

# **Design and Testing of Wireless Power Transmission**

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In 1888 Nikola Tesla envisioned the Tesla Coil. This system allowed for the wireless transmission of energy. A small-scale prototype of the Tesla Coil has been created and can be used with low power-draw devices, such as an LED. The Tesla Coil utilizes resonance to achieve greater distance than our current near field devices. This study will analyze the importance of resonance and the observed results of the wireless power transmission capabilities of the prototype device.

Nikola Tesla patented his “System of Transmission of Electrical Energy” (U.S. Patent No. 645,576) on 20 March 1900.<sup>1</sup> This patent begins by explaining that a gas such as air has insulating properties and can be considered a true conductor. Although this conductor is high in resistivity, it can be concluded that air and other gases with similar properties can be used as a viable medium for the transmission of electrical energy. Nikola Tesla then uses this concept as the main idea for his apparatus. His design involves a transmitting device and a receiving device. The transmitting device consists of a generator, which will send current through a primary coil with one end connected to ground and the opposite end connected to the generator. A secondary coil is located at the center of the device and is also connected to ground on one end and a conducting rod on the opposite. The primary coil wraps around the secondary, forming a spiral into the center of the base in the shape of a pancake. The current is then directed through the conducting rod to a spherical load which will discharge electromotive forces after reaching a particular electrical surface charge density. A similar device is used as the receiver. The receiver consists of coils which mirror those of the transmitter and its pancake shape. The receiver is connected to devices such as a motor or light through its primary coil that will then make use of the received current. His design can be found in Figure 1.

Tesla created this device with the mind set of powering entire households and companies. The electrical companies did not like this idea because they could not monitor and charge for the amount of energy received. If Tesla would have succeeded in his ventures, the world would be an entirely different place. More than a hundred years later, we finally see the potential that this device would bring. However, Tesla's global scale might not be reached anytime soon, but a smaller, more portable device could be marketed. One could set up a transmitter in a room and plug in a receiver into whatever device they wish to be charged.

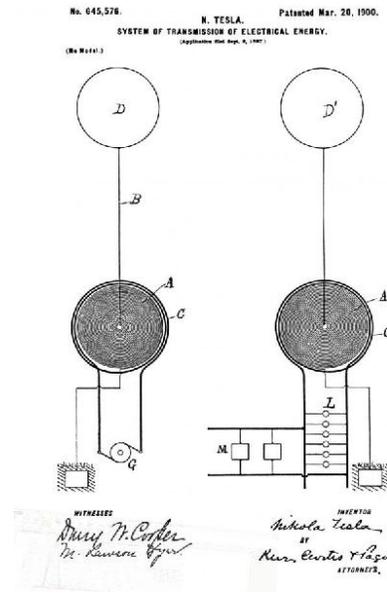


Figure 1: Tesla's Patent<sup>1</sup>

The design that we shall use institutes the same theories of Tesla's concept with some modification of proportions and the differentiation of the primary and secondary coils. The primary coil is helical. This will raise the top of the primary coil closer to the top load and increase the coupling between the secondary and primary coils. This shape also maximizes the effect of Faraday's Law increasing the flux passing through the primary and secondary coil. The secondary coil encompasses the insulated rod until it reaches the spherical load. The transmitter and receiver are approximately 20 cm in length and width and 45 cm in height. The transmitter operates within the range of 1-10 V and receives power through a function generator. The transmitter can be used to power a LED or any other low-power device. The setup can be seen in Figure 2.

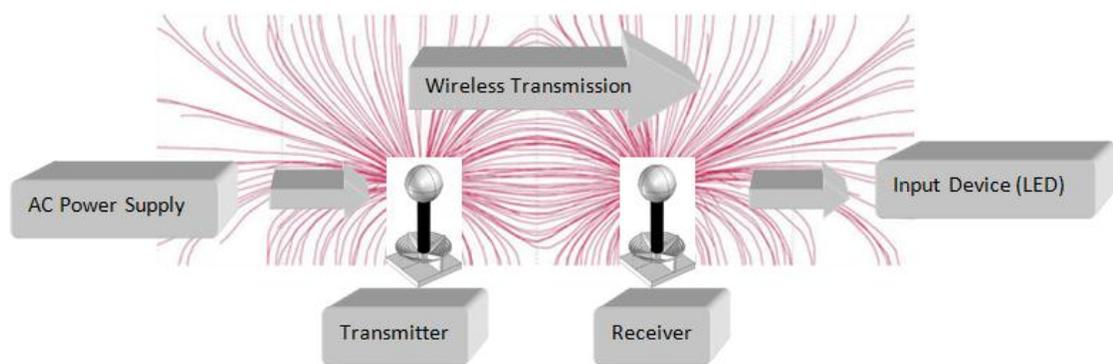


Figure 2: Design Setup

Used to produce very high voltages ( $\sim 200\text{kV}$  on top) at high frequencies ( $\leq 500\text{ kHz}$ ), the Tesla Coil is a resonant air core transformer. While input and output voltage ratios of conventional transformers are strictly mandated by their turn ratios and their magnetic fields directed along the iron cores, Tesla Coils work based on Resonance Phenomena.

