DEPARTMENT OF COMMUNICATIONS ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA - NIGERIA

Proceedings of the 1st National Communication Engineering Conference 2018

Wireless Power Transfer and Charging System: System Overview and Development Trends

Francis E. Chinda, Aliyu N. Shuaibu, Danjuma D. Dajab
Department of Electrical and Electronics Engineering, University of Jos, Plateau State, Nigeria

ABSTRACT—Strong coupled magnetic resonance wireless power transfer is proposed by researchers at Qi in 2007, and attracted the world's attention by virtue of its mid-range, non- radioactive and high-efficiency power transfer. In this article, current developments and research progress in the technology of WPT are presented. Advantage of WPT are analysed by comparing it with other wireless power transfer (WPT) technologies and different analytic principles of WPT are elaborated in depth and further compared. The hot research spots, including system architectural analysis, frequency splitting phenomena, impedance matching and optimization designs are classified and elaborated. Finally, current research directions and development trends of WPT are discussed and the simulation results are presented.

KEYWORDS—WPT, Frequency, Impedance and Optimization

INTRODUCTION

Due to globalization, power transfer efficiency is an important objective in designing wireless power transfer (WPT) system [1]. Wireless Power Transfer (WPT) [2] or wireless power transmission is the process of transmission of electrical power source to the consuming device without the use of solid wires or conductors, this is a generic term that refers to the number of different form of power transmission technologies that use time varying electromagnetic fields [3]. Wireless transmission is very useful to power electrical devices in cases where interconnecting wires are inconvenient, hazardous or completely not possible. In wireless power transfer process, a transmitter device is connected to a power source such as mains power line, transmits power using electromagnetic field across all the intervening space to one or more receiver devices, where it will be converted back to electrical power for utilization. These will be similar to how Wi-Fi and Bluetooth become globally very standardized by implementing this work, users can forget about the use of different chargers anymore for a different portable electrical devices in the feature and be able to use wireless means to aid their charging efficiently.

The theory and the idea of wireless power transfer and charging system started long time ago by Nicola Tesla who began demonstrating wireless broadcasting and power transmission in early 1900s. He could able to power lights in the ground at his Colorado Springs experiment station remotely [4]. Michael Faraday formulated the law of electromagnetic induction whereby is now possible to transfer energy from one environment to another using Electromagnetic waves. All contributed to enhanced efficient wireless charging. At present wireless charging has already been developed for low-power devices that can powered up to 5W such as mobile phones and wireless powered access card. In the year 2000, Professor Shu Yuen Hui from The City University of Hong Kong invented a planar wireless charging pad that can able to charge several electronic loads simultaneously. Also in the year 2007, MIT researchers demonstrated an efficient wireless power transmission based on a strong coupled magnetic resonance and was successfully powered a 60W light bulb with 40% efficiency remotely at 2 meters [4]. In the subsequent year, Intel successfully lighted an electric bulb with 70% efficiency at 1 m distance.

Generally, wireless charging is multidisciplinary field that includes power electronic circuits, coils and a control circuitry. Comparing to wired topology, wireless charging has lower efficiency due to added losses on coupling and power conversion units. This will increase resistive heating losses and causes overheating on battery which will reduce its life time. Thus this article addresses the efficiency issues which is the main concern on wireless charging technology using the most advanced solutions, the coupling efficiency can achieve 85% and the overall system efficiency can achieve up to 75% [5].

So many other research work has been conducted to extend the possibility and the efficiency of wireless charging to 2-ways and 4-ways radios but the limitations is that must of the 2-ways and 4-ways radios required only 7.5V battery for its operations and the efficiency of the wireless charging was considerably low compared to the traditional wired charging. This work basically is to make improvement on the efficiency of the RF Wireless Power Transfer and Charging System already on ground and to extend the charging voltage up to 8.5 V and 12V and the transmitter toemit a low- power radio wave at a frequency of 500-900MHz.

TYPES OF RF WIRELESS POWER TRANSFER

Radio Charging: This charges low- power electronic devices within a distance of 10 meters from the transmitter which sent out low-power radio wave to the receiver which converts the signal to energy. This could activate advanced RFID (radio frequency identification) chips through a considerable enhanced induction.

