Department of Electrical Engineering
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EE 198B Senior Project Proposal

Truly Wireless Charging

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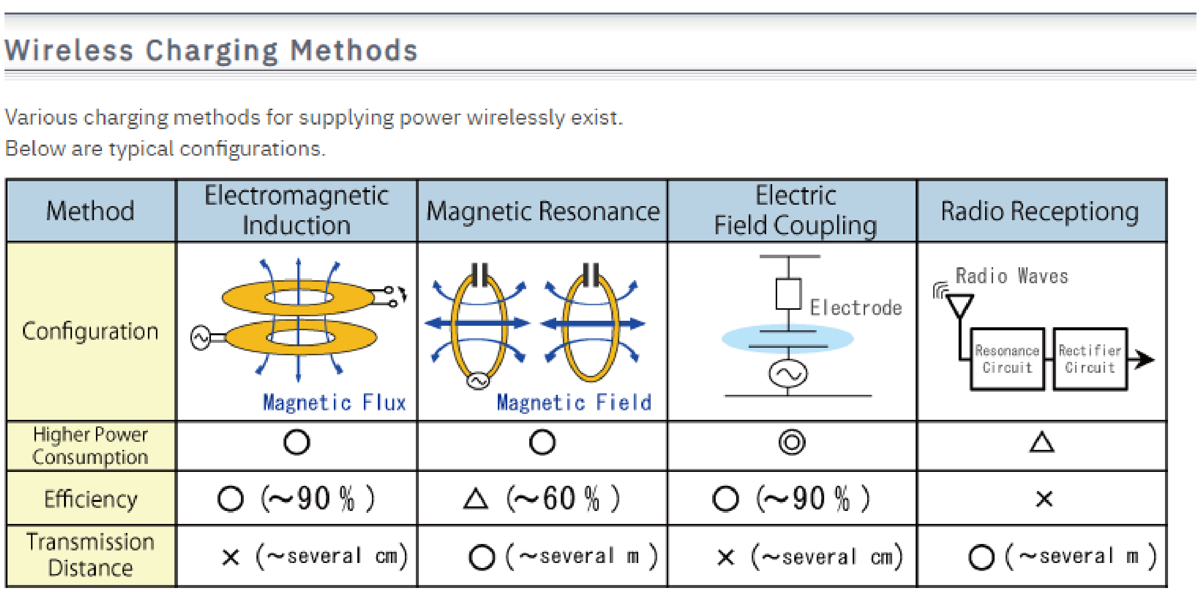
1. Introduction

The invention of the truly wireless charger promises to revolutionize the personal electronics market. With this product, people will no longer need to buy cable chargers or wireless pads and can simply place their device on a table and it will automatically begin charging without needing to be placed in a specific location or orientation. This new technology will bring convenience to everyday life by eliminating the need for people to actively charge their smartphones and other personal electronics. This invention will reduce power consumption which means reduced rates on electricity. With more access to charging in public spaces, charging cannot be denied to certain groups of people and is a proponent of equality, diversity, and against systematic inequality. Our company is confident that the true wireless charger will become the new standard for charging. Our product will use resonance technology that allows for longer transmission distance for power than current wireless charging standards. This will consist of a power supply with a transmission coil that acts as an antenna. As of right now, we are mainly trying to do a proof of concept to see if we can transmit power wirelessly over a distance. Current wireless chargers use induction charging which also uses coils, but the transmission distance is very short and essentially has the convenience of wired charging.

2. Methodology and Design

Project Idea

For this project, we have chosen to create a wireless charger that can charge from a distance further than current wireless standards at a rate of 1 watt. To do this resonance technology will be used as it has a further range than the technology being used right now for wireless charging which is electromagnetic induction. This can be seen in the field study we have found that is seen in Figure 1.


Wireless Charging Methods

Various charging methods for supplying power wirelessly exist.
Below are typical configurations.

