

ECE 445 Design Document - Spring 2024

Wireless Drone Charging Station

Project # 29

Pranshu Teckchandani, Samuel Fakunle, Jason Wuerffel

Professor: Jonathon Schuh

TA: Matthew Qi

Contents

1.	Introduction
1.1.	Problem
1.2.	Solution
1.3.	Visual Aid
1.4.	High Level Requirements
2.	Design
2.1.	Block Diagram
2.2.	Physical Design
2.3.	Requirements and Verifications
2.4.	Subsystem 1: Inverter
2.5.	Subsystem 2: Resonant Coils
2.6.	Subsystem 3: Full Bridge Rectifier
2.7.	Subsystem 4: DC-DC converter and Battery Charging.
2.8.	Subsystem 5: Micro Controller Unit
2.9.	Tolerance Analysis
3.	Cost and Schedule
3.1.	Cost Analysis
3.2.	Schedule
4.	Ethics and Safety
5.	Citations

1. Introduction

1.1. Problem

Drone technology is becoming more vital for our modern society because it improves productivity and precision for several applications. Despite this, the operation time continues to be a key technological challenge because of the drone's battery life limitations. As a result, our project aims to address this issue by implementing an automated drone charging system that extends the drone's flight time without human intervention.

1.2. Solution

Our group aims to use resonant inductive coupling to develop a wireless drone charging station that allows the drone to land and charge its battery within an acceptable distance from the transmitter. The combination of the coils on the drone and on the charging pad will essentially act as an air gap transformer. Circuitry leading up to the coil on the charging pad side will consist of a power source, half bridge synchronous rectifier, and resonant tank. Circuitry after the transformer on the drone side will include an AC-DC converter followed by a synchronous buck converter and ending with a BMS. An MCU will be used to provide PWM to the MOSFETs used throughout the project. In addition, our system should start power transfer only when the drone lands in close proximity to the coil on the pad. We may also add an optional feature where the drone can track back to the pad when low on battery but it is an additional feature we will implement only if time permits.

1.3. Visual Aid



Figure 1: Visual Aid

1.4. High Level Requirements

1. The system is able to supply $3.7V \pm 3\%$ V DC to 1S LiPO battery, when supplied with 24V DC power from the power supply.
2. The charging pad is able to charge the drone successfully without human interference with an efficiency of at least 50% only after the coils are within the set proximity of 5 cm.
3. The system will operate at the resonant frequency of 120kHz. The system should operate within the 3dB range.

