Wireless Electrical via Electromagnetic Induction

Muhammad Syafiq Noor Azizi, Najmiah Radiah Mohamad, Azahari Salleh, Nornikman Hassan
Department of Telecommunication Electronics, Faculty of Electronic & Computer Engineering,
Universiti Teknikal Malaysia Melaka (UTeM), Malaysia.
m021410026@student.utem.edu.my

***Abstract*—Wireless Electricity transmission or wireless power transmission is a process that takes place in any system, where electrical energy is transmitted from a power source to an electrical load without interconnecting wires. The traditional ways using electric power cables and electric batteries are often not satisfactory for mobile devices as the use of plugs and wires will limit the mobility. Therefore, the objective of this project was to build and demonstrate the concept of wireless power transfer at relatively large distances based on magnetic induction coupling between electromagnetic resonant objects. It consists of a transmitter as an electromagnetic resonator and a receiver to which the device to be powered was attached. The transmitter emits a non-radioactive magnetic field resonating at MHz frequencies, and the receiving unit resonates in that field. The maximum voltage absorbed by the receiver load was 10V at 0 distances and decreased to 0.567V at 6 cm distance. From the experiment, the receiver had the voltage of 2.582V for input current 3A, 1.356V for input current 1A and 0.678V for input current 500mA at 0 distances. The basic principle adopted was using two coils having the same magnetic resonance, in which one was coupled to the source and the other one was coupled to a device. However, the short distance between the two coils and the large coil size that used more space created a problem. Thus, the number of turns of coil with better quality of copper wire and input current source can be increased to improve the strength of the magnetic field. This is because when the strength of the magnetic field increases, the distance between the two coils can be longer, while the smaller size of coil can be used to reduce space.**

***Index Terms*—Wireless Electricity; Electrical Energy; Electromagnetic Induction.**

I. INTRODUCTION

Electricity is a necessity of today’s present day life. Without it, people live in troublesome as day passes by. The traditional utilization of electricity is made conceivable using wires. Propelled innovation has empowered the purchase of an assortment of compact electronic devices. However, users are still required to physically connect these devices when the battery has been used up. Subsequently, wireless energy transfer (WET) is recommended to understand the likelihood of the connector battery-free electronic devices, which could enhance both the size and quality. Therefore, there is a longing dream to utilize WET technology and remove the remaining wired energy connection.

There is an increase interest for wireless energy transfer system. Wireless data transfer by means of the Ethernet protocol or generally known as WIFI was produced around 1988 by NCR Corporation, and broadly marketed in 1999. Analysts anticipate that 100 million individuals will be utilizing Wi-Fi by 2006. Homes, workplaces, universities and schools far and wide have introduced Wi-Fi hardware to cover their premises with remote access to the web. Wi-Fi access is accessible in an increasing number of cafés, airplane terminals and lodgings [1]. Accordingly, it is not difficult to feel that a created wireless energy transfer technology would offer the same potentials at home and in business applications. There are numerous applications, for example, mobile phones, portable PCs, and home theater hardware, in which remote vitality exchange would be attractive.

Many of the contactless feed systems are based on the electromagnetic induction’s principle. Little separation wireless energy transfer is shown through the utilization of affectation. Information of electric circuit rationale and electromagnetic hypothesis is vital to understand the functional configuration. The idea of Wireless electricity started with the analyses of Heinrich Hertz and Nikola Tesla at around the 1890s, and it still under the exploration until today. It has been strived ordinarily all through the most recent century [2].

The main benefit of inductive wireless power transfer is the minimal effort and exceedingly productive strategy for transferring power. The design of an induction link is straight forward and proficient at small distances.

Therefore, the aim of this project was to build and demonstrate the concept of wireless power transfer at relatively large distances based on magnetic induction coupling between electromagnetic resonant objects [3]. It consists of a transmitter as an electromagnetic resonator and a receiver to which the device to be powered is attached. The transmitter emits a non-radioactive magnetic field resonating at MHz frequencies, and the receiving unit resonates in that field. The basic principle adopted was using two coils having same magnetic resonance, in which one was coupled to the source, while the other one was coupled to a device. However, the short distance between the two coils and the large coil size that used more space created a problem. Thus, the number of turns of coil with better quality of copper wire and input current source can be increased to improve the strength of magnetic field. This is because when the strength of the magnetic field increases, the distance between the two coils can be longer, while smaller size of coil can be used to reduce space.

