Wireless Power Transfer for Short Range Low Powered Devices

6.2300 Class Project: Detailed Plan
TeamID: HelixPowerTransfer

Justin Buonato
EECS
buonato@mit.edu

Brady Cruse
EECS
bcruse@mit.edu

Charlie Glass
Physics
charl276@mit.edu

Mark Mitchell
Physics
markmit@mit.edu

***Abstract*—Our group developed a wireless power transfer (WPT) system to transmit power over a 1-meter distance at 915 MHz for high-efficiency, mid-range applications. We chose this design because we are motivated to offer a convenient and efficient solution to transferring power to everyday devices. The transmitter employs a directional parabolic reflector and a helical coil antenna to concentrate energy delivery, with a total antenna gain of 15.9 dBi. On the receiving end, a small directional helical antenna is tuned for maximum power capture, with a maximum theoretical received power of 10W. The system is optimized for high power transfer efficiency by precise impedance matching, low-loss rectification, and frequency-tuned resonant structures. Directionality is crucial to maximize energy transfer while reducing off-axis radiation and interference. In-depth electromagnetic full-wave simulations inform antenna design and system topology, and hardware validation confirms performance under real-world operating conditions. The resultant platform facilitates scalable wireless power delivery, with applications in autonomous systems, industrial sensing, and consumer electronics.**

I. Introduction & Motivations

The rapid development of mobile technology has led to a continuous change in the distribution of power to small electronics. The annoyance of the mess of tangled cables have led to the development of inductive charging technologies. Electronic devices are so common place in society with more useful devices constantly being developed, the need for power is rapidly increasing. The development of next generation charging for low power devices is wireless power transfer (WPT). This is the development of antennas with the capability of sending high-power electromagnetic waves in ambient space to charge devices at a distance. Developing and operating an antenna at an optimal frequency that focuses on power transfer to a specific device will aid in the advancement of WPT devices by increasing overall efficiency of the system.

Directional WPT has been studied by various groups recently. One of the most similar experimental designs to ours is by researchers at Cornell University, who published a paper earlier this year on designing a WPT system for in-home use. Their findings showed 37% efficiency in a 3m × 3 m × 2 m room [1]. Another group at the University of Padua also researched directional short-range charging, with more focus on higher power delivery and bi-directional transfer between homes and EVs [2].

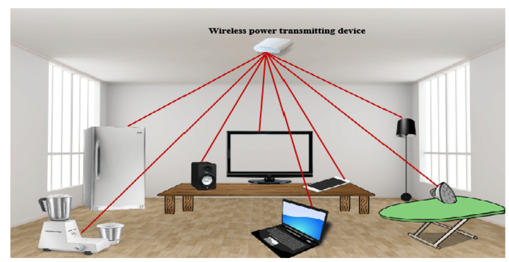

Fig. 1. Example of Wireless Power System powering short range home devices [3]

Wireless Power Transfer is a versatile field with research in many areas. For example, NASA has explored using WPT to transmit solar power from spacecraft to Earth [4]. Our system uses a similar antenna design but for lower power and shorter range. Researchers at Worcester Polytechnic Institute have published work on WPT applications in biomedical devices used in NICUs [5]. Their work shares our focus on close-range WPT, but with emphasis on biomedical use and EM exposure. We aim to build a general-purpose WPT system for everyday distances.

We demonstrate the feasibility of a safe, precise WPT system by lighting an array of LEDs from an array one meter away. This shows both safety and high precision. In the results section, we analyze collected efficiency data and discuss its implications for future WPT systems.

II. Approach

Four potential antenna designs were considered: parabolic, Yagi, Moxon, and helical. The parabolic reflector antenna excels in its ability to capture electromagnetic waves over a wide area and concentrate them onto a single focal point, making it highly effective for directional applications [6]. The Yagi antenna, while offering moderate forward gain, is inherently bidirectional, meaning it exhibits gain both in the direction of transmission and in the opposite direction [7]. This

characteristic reduces its efficiency for applications requiring highly focused energy transmission. The Moxon antenna, a compact two-element parasitic array optimized for a single frequency, offers reasonable performance over longer ranges [8]. However, its gain is insufficient for our short-range application of approximately 6 feet. In contrast, the helical antenna operating in axial mode demonstrates strong unidirectional gain, making it well-suited for directional wireless power transfer at close range[9].
To effectively transmit power with minimal loss we have elected to go with helical antenna in axial mode, with a parabolic reflector to focus the power on the specific device. Helical antennas are known for having excellent directional gain patterns which helps focusing electromagnetic waves in a single direction The goal is to maximize power transfer with minimal ambient electromagnetic radiation. To calculate the key aspects of the device's design, we use the fundamental concepts of electromagnetic radiation and antenna communication taught in this class.