2. Design

2.1. Block Diagram

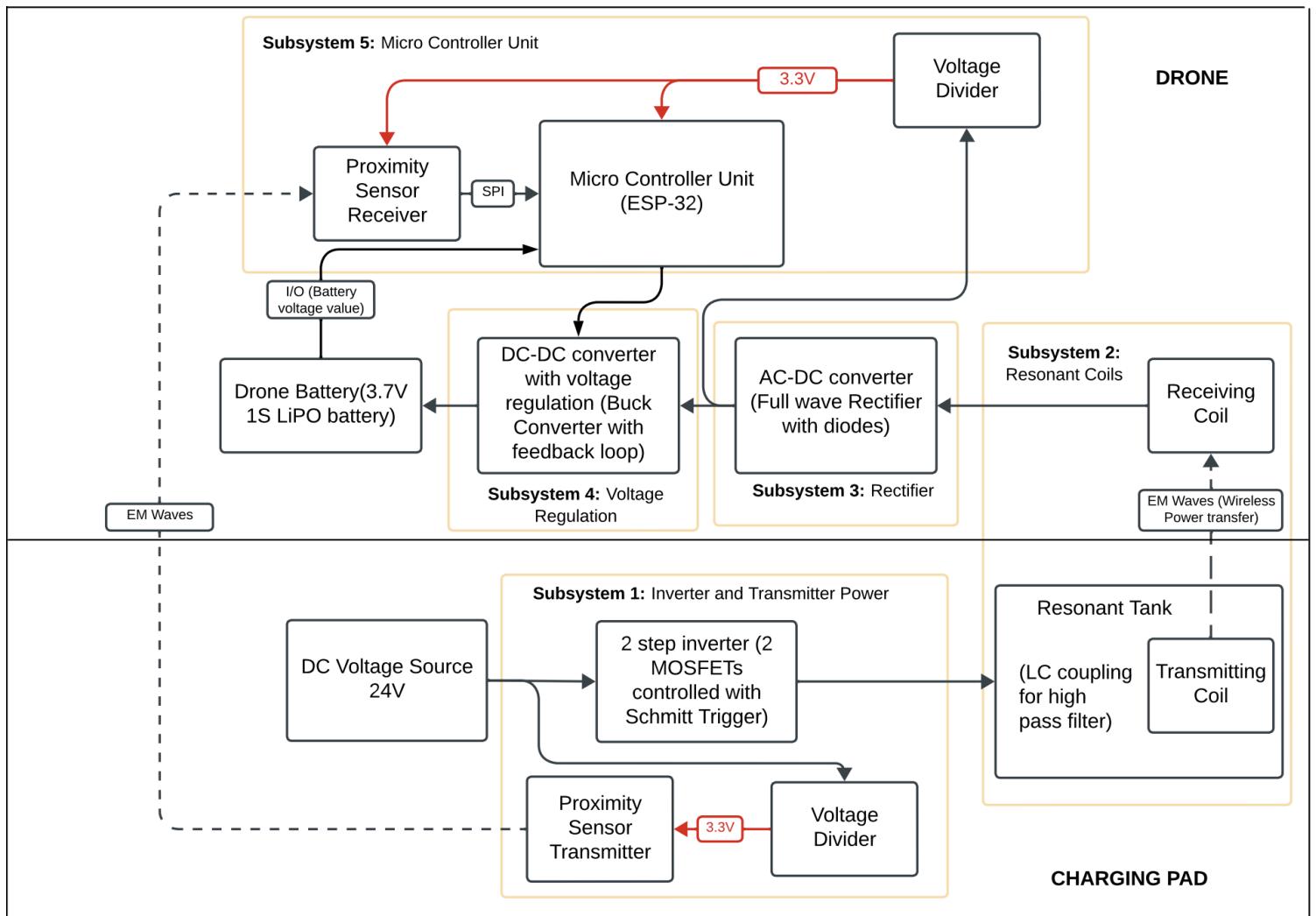


Figure 2: Block Diagram

2.2. Physical Design

The Wireless Charging pad will be a box of the following dimensions - 25cmx20cmx10cm.

There will be a transmitter coil of outer diameter 20cm, 4cm from the upper surface of the box.

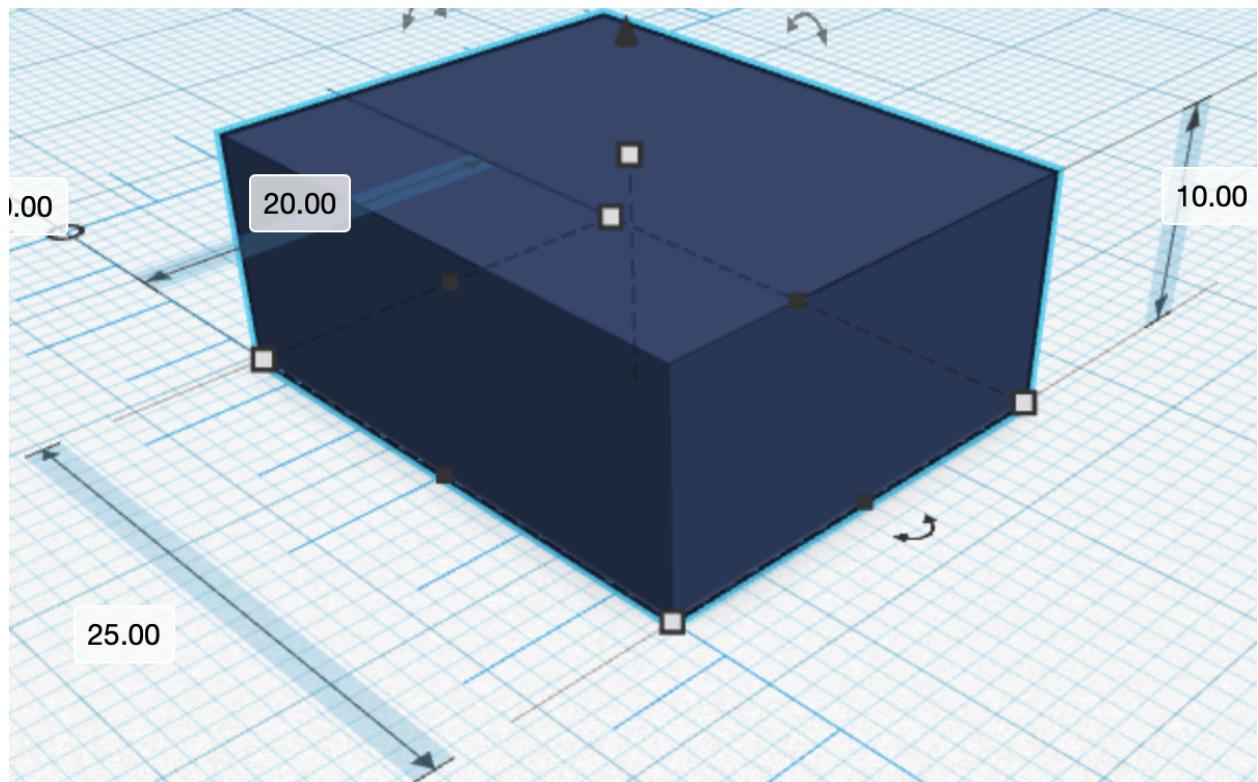


Figure 3: Box

The receiver coil will have an outer diameter of 10cm.

The next sections explain the subsystems mentioned in the block diagram. The requirements and verifications for all the subsystems are mentioned after the explanation of the subsystems.

2.3. Subsystem 1: Two Step Inverter and Transmitter power

This subsystem consists of a 24V DC power supply and a half bridge inverter circuit. We also provide power to the transmitter of the proximity sensor as a part of this subsystem.

Inverter Circuit:

Our inverter circuit consists of two MOSFETs as seen in the figure. The circuit takes input from a 24V DC Power Supply and it outputs a square wave. This is a 2 step inverter meaning the output will only have two voltage values 0V and 24V. The inverter circuit will be based on the following topology.