Inductive Charging: This is the most important method of transferring energy wirelessly through and inductive coupling. It is used for near field power transmission. The power transmission takes place between two conductive materials through the mutual inductance. The typical example of inductive coupling transmission is a transformer.

Resonance Charging: this applies the concepts of resonance whereby both the transmitter and the receiver coils are turn to the same electromagnetic frequency. At resonance, the receiver coil can pick up the signal when energy at resonant frequency is applied.

An inductive charging method will be the technique to be used in implementing this project for it is the commonly used method for electronic devices. This will ease the use for both the consumers and the developers, Wireless Power Consortium (WPC) has established Qi as the global standard for wireless power system with the output power of up to 5W to create interoperability between the transmitter and the receiver [6]. Under WPC standard, the type of inductive coupling and communication protocol are always defined.

Wireless charging system consists of two distinguishable devices:

a) The wireless power transmitter coil section: the wireless transmitter section converts the DC power from an oscillator to a high frequency AC power signal. This high frequency alternating current, which is linked with the wireless transmitting power, would create an alternating magnetic field in the coil due to induction to transmit energy.

b) Wireless power receiver section: in this section the receiver coils receives the energy as induced alternating voltage (due to induction) in its coil and rectifier in the wireless power receiver converts the AC voltage to a DC voltage. Finally the rectified DC voltage would be feed to the load through the voltage controller section. That means the main function of a wireless receiver section is to charge a low-power devices through an inductive coupling.

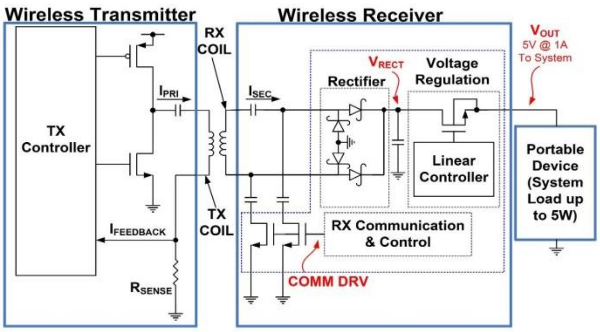


Fig. 1. Qi- Complaint Wireless Power System [7]

I. DESIGN FLOW AND OPTIMIZATION

Generally the design process for an inductor coil is very complicated as the physical and electrical parameters that affect the performance of the coil are interrelated where by any change in one of the parameters will have an effect on another. Thus, a design flow for the coils is developed to model the inductor coils based on the design of solenoid shaped coil and PSC where the performance is compared between the two designs. The ultimate goal of this design flow is to optimize the power transfer efficiency between two coils while meeting the design specifications and constraints as per the application system requirements. The design flow for the inductor coil is described systematically as shown below first by explaining the parameters and good shape and size of the coil used.

In wireless power transfer, charging coil is formed by winding a conducting wire to a certain configuration. This tends to concentrate the magnetic field by coil, hence improving the induced voltage collected. This will also improves the inductive coupling between coils. The Printed Circuit Board (PCB) gives an easier concept in designing a Printed Spiral Coil (PSC) because it can be manufactured using PCB process, which is term as a standard process for manufacturing PSC. This also can be integrated in the receiver circuit, which reduces the size of the receiver. The coil area and the number of layers are limited by PCB where higher self-inductance is very difficult to be achieved. Accurate inductance has to be calculated as it cannot be modified once the PCB is fabricated [8]. Commonly used structures for wireless charging are, Helical coil, planar spiral coil and printed spiral coil as shown in the Fig. 2.

The structure of a helical coil is similar to an inductor and can easily be constructed compared to a planar coil. This gives a better magnetic field with longer wavelength but this does not have advantage to short range charging [9]. Helical coil occupies more space to obtain a desired inductance compare to a planar coil. Helical coil produces a horizontal magnetic flux as shown in figure. Both the coils are required to be positioned perpendicular to each other in order to allow capturing of magnetic flux, which is not suitable for a slim design of portable devices.