We also chose a frequency of 915 MHz as our transmitting wave. The main driver in this decision was to minimize interference with Wi-Fi signals at 2.4 GHz. It is understood that Wi-Fi signals have a wide frequency spectrum and are highly time dependent, but at a sufficient distance from a Wi-Fi access point, there should not be any interference. Although lower frequencies travel farther at less power loss through the air, lower frequencies require larger antennas [10]. The directivity radiation pattern of our antenna is extremely polarized along the helical axis [9]. This polarization is because the circumference of the turns is on the order of our transmitting wavelength, leading to an axial radiation mode for the antenna. The half power beam width of the antenna is given by $HPBW = \frac{65\lambda^{3/2}}{C\sqrt{NS}}$, with N being the number of turns, C being the circumference of the turns, and S the distance between them [9]. For our design, $N = 4$, $C = \lambda$ and $S = \lambda/4$, giving $HPBW = 37°$. The first null in the radiation pattern is calculated as $\frac{115\lambda^{3/2}}{C\sqrt{NS}}$, which means that the first null in our design happens at $66°$ [9]. The helical antenna yields a high gain system at 915 MHz with a relatively small antenna size. We calculated gain with this equation: $G_{helix} \approx 10 \cdot \log_{10} \frac{NC^2}{\lambda}$ [8]. In deciding the parameters for each antenna, we wanted to optimize gain vs size. For the helical antenna, we chose a length of 18 cm, a 4 cm diameter, with 7 evenly spaced turns, which yields a gain of $G_{helix} \approx 11$ dBi.

With this gain in mind for our antenna, we calculate the free space path loss when using this antenna for transmitting and receiving the signal. The equation for free space path loss is $FSPL = 20\log d + 20\log f + 20\log\frac{4\pi}{c} - (G_t + G_r)$, where $d = 1[m]$ is the distance between antennas, f is our transmitting frequency, and G_t and G_r are the values for gain. We also note that the medium we are considering in this case is only air. When we plug in our calculated values, we get $FSPL = 10dBi$. Because of this calculation, we can be confident that the antenna can successfully transmit the necessary amount of power.

We use the frequency generator as the carrier frequency for our power circuit and to provide sufficient power to the transmitting antenna, we utilize a 4-watt power amplifier. In order for the power transferred from our transmitting antenna to our receiving antenna to power our LED array, we use a Schottky diode to rectify the signal into direct current.

Testing is conducted with a nanoVNA, oscilloscope/frequency generator, and load device (LED array). The nanoVNA is used to tune the antenna to 915 MHz and measure the S11 and S21 coefficients. We use the oscilloscope to measure the receiving antenna under load to derive efficiency. And we use the frequency generator as the carrier frequency for our power circuit. The materials for this project are mainly sourced from maker spaces on campus and components that members of the group have personally.

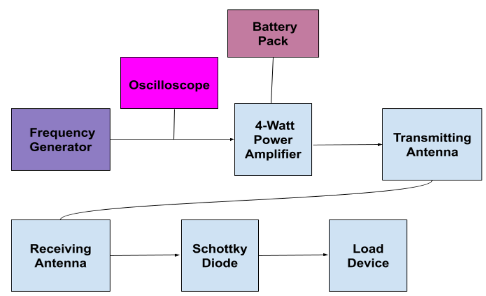

Fig. 2. Block diagram of the design of the device.