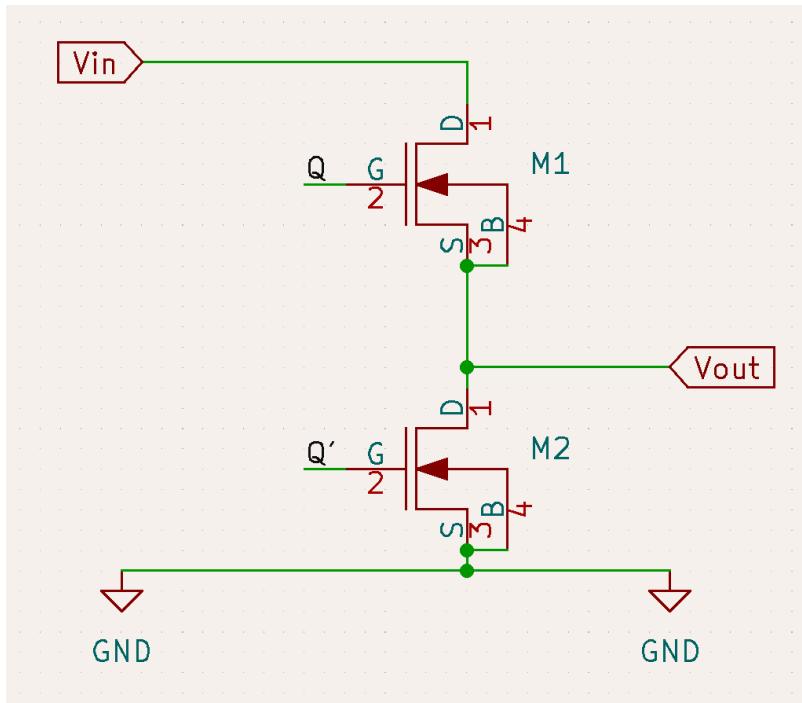


Figure 4: Half bridge inverter

The MOSFETs will be controlled by complementary PWM signals which will be generated by a Schmitt trigger. The figure below shows a schematic based on which we will be generating Q and Q' for the MOSFETs.

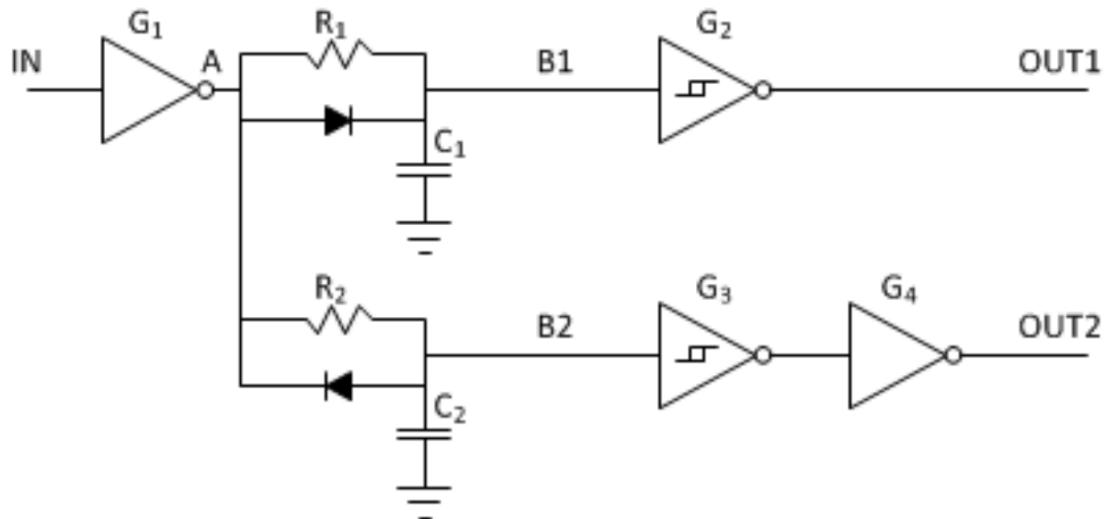


Figure 5: Schmidt Trigger Schematic

The output of this subsystem is going to be a square wave with voltages 24V and 0V.

Power for the transmitter Circuit:

This will be a basic circuit which will involve a Voltage divider topology to provide the Transmitter with 3.3V power. We will be using resistances of different values to get the desired output.

Requirements	Verification
The output of the circuit is a square wave with voltages 0V and 24V	Input 24V DC and use an oscilloscope to check the waveform of the output
The power supplied to the proximity sensor transmitter should be 3.3V	Input 24V Dc and check the output of the voltage divider with the help of an oscilloscope

2.4. Subsystem 2: Resonant Coils

This system consists of the LC Resonant tank and the transmitting and the receiving coils. The LC coupling will be used as a high pass filter for the incoming square wave. The Inductance over here will be the inductance of the transmitting coil. We will be designing the circuit to output only AC with 120kHz. The schematic for this subsystem will be similar to the following figure:

