

# Magnetic Resonance used in Wireless Power Transmission

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## Introduction:

As early as the beginning of the 20<sup>th</sup> century, Nikola Tesla foresaw the immense advantages of wireless power transmission. Much of his work in this field was spent trying to develop a means to transmit large amounts of power over great distances without the use of an electrical grid. Sadly his work went unfinished due to a number of technological and financial obstacles [1]. Within the past few decades, the foreseen benefits of wirelessly powering items like laptops and cell phones has brought a renewed focus to wireless power transmission. The basis for our experiment used coils designed by former Cornell College graduates, Lucas Jorgensen and Adam Culberson (Class of 2008) [2]. Their design was modeled after a paper published by a MIT research team in 2007.

## Theory of Experiment:

The foundation of our experiment revolves around a means of safe efficient power transfer. The most significant difference between Tesla's original wireless system and ours comes from our emphasis on magnetic resonance. Tesla's initial experiments involved Tesla coils that would radiate power omnidirectional using electric fields. This antenna-like form of radiative transfer is ideal for transmitting information; however, when used as a means of power transfer its efficiency is minimal. Another substantial drawback to his design was the large electric fields that were radiated. These radiated electric fields can interact with organic matter resulting in many safety hazards. With this in mind, the overall goal of our project was to examine the use of magnetic resonance as a means for wirelessly transmitting power safely and efficiently.

Resonance is the tendency of a system to oscillate with greater amplitude at some frequencies than at others [3]. The term magnetic resonance evolves from this definition. Magnetic resonance occurs when the oscillating waves of the system are magnetic waves. This is the center for creating an efficient and safe wireless system.

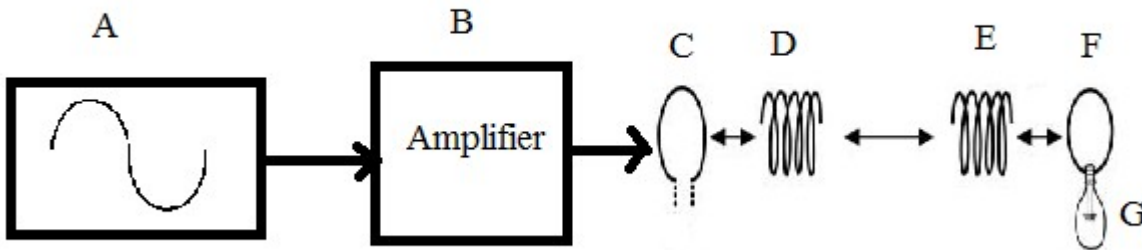
In theory and practice, you can produce magnetic waves by sending a current through a coil of wire. These magnetic waves are known as evanescent waves because they oscillate with respect to time, but their amplitude decreases exponentially with distance [4]. This was proven at low powers in an experiment conducted previously at Cornell College. Their results can be seen at the following link: <http://www.cornellcollege.edu/physics/courses/phy312/Student-Projects/Magnetic-Resonance/Magnetic-Resonance.html>. By utilizing these evanescent magnetic waves as our means for transmitting power, we should in theory be able to increase the efficiency of our system. This is due to the fact that most off-resonant environmental objects

will cause little to no power interruption [5]. The employment of evanescent waves will also allow energy to be transmitted from one object to another without a direct line of sight [6].

### Experimental Design:

Our experimental design is based off work that was performed in a previous experiment conducted by a research team at MIT and work done at Cornell College. Figure 1 below illustrates the basic outline for our system. Object A represents our high frequency oscillator. The Cornell College experiment used a signal generator to achieve a signal, but we chose to create our own oscillating circuit and try to use it. Object B is representative of our signal amplifier. This is the largest difference between our research and the research done by the previous experiment. By including a signal amplifier in our system, we should be able to amplify the amount of power that is transmitted. This is crucial for conduction tests at high power. From the amplifier the signal is then dumped into object C which acts as a driving antenna. This transmitting antenna is located at the top of the transmitting coil, object D. This allows for the resonate frequency to pass from the transmitting antenna to the transmitting coil. When the transmitting coil begins to resonate it generates the evanescent resonate waves. Object E, the receiving coil, will pick-up these waves. However, this will only happen if the receiving coil is designed to have the exact same resonant frequency as the transmitting coil. From the receiving coil, the signal is then passed to the receiving antenna, object F. The receiving antenna will then pass the signal on to the load, object G.

