ECE 4800: Project 2 Report
Wireless Power Transfer

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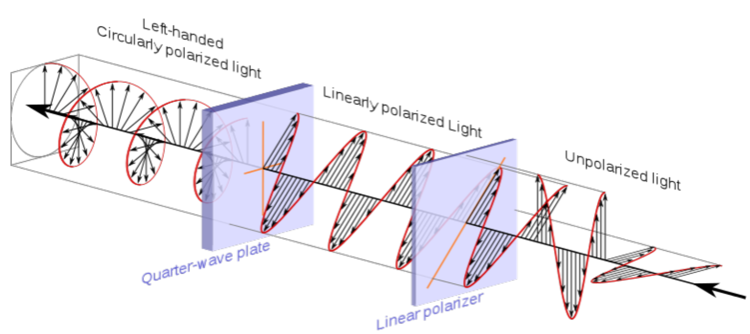


Introduction:

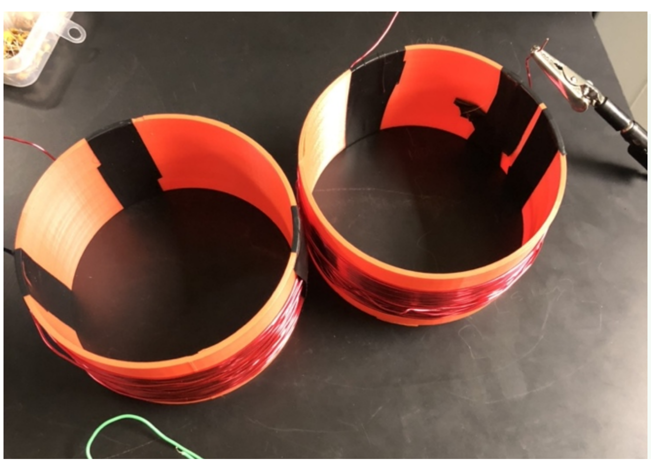
ECE 4800 project 2 explored the concepts of magnetic coupling, an important mechanism allowing for the implementation of wireless power transmission (WPT). This project details the theoretical and practical measurements relevant to magnetic coupling between two hand-made coils. WPT plays an ever-growing and significant role in the efficient charging of a wide range of devices, from cellphones to medical implants and even electric vehicles.

The project comprised two main parts. Part A involved constructing and analyzing two circular coils, focusing on their resistance, inductance, and mutual inductance at various distances, to demonstrate the dynamics of magnetic field interaction. Part B extended this exploration into a practical circuit application, demonstrating resonance and power optimization in a wireless transmission setup.

This report outlines the methodologies employed in creating the coils and circuits, presents detailed experimental findings, and compares these results with theoretical predictions. Through this investigation, I gained valuable insights into the principles of magnetic coupling and wireless power transmission.

Methodology, Set-Up, and Results:

The first task was to build the matched coils, according to the specifications provided. Using two identical 3-D printed cylinders and 20-gauge copper wire, I created two coils, as similar as I could. Each coil had a radius of .05 meters and a length of .052 meters. Each coil had 30 turns. It is worth noting, however, that to increase the inductance of each coil, I shifted the turns of wire much closer to one another. The actual length of the copper wire turns was approximately .023 meters.



radius of coils in METERS

$$\frac{\left(3+\frac{14.5}{16}\right)}{2}\cdot .0254=0.05$$

length of coils in METERS:

$$\left(2+\frac{1}{16}\right)\cdot .0254=0.052$$

The following two figures show the measurements being made:

Theoretical Inductance based on given parameters:

Theoretical Value of Inductance for each of our coils:

$\mu := 4 \cdot \pi \cdot 10^{-7} \cdot \frac{H}{m}$ $\qquad N := 30$ $\qquad r := .05 \cdot m$

$a0 := \frac{0.0320}{2 \cdot 39.3701} \cdot m = \left(4.064 \cdot 10^{-4}\right) m$

$L_T := \mu \cdot N^2 \cdot r \cdot \left[\ln\left(\frac{8 \cdot r}{a0}\right) - 1.75 \right] = [0.0002907666]\ H$

This is approximately 291 microhenries of inductance per coil.