Tendency of a system to oscillate at greater amplitude at some frequency than others is called Resonance Phenomena, and the frequency that this tendency occurs is called resonance frequency. Resonance is what allows for a much greater distance to be achieved when transmitting power. A good example to explain Resonance Phenomena would be to look at sound. Sound oscillates at different frequencies. Figure 3 shows the difference in these frequencies.

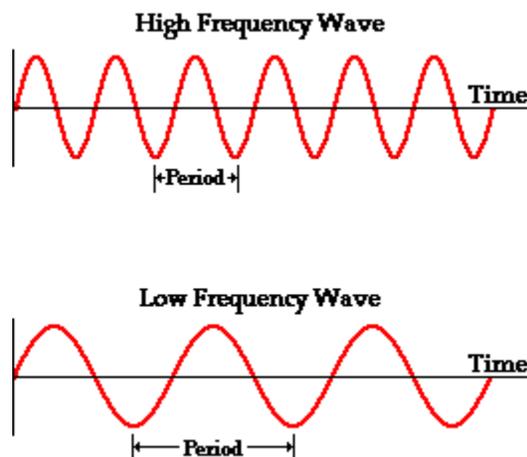


Figure 3: High and Low Frequency Waves<sup>2</sup>

The physical properties of an object, such as that of a trombone, will determine the resonance frequency of the object. For those who are unfamiliar with a trombone, a trombone is a musical instrument that is played by blowing air through the horn and adjusting a large tuning slide to change the pitch. When the slide has not been moved and is at a position closest to the horn, i.e. the trombone is at its smallest, the frequency will be higher. When the slide is moved away from the trombone, i.e. the trombone becomes larger, the frequency will be lower and therefore the trombone will resonate at a different oscillation.

However, this process of wireless power transmission requires both a transmitter and a receiver. Because of this, let's look at two trombones. If both trombones are playing with their slides closest to the horn, then their sound will be maximized becoming louder because they are playing the same note, or better put their horns are resonating at the same frequency. If one trombone stays in its original position while the other begins to move their slide down, the two frequencies will begin to clash making an unpleasant sound, or playing out of tune. Now when the slide is moving down it will eventually play a note that sounds good with the other trombone. While the trombones are resonating at different frequencies, the peaks will begin to fall in line with each other. This is the reason the notes sound good, because the frequencies lay in the same harmonic. This is demonstrated in Figure 4.

The receiver tesla coil will resonate at a particular frequency based on its physical properties as demonstrated above. The calculated resonance frequency was about 477.4 kHz. This was found using the following equation:

$$f = \frac{c}{4L}$$

With  $c \approx 3 \times 10^8$  m/s and  $L = 157.1$ m

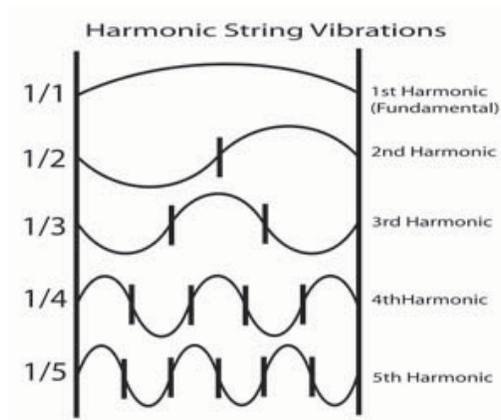


Figure 4: Harmonic Alignment<sup>3</sup>

The resonance frequency was found experimentally to be about  $675 \pm 1$  kHz. This gives a percent difference of about 34%. Just as before when the second trombone moved their slide further, the transmitter is adjusted by changing the input frequency from the AC generator. By adjusting the frequency the resonance is changed until the voltage being received is at its peak. This is the frequency at which the transmitter is resonating. As the trombones began to play notes at different frequencies, chords began to form at different harmonics. Just as in this case, the tesla coils will have peaks at different harmonics as well. Figure 5 shows the range of harmonics for the transmitter and receiver while powering a LED. The following Figures are found at a distance of 1 meter.