Figure 1



Objects C through F were provided to us by the previous experiment conducted at Cornell College. The specifications for the antennas and coils are as follows:

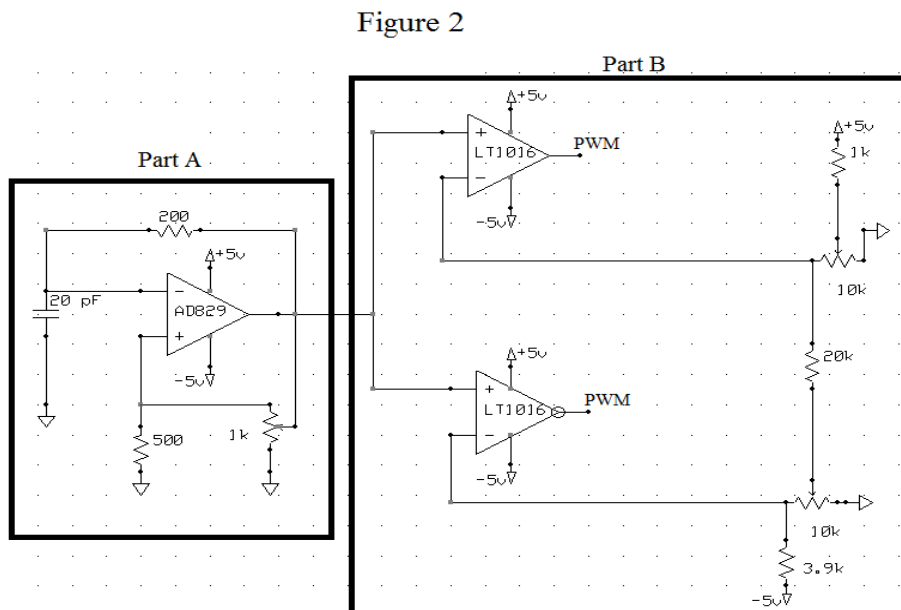
The signal generated is put into our driving loop of 10 gauge wire. The loop is just smaller than our primary coil (approximately 55.5 cm in diameter).... Both the primary coil and the secondary coil are made of copper tubing that is 1/4 inch inner diameter (3/8 inch outer diameter). The coils use 60 feet of tubing each, and have about 10 turns (57.5 cm in diameter). [7]

It is essential that both coils be as close to these specifications as possible in order to achieve similar resonant frequencies. The previous experiment showed that these coils had a resonate frequency of 4.8 MHz to 5.3 MHz [8].

### Oscillator Design:

The first major task of our experiment was to create a stable high frequency oscillator. We tried several circuit designs to achieve this goal. The most stable oscillator that we created was a simple design using a single AD829 op-amp. This design can be seen in Part A of Figure 2 [9]. This design was ideal for our task because it gave a fairly symmetric signal and was stable. The only drawback that resulted from using this circuit is that the signal was not a perfect sine wave. At around 1.6 MHz (the lowest allowable frequency in our circuit), we had a square wave output. However as we increased the frequency our output began to change from a square wave to a sine wave. At 9.6 MHz (the maximum frequency our circuit would allow), the signal is a fairly ideal sine wave. It should be noted that the minimum and maximum frequency are measured when only an oscilloscope is hooked to  $V_{out}$ . These frequencies will vary slightly depending on the resistance and/or impedance of the load. Also the amplitude of our signal changes from high to low as the frequency is increased.

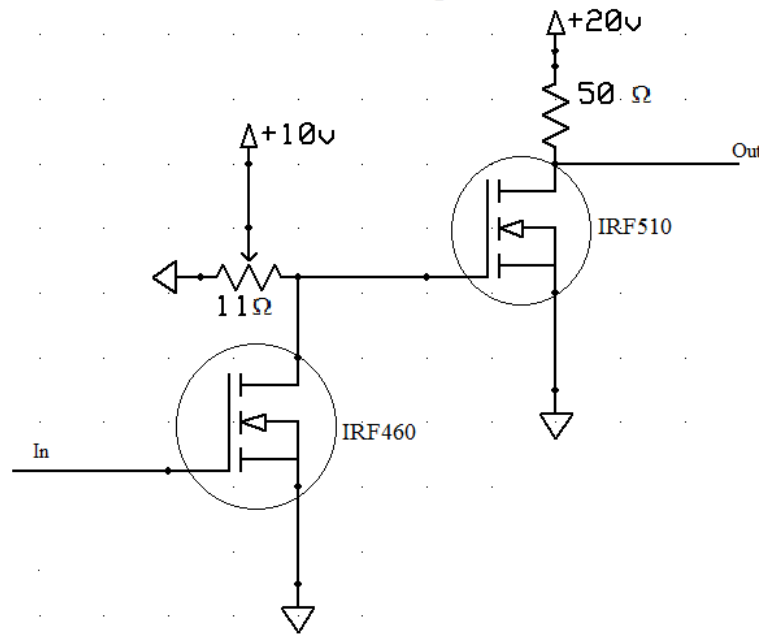
We were able to alleviate the changing signal and varying amplitude by expanding our oscillator. By running our signal through LT1016 comparators, we were able to transform our signal into a pulse signal. These pulses go from 0 volts to positive 5 volts regardless of the frequency. In order to control the width of our signal, we utilized a simple voltage divider. This allowed us to control the dc reference voltage that tells the comparator when to transmit high signal and when to transmit low signal. This is known as pulse width modulation (or PWM). This expansion can be seen twice in Part B of Figure 2. The first comparator gave us one set of pulses in which we could adjust the pulse width using the first 10k variable resistor, and the second comparator gave us another set of pulses that we could adjust the pulse width using the second 10k variable resistor. The signals from the first and second comparators are inverses of one another. This means that while one is low the other is high and vice versa.



