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LIST OF ABBREVIATIONS

WPT	Wireless Power Transfer
WiTricity	Wireless Electricity
CST MWS	Computer Simulation Technology Microwave Studio
ICs	Integrated Circuits
PCB	Printed Circuit Board
PSC	Printed Spiral Coils
CMT	Coupled Mode Theory
IM	Impedance Matching
ADS	Advance Design System
MIT	Massachusetts Institute of Technology
ICPT	Inductively Coupled Power Transfer
MCRC	Magnetically Coupled Resonant Circuits
MHz	Megahertz
dB	Decibel

LIST OF SYMBOLS

S_{11} = reflection coefficient

S_{21} = transmission coefficient

C_p = capacitance

f_o = resonant frequency

g = air gap

n = turn

w = width

s = spacing

t = thickness

d_{in} = inner diameter

d_{out} = outer diameter

L_{gmd} = inductance (geometric mean distance)

L_{mw} = inductance (modified wheeler)

d_{avg} = the average diameter

ρ = fill ratio

d_{out} = the outer diameter

d_{in} = the inner diameter

μ_o = Permeability of free space

Kajian Pemindahan Kuasa Tanpa Wayar Berdasarkan Salunan Magnetik Menggunakan Gegelung Induktif

ABSTRAK

Pemindahan kuasa tanpa wayar berdasarkan salunan frekuensi telah menjadi satu bidang utama bagi penyelidik. Kajian terkini mengenai pemindahan kuasa di ruang udara telah berjaya dicapai. Penggunaan peralatan elektrik kecil seperti telefon bimbit, komputer riba dan peralatan elektrik yang besar seperti kenderaan elektrik telah diperkenalkan. Dalam kertas ini, kami mereka bentuk pemindahan tenaga tanpa wayar pada jarak maksimum dengan efisien menggunakan salunan magnet. "Computer Simulation Technology Microwave Studio (CST MWS)" telah diperkenalkan untuk mereka bentuk model sistem pemindahan kuasa. Dalam kajian ini pengiraan induktor berdasarkan "Current Sheet Approximation" dan "Modified Wheeler Formula" diperkenalkan. Simulasi menunjukkan perubahan bilangan lilitan dan jarak memberi kesan kepada kecekapan pemindahan kuasa. Keputusan simulasi menunjukkan bilangan lilitan 4 mencapai efisien tertinggi iaitu 99.5% pada jarak 30 cm pada salunan frekuensi 12.05 MHz.

Study on Wireless Power Transfer based on Magnetic Resonance using Inductive Coil

ABSTRACT

Wireless power transfer (WPT) based on magnetic resonance has become a major field of interest for researchers. Transferring power across air gaps has been achieved according to recent researches. Both small electric equipment such as mobile phones, laptops and large electric equipment such as electric vehicles have been proposed. In this thesis, we design the WPT on maximum air-gap and efficiency based on magnetic resonant coupling. Computer Simulation Technology Microwave Studio (CST MWS) was used to design the models of power transfer systems. In this research, the inductance expression based on Current Sheet Approximation and Modified Wheeler Formula are proposed. Simulations show that the change of the number of turns and air gap distance are found to be affecting the power transfer efficiency. Simulation results showed that the model of WPT system achieved the highest efficiency 99.5% at a distance of 30 cm and resonant frequency of 12.05 MHz.

CHAPTER 1

INTRODUCTION

1.1 Overview

Power is important to the modern systems. It can be found from the smallest sensors, laptops, bionic implants, consumer products to satellites and oil platforms. It can be able to deliver power other than classical wires or transmission lines (Sah, 2013).

In Information Technology era, wireless technology is the focus of attention as demonstrated by wireless devices such as wireless internet, mobile phones, and blue tooth technologies. The demand for batteries was increase because of the increasing consumer. Wireless power transfer (WPT) or wireless electricity (WiTricity) is defined of the transfer electrical power from a power source to an electrical load without using wires. This is a proof of concept technology such as for charging laptops, cell phones, and other electronic devices wirelessly. The wireless technology provide constant power transfer to the device, it will help reduce battery size as well. Therefore it will also serve to increase the portability and reduce the product price. Nowdays, the WPT technology is popular and have a high demand because of its convenience to consumer and industrial marketplaces (Ramachandran, 2007).