Method	Electromagnetic Induction	Magnetic Resonance	Electric Field Coupling	Radio Receptiong
Configuration	Magnetic Flux	Magnetic Field	Electrode	Radio Waves, Resonance Circuit, Rectifier Circuit
Higher Power Consumption	○	○	◎	△
Efficiency	○ (~90 %)	△ (~60 %)	○ (~90 %)	×
Transmission Distance	× (~several cm)	○ (~several m)	× (~several cm)	○ (~several m)

Figure 1: Field study of different wireless charging methods. Current standard wireless chargers use electromagnetic induction, but our plan is to use magnetic resonance for its transmission distance. (ROHM Semiconductor, 2018)

In order to use resonance a base power supply will be used to power a transmission coil that sends power to a receiver coil on the device being charged. This receiver coil rectifies the signal to a dc voltage that is used to charge the device. The goal is to supply 1 Watt of power to the device. For testing purposes, a signal generator was used as a power supply to generate the signal for resonance. The outline of this charging circuit can be seen in Figure 2.

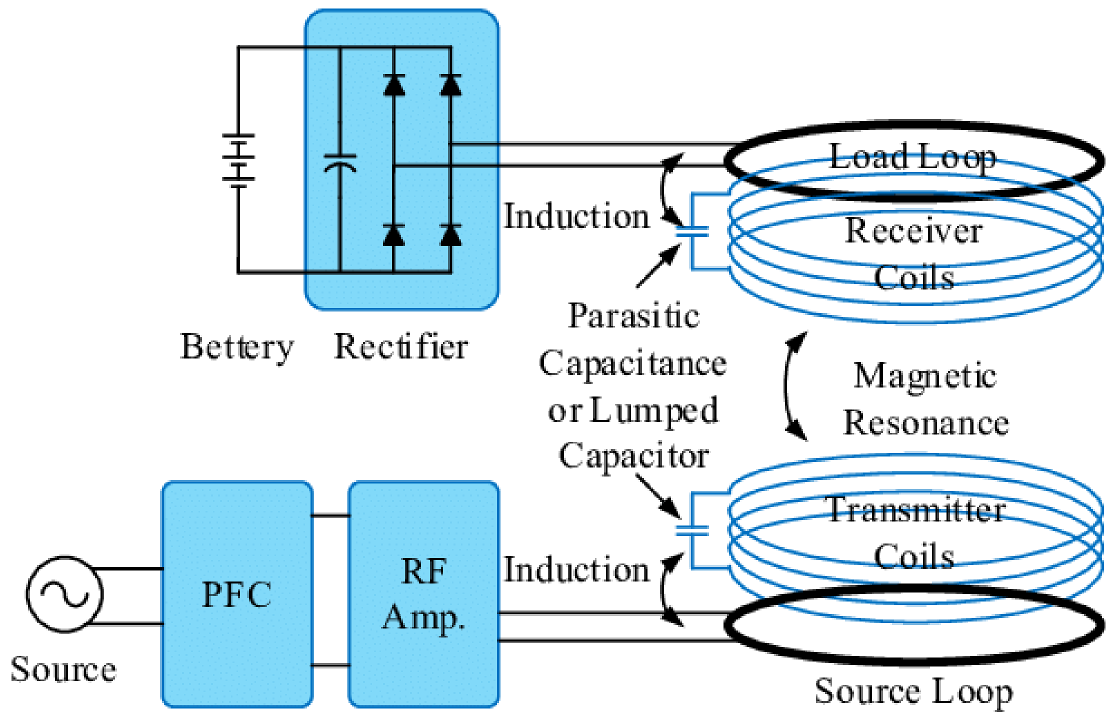


Figure 2: Circuit outline to be implemented for the wireless charging device. A power supply is connected to a source loop to transmit power and a receiver coil receives the power signal and is rectified to charge the device. (Chunhua, 2013)

The signal generator takes the place of the power source and RF amplifier and provides around 1 Watt of power. This device can be placed anywhere from homes, to offices, to cafes and stores.