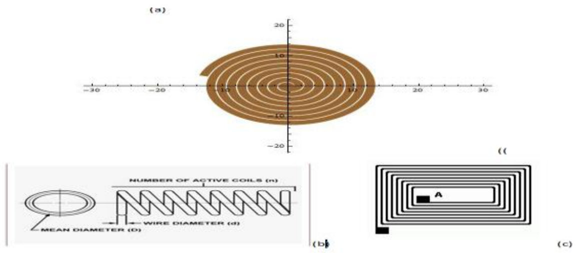


Fig. 2. Different Ty pes of Winding Structures on WCC, (A) Spiral Coil (B)Helical Coil (C) Planar Spiral Coil

Planar coils generate vertical flux where both charging coils can be positioned in parallel position to each other. Hence, it is more suitable for implementation in wireless charging application [10]. The inductance and the design of coil can be easily modified with a planar spiral coil configuration. Planar Spiral Coil (PCB) is commonly made up of Litzwire which tends to increase the impedance of a conductor caused by eddy current effects as discussed in the previous chapter. For this article, Planar Spiral Coil is the targeted coil design to be implemented as it tend to give higher efficiency with Litz wire and is allows for slim design at higher frequency.
The shape of coil will also affect the magnetic properties, as such, the choice of better shape of coil will lead to an efficient power transfer between the transmitter and the receiver coils. Hence, the typical coil shapes available includes circular, square and rectangular structure [11]. Segmented shape, which splits the rectangular area into two parallel-connected

coils, is also considered. The shape of the coil also affects the coupling factor (K) as in figure .In all the four shapes of coil circular shape gives the highest coupling factor [12], in other hand, the coil with higher area has higher coupling factor .for the purpose of this design circular coil will be used based on it advantage as discussed and shown in Fig. 3.

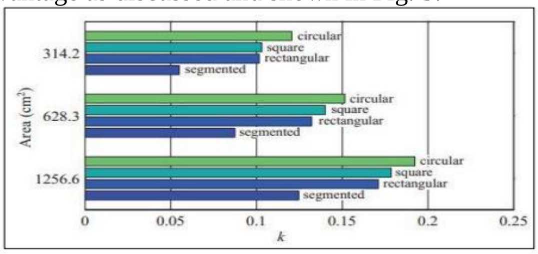


Fig. 3. Areas against Coupling Factor of Different Coil Shapes and Area

Computer Simulation Technology (CST) Microwave Studio was used to carry out the design process it has the ability to simulate 3D electromagnetic coil at high frequency using frequency domain solver and provides full circuit simulation tools and present results in 3D electromagnetic form. The CST software also have many features such as; parameter sweep , mesh properties and mini-match to match the two port of transmitter and receiver coils, it also provides other features for optimisation and model construction to enhance efficient wireless communications within the circuit.

TABLE I. ENVIRONMENT SETTING IN CST MICROWAVE STUDIO

Frequency level	High Frequency
Setup Solver	Frequency Domain Solver
Mesh Type	Tetrahedral
Frequency Range	650MHz -750MHz
Surrounding Space Diameter	300mm

Basically to start with, 3D model type of inductive coils are constructed for transmitter and receiver sections of wireless power transfer in CST Microwave Studio using FEM behavioural approach for the 3D and circuit combination study. The settings in Table 1 are maintained in the simulation environment for the coils model. As in Table 1, for wireless power transfer and charging, the commonly used applications on CST microwave studio are frequency domain solver with tetrahedral meshing. The air domain for model surrounding is represented by normal background material which is 300mm apart for this project.

Listed in Table 1, are the design specifications for transmitter and receiver modelled coils shown in Fig. 4. To reduce the complexity of the coil design and simulations in CST MWS, a single core copper wire is used for the modelling for coils instead of earlier proposed Litz wire in the literature review. All the parameters of transmitter section are kept constant during the modelling with modification on the outer radius of the receiver coil section and changing the distance between. Other parameters are kept constant to meet the design specifications and to enhance energy transfer within the coils. This will results in given a better coupling performance within the coils with the separation Gap of 50mm.