### Power Amplifier Design:

The second major task of our experiment was to create a power amplifier that was capable of dumping watts of power into our transmitting antenna and coil. This step proved to be one of the most difficult steps within our experiment due to the nature of high frequencies. We were successful however in creating a simple class-d (on/off) power amplifier. A class-d amplifier is an amplifier that switches a signal from positive voltage to zero to positive voltage. This circuit can be seen in Figure 3. Our oscillation signal is put into an IRF460 mosfet which acts as a switch on the 10 volt power supply. The input signal will cause the IRF460 to switch on/off at the same frequency that is input into the gate. This signal was then used to switch on/off an IRF510 mosfet which acts as a switch on the 20 volt power supply. By cascading the IRF460 and the IRF510 in this manor, we protect our oscillator from having extreme amounts of current pulled from it. It should be noted that the input signal going into the first mosfet needs to have significant enough current to trigger the IRF460 on/off at high frequencies. Due to time constraints, we were unsuccessful in driving our amplifier with our oscillator circuit. This problem arises because we are not getting enough current at the correct signal from our oscillator. In order to remove this issue, we used a signal generator that would allow us to drive the IRF460 with enough current and the correct signal.

Figure 3



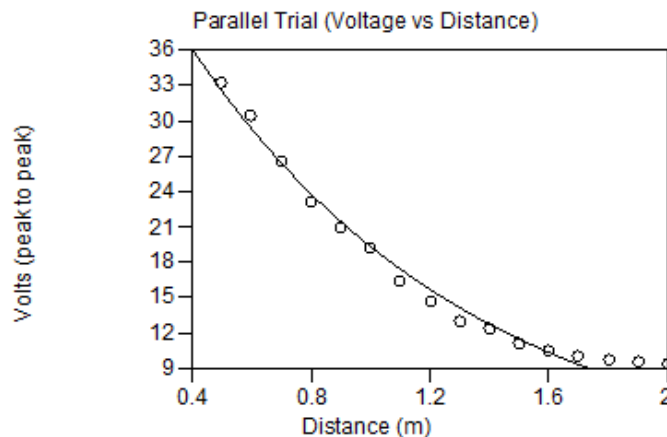
## Results:

All major results that we got from our circuit involved a signal generator switching the IRF460 of our amplifier on and off. The IRF460 was powered with positive 10 volts and the IRF510 was powered with between 15 volts and 30 volts.

Our first test involved an LED hooked to the receiving coil. Our goal with this test was to be able to transmit enough power to burn out the LED. This test was successful on the first attempt with only 10 volts powering the IRF510. Our next test involved a 40 watt evanescent light bulb hooked to the receiving coil. By hooking this bulb to the coil, it slightly altered the resonant frequency of the receiving coil. When the signal generator is tuned properly and with 10 volts powering the IRF510 we were able to light this bulb dimly. In order to increase the brightness of the bulb, we slowly increased the power supply voltage to the IRF510. You can visibly see the bulb get brighter. This demonstrated that our class-d amplifier was amplifying the signal correctly. The luminosity of the bulb was also affected by separation between the coils. As the coils were closer together the bulb was brighter than at larger separations. We also demonstrated that these types of coils would be ideal for household use by placing objects between the coils and observing that they don't affect the brightness of our bulb. A direct line of sight between the two coils was completely removed using both cardboard and wood. These steps were successfully repeated using another 40 to 60 watt light bulb.

In order to illustrate that we are utilizing evanescent waves, we took measurements of the peak to peak voltage across the receiving coil using an oscilloscope. Our measurements started with a .5 meter separation between the coils and increased by .1 meters until we reached a separation of 2 meters. We supplied 20 volts to the IRF510 portion of our amplifier. The results of this test can be seen below in Figure 4. Our data is illustrated by the points, while the line illustrates an exponential decay curve. The graph plots voltage verse distance and demonstrates that we are utilizing evanescent waves. However because this is only voltage measurements it doesn't conclusively illustrate that power will decay exponentially.