In the project 2 guidelines, I was provided with the following formula for estimating the inductance of a cylindrical coil. The above image shows that the theoretical value of inductance for a coil with the specified radius and gauge of the wire was estimated to be 291 microHenries.

Experimental Inductance Value:

The inductance of the coils was experimentally determined in the same way as for the inductance of the inductors in project 1, using this set-up shown in figure 5. The DC resistance of the coils and the resistor used were also measured beforehand.

Resistance of Coil 1 (Ω):	.493
Resistance of Coil 2 (Ω):	.475

Test Resistor: 49.912 Ω

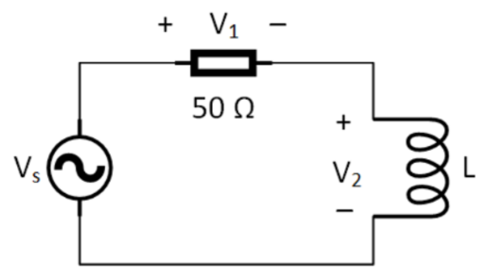
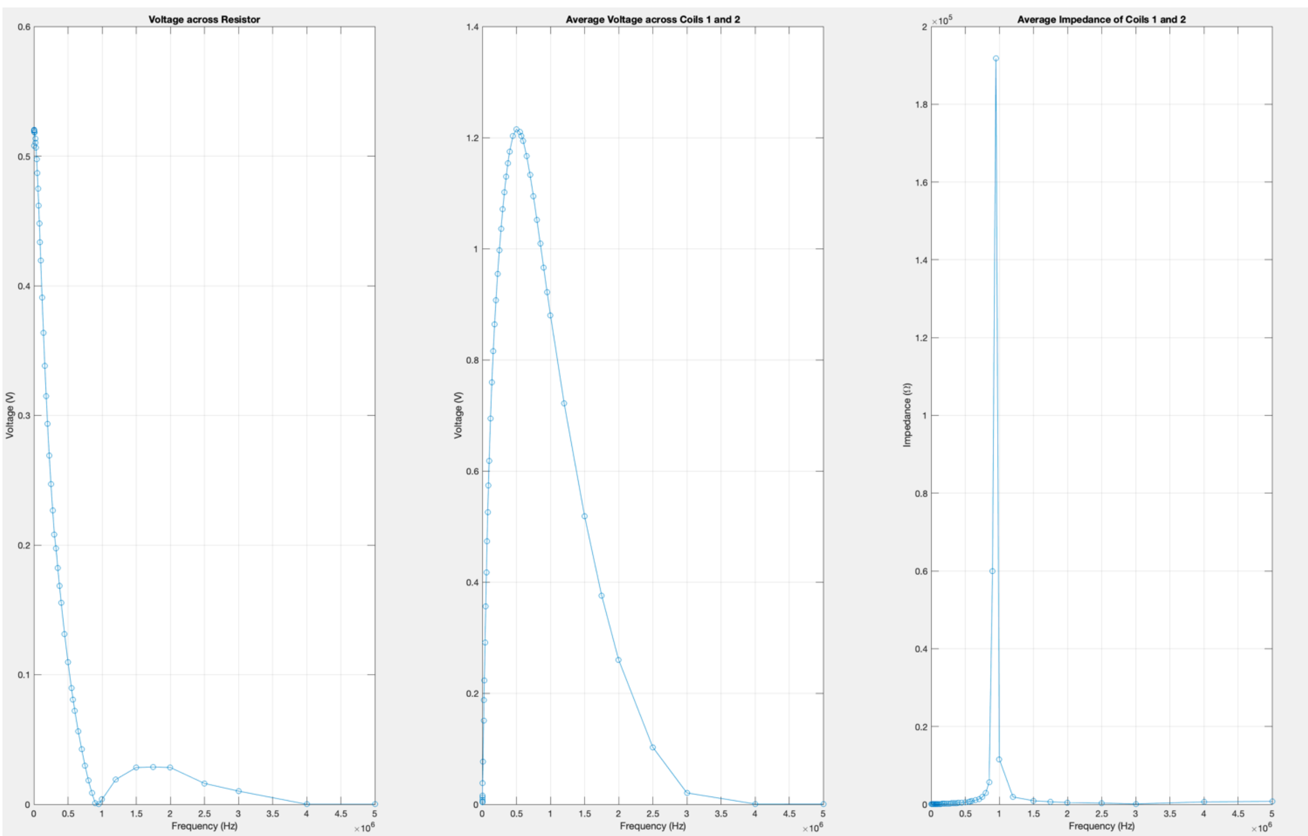