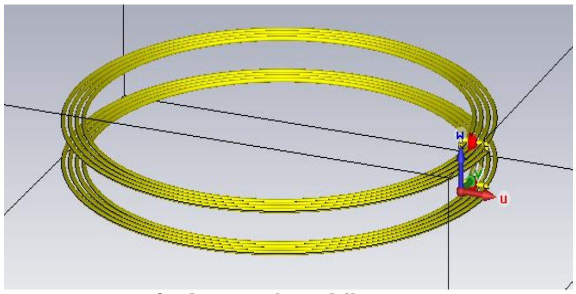


Fig. 4. 3D View of Inductor Coils Modelling In CST Microwave Studio

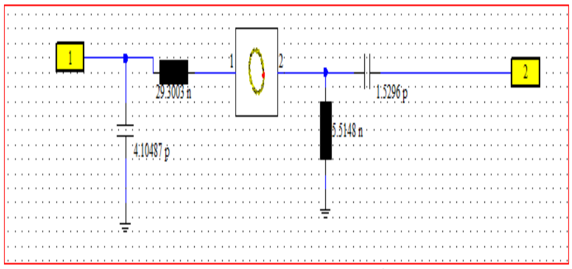


Fig. 5. Resonant Matching Circuit Diagram for inductor coil Model

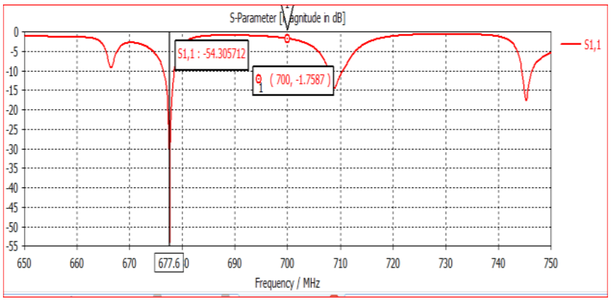
For the receiver coil, the capacitor in the inductive loop ofone coil model is simultaneously altered until the surface coil is turned to 700MHz called the resonance frequency at the resonance frequency the magnitude of $S_{11}S_{11}$ is at minimum. The voltage and current through the inductive loop should be close to the maximum. Once the coil has been turned, the turning capacitors and inductors are noted. The basic reason for this is to allow the implanted coil to be turned to 700MHz while still being inductively coupled to the surface coil; this is to avoid frequency splitting during the energy transfer. Shown in Fig. 5 is the designed matching circuit for this work that resonate the frequency at 700MHz alongside the component value of resonant circuit matching presented in Table 2.

TABLE II COMPONENTS VALUE OF RESONANT CIRCUIT MATCHING

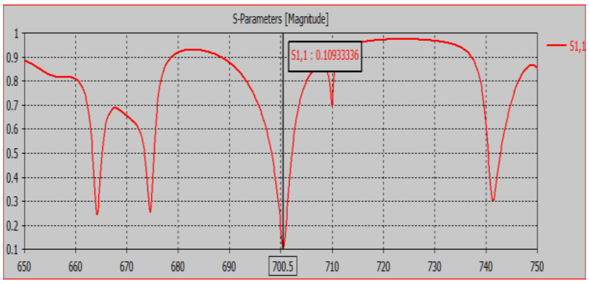
Components		Value
Transmitter Capacitor	C1	4.104 pFpF
Receiver Capacitor	C2	1.529. pFpF
Transmitter Inductor	L1	29.300 nHnH
Receiver Inductor	L2	45.51 nHnH

RESULTS FROM RESONANT CIRCUIT DESIGN ON CST

Initially, simulation is carried out for the weak inductively coupled transmitter and receiver coils in CST for coupling performance study. The s-parameters results are obtained for power transmission analysis in coils as shown in Fig. 6 (a). In s-parameters, S21 represents the transmitted power from transmitter coil to receiver coil while the S11 and S22 represent the reflected power in between two coils.



(a) With Matching



(b) Without Matching

Fig. 6. S-Parameter S11 With and Without Matching

At operating frequency of 700 MHz, the power transmission efficiency obtained for the coils model is 0.321 % with S21 of -24.935 dB. Therefore, wireless power transfer in the coils model is impossible with almost no coupling between coils. After matching the resonant circuit the resulting resonant efficiency was enhanced as shown in Fig. 7.

From Fig. 7 the coils model is matched at resonant frequency of 700MHz with maximum amount of power transfer and minimum amount of power reflection. This gives the maximum power transmission efficiency between coils of 93.1 % for the inductor coils with separation gap of 50mm at operating frequency of 700MHz.