Originally in the late 19th and early 20th centuries, it was Nicola Tesla who first demonstrated wireless power and proposed the first idea of WPT via ionized air. Tesla used a conductive coil connected in series with a Layden jar to form a loop resonator.

Tesla developed one loop (primary coil) as the power transmitter and a second loop resonator (secondary coil) as a power receiver (Alwadiya, 2013). The diagram of WPT systems as shown in figure 1.1.

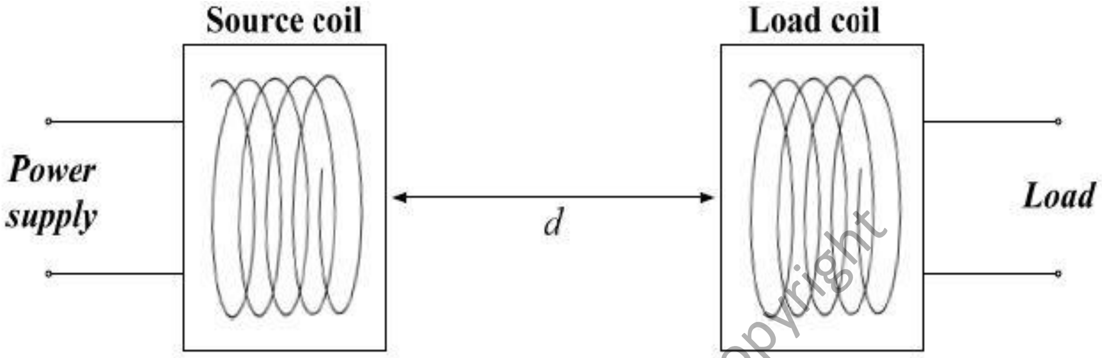

Figure 1.1 : The diagram of wireless power transfer systems (Bodrov & Sul, 2012).

It has two major disadvantages of magnetic coupling in WPT technology regarding physical sizes. If the size of the receiver is reduced, the magnetic flux linked to the secondary coil is reduced. To ensure the magnetic flux is high enough for efficient energy transfer, a large current must flow in the primary coil. Even though the larger power supply is provided to the device, but the transmitting distance is still short less than 10cm and the efficiency is about 0.01%. Therefore, magnetic coupling is not suitable and practical in real life engineering application. Several methods previously proposed to accommodate power pickups, which are located at various lateral positions.

There was no serious interest in wireless power transmission research to the knowledge of the people realized that the efficient point to point transmission of power depends upon concentrating the electromagnetic energy into narrow beam before in 1930(Alwadiya, 2013). Recently, attentions to wireless power transfer have been increasing dramatically since Andre Kurs, et al has published "Wireless Power Transfer via Strongly Coupled Magnetic Resonances". Many researchers are going on the inductive coupling, which is the basic core of WPT.

1.2 Problem Statement

Over the years, technology has allowed the laptops, iPods and others to shrink on the size of the Integrated Circuits (ICs) and also the batteries. The mobility degree of the devices is strongly relied on how often you have to manually plug in for recharging the batteries. Most people might accept that will never change so they carry an extra batteries or charger with them. Furthermore, as portable devices shrink, connectors cable become a larger fraction of system size. Nowdays, the market for electric power is more competitive. Improving the effectiveness of transfer computations for the areas of power systems would prove a strong economic incentive.

1.3 Objective of Research

The objectives of this thesis is to design magnetic coupled resonators for wireless power transfer. The specific objectives are:

a) To study on the inductance expression based on Current Sheet Approximation and Modified Wheeler Formula.

b) To design wireless power transfer systems using the Computer Simulation Technology Microwave Studio (CST MWS).

c) To study on distance air-gap and efficiency of magnetic resonant coupling for wireless power transfer.