Fig. 5: Measurement of an inductance.

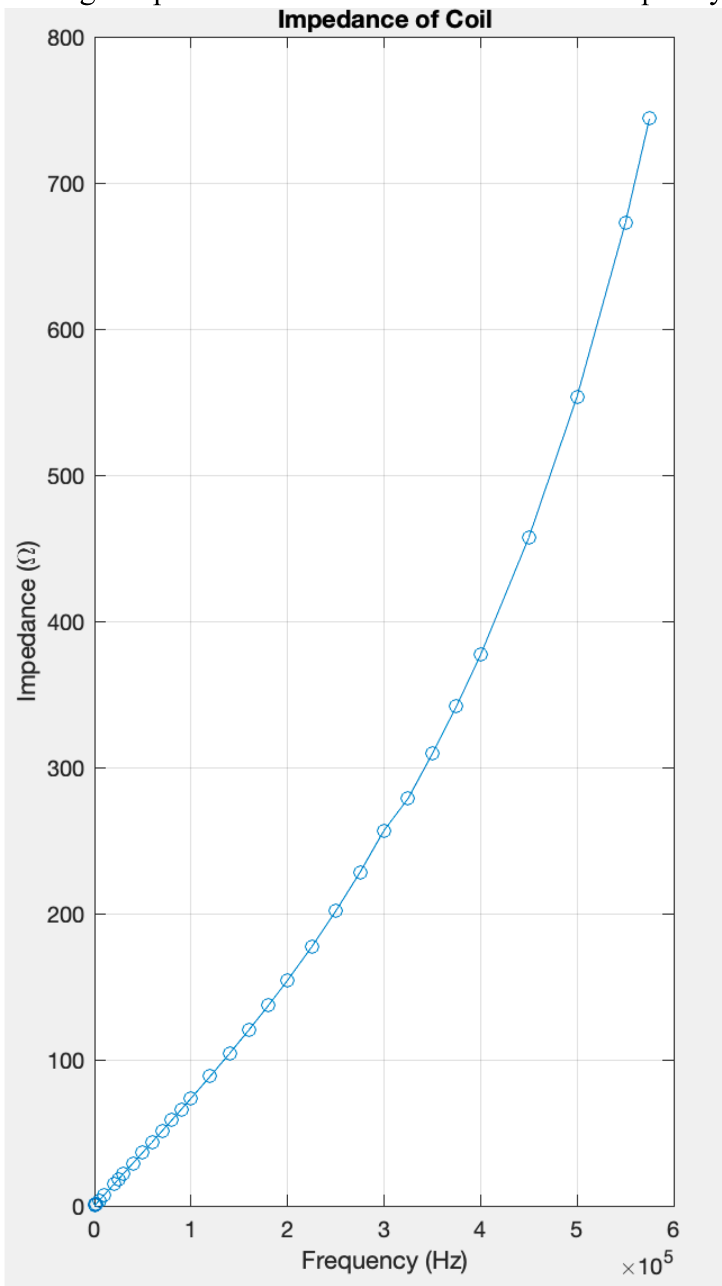
This was done for both coil 1 and coil 2. The voltage across the 50-ohm resistor was measured to deduce the current across the circuit, and the voltage across the coils was measured to determine the impedance of the inductors, as a function of frequency. These values were averaged (as they were identical for both coils) and plotted.



