Connect voltage and current probes to the primary side transformer to see the reset.	a. Voltage and Current waveforms reset to zero with little ringing. b. Vc was found to be 40V