Wireless Power Transfer Experiment by Using Magnetic Coupling Resonance

Wuhao Zhang

Beijing NO.12 High School, Beijing, 100071, China

Abstract: Wireless power transfer experiment by using magnetic coupling resonance can be used for electric vehicles, portable electronic equipment, etc. It is clear that this technology will bring convenience and productivity. So how can we do the wireless power transfer experiment? This thesis will show the experiment from two aspects: the first is to understand and explore the theory of this experiment. The second is to raise the questions I met and the utility of this technology. By studying the knowledge[1] of the theory, I have the fundamental understanding of alternating current, resonance circuit, and electro-magnetic induction[2]. After the experiment, I also collect analyze the data.

Keywords: wireless power transfer; alternating circuit; resonance circuit

1 Background

1.1 Previous research[3]

The first attempt of wireless power transfer experiment can be found in 1901. At that time, Nicola Tesla built a wireless power transferring tower in New York, US. However, because of the limitation of technology and fund, this project could not be used widely. The distance and efficiency of the power transferring have been the difficulty what we met and what we are meeting.

Recently, more and more mobile phones have wireless power transferring function. However the problem is that when we charge the mobile phones, we must put them right up the charging devices without any distance. If we take mobile phones away from the charging devices about 1cm, the efficiency of the power transferring will decrease to approximately 2%.

In 2007, the professor in the MIT, Marin Soljačić, proposed the method of, wireless power transfer using magnetic coupling resonance. The efficiency of which can even reaches 40% while the distance between the device and receiver are as far as 2m. This equipment lit a 60W-bulb. This project showed a technology which are possible to use, and it also has been widely studied by academia and industry.

1.2 Significance of the study

1.2.1 Charging equipment

This equipment can be applied to charge the electro-automobile, portable electric equipment (mobile phones, laptops, tablet computers, etc.) and medical equipment (embedding microchips).

1.2.2 Development of electromagnetism

This experiment involves the substantial contents and concepts of electromagnetism, including resonance circuit, electro-magnetic induction, alternating current, frequency selectivity, power of AC, etc. By synthesized these fundamental knowledge of electromagnetism, I have understood and explored this field much deep.

2 Documents[4]

By looking up some specialized books, correlated documents and thesis about this experiment, I studied the knowledge of electromagnetism. The knowledge of this experiment included the fundamental knowledge and recent results of this field[5].

2.1 Experiment to measure the wireless charging efficiency of mobile phones

Before the real experiment, I use a device for wirelessly

charging mobile phones in the market and then I measure the charging efficiency. This equipment includes a pedestal and a receiver. For calculating the efficiency, I used two USB current and voltage monitors, which was used to determine the current and voltage of the pedestal and receiver, and thus I would calculate the power of this device.

Then I changed the distance between the pedestal and receiver to obtain the charging efficiency. The data is shown as table 1.

Table 1. Data of charging efficiency with and without distance between the pedestal and receiver

	Input power	Output power	Charging efficiency
Without any distance	5.12V×0.38A=1.95W	4.95V×0.14A=0.69W	35.6%
The distance between the pedestal and receiveris1cm.	4.27V×1.05A=4.48W	3.97V×0.02A=0.08W	1.8%

According to this table, I found that when there is no distance between them, the charging efficiency was about 35.6%. However, when the distance is about 1cm, this equipment could not charge efficiently.

After I understood the theory and process of this experiment, I started the real experiment.

3 Processes

3.1 Experimental purpose

Learn the methods to use electrical measuring instrument;
Understand and build the equipment;
Measure the Q value of the coils in different distance and transferring efficiency.

3.2 Experimental principles

The principles of this experiment are similar to a voice maker which can provide energy for glass battle with the same frequency with glass battle. In the MIT experiment, the transmitting coil and the receiving coil have the same frequency (about 9.9MHz). By adjusting the frequency transmitted by the transmitting coil, I needed to let the receiving coil to have same frequency. As the transmitting coils and receiving coils are in resonance, they transmit more power and light the bulbs. Because the nearby objects rarely have the same frequency with the coils, the effect of their effect on the resonance is weak and has less influence on the mutual interaction between the coils.