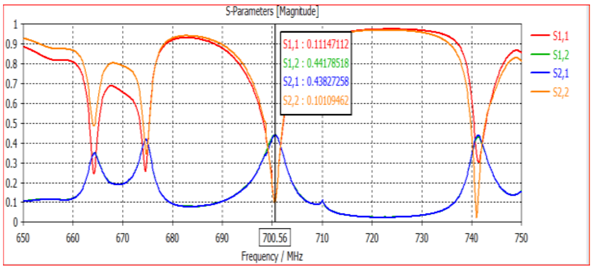


Fig. 7. Combined S-Parameter Results after Matching

CONCLUSION

In conclusion, the proposed coils model meets the design specifications. It is capable of providing efficient wireless power transfer to portable charging devices through resonant inductive coupling method with maximum power transmission efficiency of 93%. Furthermore, it passes the coils performance evaluation test that is subjected to different external factors in real situation. The additional adjusting freedoms existing in CST systems architectural design are beneficial for optimizing system transfer characteristics. The global optimization design and regulations methods by considering multi-effects factors are also valuable for its engineering applications.

In real practice, a certain rated power is required but this MHz resonant frequency may bring a great challenge to some portable electronics components, for example the circuit rectifier, MOSFET driver and so on. Fortunately with the rapid development of semiconductor and material industry this will overcome these challenges. Generally, WPT actually belongs to a marginal discipline between physics and electronics as such it needs the efforts from different research fields. The simulations of high frequency range WPT need a super speed for its simulations process in order to obtain high efficiency and high quality factor.

REFERENCES

[1] B. Johns, “An introduction to the Wireless Power Consortium standard and TI ’ s compliant solutions (sylt401),” *Analog Appl. J.*, 2011.

[2] A. O. Hariri, A. Berzoy, A. A. S. Mohamed, S. Members, O. A. Mohammed, and F. Ieee, “Performance Evaluation of a Wireless Power Transfer System using Coupled 3D Finite Element-Circuit Model,” pp. 7–10, 2015.

[3] D. Kurschner, C. Rathge, and U. Jumar, “Design Methodology for High Efficient Inductive Power Transfer Systems With High Coil Positioning Flexibility,” *Ind. Electron. IEEE Trans.*, vol. 60, no. 1, pp. 372–381, 2013.

[4] J. Agbinya, “Investigation of Near Field Inductive Communication System Models, Channels and Experiments.,” *Prog. Electromagn. Res. B*, vol. 49, no. February, pp. 129–153, 2013.

[5] Anuradha Menon and A. Menon, *Intel’s Wireless Power Technology Demonstrated*. The Future of Things e-magazine, 2008.

[6] H. J. Choi, E. H. Ahn, S. Y. Park, and J. R. Choi, “Portable battery charging circuits for enhanced magnetic resonance Wireless Power Transfer (WPT) system,” *Conf. Proc. - 9th Conf. Ph. D. Res. Microelectron. Electron. PRIME 2013*, pp. 273–276, 2013.

[7] “WiTricity Corporation.” [Online]. Available: http://www.witricity.com/assets/highly-resonant-power-transfer-kesler-witricity-2013.pdf. [Accessed: 26-Jul-2015].

[8] S. Davis, “Wireless power minimizes interconnection problems,” *Power Electron. Technol.*, pp. 10 – 14, 2011.

[9] A. K. Sah, A. Christ, M. G. Douglas, J. M. Roman, E. B. Cooper, A. P. Sample, B. H. Waters, J. R. Smith, N. Kuster, and R. M. Cano, “Evaluation of Wireless Resonant Power Transfer Systems With Human Electromagnetic Exposure Limits,” *IEEE Trans. Electromagn. Compat.*, no. 1, pp. 1–10, 2012.

[10] S. Y. Hui, “Planar wireless charging technology for portable electronic products and Qi,” *Proc. IEEE*, vol. 101, no. 6, pp. 1290–1301, 2013.

[11] P. Grover and A. Sahai, “Shannon meets tesla: Wireless information and power transfer,” *IEEE Int. Symp. Inf. Theory - Proc.*, pp. 2363–2367, 2010.

J.-P. Curty, M. Declercq, C. Dehollain, and N. Joehl, *Design and Optimization of Passive UHF RFID Systems*. Springer, 2006.