A. Early History of Wireless Energy Transfer

The early history of wireless energy transfer involves two main figures that are Nikola Tesla and a group of researchers from Massachusetts Institute of Technology (MIT).

a. Nikola Tesla

Nikola Tesla was born on July 9, 1856 in Yugoslavia. Tesla had an uncommon ability, in which he can envision things so well that they appear to be genuine. This permitted him to assemble mental as opposed to physical models that prompted successful design. His weakness was he took extremely poor notes. He just recorded those things that he thought to be completely fundamental or vital. Tesla had passed his time in his experimentation. In 1899, he went to Colorado Springs to construct a research center and attempted to discover some new thoughts. One of the thoughts was the wireless transmission of energy. He had manufactured a resonant transformer called as Tesla loop, accomplished a noteworthy achievement in his work by transmitting 100 million volts of electric vitality remotely. In his trial, he could light 200 lights, 26 miles far from his lab to illuminate a bank and run one electric motor.

Tesla asserted that can transfer electrical power at 95% proficiency, yet the innovation must be racked in light of the fact that the impacts of transmitting such high voltages in electric circular segments would have been awful to human and electrical region [2]. Tesla theories of the wireless transmission of energy were somewhat not quite the same as today's vision. His theories were focused on his thought of the earth as a mammoth conductor. Tesla transferred energy directly through the earth's surface [3].

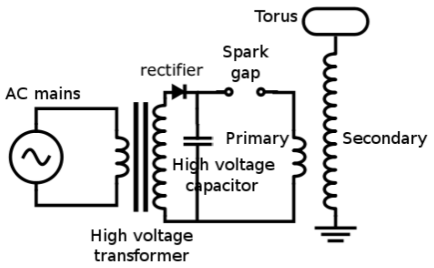

Figure 1: Basic configuration of Tesla coil

By referring to Figure 1, the high voltage capacitor frames two resonant circuits: One with the primary coil, and another with the secondary coil. The voltage is supplied by the high voltage transformer. The sparkle crevice comprises of two terminals isolated by a hole, loaded with an idle gas. At the point when sufficiently high voltage is connected crosswise over it, a sparkle frames, ionizing the gas, and permitting conduction. As the voltage over the sparkle hole expands, the charge over the capacitor likewise increases. When the gap sparks, the capacitor discharges into the primary and the secondary. In this way, the voltage "bounces" forward and backward to a great degree high rate. At the point when the rate of release between the capacitor and primary loop coordinates that of the capacitor and secondary coil, the two circuits will be in resonance. The voltage ascends to such abnormal states that it is discharged through the discharge terminal as an electric circular segment [2].

Another procedure for guaranteeing that a 3-Coil remote force exchange framework is more vitality effective than a 2-Coil partner was exhibited by Zhong, W., and Zhang, C. They figured out how to enhance the present rating and the cost of the driving circuit that can be reduced, and the general quality factor and system energy efficiency. They said that this methodology uses the consolidated preferences of the maximum efficiency principle and the utilization of hand-off resonator to conquer the vitality effectiveness issue for applications with amplified energy transfer distances. Besides, they likewise investigated the hypothetical of 2-coil wireless power transfer system and 3-coil wireless power transfer system. They thought about the productivity between 2-coil and 3-coil. At that point, they watched that the 3-coil system has vitality proficiency higher than that of the 2-coil system all through the whole load range [6].

At that point, Valenta, C., and Durgin, G. from Georgia Institute of Technology, Atlanta described the wireless power transfer systems. They said that, RF/microwave power must be created at the base station normally through a magnetron or strong state source. They likewise expressed the RF energy harvesting principles and diode rectifier performances. They said that when a diode is utilized as a rectifier, the maximum dc voltage over the diode Vo, dc is constrained by the opposite breakdown voltage.