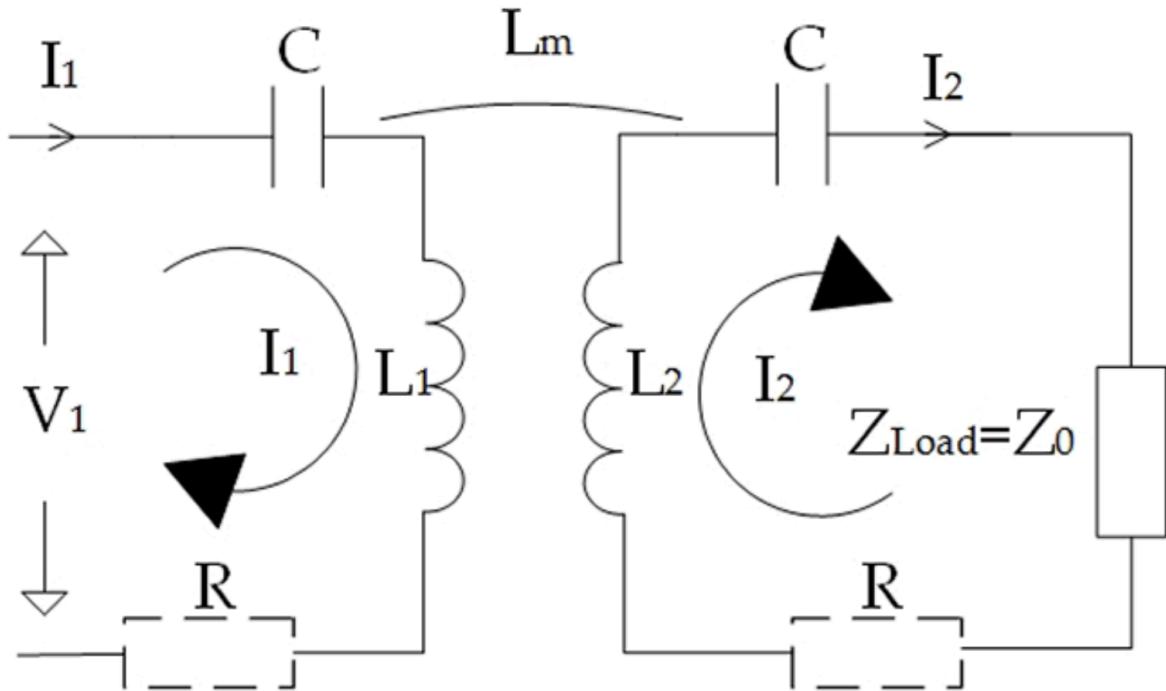


Figure 6: Coil Network with LC Resonant Tank

The left side will be the transmitting side. The input to the transmitting side will be the square wave. L1 represents the inductance of the transmitting coil. The capacitor will be chosen in such a way that the resonant frequency of the circuit is equal to 120kHz. For our design, we won't be including the capacitor on the receiving side(right side). The resistances indicate the resistances of the wires and L2 indicates the inductance of the receiving coil. Lm is the mutual inductance.

The main thing in this subsystem is to keep the quality factor of the LC circuit high to ensure that the waveform for wireless power transmission is of high frequency.

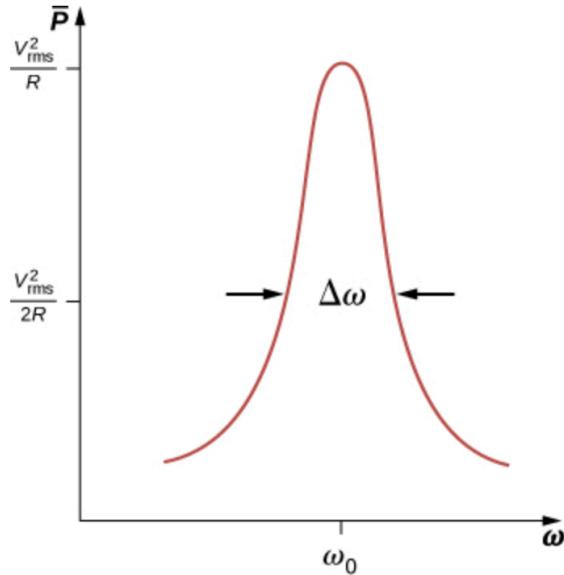


Figure 7: Bode Plot

To ensure high efficiency the peak of this plot should be as narrow as possible. The quality factor is a function of L,C, and R and all of them will have to be tuned appropriately to get a high quality factor.

Another factor to consider here is the coupling coefficient of the coils. The coupling coefficient depends on the individual inductances of the coils and the mutual inductance.

Requirements	Verification
The efficiency of the wireless power transmission should be more than 50%	Given an input AC, the input power on the transmission side and output power on the receiving side will be measured with the help of watt meters. The output power should be greater than 50% of the input power.
The LC circuit on the transmission side should be operating within the 3dB of the resonance frequency i.e. 120kHz.	We will check this by testing the transmission side circuit separately. We will input an AC voltage and check the current. Under resonant conditions, the circuit should be purely resistive.
The distance between the coils should be less than 5cm	Checked physically with the help of a tape measure/ruler.

2.5. Subsystem 3: Full Bridge Rectifier

This subsystem includes a full bridge rectifier with a filter, which is responsible for converting 12V AC to 10V DC. The filter would include a capacitor tank to allow for more flexibility. The rectifier would utilize four 1N4007-T diodes, hence communication with ESP32 microcontroller is not required.