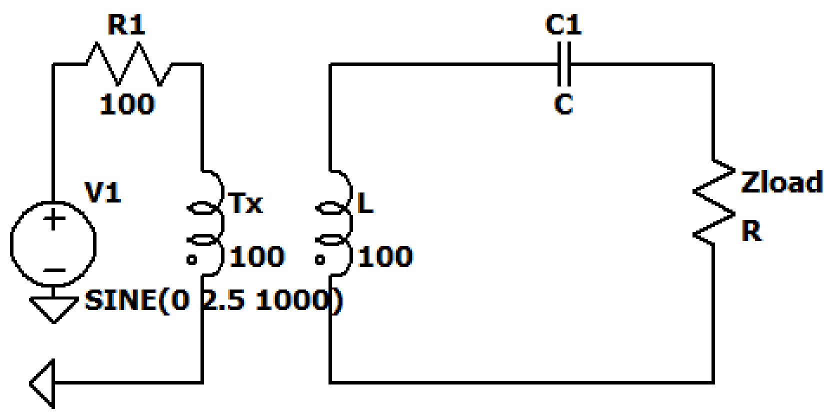


Figure 3 LTSpice diagram showing concepts.

The B-fields from the Tx induce an alternating EMF in the small coil modeled as a voltage source. The Rx captures the b-fields and induces an EMF, an equivalent alternating voltage source. The Rx also has self-inductance which impedes the time-varying currents. The impedance of the Rx (L) is +jwL, choking current flow The impedance of the C is -j/wC. If you adjust C so that +jwL -j/wC = 0 which is resonance, The LC series will have zero impedance and the current driven by the B-fields in the coil will be unchoked.

$$I_1 = \frac{-j\varepsilon[\omega L_2 - (1/\omega C_2)]}{\{[\omega L_1 - (1/\omega C_1)][\omega L_2 - (1/\omega C_2)] - \omega^2 M^2\}}$$

$$I_2 = \frac{-j\omega M\varepsilon}{\{[\omega L_1 - (1/\omega C_1)][\omega L_2 - (1/\omega C_2)] - \omega^2 M^2\}}$$

$$\left(\frac{\omega^2}{\omega_1{}^2} - 1\right)\left(\frac{\omega^2}{\omega_2{}^2} - 1\right) - k^2\left(\frac{\omega^2}{\omega_1{}^2}\right)\left(\frac{\omega^2}{\omega_2{}^2}\right) = 0$$

$$\left(\frac{\omega^2}{\omega_0{}^2} - 1\right) = \pm k\left(\frac{\omega^2}{\omega_0{}^2}\right)$$

$$\omega = \frac{\omega_0}{(1 \mp k)^{1/2}}$$

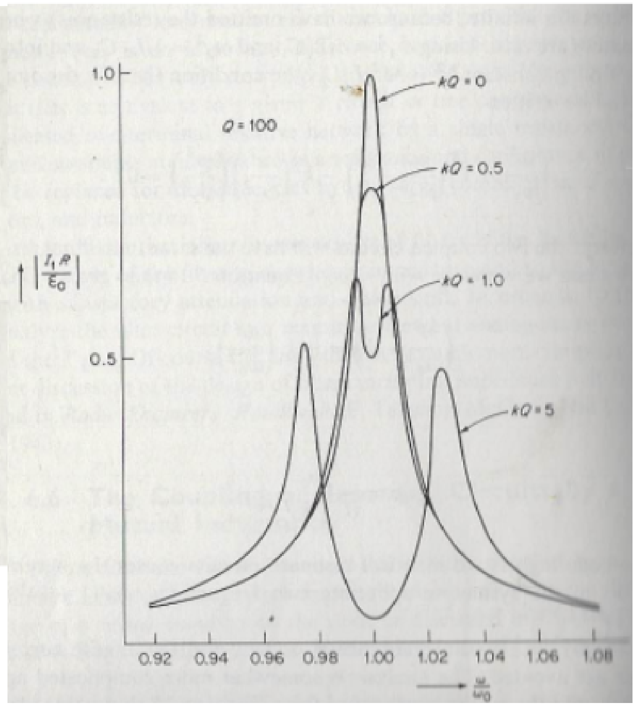


Figure 4: equations and graphs expanding upon LC values (Anderson, L. W., & Beeman)

These formulas are used to calculate the current flowing through the Tx (I1) and Rx (I2). when the resonance conditions are met, the power on the receive side which is a function of current, (shown on the y-axis of the graph) is maximized at the normalized resonance frequency and tapers off as the inductive or capacitive inductance dominates and resonance conditions are not met.