III. Legality, Safety and Ethics

The FCC's Knowledge Database (KDB) publication 680106 clarifies that wireless power transfer devices are bound to the rules of Part 18 when transmitting power [11]. Part 18 of the FCC regulations provides a proper protocol for scientific devices. According to the eCFR rule §18.109, devices need ”sufficient shielding and filtering to provide adequate suppression of emissions” [12]. We meticulously designed and monitor the frequencies we transmit using the RF generator chip and oscilloscope. Since our WPT is operating at 915 MHz, an authorized frequency band under §18.301, according to rule §18.305 we are permitted unlimited radiated energy within the 915 MHz band [12].
OET Bulletin 65 clarified that even though §18.305 permits unlimited radiated energy, devices that fall under part 18 of the FCC guidelines must comply with the max Specific Absorption Rate (SAR) and RF exposure guidelines [13]. The OET Bulletin 56, states the SAR limit for uncontrolled exposure is 1.6 W/kg for the partial body for 30 minutes [14]. The maximum safe transmit power to remain below the MPE limit of 0.6 mW/cm^2 (equivalent to 6 W/m^2) is calculated using the equation: $P_{transmitted} = \frac{S*4\pi r^2}{G}$ where S is the MPE limit (6 W/m^2), $r$is the distance (1.2m), and G is the linear antenna gain (31.56). This results in a safe transmit power of approximately 108.57 watts. Based on the calculation for the largest possible gain of our antenna being 10.1 dBi,

it would require significantly more input power into our transmitting device than we intend to supply to even get close to the level of 108.57 watts of power transfer.

We collect data on the dBi gain, reflectance at target frequency, path loss, power received, and efficiency of the device. The data confirming the safety and legality of the device is procured using a nanoVNA, oscilloscope, and the LED array. These tests ensure that there is no chance of unintended power transfer from reflected waves and confirm that our calculations for the gain and power transfer of the antenna are correct. And by confirming the gain of the antenna, we can be confident that if the device does not work as expected, it does not pose any safety risk and only fails to transmit necessary power to the LED array. We have designed all aspects of the device in order to comply fully with both MPE and SAR safety limits.

Wireless Power Transfer (WPT) is a groundbreaking technology with significant potential, but it also presents ethical concerns for various stakeholders. Direct stakeholders include low-income consumers who may face higher costs due to the premium pricing of WPT-enabled devices, deepening the digital divide. Workers in traditional power sectors, such as cable manufacturing and electrical infrastructure, risk job displacement as demand shifts toward wireless alternatives.

Indirect stakeholders are also at risk from broader systemic changes. Communities near large-scale WPT deployments could be involuntarily subjected to EMF exposure, raising concerns of environmental justice. Wildlife ecosystems could also be disrupted, as EM-sensitive species may experience interference in navigation, migration, or reproduction. These secondary effects highlight the importance of inclusive, sustainable, and transparent WPT development that safeguards both human and environmental well-being.

IV. Results

The final antenna design with dimensions is shown in Fig. 3. To determine the effectiveness of our design, we tested the gain

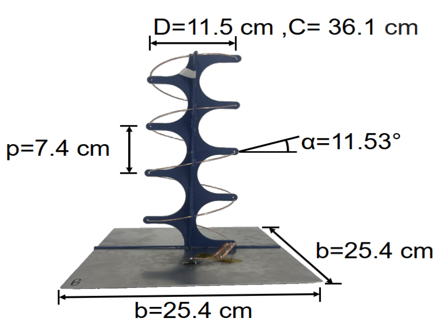

Fig. 3. Picture of the helical antenna

of the antennas while each was facing each other. The result for gain of the antenna was 11.83 dBi. This is expected because the equation used to calculate gain is known to undershoot the actual value of gain of the helical antenna [9]. We measured the power from the receiving antenna with an input power to the transmitting antenna of 100 mw.

TABLE I
Power Received and Gain Measurements

Parameter	***Expected***	***Measured***
Directivity	11.2 dBi	11.8 dBi
Power at 1.5m	5.3 mw	5.0 mw

And we tested how the gain varied at a constant distance of 1 meter but varied the angle between the antennas. We took data on the peak-to-peak distance on the oscilloscope while varying the angle of the antennas towards each other. We used the compass app on our phone to make sure each measurement differed by 5 degrees and obtained a polar graph of the antenna's directivity gain. These results are very exciting because they show that our antenna displays the desired properties of a helical antenna. This means that our antenna will be effective for its specific powering application and minimize wasted power in other directions.

From informal tests, we also concluded that a deficiency in the design is that while power can still be transferred when obstructing objects like people get in the way, it significantly attenuates the power transferred.