Furthermore, the authors asserted that the WPT group has created varieties of energy harvesters to empower the hypothetical exchange of gig watts of force from space the distance down to modest charge pumps equipped for extricating usable vitality from under 5 mW of incident power. Additionally, the emphasized that the decision of correcting element(s), alongside smart configuration and design of the energy-harvesting circuit can accomplish maximum transformation efficiencies with an abundance of 90% [7].

b. MIT Scientists

In 2007, for the first time after almost 120 years, a group of scientists from the Massachusetts Institute of Technology (MIT) led by professor Marin Soljacic had a breakthrough in the principle of wireless energy transfer and carried out a middle distance wireless energy transfer by resonance coupling of electromagnetism, where its efficiency was about 40%[4]. By using electrodynamics induction, they succeeded to wirelessly power a 60W light bulb from a distance of 2 meters. MIT researchers proposed a high frequency more than 10MHz scheme based on a strongly coupled resonance for medium range and non-radiative wireless energy transfer. The scheme which was considered to be non-radiative and anti-jamming could achieve a medium range wireless energy transfer. They investigated the range and rate of coupling and the interference of extraneous objects in the view of magnetic field coupling [5].

II. METHODOLOGY

Transfer energy wirelessly was chosen based on magnetic couple resonator. For the aspects of hardware, it consists of a transmitter, a handmade air core inductor which acts as an electromagnetic resonator and a receiver, another copper coil of similar dimensions to which the 3V LED to be powered was attached. We used 12V transformer to step down voltage from 240V to 12V. We supplied 12V AC to make the coil to oscillate and produce magnetic field. It was also connected to function the generator to supply high frequency to transmitter. We analyzed the parameter based on frequency and distance. This allows us to show how the distance will affect the transferring of electrical energy transmitter to receiver using the prototype. In this project we need to improve the distance in range of 6cm-12cm with about 200 numbers of turn of coil and 6cm of coil radius.

This experiment was conducted to investigate the energy transfer efficiency of Wi-tricity system. In this case, it is important to design the project circuit to ensure the efficiency of the system. Last but not least, the troubleshooting was conducted to detect the problems that arise in order to complete the research.

A. Experimental Procedure

This system involved the construction of transmitter and receiver. First, the coil's diameter, inductance and resistance were measured. Then, the resonant frequency of the coil was found and the required capacitance needed for resonance was matched. The frequency was achieved by using the function generator to power the primary coil. The wave function from the function generator was sine wave. The system that transfers powers was determined by attaching the LED to the receiving coil and an observation was made to detect, if the LED lights up. When the system was found to be working, the secondary coil was attached to the oscilloscope. The voltage from the oscilloscope was recorded with the two coils as close as they can be by measuring the distance they were apart from each other. After that, the distance by half a centimetre that recorded the voltage was increased for each distance until there is no voltage. The distances indicate that the LED does not light up anymore. The voltage, current, frequency and wavelength need to be determined by the oscilloscope and formulas. Lastly, the results of the experiment were recorded.

a. Construct of Transmitter Coil

By using a plastic circular coil former and enameled cooper wire, we winded a transmitter coil. We did about 280 turns with the diameter of enameled cooper wire 16AWG.We used about 100 meter of enameled cooper wire. The construction of handmade inductor must be done with care because it is very sensitive. It is to make sure that we get the accurate value of inductance. If we do not get the actual value of inductance, it is difficult for us to setup the proper frequency which enables to transfer electrical energy wirelessly. Enameled cooper wire has a very thin coating on the top of it. The end of the wire was put in the flame for a few seconds to get this off. After that, two ends of the coil were connected with the series of $7.6pF$ and $50fF$ capacitor. Next, 240V AC voltage supplied was connected with step down transformer to supply 12V AC voltage to the transmitter coil. The LED connected to the receiver coil was observed.

b. Construct of Receiver Coil (Radial inductor)

Radial inductor is another way to do the receiver coil without manufacturing another receiver coil. The step to build the transmitter coil in "Transmitter and Receiver Coil Manufacturing (Normal Receiver Coil)" was followed. The Radial inductor with 800mH was used in the receiver coil. The resonance frequency was calculated to match with the transmitter coil. After that, the LED lamp was observed without connecting the transmitter to the function generator.

III. RESULTS AND DISCUSSION

Figure 2 shows the basic block diagram of a simple Wi-tricity system with the used of radial inductor as the receiver coil. This system was divided into five stages, which are the power supply, transmitter coil, receiver coil (radial inductor), rectifier and load.

Figure 3 shows the circuit diagram of simple Wi-tricity system with radial inductor. This method did not use any source frequency. It is simpler compared to the previous method shown in Figure 5.1.1. First, the transmitter coil was built, while 820mH radial inductor was used as the receiver coil. For the transmitter, N = 187, r = 1.457 inch, l = 0.63 inch and d = 0.315 inch [refer to Equation (1)].