Project Significance

With the increase in personal electronic devices the power consumption to charge all these devices has increased. With a wireless charger that is capable of charging multiple devices, this power consumption can be reduced. This in turn will help lower electricity rates and prevent poor communities from being overcharged for electricity usage. It will also help reduce the number of chargers that get thrown away since a wireless charger can be universal. It will also increase the number of people that get access to charging especially in public. Since you do not have to be near an outlet or need a cable anyone near a wireless charging device can get a charge. The charger will also let users move around with their device, and not be forced to stay near a charging station. This kind of device can help other societies outside of the US as well where electricity is limited. Many other countries such as South Africa go through periods of blackouts due to the electric grid not being able to handle the load of its citizens. With our project, we can reduce overall power consumption and help this society have more consistent electricity.

Project Team

As explained above in the previous sections, after excelling at course EE140 at SJSU, our team deeply understands the core principles behind a wireless charger. Inputting AC current through a wire loop will induce a magnetic flux perpendicular to the direction of the coil, which will then create an AC current on the receiver coil that will then be rectified into DC current to charge the personal electronic’s battery. This introduction theory has been reviewed in EE140 for a solid understanding of the fundamentals. Reviewing the literacy that is currently published, such as IEEE standards and reading patents on patents.google.com, our team has devised a plan to test the physical implementation of creating a resonance frequency with a signal generator for the upcoming second semester of the senior project.

Dawinderdeep Sekhon is in charge of the design and fabrication of the product with previous experience in San Jose's robotics club he has experience with working with groups to accomplish tasks as well as the design process for projects. His experience includes many skills including schematics on easyEDA computer software and implementing these circuits on a real-life machine. Making this product a reality is well within his skill set. Andrew Wang will be in charge of the production, testing, selling, and technical support of the truly wireless charger. In his last internship with Lockheed Martin in Boston, he designed, fabricated, and tested next-generation Gallium Nitride (GaN) inside the fab. I created automated scripts to control the test equipment. With the automated testing scripts, I was able to save an engineer or technician 12x the amount of time it would take to manually test each device. The projected time went from 1 hour to 5 minutes to test a new wafer with an automated script. With their previous experience, Andrew Wang is confident in his skills to test, sell, and support the next generation of true wireless chargers.

Our schedule is highlighted in the next section with our Gantt chart detailing the next semester's plans. For the foreseeable future of this project, the cost of the project should be relatively low, less than $50. Right now, the only needed materials are coil loops that should wrap around a 3-foot squared area. This means that the project materials will be self-financed by Andrew and Dawinder until new circumstances for more money are needed.

Finances

The finances for this project were tried to be kept minimal. The major components of the circuit include a power supply for which a signal generator was used to supply power and create the frequency. The first attempts tried to use the receiver coil already on iPhones, but that turned out to be unsuccessful. A coil was then made from various materials that we had already such as solid core wire and stranded copper wire. As most of the project was for proof of concept the cost was very minimal close to $50 for the Qi wireless charging kits and copper wire.

3. Results and Discussion

Initial Testing Results for Charging

The initial testing for this circuit was to try to take a copper wire and use a signal generator to match the current wireless charging frequency and see if we can charge a device. These tests ultimately failed due to the safety features (foreign object detection) behind the wireless charging standards. There is a safety protocol that requires a communication protocol signal before power is sent and received so that any random piece of metal does not start conducting power from the wireless charging base. This protocol was hard to complete by only the two partners so the idea of charging was changed to just attempt wireless power transfer.

Proof of Concept For Wireless Power Transmission

The testing for the wireless power transmission with resonance acts as a transformer. A transmission coil is connected to a signal generator which is set to vibrate at a frequency that matches the receiver coil. The receiver coil is an inductor in series with a capacitor that is vibrating at a certain frequency and when the transmission coil meets that resonant frequency the power received is peaked. At first, the resonant frequency was attempted to be calculated, but since the inductors are custom made the inductance measured is not accurate so the way to find the resonant frequency was to sweep through various frequencies and find where the power received is the highest. Once the best frequency was found the distance at which the power received was measured. At first, we used single-stranded solid core wire which had a low transmission distance of a few inches. We then switched to a multi-stranded insulated copper wire that was made into loops of 5 turns with a diameter of 12 inches. This loop gave the best results of transmission distance. The transmission power was around 1 watts and at the closest distance, the power received was 0.74 Watts giving a 74% efficiency. To see the received power a rectifier was used to light up an LED and up to 6 inches the LED remained at full brightness. After this distance, the LED started to get dim but remained on up to 15 inches away. At 12 inches the power received was around 0.05 Watts giving an efficiency of 5%. Although the efficiency at this distance is low there is still a decent amount of received power, especially for the distance.