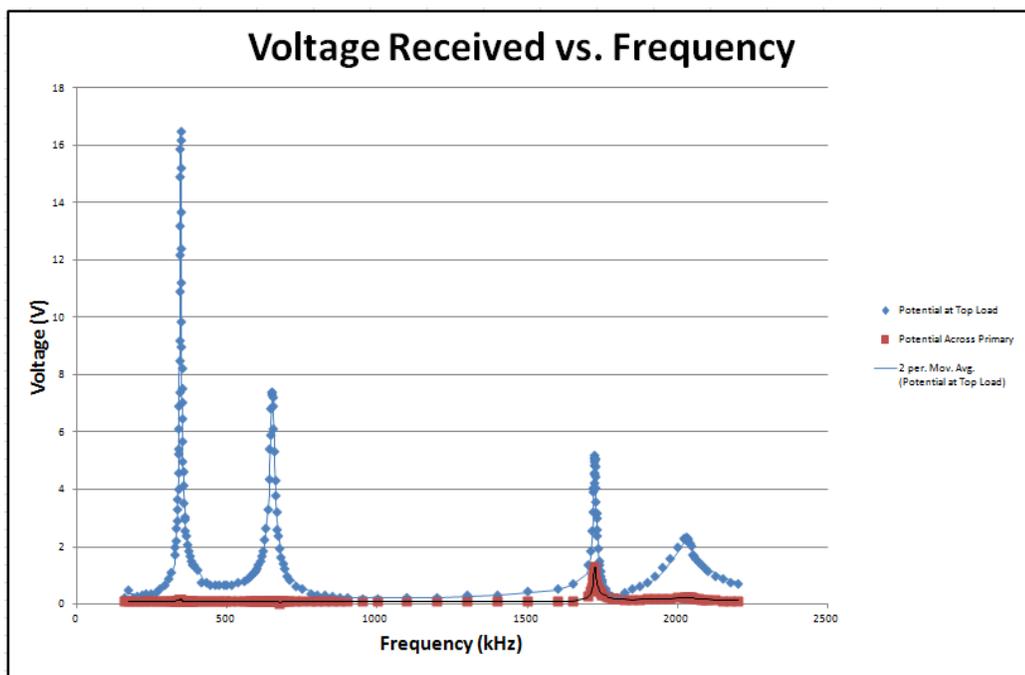


Figure 5: Voltage Received Across Top Load and LED

The first set of data consists of the values for the voltage that is received across the spherical top load; the second is the voltage across an LED.

It is important to look at the voltage being transmitted, but we must look at power to consider the effectiveness of transmission. Energy transmission has been around for quite some time. If you have a radio, television or a computer, than you have a wireless energy device. Radio waves, television broadcasting and the internet are all energy and are transmitted by large towers to be received by our devices. It is the ability to send and receive power that sets tesla coils apart from these other devices. Figure 6 shows the power received while using a 56.5  $\Omega$  load resistor.