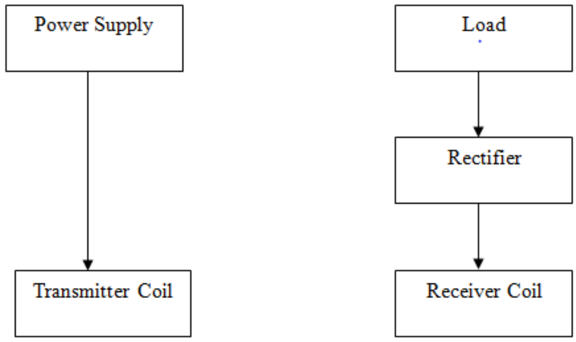

Figure 2: Basic block diagram of a simple Wi-tricity system with radial inductor

$$L = \frac{0.8(1.5)^2(200)^2}{6(1.5)+9(0.25)+10(0.25)} = 5.236\, mH \quad (1)$$

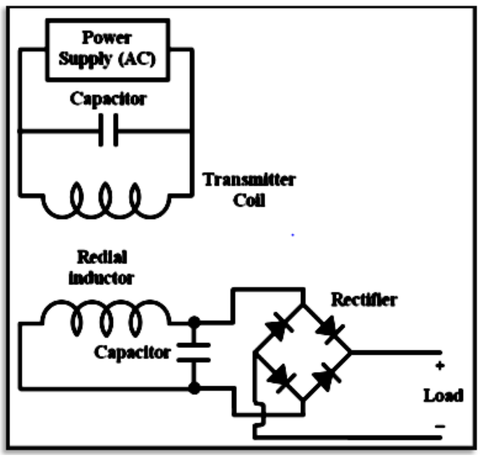

Figure 3: Circuit diagram of simple Wi-tricity system with radial inductor

Figure 4: Prototype Model of simple Wi-tricity System with Radial inductor as the receiver coil

The voltage and the current supply to the transmitter were 15V and 3A. The relationship between the distance (cm) and voltage of receiver coil (V) relationship between the distance (cm) and current of receiver coil (mA) was observed.

Table 1
Relationship between distance (cm) and load voltage (V)

Distance (cm)	Load Voltage
0	10.001
1	7.903
2	5.245
3	3.744
4	2.582
5	1.225
6	0.567

Table 2
Relationship between distance (cm) and load current (mA)

Distance (cm)	Load Current (mA)
0	20.267
1	14.782
2	10.289
3	6.578
4	4.109
5	2.324
6	1.098

Figure 5 shows the impact on the voltage and current of receiver coil caused by different transfer distance. It is obvious that the longer is the distance between the two coils, the lower is the voltage and the current of the receiving coil. The value in the graph was compared to the graph in Wi-tricity System with Source Frequency. It shows that the energy of transmission increased as the input current and the number of turn increased.

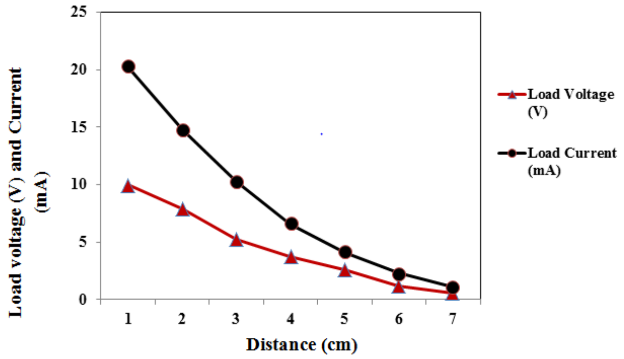

Figure 5: Relationship between distance (cm), load current (mA) and load voltage (V)

Figure 6: Transmitter coil with N = 150

Figure 7: Transmitter coil with N = 200

Figure 8: Transmitter coil with N = 187

Table 3
Relationship between distance (cm) and load voltage (V) for N = 80, 140 and 200

Distance (cm)	Load Voltage (V) N=150	N=187	N=200
0	0.672	2.018	3.744
1	0.460	1.356	2.582
2	0.325	0.567	1.225
3	0.240	0.223	0.567
4	0.018	0.178	0.234
5	0.002	0.056	0.123
6	0.002	0.012	0.021

Figure 9 shows the effect on the load voltage caused by different transfer distance for different number of turns. It shows that higher number of turns resulted in stronger magnetic field.

