ECE 445

Spring 2024

Automatic Drone Wireless Charging Station

Team 29

Samuel Fakunle (sof2)

Pranshu Teckchandani (pat4)

Jason Wuerffel (jasonmw2)

TA: Matthew Qi

Introduction:

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.

A. 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. In addition, our system should indicate when sufficient charging has been completed, and 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.

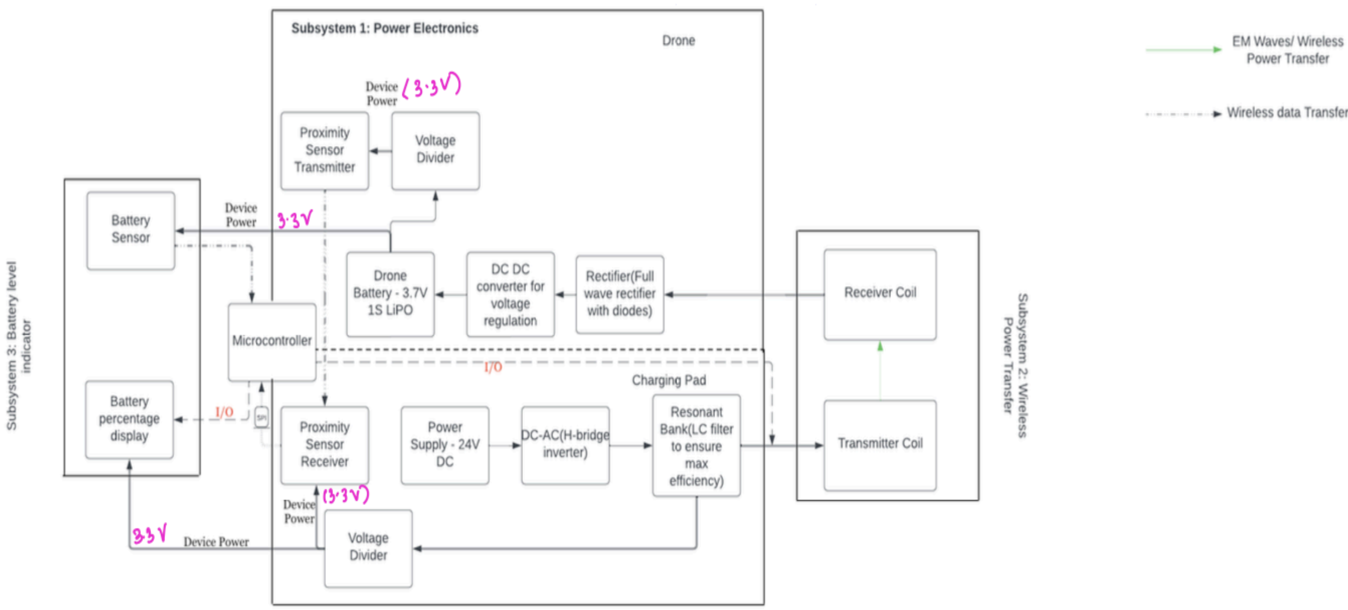
Visual Aid:

High Level Requirements:

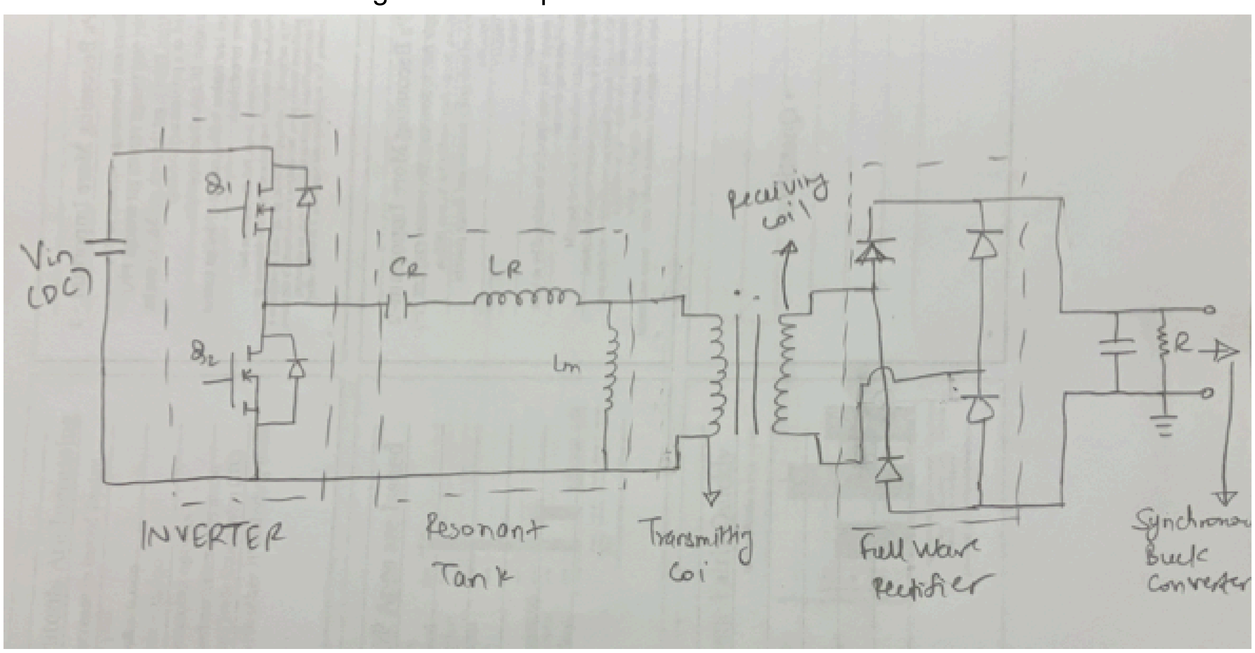
- The system is able to supply 3.7V± 3% V DC to 1S LiPO battery, when supplied with 24V DC power from the power supply.
- The charging pad is able to charge the drone successfully without human interference with an efficiency of at least 50% only after the drone is within the set proximity.
- The LED displays are able to visually indicate the charging status of the drone's battery.
- Power Transfer in close proximity to the coil.(Refer to tolerance analysis for more details.)

Design:

Block Diagram:



This is a reference circuit diagram for our power electronics circuits



Detailed specifications are mentioned in the following sections.

Subsystem Overview:

- **Power Electronics for Charging Pad and Drone**
  - This subsystem includes all circuitry that converts voltage to appropriate levels for the charging pad and drone. This unit is expected to supply AC voltage to the transmitting coil through DC-AC converters integrated with filters. In addition, the subsystem would also supply regulated DC voltage from the receiving pad to the 1S lithium battery pack of the HS210 mini drone by using AC-DC and DC-DC converters. Communication is required with the ESP32 microcontroller to implement the switch's control signals and ensure safe power distribution throughout the system.
- **Wireless Power Transfer System**
  - The WPT system involves the transmitting and receiving coils, integral to achieving wireless power transmission. This transmitting coil will be integrated with an LC resonant tank to ensure optimal wireless power transfer. This can be achieved because the resonant tank would make sure power is transferred wireless at the natural resonant frequency.
- **Battery Indicator System**
  - This indicator subsystem consists of the ESP32 microcontroller, the battery sensor, and LED displays. The main role of the battery sensor is to precisely measure the voltage across the drone's battery. The ESP32 microcontroller needs to be able to receive and process data from the battery sensor. Specifically, the microcontroller would determine how much voltage is required to fully charge the lithium battery pack, and communicate with the LED displays during charging and fully charged states. The ESP32 would also need its own voltage regulator to obtain appropriate voltage levels for operation. The purpose of the LED displays is to visually convey the status of the drone's battery. The three states would include: not charging, charging and fully charged.