The figure below shows a typical full bridge rectifier circuit [9]:

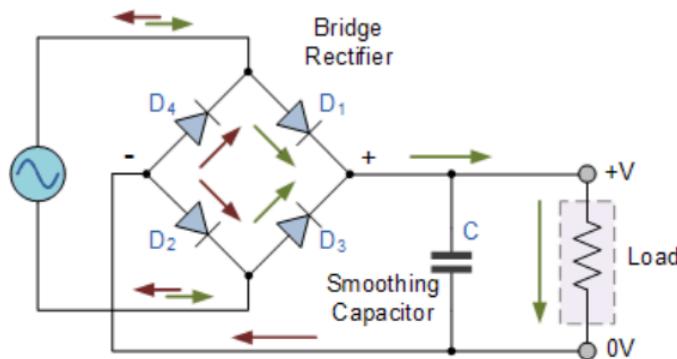


Figure 8: Full Bridge Rectifier

Requirements	Verification
The full bridge rectifier must be able to convert $12V \pm 5\%$ AC voltage from the WPF system to $10 \pm 3\%$ V DC.	We will use the variac, wattmeter, and oscilloscope in the lab to confirm this AC-DC conversion.

2.6. Subsystem 4: Synchronous Buck Converter with Voltage Regulation

This subsystem includes a synchronous buck converter responsible for converting $10 \pm 3\%$ V DC to $5 \pm 3\%$ V DC for the drone's battery. The buck converter would use two MOSFET switches, which require complementary PWM signals; hence, communication between converter and ESP32 microcontroller is required. This unit would also include a TPS54561 (TI) buck converter chip responsible for converting $5 \pm 3\%$ V DC to regulated $3.7 \pm 3\%$ V DC. We will rely on the feedback control loop capabilities of the chip to perform output voltage dynamic regulation. It is vital to ensure effective and safe charging of the drone's battery in all scenarios, thus ensuring system stability. This would be achieved by controlling the duty ratio of the converter chip.

The figure below shows a typical schematic for a synchronous buck converter [11]:

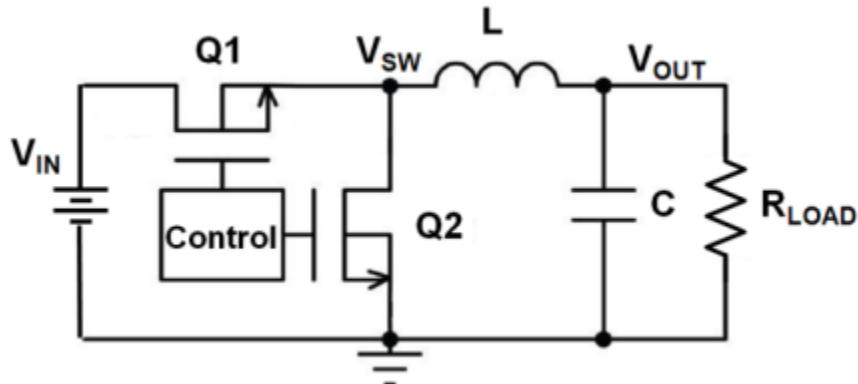


Figure 9: Synchronous Buck Converter

Requirement	Verification
The synchronous buck converter should be able to convert $10 \pm 3\%$ V DC to regulated $5 \pm 3\%$ V DC.	This DC-DC conversion would be confirmed using a testbench DC power supply and oscilloscope.
ESP32 microcontroller successfully sends complementary PWM signals to the MOSFET switches	This would be verified by observing the MOSFET switch voltages on the oscilloscope.

The synchronous buck converter operates at 100kHz switching frequency.	This would be confirmed using an oscilloscope.
Output power must be between 15-25 W.	This would be confirmed using the wattmeter.
Successful dynamic regulation of output voltage.	We will use the testbench DC power supply to send low input voltages into the converter to verify that the chip is able to control the duty ratio in order to maintain output voltage. Additionally, we will also test to see if the chip changes the duty ratio to prevent overcharging of the drone's battery.

2.7. Subsystem 5: Micro Controller Unit

This subsystem would include the ESP32 microcontroller responsible for sending PWM signals to all MOSFET switches, successful communication with the proximity sensor, and communication with the TI buck converter chip and battery sensor for voltage regulation. If time permits, this unit would also be responsible for communicating with LED displays to visually convey the charging status of the drone's battery.

Requirement	Verification
Successful communication between proximity sensor, battery sensor, and ESP32 microcontroller over bluetooth or Wifi.	Confirmation that other subsystems work. Also, serial printing onto the monitor would also be used to validate this subsystem.
Successful communication with TI buck converter chip	Validated via serial printing onto the monitor.

2.8. Tolerance Analysis:

The frequency of the LC circuit should be within 3db of the resonant frequency i.e. 120kHz.

The capacitors we are using have a tolerance of $\pm 20\%$ and the inductance of the transmitting coil will also have a general tolerance of $\pm 20\%$.

Thus the frequency of the LC circuit would be between 100kHz and 150kHz.

This can be explained as follows :

The formula for the resonant frequency is:

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

If we take the worst case values of L and C, i.e. $1.2*L$ and $1.2*C$, we will get a new frequency of 100kHz. If we take the values of L and C on the other spectrum, we get a frequency of 150kHz.

Now, let's calculate our 3dB frequency range. It is the frequency when the power output of the system is half of the maximum power output of the system.

The lower cutoff frequency is given by the formula -

$$\omega_L = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

Whereas the upper cutoff frequency is given by the formula-

$$\omega_H = +\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

The wire we are using for the circuits has a resistance value of 1.029 ohms per foot. We will be using at maximum 2 feet of wire and the recommended tolerance for this thickness of wire is $\pm 5\%$. The 3dB bandwidth of the circuit is given by

$$BW = \frac{f_r}{Q}, \quad f_H - f_L, \quad \frac{R}{L} \text{ (rads)} \quad \text{or} \quad \frac{R}{2\pi L} \text{ (Hz)}$$

For our case, the worst case bandwidth is 50kHz. Based on the inductor we will be using, this bandwidth range is easily achievable and we will be able to operate our circuit properly with the real components.