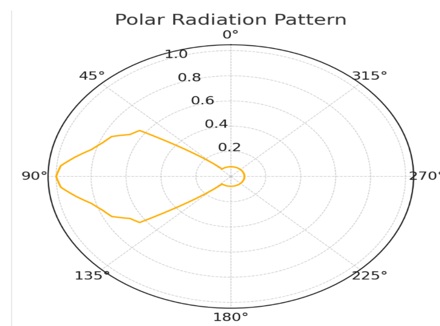

Fig. 4. Polar graph of the radiation directivity.

V. Discussion

While these results show that the antenna worked very well at transmitting and receiving the power supplied to it, we were not able to transfer the necessary amount of power to light up an LED. This was because we were unable to integrate the power amplifier component needed to provide the input power to the transmitting antenna. This was the only problem holding the device back from lighting up the LED as the tests of the antenna showed that it was fully capable of achieving the necessary gain. In the future we can use a power amplifier that is easier to integrate into the device.

VI. Conclusion

So our antenna design had a sufficient gain of 11.83 dBi and could transmit and receive 5 mw of power from a 100 mw source. This exciting result shows that a wireless power transfer device can work using this specific helical design. This type of wireless power transfer could have applications in powering low power drones or biomedical devices.

References

[1] Sasatani T, Sample AP, Kawahara Y. Room-scale magnetoquasistatic wireless power transfer using a cavity-based multimode resonator. Nat Electron. 2021;4:689–697

[2] Kumar A, Bertoluzzo M, Sagar A. A novel bi-directional wireless power transfer design for smart homes. Int J Inf Technol. 2024;16(62). doi:10.1007/s41870-024-01965-0

[3] Sumi FH, Dutta L, Sarker F. Future with Wireless Power Transfer Technology. J Electr Electron Syst. 2018;7(4):279. doi:10.4172/2332-0796.1000279

[4] Vazquez Ramos G, Yuan J-S. Wireless Power Transfer for Space Applications. NASA Technical Paper 20110015860. John F. Kennedy Space Center, FL: National Aeronautics and Space Administration; 2011. https://ntrs.nasa.gov/api/citations/20110015860/downloads/20110015860.pdf

[5] Hazrati Marangalou A, Gonzalez M, Reppucci N, Guler U. A design review for biomedical wireless power transfer systems with a three-coil inductive link through a case study for NICU applications. Electronics. 2024;13(19):3947. https://doi.org/10.3390/electronics13193947

[6] Electronics Notes. Parabolic reflector antenna gain: Formula calculation. 2025. https://www.electronics-notes.com/articles/antennas-propagation/parabolic-reflector-antenna/antenna-gain-directivity.php

[7] Zhao H. Yagi antenna design formula: Understanding its parasitic elements and more. WellPCB. 2021 Dec 21. https://www.wellpcb.com/blog/pcb-projects/yagi-antenna-design-formula/

[8] Portable-Antennas.com. Moxon antenna design. 2025. https://portable-antennas.com/support_ants.php#moxon-des

[9] Antenna-Theory.com. Helical antenna (helix). 2025. https://www.antenna-theory.com/antennas/travelling/helix.php

[10] Zhang W, Mi C. The power loss analysis for resonant wireless power transfer. In: 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014. IEEE; 2014. p. 139–44.

[11] Federal Communications Commission. KDB Publication 680106: Wireless Power Transfer (WPT) [Internet]. Washington (DC): FCC Office of Engineering and Technology; 2023 Oct 24 [cited 2025 Apr 22]. https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?id=41701&switch=P

[12] Code of Federal Regulations. Title 47, Part 18 – Industrial, scientific, and medical equipment [Internet]. Washington (DC): U.S. Government Publishing Office; [cited 2025 Apr 22]. https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-18

[13] Federal Communications Commission. Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields. OET Bulletin 65. Edition 97-01. Washington, DC: FCC; 1997 [cited 2025 Apr 22]. https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf

[14] Cleveland RF Jr, Ulcek JL. Questions and answers about biological effects and potential hazards of radiofrequency electromagnetic fields. OET Bulletin 56, Fourth Edition [Internet]. Washington (DC): Federal Communications Commission, Office of Engineering and Technology; 1999 Aug [cited 2025 Apr 22]. https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet56/oet56e4.pdf

[15] Federal Communications Commission. Understanding the FCC Regulations for Low-Power, Non-Licensed Transmitters (OET Bulletin No. 63). Washington, DC: Federal Communications Commission; 1993. https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet63/oet63rev.pdf