Subsystem Requirement:

- **Power Electronics for Charging Pad and Drone**

- The H-bridge inverter circuit should be able to convert 24 V DC to 12V ± 5% V AC into the wireless transfer system.
- The full bridge rectifier must be able to convert AC voltage from the WPF system to 12 ± 3% V DC.
- The synchronous buck converter should be able to convert 12 ± 3% V DC to 5 ± 3% V DC.
- The voltage regulator should successfully regulate DC voltage to 3.7± 5% V DC for the drone's battery.
- Output power must be between 15-25W.
- System's efficiency must be between 50-60%.
- Switching frequency must be 6.78MHz, as prescribed by Rezence [3].
- ESP32 microcontroller successfully implements the control scheme of the converters, while also ensuring safe power conversion.

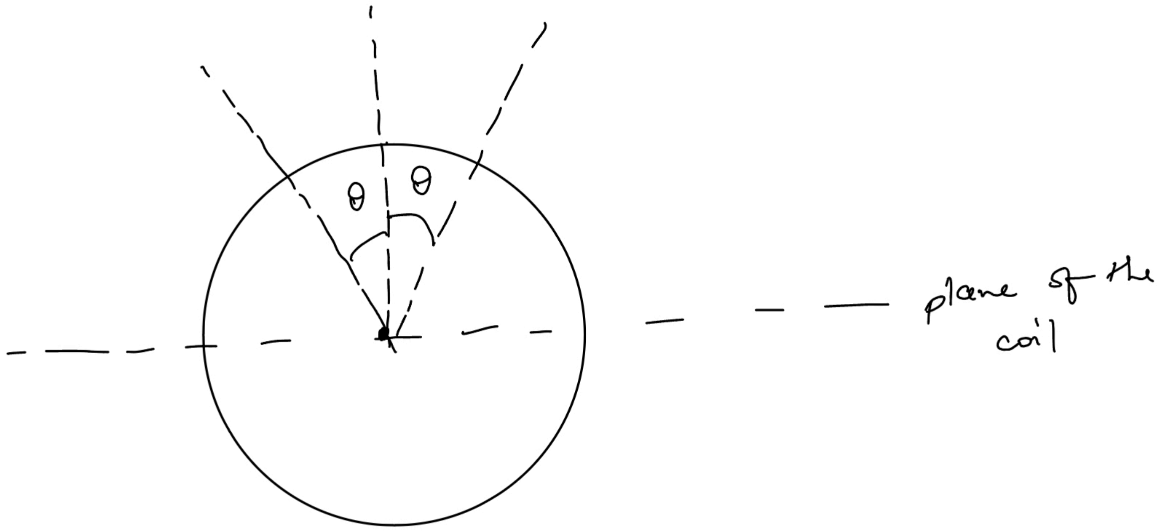
- **Wireless Power Transfer System**
    - This subsystem must operate at resonant frequency. This would be verified using lab equipment.
- **Battery Indicator System**
    - Successful communication between battery sensor and ESP32 microcontroller over bluetooth or Wifi.
    - ESP32 microcontroller sufficiently controls the three states of the LED displays.
    - LED displays accurately relay the current status of the drone's battery.

Tolerance Analysis:

The wireless power transfer poses a significant risk to design. The efficient working of the wireless power transmission depends a lot on the coupling coefficient of the coils. This coefficient is directly linked to the directivity of the coil. Directivity refers to how focused the transmitted power is in a particular direction. Higher directivity means more focused transmission, which can lead to better efficiency since more of the transmitted power is directed toward the receiver. For efficient wireless power transmission we need high directivity.

We need to align the center of the transmitter coil on the pad and the center of the receiver coil on the drone to ensure high efficiency. We should enable charging only when the receiving coil is within this region (close proximity as mentioned in the high level requirements.). The directivity depends on the solid angle that the region makes with the source.

Suppose we imagine a sphere with radius of the coil and center the same as that of the coil. We use this as a reference to see where the directivity is going to be higher for more efficient power transmission. To help with visualization, we take a 2D projection of this sphere as shown in figure.



The directivity is going to be high when the angle is less than 45 degrees(by symmetry). Since we are going to have leakage, we safely assume that if the center of the drone is the region that makes an angle of 30 degrees with the center, we will have high directivity. By simple mathematics, we deduce that the drone should land in a region such that its center is within R/2 distance from the center of the coil where R is the radius of the coil.

Ethics and Safety

Ethics:

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.

Safety:

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].

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