3. Cost and Schedule

3.1. Cost Analysis

Our total cost comes out at \$36626.48. This takes into account our parts and labor. The following table shows how we came to that number, with a quick explanation of labor costs below.

3.1.1. Parts List

Part (Part Number)	Manufacturer	Link	Quantity	Cost
MOSFET (IRLB3813PBF)	Infineon	https://www.digikey.com/en/products/detail/infinion-technologies/IRLB3813PBF/2118485?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_Medium%20ROAS%20Categories&utm_term=&utm_content=&utm_id=g_o_cmp-20223376311_adg_-ad-dev-c_ext-prd-2118485_sig-CjwKCAiA_tuuBhAUEiwAvxkgTuPPsYb3EiOdGlqC0JndHG3iqG8MVmrPIQXvKobnw0dR_OFwyqUI8RoCjIQQAvDBwE	8 (4 spare)	\$1.80 each
Capacitor (UPW1E471MPD)	ALLECIN	https://www.digikey.com/en/products/detail/nichicon/UPW1E471MPD/589567?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_Medium%20ROAS%20Categories&utm_term=&utm_content=&utm_id=g_o_cmp-20223376311_adg_-ad-dev-c_ext-prd-21589567_sig-UPW1E471MPD_tuuBhAUEiwAvxkgTuPPsYb3EiOdGlqC0JndHG3iqG8MVmrPIQXvKobnw0dR_OFwyqUI8RoCjIQQAvDBwE	3 (2 spare)	\$0.59 each

		tm_term=&utm_content=&utm_id=go_cmp-20223376311_adg-ad-dev-c_ext_prd-589567_sig-CiwKCAiA_tuuBhAUEiwAvxkgTusE3IxOuFCNMHoKxn-HJtYePX-fcTdnDAo_INIRi_Yj8WG2JzjRoCp-0QAvD_BwE		
Capacitor Testing Pack	ALLECIN	https://www.amazon.com/ALLEGICIN-Electrolytic-Capacitor-Assortment-Kit/dp/B0C1VBXCQM/ref=sr_1_2?crid=1ZD60WAVAN1T&dib=eyJ2ljojMSJ9.ekYH7ix2EeGYfnpDMkTUbA5_8nAZM5NXRF7ISTCDYReMmOwAcz_WBG12o_zM15V-_J9McCOVTTq2N06Og5WI8Z2AxIOTclVbBy8COvpj-l6t7YHM59rz_91u-DqlIdHTYGz7OrDV1PRImfH8Jb8Rm04s_LL0hnPKfc7SygutB65qRv-I5P2MvsyD1GGPD2TvTML9zF1KEFGkOPaN6fYa-8GtmXIRgRLLuc09pfkZal.zDdxTqqS89p-u2ovmHT_KQj12EITkMu7Mtvt3N7day8&dib_tag=se&keywords=capacitor+pack&qid=1708663393&sprefix=capacitor+pack%2Caps%2C128&sr=8-2-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1	1	\$9.99
Inductor (SMV40)	ROXBURGH EMC	https://www.newark.com/roxburgh-emc/smvy40/choke-0-2mh-4a/dp/01M8908	1	\$6.18

Wire (40 AWG)	Remington Industries	https://www.remingtonindustries.com/magnet-wire/magnet-wire-40-a-wg-enameled-copper-6-spool-sizes/	2 oz spool	\$10.14
Diodes (1N4007-T)	Diodes Incorporated	https://www.digikey.com/en/products/detail/diodes-incorporated/1N4007-T/607	8 (4 spare)	\$0.20 each
ESP32 (ESP32-DEVKITC-VIE)	Espressif Systems	https://www.digikey.com/en/products/detail/espressif-systems/ESP32-DEVKITC-VIE/12091811?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PM%20Shopping_Product_Low%20ROAS%20Categories&utm_term=&utm_content=&utm_id=go_campaign-20243063506_adgroup-dev-c_ext_prd-12091811_sig-CjwKCAiA8NKtBhBtEiwAq5aX2Nvf7wYIrlJvAtHab7cw0ecCOE7rdqjRA_ly8-0jjQLICNVKipQhMVRoCsIsQAvD_BwE&gad_source=1&gclid=CjwKCAiA8NKtBhBtEiwAq5aX2Nvf7wYIrlJvAtHab7cw0ecCOE7rdqjRA_ly8-0jjQLICNVKipQhMVRoCsIsQAvD_BwE	1	\$11.00
Proximity sensor	Vishay Semiconductors	https://www.mouser.com/ProductDetail/Vishay-Semiconductors/VCNL3040?qs=bZr6mbWTK5m90GodUNdcvA%3D%3D&mgh=1&gad_source=1&gclid=CjwKCAiA_tuuBhAUEiwAvxkgTi9JXUrQu7ki2TgvuT9pqO44-9wRnVw8RYTinS2h7-P4M8UITnP	2	\$2.07 each