1.4 Scope of Research

The scopes of research are :

a. Comparison of various numbers of turn (*n*) between expression based on Current Sheet Approximation and Modified Wheeler Formula.

b. The wireless energy transmission resonator having same size transmitting and receiving has been simulated by varying the number of turn and transmission distance air gap.

c. The efficiency expressions were computed for the measured parameters for frequencies between 9MHz to 14MHz.

1.5 Structure of Thesis

Chapter 1: Introduces on the aim and objectives of this research, problem statement, scope of project and structure of the thesis.

Chapter 2: Presents a detailed discussion of the available literature on the characteristic of traditional magnetic inductive coupling wireless power transfer and electromagnetic resonant wireless power transmission technology.

Chapter 3: Describes the method of research and designing the wireless power transfer by using Computer Simulation Technology Microwave Studio (CST MWS).

Chapter 4: Demonstrates the measurement result and compares the result with published work reported in literature.

Chapter 5: Gives the conclusions of the thesis and the suggestion for further work as an extension of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Generally, WPT was categorized as radiative and non-radiative. Radiative or far-field power transfer relies on high frequency excitation of a power source and radiative power emitted from an antenna and propagates through a medium (such as vacuum or air) over long distance in the form of electromagnetic wave. It is not feasible to use the radiative techniques for consumer electronics. This is because of the necessity of high power levels and large antenna requirements. Non-radiative wireless power transfer relies on the near-field electromagnetic coupling of conductive loops. Magnetic resonances are safe since the biological tissues interact weakly with magnetic fields (Ramachandran, 2007). The resonant coupling produces can transmit over wide distances than the traditional magnetic induction method. In the last few years, many applications were proposed via WPT such electronic devices cell phones, laptops or electric cars and whose batteries need to be recharged (Alwadiya, 2013).

2.2 WPT Classification

The WPT systems can be mainly classified into three categories: two are the near-field energy transfer ones and the other one is the far-field energy transfer system . The typical exponential decay curve of the efficiency as a function of transmission distance (*d*) for wireless power transfer as shown in figure 2.1 and table 1.1 shows the different wireless power technologies.

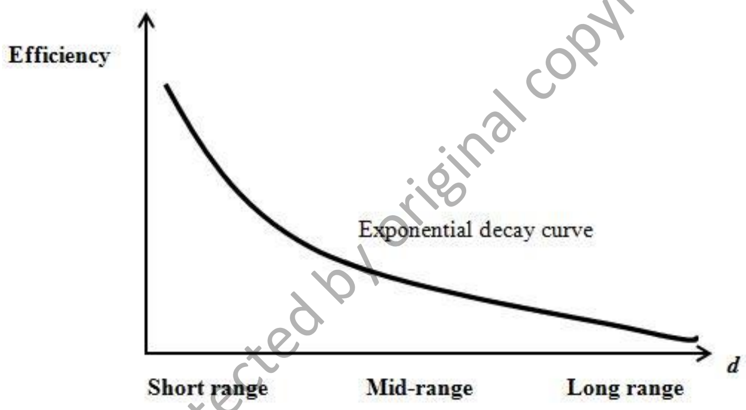

Figure 2.1 : Typical exponential decay curve (Alwadiya, 2013).

Table 2.1 : Comparison of different wireless power technologies (H.Yoon, 2012)

	Induction Coupling	**Resonant Coupling**	**Radiative Transfer**
Wave	Magnetic Field (Wideband)	Magnetic Field (Narrow band)	Electro-magnetic wave
Range	Very short (~cm)	Short (~m)	Medium and Long (~km)
Efficiency	High	Medium	Low
Operating Frequency	LF-band (~several hundred kHz)	HF-band (6.78 MHz, 13.56 MHz)	RF-band (2.4 GHz, 5.8 GHz)

Typical Load	Varying load (battery)	Fixed Impedance	Fixed Impedance
Advantage	High Efficiency	Medium efficiency in a short range	Long range
Bottleneck	Very short range	Difficulties in maintaining high Q (Quality Factor)	Low efficiency, Human Safety

2.2.1 Short range Near-Field Systems

One of the two categories of the near-field WPT systems based on the magnetic induction method for coupling energy from the source to the charging device like some smart mobile phones with charging plates. This kind of the near-field WPT technology has already been revealed in commercial use (Pu, Hui, & Member, 2013). One drawback of the near field magnetic induction method is kind of the WPT systems can work like an electrical transformer only. The relatively short range due to the amount of power required to produce an electromagnetic field. Over greater distances the non-resonant induction method an efficient and wastes much of the transmitted energy just to increase the range (Salman, Abbas, & Maqbool, 2014). The WPT system for a low power electronics charging applications using magnetic inductive as shown in figure 2.2.