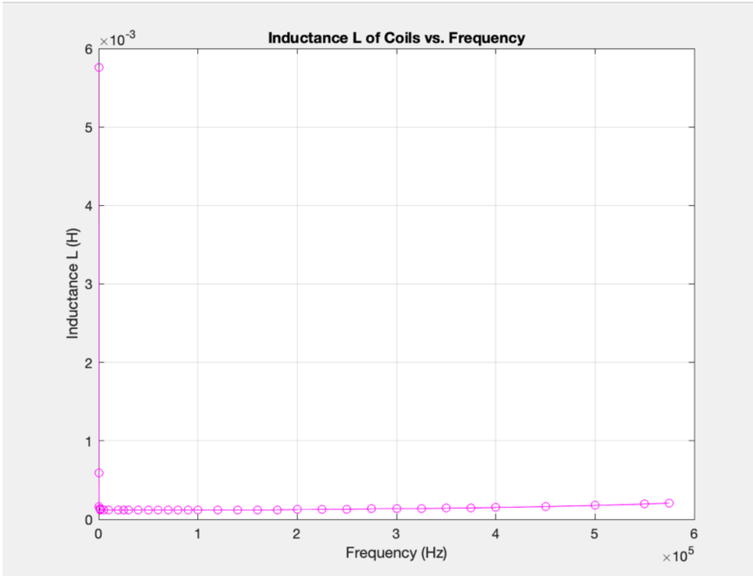
As can be seen from the third graph above, there appeared to be resonance in the coils at approximately 1MHz.

Now, this analysis was repeated for frequency values between 10Hz-600kHz, to show the linear relationship between impedance of the coils vs. Frequency. Then, to calculate the average experimental impedance of the coils, I calculated the following: `L = Z ./ (2 * pi * frequencies).` The results of this calculation shown the constant impedance of our coils.

Average Impedance of Coils as a Function of Frequency:



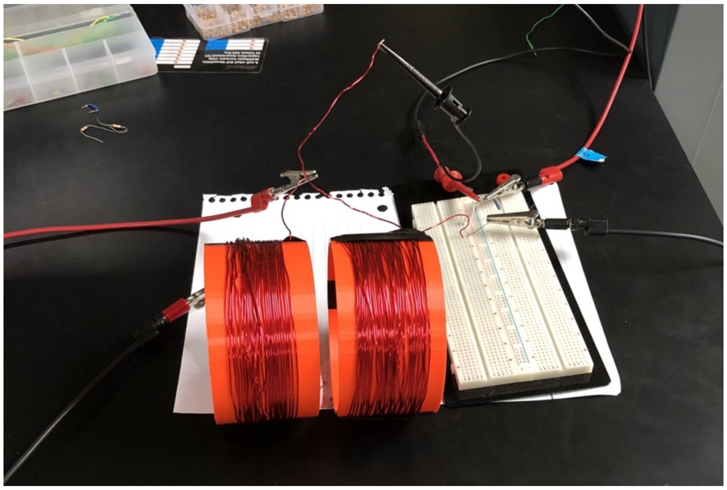
Average Inductance of Coils as a Function of Frequency



We can see that within these frequencies, the coil's experimental inductance stays steady. The experimental average impedance for the two coils was 169.43 microHenries. As mentioned, due to the horizontal length of the inductors and the spacing between the turns, the experimental measurement of inductance was significantly lower than the theoretical value.

Measuring and Calculating Mutual Inductance:

The next step in our experiment was to measure the mutual inductance between the two coils. A 1V amplitude sinusoidal signal was applied to a 50-ohm resistor in series with coil 1. The 2nd coil was then placed at varying distances from the first coil, and the voltage across the 2nd coil was measured. This was repeated for both coils. The image below shows this being done in the lab. The following tables summarize the experimental results for experimental M1,2 and M2,1.