3.3 Experimental equipment

1. Bigger coils (6 turns), Diameter: 50cm;
2. Smaller coils (2 turns), Diameter: 34.5cm;
3. Network analyzer (Keysight, E5063A);
4. Signal generator (Tektronix, AFG1062);
5. Wires;
6. A 2w LED bulb.

3.4 Experimental processes

At first I fixed tow small coils, and then I put tow bigger coils parallel between the two small coils—remember, when I measured one coil, I put another far away to decrease influence. After that, I measured the resonance frequency of the bigger coils (This experiment was under the conditions of 20Vpp, 9.410MHz.)

Because of the inaccuracy of the equipment, so every time when I did this experiment, I needed to adjust the resonance frequency, decreasing the error.

According to the formula, from the given resonance frequency of the bigger coils, I could figure out the coupling coefficient.

Fixing the distance between the small and big coils, changing the distance between two big coils, I used network analyzer to measure the loss ratio. Ultimately, I could calculate the transferring efficient of this equipment.

Attaching the 2w-bulb to the receiving coils, I changed the distance between the two big coils to observe the luminance of the bulb.

Gauging the resonance frequencies, Q values, loss ratio of two big coils, by changing the distance of two big coils, I made their resonance frequencies (f_0) closer. The data is shown as table 2.

Table 2. Data of the resonance frequencies, Q value, and losses of two bigger coils

	f_0(MHz)	Q value	Loss(dB)
The bigger coil 1	9.322	815	-22.8
The bigger coil 2	3.326	849	-24,5

According to the formula:

$$\text{Coupling} = \frac{2(f_2 - f_1)}{(f_2 + f_1)}$$

I used network analyzer to measure the loss ratio of different frequencies under different distances. The data is shown as table 4.

Table 3. Data of f_1, f_2, and strength of coupling with different distance between coils

Distance between coils (m)	Frequency f_1 (MHz)	Frequency f_2 (MHz)	Strength of coupling
0.50	9.1913	9.5374	0.0370
0.75	9.2887	9.4353	0.0157
1.00	9.3261	9.3978	0.0077
1.25	9.3408	9.3819	0.0044
1.50	9.3474	9.3717	0.0026
1.75	9.3335	9.3547	0.0023

Table 4. Data of central frequency, loss ratio, and efficiency with different distance between coils

Distance(cm)	Central frequency(MHz)	Loss ratio(dB)	Efficiency
40	9.74	-1.12	77.3%
80	9.45	-1.32	73.8%
120	9.40	-2.09	61.8%
140	9.40	-3.24	47.4%
160	9.39	-4.26	37.5%
180	9.38	-5.17	30.4%
200	9.39	-6.40	22.9%

Changing formula of dB = 10*log(η); $\eta = 10^{\wedge}(dB/10)$.

4 Conclusions

It can be seen from the data in the table that the greater the distance between the coils, the smaller the transmitted power and the lower the efficiency. If the distance of each set of coils fixed, the transmission efficiency can reach about 23% when two small coils are 2 meter apart.

5 Problems and outlooks

Recently I have finished this experiment, but I found that there were so many factors that affect the efficiency, such as surrounding, and the material of the coils. I will continue to study and analyze the data and factors.

In recent years, there are lots of universities are studying wireless power transfer, but the difficulties are also the transfer efficiency and accuracy. This is why we cannot use this technology in daily life.

Innovation

In the experiment, I raised two main problems: If we use huge equipment, it's so hard to use it in mobile phones or other electrical equipment; but if we use smaller equipment, the high frequent electricity will appear at the surface, and then the resistors will increase, decreasing the Q value and efficiency.

References

[1] Franklin H. MIT team experimentally demonstrates wireless power transfer, 2007.

[2] Feynman Lectures on Physics. The first volume(SHM).

[3] Sid Assawaworrarit, Xiaofang Yu, Shanghui Fan. Robust wireless power transfer using a nonlinear parity-time-symmetric circuit, 2017.

[4] Zhang SH. College Physics and Electromagnetism(the third edition). Tsinghua University Press.

[5] Chen KH. New Concept Physics Tutorial Electromagnetism(the second edition), Higher Education Press.