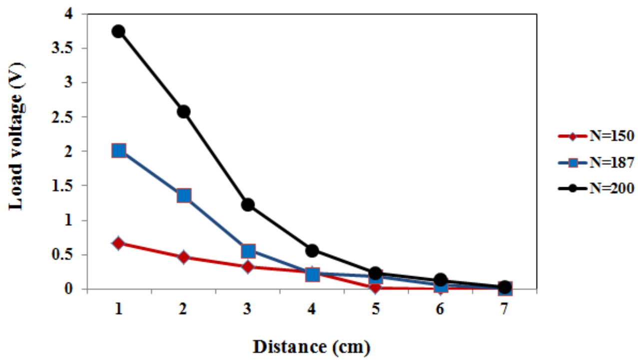

Figure 9: Relationship between distance (cm) and load voltage (V) for N = 200, N = 187 and N = 150

Table 4
Relationship between distance (cm) & load voltage (V) for input current 500mA, 1A and 3A

Distance (cm)	Load Voltage (V) 500mA	1A	3A
0	0.678	1.356	2.582
1	0.272	0.567	1.225
2	0.189	0.223	0.567
3	0.089	0.178	0.234
4	0.035	0.056	0.123
5	0.002	0.012	0.021
6	0.001	0.002	0.003

Figure 10 shows the impact on the load voltage caused by the different transfer distance for different input current. It is obvious that higher input current resulted in stronger magnetic field.

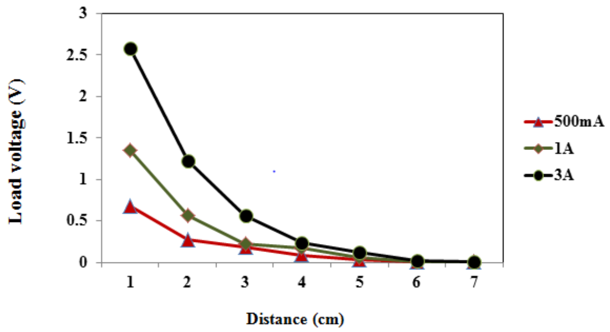

Figure 10: Relationship between distance (cm) & load voltage (V) for input current 500mA, 1A and 3A

Table 5
Relationship between distance (cm) & load voltage (V) for transmitter coil radius 2.5cm & 5.5cm

Distance (cm)	Load Voltage (V) 2.5cm	5.5cm
0	0.889	2.582
1	0.682	1.225
2	0.388	0.567
3	0.129	0.234
4	0.089	0.123
5	0.003	0.021
6	0.002	0.003

Figure 11 shows the impact on the load voltage caused by different transfer distance for difference coil radius. It is obvious that the voltage as the transmitter coil radius increased.

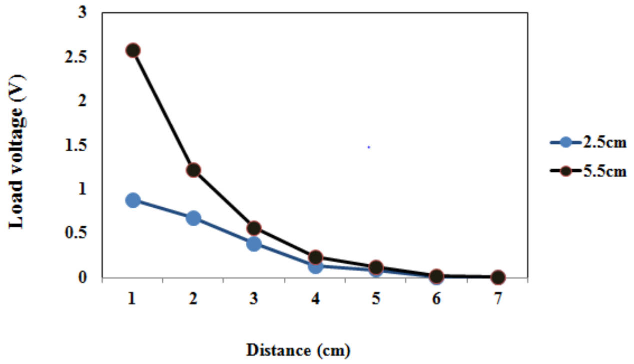

Figure 11: Relationship between distance (cm) & load voltage (V) for transmitter coil radius 2.5cm and 5.5cm

Table 6
Relationship between distance (cm) and energy transfer efficiency (%) for transmitter coil radius 2.5cm & 5.5cm

Distance (cm)	Energy transfer Efficiency (%) 2.5cm	5.5cm
0	2.70	16.70
1	2.40	12.25
2	1.00	5.10
3	0.50	0.90
4	0.25	0.50
5	0.40	0.80
6	0.01	0.01

Figure 12 shows the impact on the load voltage and energy transfer efficiency caused by different transfer distance for difference coil radius. It is obvious that the power inefficiency increased as the radius increased.