The following formula provided to us was used to calculate M1,2 and M2,1:

$$M_{21} = V_2/(\omega I_1);$$

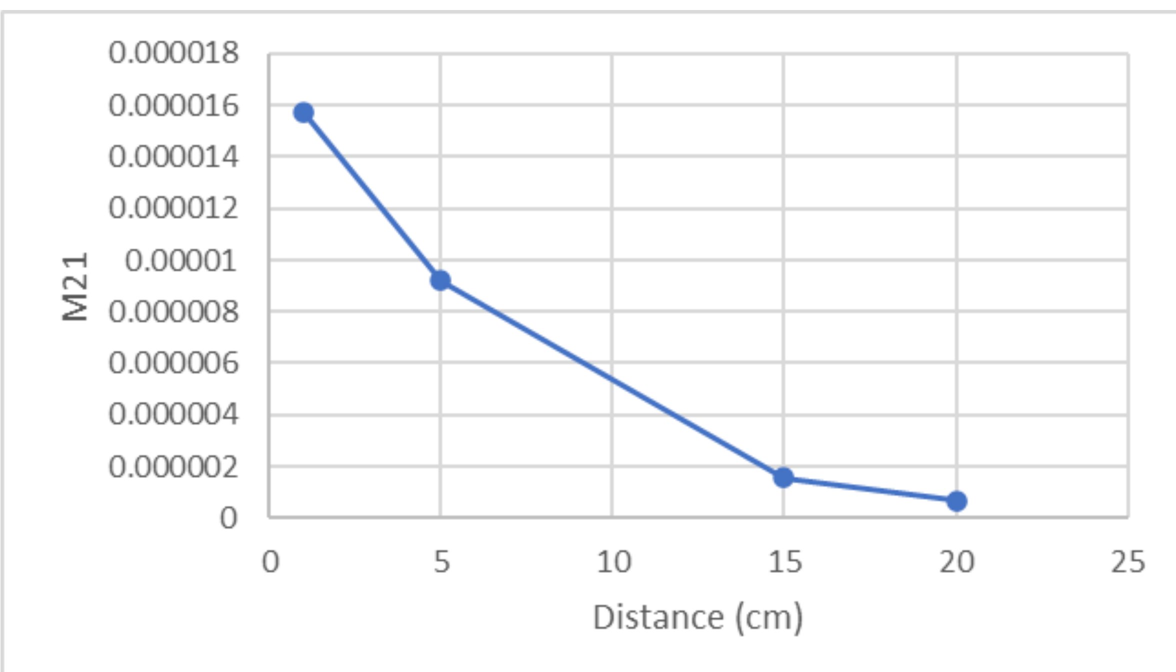
By measuring the voltage through the resistor in series with the coil, I1 was calculated. The frequency in Hertz was converting to radians per second, and the voltage across the open coil was used as V2.

Coil 1 connected to Signal Generator:

300kHz sine wave of 2vpp (1V amplitude)

Distance (cm):	Coil 2 Voltage (mV):	50 Ω Resistor Voltage (mV):
1	90.683	152.731
5	53.135	153.09
15	9.157	154.893
20	3.940	154.979