Figure 2.2 : The Electric Toothbrush Battery Charger (Alexzander & Anbumalar, 2011).

2.2.2 Mid-range Near-Field System

However, relying on the strongly coupled magnetic resonance method, the other category of the near-field WPT systems is much more potential for application. Via the magnetic resonance method, the transfer distance will be extended to be much farther than that of near-field WPT systems designed by using the magnetic induction method. In the meanwhile, the strongly coupled magnetic resonance method WPT system is still working involved in the near-field area and specifically in the tail region of the evanescent modes. figure 2.3 show the WPT system using magnetic resonance for electric vehicles.

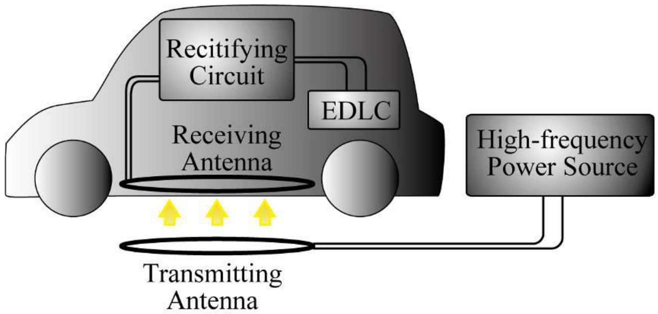

Figure 2.3 : The WPT for Electric Vehicles (Imura, Uchida, & Hori, 2009)

2.2.3 Long Range Far-Field System

The transfer distance of far-field WPT system with much higher operating frequency is rather long for radiative energy propagation, the radiation loss occurs more significantly and therefore the far-field WPT system needs more input power when its compared with the near-field WPT ones. Long Range Far-Field System using high directional antennas could be used for WPT, even over long distances but requires the existence of an uninterrupted line of sight that may harm the human body (Jang et al. 2012). The long distance method uses microwaves and radio waves power transmission via radio waves as shown in figure 2.4.

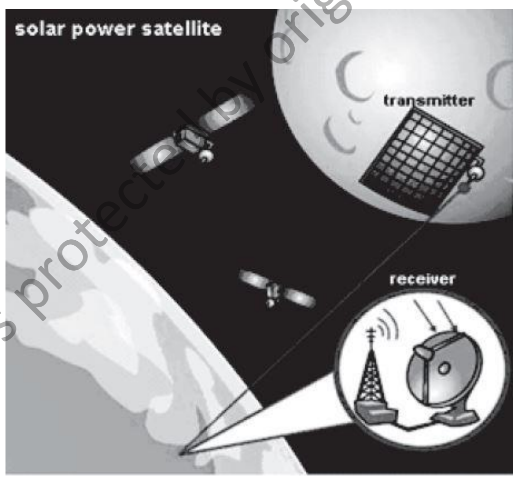

Figure 2.4 : Solar Power Satellite (Alexzander & Anbumalar, 2011)

2.3 Developments of Wireless Power Transmission

Many researchers have experimented with the design of Tesla's wireless energy transmission system and made observations that may be in considered with a basic tenet of mainstream physics which are presently considered to be nonphysical.

The Tesla wireless energy transmission system combines electrical power transmission together with broadcasting and wireless telecommunications, and it did not need most of the existing power transmission lines, the electrical generation plants.

The initial idea of wireless power transmission by magnetic resonance method was introduced by Nikola Tesla. In 1899, Tesla achieved a great progress by designing a resonance transformer that was recognized as Tesla coil. It was transmitted 100 million volts of electrical energy to a distance of 26 miles and lit 200 lamps. It was turned on an electric motor. Unfortunately, Tesla's experiments were halted due to lack of financial resources and he failed to finish his plans (Javadi & Mohamedi, 2011).