		RdBoCqroQAvD_BwE		
Mini RC Drone with 3 batteries	Holy Stone	https://www.amazon.com/dp/B07P62LD88?ref_=cm_sw_r_cp_ud_dp_MNEMAZHTJRABW6K4VOAE&th=1	1	\$36.99
QFP socket adaptor header	Chip Quik Inc.	https://www.digikey.com/en/products/detail/chip-quik-inc./PA0214SOCKET/5978283?utm_adgroup=&utm_source=google&utm_medium=cpc&utm_campaign=PMax%20Shopping_Product_High%20ROAS%20Categories&utm_term=&utm_content=&gad_source=1&gclid=CjwKCAiA_tuuBhAUEiwAvxkgTgy7GQUpD-oNEIWdn2DjADGn6hNCHCbLLX5RvgxOiriGD88n6HQAh0CCXYQAvD_BwE	1	\$17.89
TI buck converter chip (TPS54561)	Texas Instruments	https://www.ti.com/product/TPS54561	2 (1 spare)	\$2.23 each
Resistor pack	BOJACK	https://www.amazon.com/BOJACK-Values-Resistor-Resistors-Assortment/dp/B08FD1XVL6/ref=sr_1_3?crid=3DTANJU85K9Q4&dib=eyJ2ljoimSJ9.8EDLQctdt9NzqYQqREI7yu hvnrjfmWCxOOmofr1JE BcE4uFPCAWQ94iDJn-8Os92BYRdEtFGWkZH Lxkfc4QiCC6aqvXS1KoM 0mWj8A9xPrNyexsUJxte hgfzW7vAqYh-yZdu5fJM J0TzTlzqhpuezo1mrUOA8xkhauSlzqChs9qqNp1 JzlGhMPS77P4rxN9lzKS 3EbdKLt5EULgemPUMu	1	\$9.99

		S2liOX0mPQFVzkuwmp M.rfwBK7RqqQ34i7_qn OXcLJuvSpte4R0la6-LpT 1Nang&dib_tag=se&keyw%2Bpack&q_id=1708664185&sprefix=resolver%2Bpack%2Caps%2C122&sr=8-3&th=1		
Machine Shop	University of Illinois at Urbana-Champaign	Box for the charging pad and the stand for testing.	10 hours	\$500
Labor		3 people(team members)	360 hours in total	\$36000
Total				\$36626.48

3.1.2. Labor Cost Analysis

With the assumption that each group member will do about 12 hours of work per week on average, the total amount will come out to $12 * 10 \text{ weeks} * 3 = 360$ hours to complete the project. Assuming an average UIUC graduate salary of \$40 per hour, the total labor cost can be calculated at $\$40 * 2.5 * 360 = \36000 .

The machine shop has given us the quote of 10 hours to complete the mechanical part of the project. If we assume a cost of \$50 per hour for machine shop work, the total machine shop cost can be calculated at $\$50 * 10 = \500 .

3.2. Schedule

The tasks for each group member during the week will be discussed in the weekly check-in meeting based on availability during the week and skill in that area. We will all be working together on different parts of the project but each person will be taking the lead on certain tasks. We have mentioned the person against the task.

Week Number	Dates	Main Person Working on the task	Tasks
6	February 19 - February 25	Jason	<ul style="list-style-type: none"> - Finalize proposal resubmission and design document - Research parts needed for power electronics - Get time estimate from machine shop
7	February 26 - March 3	Pranshu	<ul style="list-style-type: none"> - Design review with Professor Schuh - Make adjustments to project based on feedback - Design PCB and finalize parts order
8	March 4 - March 10	Samuel	<ul style="list-style-type: none"> - First round PCBway Orders - Teamwork Evaluation I - Begin using breadboard to test design if parts have come in
9	March 11 - March 17	Pranshu	<ul style="list-style-type: none"> - Spring Break - Catch up on anything from above that has not been completed
10	March 18 - March 24	Samuel	<ul style="list-style-type: none"> - Second Round PCBway Orders - Test all parts including board if in by this time - Begin coding ESP32
11	March 25 - March 31	Pranshu	<ul style="list-style-type: none"> - Individual Progress Report - Begin soldering parts into PCB if everything works as expected on breadboard
12	April 1 - April 7	Jason	<ul style="list-style-type: none"> - Finish soldering PCB - Test completed PCB and debug as necessary
13	April 8 - April 14	All	<ul style="list-style-type: none"> - Attach boards to drone and pad - Test our design
14	April 15 - April 21	All	<ul style="list-style-type: none"> - Mock demo with Matthew

			- Continue debugging as necessary
15	April 22 - April 28	All	- Final Demo - Mock Presentation
16	April 29 - May 2	All	- Final Presentation - Final Papers

4. Ethics and safety

Most ethical concerns to do with this project are more so about the drones and their enhanced capabilities when used with our wireless charger than the actual wireless charger itself. The biggest ethical concern to do with drones is privacy because they have the capability to record people without their knowledge or permission. Another ethical concern is the potential weaponization of drones. Drones are already used in combat, and cutting out the need for them to get plugged in in order to charge could make them more useful in this area. Our project is not intended to be used in either of these ways. It is, however, intended to be used for research purposes. This would create environmental ethical concerns such as noise and congestion issues. We would hope that the drones would be used in moderation to limit these concerns. The last potential ethical issue would be the loss of jobs as this technology would take over the need for people to charge the drone. We do not really foresee this becoming an issue.

There are a few safety issues to consider with both the drone and charger components of the project. The biggest potential issue would be the drone colliding with people or objects. This could be caused by control malfunction or, more related to our project, the battery runs out. There are also risks related to cybersecurity and drones getting hacked. The drone we will use will follow IEEE 1936.1-2021 for drone applications[1].