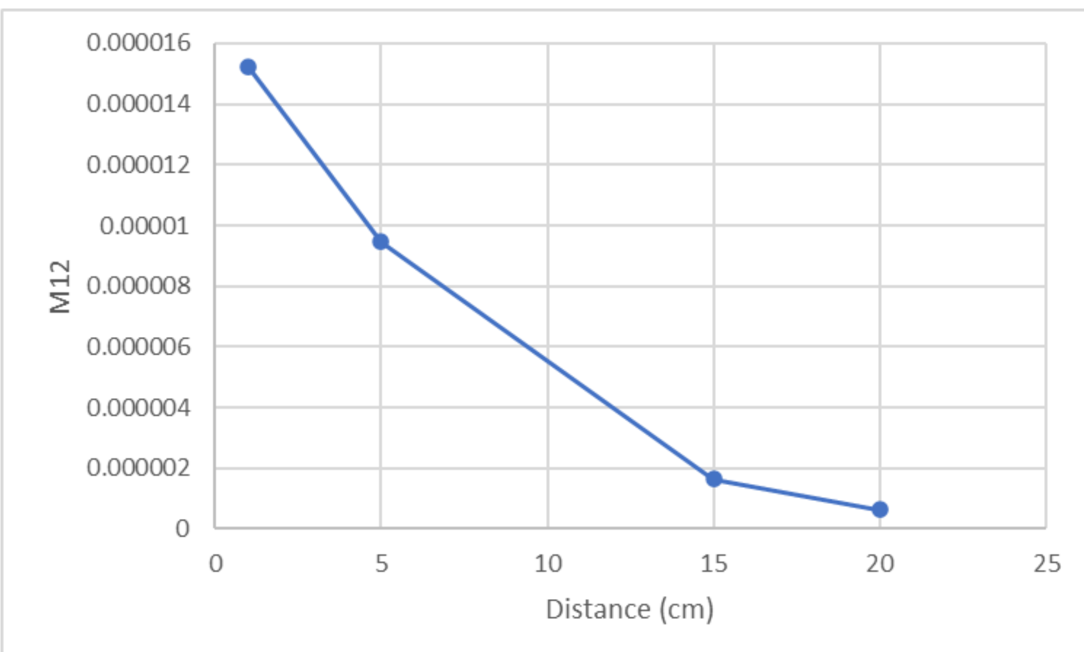
Current of Coil 1 (mA)	M21
3.06000561	1.57218E-05
3.06719827	9.19047E-06
3.10332185	1.5654E-06
3.10504488	6.73174E-07



Swapping Coils (Coil 1 receiving wireless)

Distance (cm):	Coil 1 Voltage (mV):	50 Ω Resistor Voltage (mV):
1	98.353	171.122
5	61.491	172.156
15	10.693	171.917
20	4.175	171.918

Current of Coil 2 (mA)	M12
3.42847411	1.5219E-05
3.44919058	9.45787E-06
3.44440215	1.64697E-06
3.44442218	6.43041E-07



As we can see from our above results, the mutual inductance for our coils was maximized when the distance between the two coils was smallest, 1 centimeter.

Part B:

Calculating Capacitor Value For Resonance:

Using the measured value of M from Part A, the resonant frequency ω was calculated. This frequency was then used to determine the value of the capacitor as shown below.

$$M := 1.57218 \cdot 10^{-5} \qquad L := 169.43 \cdot 10^{-6}$$

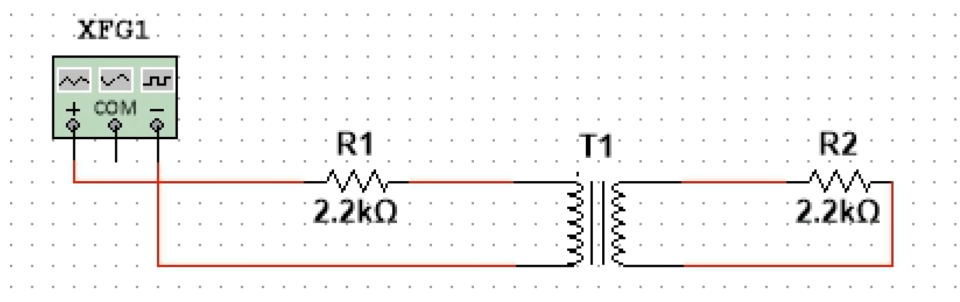
$$R_L = R_S = 50 \cdot \Omega = \omega \cdot M \qquad \omega := \frac{1}{\sqrt{L \cdot C}}$$

$$\omega := \frac{50}{M} \rightarrow 3180297.4214148507168$$

$$C := \frac{1}{\omega^2 \cdot L} \rightarrow 5.835448155344390075 1\cdot 10^{-10}$$

However, this capacitance value was quite small, and the resonant frequency was very, very large! So what I chose to do was to remove the capacitor altogether and try and approximate the frequency where the coils experienced resonance by sweeping the frequency provided by the function generator.