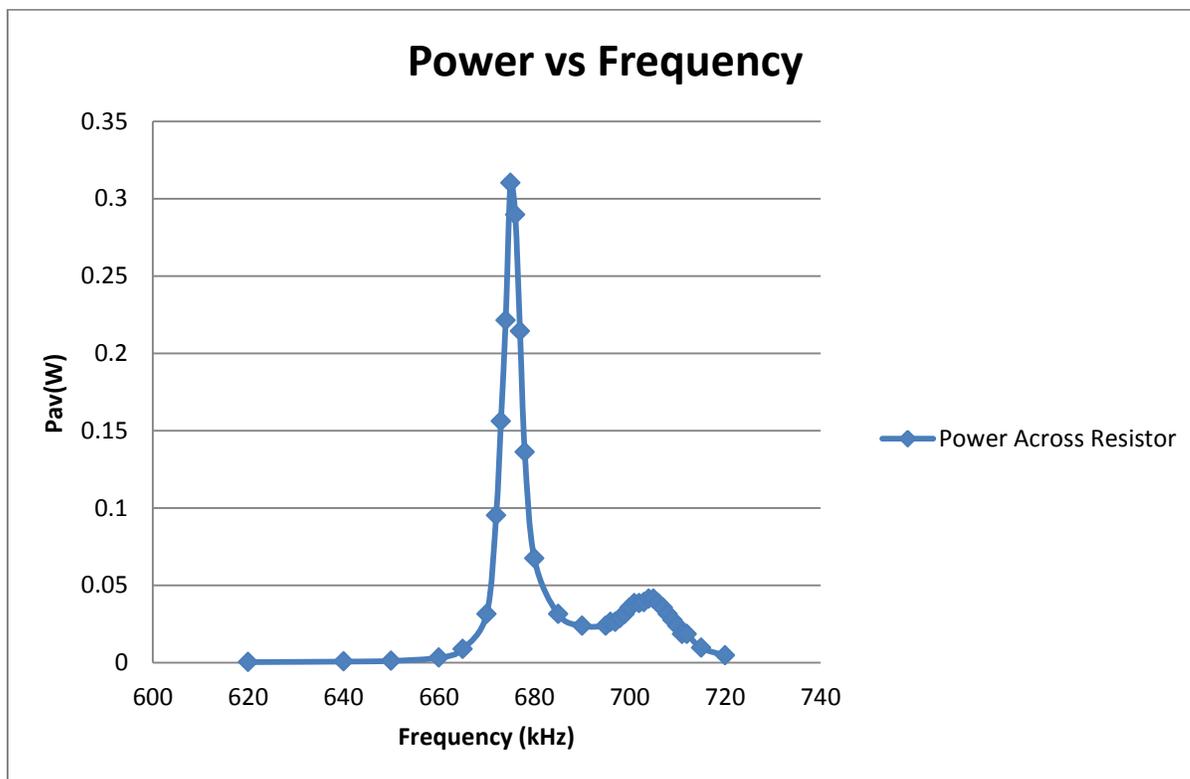


Figure 6: Plot of Power Test 1

The results had a maximum power of  $0.32 \pm 0.05$  W. The power curve follows the same curvature as its voltage counterpart. This is evident by viewing Figure 6 and Figure 7. As one might assume, if we consider the relationship between power resistance,

$$P = \frac{V_{rms}^2}{R},$$

then it becomes evident that as the resistance changes, so will the power. Figure 8 verifies this conclusion by using a 12.5  $\Omega$  load resistor. The voltages found are relatively consistent, remaining about  $6 \pm 1.5$  V. However the power is much different. The peak power for the second test gave a result of  $2.5 \pm 0.5$  W.