Figure 4

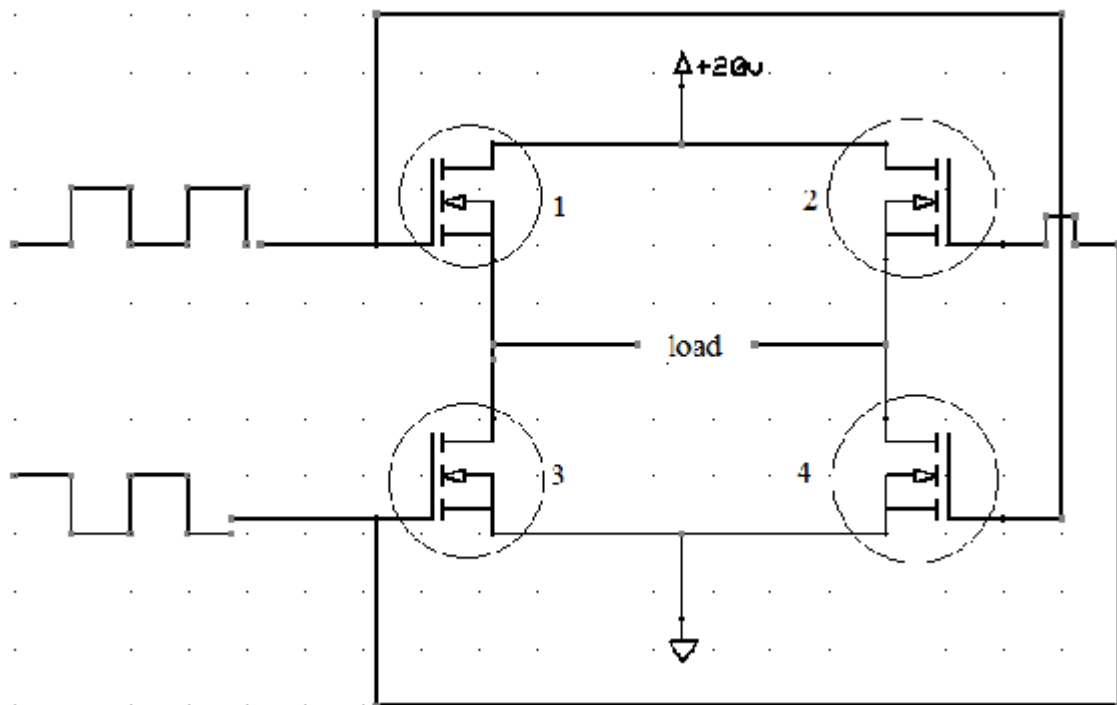


### Future Work:

There are several areas where people can expand on our experiment. The first would be to take measurements to conclusively illustrate an exponential decay for power verses distance at large

watts. This would require measurements involving both voltage and current to allow for the calculation of power. Another more involved expansion path would be to increase the current and add adjustable dc offset to our high frequency oscillator. This in theory would allow for the connection of our oscillator circuit and our power amplifier. Another major area for expansion is the power amplifier itself. In theory there are more efficient means of power amplification. One possible avenue for a more efficient power amplifier is to use an h-bridge amplifier. The basic outline for an h-bridge amplifier can be seen in Figure 5. This type of circuit could in theory be powered using the pulse-width modulation portion of our oscillator if you could set the correct signal with sufficient current to drive the mosfets. In theory, the h-bridge amplifier would be more efficient than our class-d amplifier. When mosfet 1 and 4 are turned on you have a positive voltage, when all 4 mosfets are off you have 0 voltage, and when mosfets 2 and 3 are turned on you get what appears to be a negative voltage because of the direction the current would flow. For this reason, an h-bridge amplifier would create a more efficient amplifier because we could get both positive and negative voltage from a single power supply.

Figure 5



## References:

1, 4, 5, 6. Andre Kurs, 2007. Power Transfer Through Strongly Coupled Resonances. Massachusetts Institute of Technology.

2, 7, 8. Culberson and Jorgensen, Cornell College. (2008) Wireless Power Transmission Using Magnetic Resonance. November 21, 2011, from:

[www.cornellcollege.edu/physics/courses/phy312/Student-Projects/Magnetic-Resonance/Magnetic-Resonance.html](http://www.cornellcollege.edu/physics/courses/phy312/Student-Projects/Magnetic-Resonance/Magnetic-Resonance.html)

3. Wikipedia the Free Encyclepedia. (Dec. 2<sup>th</sup>, 2011). Resonance. Dec. 8<sup>th</sup>, 2011, from: <http://en.wikipedia.org/wiki/Resonance>