The following circuit was constructed to experimentally measure maximum power transfer around the resonant frequency (This is a model of the physical circuit used in the lab):



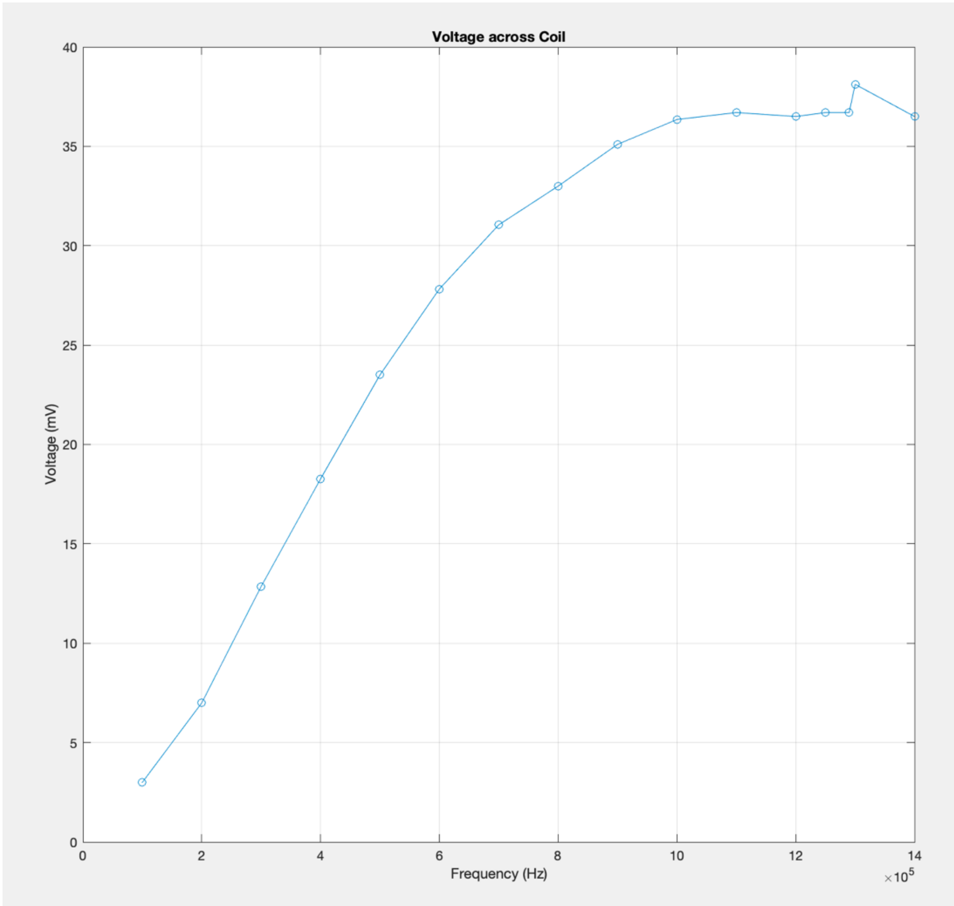
For the values of R1 = R2, several resistance values were tested in attempts to tune the resonant frequency.

When 100 Ω was used, the resonant frequency was approximately 195 kHz.

When 500 Ω was used, the resonant frequency was approximately 225 kHz.

When 2.2 KΩ was used, the resonant frequency was approximately 1.3 MHz.

The result for this resonant circuit, for when R1=R2 = 2.2kΩ is provided in the figure below.



Conclusion:

In conclusion, this exploration into magnetic coupling has yielded a deeper understanding of its principles and practical applications. The findings and experimentation emphasized the importance of how to design the coil, distance between coil turns, and the importance of resonant tuning in optimizing wireless power transmission. This project helped reinforce the theoretical principles of magnetic field measurement we've studied during this second half of the semester and offered a glimpse into the vast potential into more real-world applications regarding these subjects we have studied in ECE 4800. As technology evolves, the knowledge gained from this project will be a valuable foundation for understanding the scope of many industries advancing wireless power applications.

Thank you!