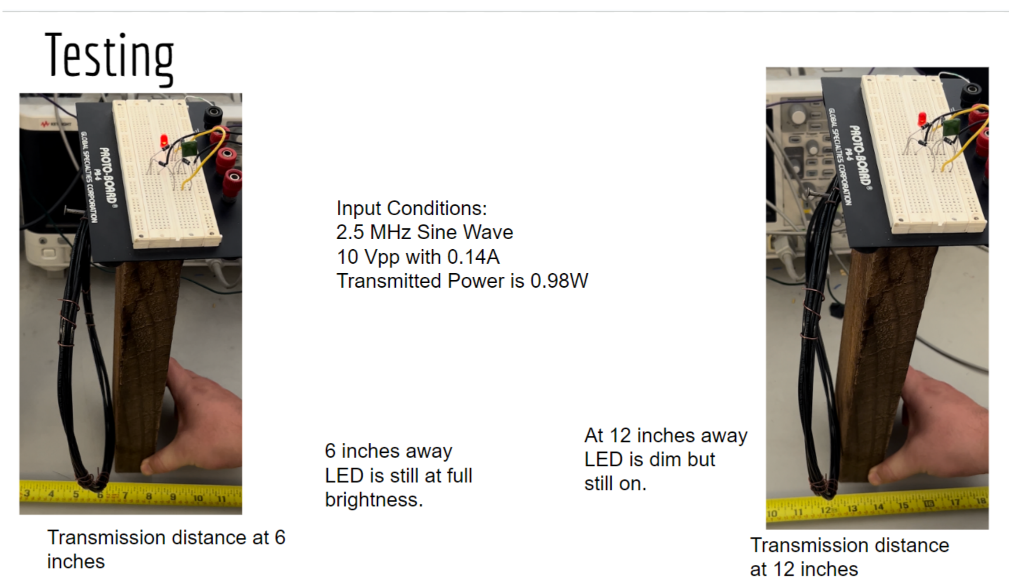


Figure 5: Proof of results over a distance of 6 and 12 inches. the transmitter is set at the 0 inch mark and the receiver is moved further back until the LED turns off.

Discussion

Although the complete charging circuit could not be made, we were able to transmit 1 Watt of power successfully over a distance of 15 inches with an efficiency of 74% initially and 5% at the max range. To increase the efficiency more materials need to be looked into and the size of the coils should be further varied to find what will increase the efficiency. The important finding from the proof of concept was that if the inductance of the two coils does not match the power efficiency is reduced to very little. Having matching impedance values leads to the most received power and higher efficiency. Also the bigger the coil the better the efficiency is as well. As far as the proof of concept for wireless charging it seems to be pretty obtainable just with a lower efficiency which is expected for inductance charging.

4. Conclusion and Recommendations

After many design iterations and reading through the current Qi charging standard, it became apparent that a student making a Qi-compliant charger is impossible because of the active data communication protocol, (DPSK modulation scheme) required to initiate the power transfer contract between Qi compliant devices. Diving deep into the Wireless power transfer literature, we realized that resonance wireless charging is still considered “inductive resonance charging” due to the nature of sending and receiving magnetic B-fields to induce a current in the receiver side inductor coil. As for the results of our project, we were able to transmit 1W, which keeps the

LED at full brightness, up until 6 inches, and after the power received begins to diminish, the LED turns off after 12 inches. We were able to see how power transfer is much more efficient with matching inductance values for the transmission and receiving coils rather than mismatched inductances.

For future work, it would be very helpful to create a Qi-compliant charger with the active data protocol to charge personal devices with our inductive resonant charger. Also, we would explore more materials and sizes that would be more practical for smartphones. Overall, understanding the Qi protocol having two different types of signal output as well as maximizing power and efficiency with the multiple degrees of freedom provided a great senior project and learning experience.

5. References

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