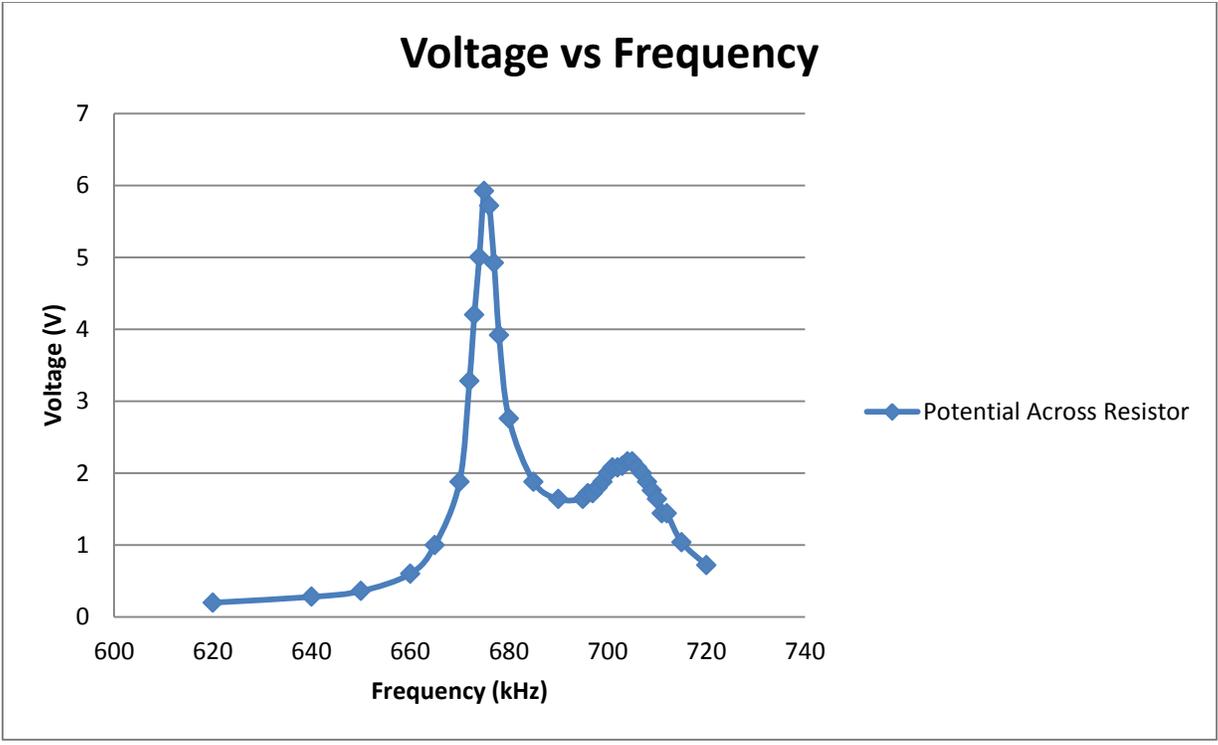


Figure 7: Potential Across Resistor From Power Test 1

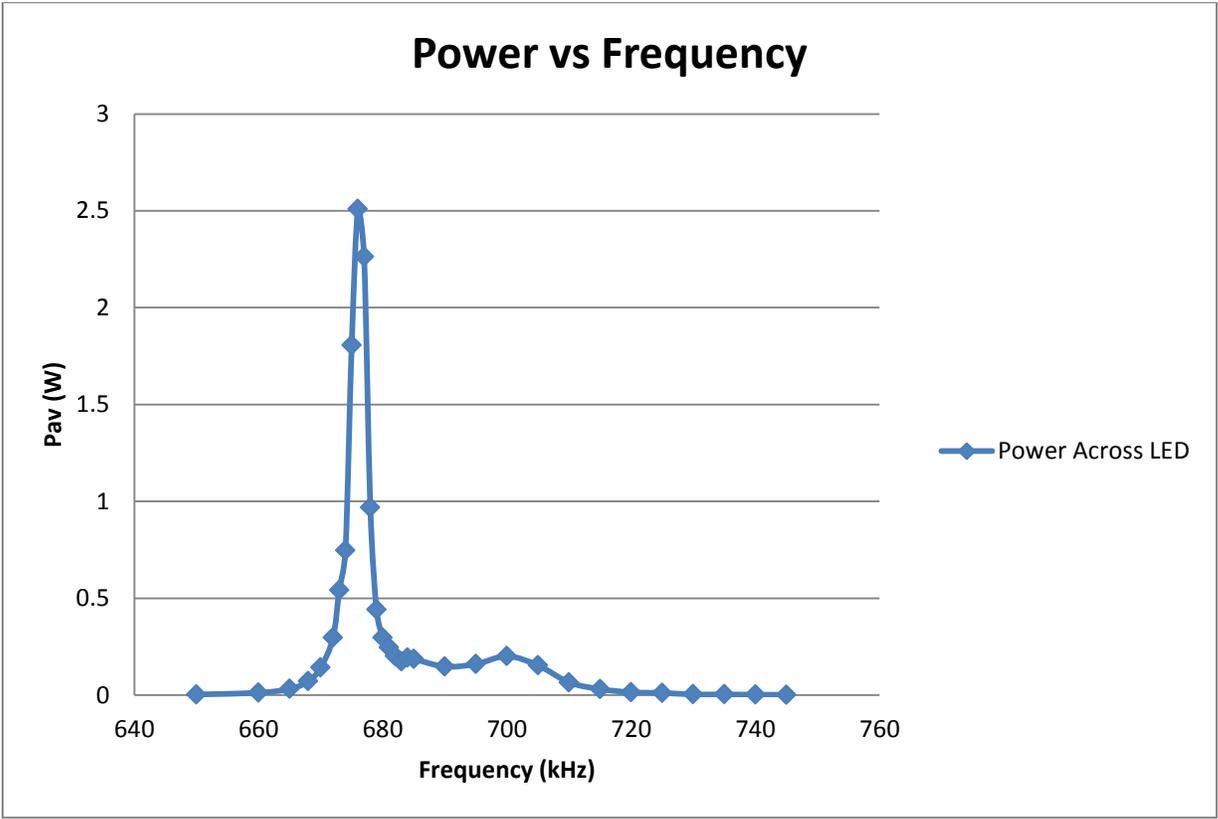


Figure 8: Plot of Power Test 2

Nikola Tesla stated in The People's Forum in 1905 that "as long as the oscillation through the earth between the transmitter and receiver is kept alive the transmission can take place at an efficiency of 99.5%." This statement seems rather high considering the calculated efficiency for this experiment was about 8.4%. However this leads to the conclusion that if the earth is being used to resonate then the efficiency is drastically increased. The effectiveness of the tesla coils is reduced because much of the electromagnetic field being transmitted is dissipated and only a small amount is being used to induce current. Modifications could be made to oscillate the earth or the surroundings of the tesla coil to match its resonance frequency and increase the efficiency to meet a viable goal of usage and the original thought of Nikola Tesla.

## **Bibliography**

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## **Biographical Information**

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