The charger safety issues include shock risks along with overheating leading to fire. The shock risk is our main concern in this project since we anticipate having exposed coils with live voltage running through them. We will make sure to follow appropriate standards to mitigate all risks involved with our project. This includes, but is not limited to, the “Interface definitions” (IEC PAS 63095-1: 2017) standard and the SAE J2954: 2020 which regulates wireless power charging[2].

The charger will be charging a 3.7 V lithium ion battery which also comes with some safety concerns. These include battery failure due to aging, thermal abuse, and electrical abuse[6]. Our group is aware of the possible risks and will abide by ISO 26262[7] as well as take the battery safety training.

5. Citations

- [1] "IEEE SA - IEEE standard for drone applications framework," IEEE Standards Association, <https://standards.ieee.org/ieee/1936.1/7455/> (accessed Feb. 7, 2024).
- [2] A. Marinescu, "Current Standards and Regulations for Wireless Battery Charging Systems," 2021 7th International Symposium on Electrical and Electronics Engineering (ISEEE), Galati, Romania, 2021, pp. 1-6, doi: 10.1109/ISEEE53383.2021.9628689. keywords: {Wireless communication;Roads;Inductive charging;Sociology;Regulation;Production facilities;Batteries;Wireless Power Charging;Standards and Regulation for Consumer Devices;EVs and PHEVs},
- [3] Resonant converter with coupling independent resonance for Wireless Power Transfer Application,
<https://cpes.vt.edu/library/viewnugget/622#:~:text=Another%20challenge%20of%20the%20resonant,transfer%20standard%2C%20is%206.78MHz.>
(accessed Feb. 8, 2024).
- [4] "Understanding LLC operation (part I): Power switches and resonant tank: Article: Mps," Article | MPS,
<https://www.monolithicpower.com/understanding-llc-operation-part-i-power-switches-and-resonant-tank> (accessed Feb. 8, 2024).
- [5] A. Raciti, S. A. Rizzo, and G. Susinni, "Drone charging stations over the

buildings based on a Wireless Power Transfer System," 2018 IEEE/IAS
54th Industrial and Commercial Power Systems Technical Conference
(I&CPS), May 2018. doi:10.1109/icps.2018.8369967

- [6] X. Zhou, L. Cheng, Y. Wan, N. Qi, L. Tian and F. You, "Research on
Lithium-ion Battery Safety Risk Assessment Based on Measured
Information," 2020 IEEE Sustainable Power and Energy Conference (iSPEC),
Chengdu, China, 2020, pp. 2047-2052, doi: 10.1109/iSPEC50848.2020.9351160.
keywords: {Lithium-ion batteries;Temperature measurement;Voltage
measurement;Thermal management;Battery charge
measurement;Safety;Risk management;lithium-ion battery;thermal
runaway;risk assessment;active safety}
- [7] S. S. Tikar, "Compliance of ISO 26262 safety standard for lithium ion battery
and its battery management system in hybrid electric vehicle," 2017 IEEE
Transportation Electrification Conference (ITEC-India), Pune, India, 2017, pp.
1-5, doi: 10.1109/ITEC-India.2017.8333870. keywords: {Batteries;ISO
Standards;Hardware;Hazards;Software;Lithium;ISO 26262;Lithium ion
battery;Battery management system;HARA;ASIL},
- [8] A. Agcal, S. Ozcira, and N. Bekiroglu, "Wireless Power Transfer by Using
Magnetically Coupled Resonators," www.intechopen.com, Jun. 29, 2016.
<https://www.intechopen.com/chapters/51254> (accessed Feb. 23, 2024).
- [9] W. Storr, "Full wave rectifier and bridge rectifier theory," Basic Electronics

Tutorials, https://www.electronics-tutorials.ws/diode/diode_6.html (accessed Feb. 22, 2024).

[10] “15.6: Resonance in an AC Circuit,” *Physics LibreTexts*, Nov. 01, 2016.
[https://phys.libretexts.org/Bookshelves/University_Physics/University_Physics_\(OpenStax\)/Book%3A_University_Physics_II_-_Thermodynamics_Electricity_and_Magnetism_\(OpenStax\)/15%3A_Alternating-Current_Circuits/15.06%3A_Resonance_in_an_AC_Circuit](https://phys.libretexts.org/Bookshelves/University_Physics/University_Physics_(OpenStax)/Book%3A_University_Physics_II_-_Thermodynamics_Electricity_and_Magnetism_(OpenStax)/15%3A_Alternating-Current_Circuits/15.06%3A_Resonance_in_an_AC_Circuit)

[11] On semiconductor is now - onsemi,
<https://www.onsemi.com/pub/Collateral/AND9135-D.PDF> (accessed Feb. 23, 2024).

[12] “H-bridge Control | Modular Circuits,” Mar. 09, 2012.
<https://www.modularcircuits.com/blog/articles/h-bridge-secrets/h-bridge-control/>

[13] “Frequency Data as per AWG size in Litz Wire,” *YDK Litz Wire & Cable*.
<https://www.hflitzwire.com/frequency-as-per-awg-size/>

[14] Electronics tutorials, “Series Resonance in a Series RLC Resonant Circuit,” *Basic Electronics Tutorials*, Jun. 04, 2018.
<https://www.electronics-tutorials.ws/accircuits/series-resonance.html>