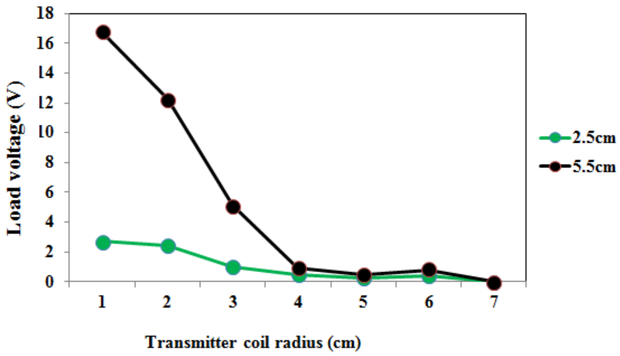

Figure 12: Relationship between distance (cm) and energy transfer efficiency (%) for transmitter coil radius 2.5cm and 5.5cm

IV. Conclusion

This project proved that this kind of technology has the potential to improve energy transfer, and magnetic resonance coupling is the most feasible method in wireless energy transfer. Besides, this technology has the potential to change human life style. This paper also has proven that the wireless energy can be transmitted without the present of control signal by using the radial choke inductor as the receiver. The impact on the voltage and current of receiver coil caused by different transfer distance was investigated and it shows that the longer is the distance between the two coils, the lower is the voltage and the current of the receiving coil. In addition, the maximum voltage can absorbed by the receiver load was 10V at 0 distances and decreased to 0.567V at 6 cm distance. From the experiment, the receiver has the voltage of 2.582V for input current 3A, 1.356V for input current 1A and 0.678V for input current 500mA at 0 distances. The strength of magnetic field depends on the number of turn of the copper wire at the transmitter coil and receiver coil and the input current to the transmitter coil. Perhaps, in future we can continue upgrading our prototype model to charge cell phones and other products consumer products.

V. Recommendation

Below are several recommendations that can be made for future improvement of this project in terms of the efficiency and functionalities. The strength of the magnetic field can be improved by using better quality of copper wire. High qualities of cooper wire will reduce radiation losses and increase the efficiency to transfer electrical energy wirelessly. Besides, the number of turn of coil and the input current source can be increased to improve the strength of the magnetic field. Not only that, more functions, such as the distance of measuring or the magnetic field measuring can be embedded to make the system more efficient. Magnet also can be used to make the magnetic field area around the coil becomes larger and stronger by rolling the coil around the magnet. Lastly, this system also can be designed by running it via solar power to reduce damages to environment.

Acknowledgement

We are grateful to Centre for Telecommunication Research and Innovation (CeTRI) and Universiti Teknikal Malaysia Melaka (UTeM) for supporting us to complete this study and

supplying the electronic components and equipment's from the laboratory.

REFERENCES

[1] Leopold Summerer, and Oisin Purcell ESA. Concepts for wireless energy transmission via laser- Advanced Concepts Team Keplerlaan 1. NL-2201AZ Noordwijk, the Netherlands. Leopold.Summerer@esa.int.
[2] Eric Dollard. 2010. Theory of Wireless Power.
[3] Prof Burali Y. N.,and Prof. Patil C.B. Wireless Electricity Transmission Based On Electromagnetic and Resonance Magnetic Coupling. Nanasaheb Mahadik Polytechnic Institute, Peth Sangli, India.
[4] Jonathan S. Shipley. 2006. Incorporating Wireless Power Transfer in An LED Lighting Application. *School of Technology, Brigham Young University.*
[5] Chunbo Z., Kai L., Chunlai Y., and Rui M. Simulation and Experimental Analysis on Wireless Energy Transfer Based on Magnetic Resonance. *School of Engineering and Automation, Harbin Institute of Technology, Harbin, China*.
[6] Zhong W., and Zhang C., Liu X., and Hui, S. 2014. A Methodology for Making a 3-Coil Wireless Power Transfer System More Energy Efficient Than a 2-Coil Counterpart for Extended Transmission Distance. *IEEE Xplore. IEEE.*
[7] Valenta, C., and Durgin, G. 2014. Harvesting Wireless Power: Survey of Energy-Harvester Conversion Efficiency in Far-Field. *Wireless Power Transfer Systems. IEEE Xplore*. *IEEE*.