There are a few WPT on the market. Massachusetts Institute of Technology (MIT) was the first to demonstrate wireless power using resonant near field inductive coupling in 2007. In 2008, Intel also achieved wireless power though inductive coupling. The methods consist of two coils. The same resonant frequency with an oscillator that sends a sinusoidal signal transmitting power at the resonant frequency (Deller et al., 2008).

2.3.1 Traditional Magnetic Inductive Coupling Wireless Power Transfer

The concept of inductive power transfer traces back to the 19th century when two key discoveries were made, Electromagnet and Induction. By combining those two discoveries, the novel technique termed inductively coupled power transfer (ICPT) arises (Raval, Kacprzak, & Hu, 2011).

An electromagnetic induction was transfer the power only a few centimeters that around 10 cm at 20-40 kHz. Electromagnetic Induction is weak when displaced and impossible if off by only a few centimeters. To use wireless power transfer everywhere you want, typical electromagnetic induction is not suitable (Imura & Hori, 2011).

An inductively coupled power transfer system has a pair of coupled coils. At the transmitting side, an alternating current flows through a coil, generating a magnetic field. A receiving coil, which is close enough to the primary coil, picks up the field and generates a current to save power. According to previous studies, the effective operating range is usually less than 30% of the diameter of coils (S.-H. Kim, Lim, & Lee, 2013).

2.3.2 The Electromagnetic Resonant Wireless Power Transmission Technology

A magnetic resonant coupling system uses a pair of coupled coils with additional capacitance, which makes the transmitter and the receiver have the same resonant frequency. It enables a highly efficient energy transmission over a longer distance compared to inductively coupled schemes (S.-H. Kim et al., 2013).

The magnetic resonance oscillate at Megahertz (MHz) frequencies, that create an efficient power transfer between the transmitter and the receiver resonator (Dumitriu, Niculae, Iordache, Mandache, & Zainea, 2012). The remarks have to be made:

i. The interaction between transmitter and receiver is strong so the interactions with no resonant objects can be neglected, and an efficient wireless power transfer is created.

ii. Magnetic resonance is particularly suitable for applications which the materials do not interact with magnetic fields.

iii. The power transfer is not visibly affected to the humans and various objects, such as electronic devices, metal and wood that are placed between the two coils that are source and device.

2.4 Design of Inductive Coil for Wireless Power Transfer

The concept of resonance involved in the design to have more coupling between the transmitter and receiver to reduce the leakage inductance and loss in the power transfer and increasing the power transfer efficiency.

(Kurs et al., 2007) from MIT proposed a new scheme based on strongly coupled magnetic resonances, thus presenting a potential breakthrough for a midrange wireless energy transfer. The fundamental principle is that resonant objects exchange energy efficiently, while non-resonant objects do not. The scheme is carried with a power transfer of 60 W and has RF-to-RF coupling efficiency of 40% for a distance of 2 m, which is more than three times the coil's diameter.

(Selvakumaran, Liu, Soong, Ming, & Loon, 2009) investigated an efficient design of inductive link for efficient power transfer. It deals with the analytical approach of design and simulation which it gives a better insight to the design. The performance of inductive link at frequency 125 KHz has been studied using the Agilent EMDS software. A circuit modeling of the coils has shown in figure 2.5.

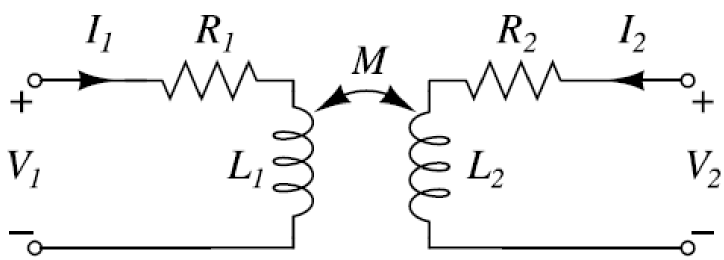

Figure 2.5 : RL model of the coil (Selvakumaran et al., 2009)