# MID-RANGE TRANSFORMER BASED WIRELESS POWER TRANSFER SYSTEM FOR LOW POWER DEVICES

LEONG KAH MENG

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Universiti Teknologi Malaysia

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Dedication to my mum and dad,

my brothers and sisters,

and my beloved friends.

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## ABSTRACT

Wireless power transfer technique for biomedical devices has drawn great interest from many researchers in the biomedical domain. Biomedical devices can be powered up either by an external power cord or by batteries. However an external power cord may limit the mobility of a patient and batteries tend to have a very limited power capacity and these methods may pose a high risk of infection towards the patient. Therefore, a wireless power transfer system is proposed to solve the problem. This study attempts to develop a mid-range transformer based wireless power transmission system which is suitable to power biomedical devices. This includes the develop of a transmitter circuit, receiver circuit, a pair of transmitter and receiver coils and transformers. This study demonstrates that magnetic coupling technique is a reliable wireless charging technique biomedical devices due to its mid-range transmission and satisfactory efficiency. In order to reduce power loss, an impedance matching method which incorporates a step-up and step-down transformers in the transmitter and receiver circuit is proposed. This study also develops a wireless power charging system that does not emit harmful radiation towards the human body. The frequency for the system is within the range of 700 kHz to 900 kHz which is in accordance to the ICNIRP regulation. Three pairs of round-shaped transmitter and receiver coils pair have been designed and fabricated with the diameter size of 30cm, 40cm, and 50cm. The power supply and frequency generator are connected to the transmitter circuit and an oscilloscope is connected to the load of the receiver circuit. The performance results are recorded using a range from 4 centimeters to 110 centimeters and based on the tabulated results, the mid-range wireless power transfer system managed to supply a transfer efficiency of 60% at a distance of 35cm for the 30cm diameter coil, 62% at a distance of 43cm for the 40cm diameter coil and 46% at a distance of 50cm for the 50cm diameter coil.

## ABSTRAK

Teknik pemindahan kuasa tanpa wayar untuk peranti bioperubatan telah menarik minat ramai penyelidik dalam domain bioperubatan. Peranti bioperubatan boleh dihidupkan sama ada dengan kord kuasa luar atau oleh bateri. Walau bagaimanapun wayar kuasa luar boleh membataskan pergerakan pesakit. Ini boleh memberi risiko jangkitan yang tinggi terhadap pesakit. Oleh itu, sistem pemindahan kuasa tanpa wayar adalah dicadangkan untuk menyelesaikan masalah tersebut. Kajian ini bertujuan untuk membangunkan satu sistem penghantaran kuasa tanpa wayar berdasarkan transformer yang sesuai dalam mengecas peranti bioperubatan. Ini termasuk membangunkan sebuah litar pemancar, litar penerima, sepasang pemancar dan penerima gegelung dan pengubah. Kajian ini menunjukkan bahawa teknik gandingan magnet adalah teknik pengecasan tanpa wayar yang paling cekap dan memuaskan. Dalam usaha untuk mengurangkan kehilangan kuasa, satu teknik padanan impedans yang menggabungkan transformer langkah-naik dan transformer langkah-turun dalam pemancar dan penerima litar juga dicadangkan. Kajian ini juga membangunkan sistem tenaga pengecasan tanpa wayar yang tidak memancarkan radiasi berbahaya terhadap badan manusia. Frekuensi untuk sistem ini adalah dalam julat 700 kHz hingga 900 Hz yang selaras dengan peraturan ICNIRP. Tiga pasang pemancar berbentuk bulat dan penerima pasangan gegelung telah direka dengan saiz diameter 30cm, 40cm, dan 50cm. Bekalan kuasa dan penjana frekuensi disambungkan kepada litar pemancar dan osiloskop disambungkan ke beban litar penerima. Keputusan prestasi direkodkan menggunakan pelbagai dari 4 sentimeter hingga 110 sentimeter dan berdasarkan keputusan yang dijadualkan itu, wayarles sistem pemindahan kuasa pertengahan berjaya membekalkan kecekapan pemindahan sebanyak 60% pada jarak 35 cm bagi gegelung 30cm diameter, 62 % pada jarak 43 cm bagi gegelung 40cm diameter dan 46% pada jarak 50cm untuk gegelung 50cm diameter.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ADS | - | Advanced Design System |
| ICD | - | Implantable cardioverter defibrillator |
| FREE-D | - | Free-Range Resonant Electrical Energy Delivery |
| LVAD | - | Left ventricular assist device |
| TET | - | Transcutaneous Energy Transfer |
| WPT | - | Wireless power transmission |
| ICNIRP | - | International Commission on Non-Ionizing Radiation Protection |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $\omega$ | - | Angular frequency |
| c | - | speed of light |
| C | - | Capacitance |
| L | - | Inductance |
| f | - | Resonant frequency |
| I | - | AC Current |
| V | - | AC Voltage |
| M | - | Mutual inductance |
| k | - | Coupling coefficient |
| Q | - | Quality factor |
| X | - | Reactant |
| n | - | Transformer ratio |
| N | - | Number of turns |
| A | - | Cross sectional area |
| R | - | Resistance |
| Z | - | Impedance |
| P | - | Power |
| S | - | Forward gain |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

This chapter will briefly discussed about the background study, problem statement, objectives, scope of study and importance of the research for the mid-range wireless charging system for biomedical applications. Mid-range defined as the transmission range can be acheived more than one antenna diameter but less than or equal to 10 antenna diameter. The backgroud study describes the recent trend about the biomedical devices used for patients. The problem statement decribes the obstacles and limitations for recent technologies about biomedical devices. The objectives are set to tackle the problems. The scope of study will serve as a guideline when doing the research. The importance of the mid-range wireless charging system for biomedical devices is also presented.

## 1.1 BACKGROUND STUDY

A medical device may refer to any instrument or apparatus to be used on human beings for the purpose of diagnosis, prevention monitoring, treatment or alleviation of disease. Medical implant devices are getting popular and critical in today and future healthcare market due to the ability to locally stimulate internal organs and communicate the internal important data to the outside world (Li *et al.*, 2012; RamRakhyani *et al.*, 2011). Riding on the advances in integrated circuit (IC) technology today, the electronic system can be made completely implantable (Chandrakasan *et al.*, 2008). For the past four decades, there is a significant development and implementation for implantable medical devices. The examples of medical implantable devices are pacemakers, defibrillators, circulatory assist devices, artificial hearts, cochlear implants, neuromuscular stimulators, and analog sensors (Sanni *et al.*, 2012).These implantable devices or low-power biosensors serve as devices for identification, monitoring and treatment of patients (Fowler *et al.*, 2012;

Zhu *et al.*, 2011). Besides that, it can also perform therapeutic, prosthetic, and diagnostic functions (Liu *et al.*, 2009b). Some research data show that the global medical device market yielded around $209 billion during year 2006.

However, these electronic devices are not self-powered. It is greatly depending on the electricity from the battery which is coupled together with the devices. Early implantable devices such as pacemakers are powered by small lithium ion batteries (Laskovski *et al.*, 2009). Even though the battery is coupled together with the implanted devices is able to supply stable electrical energy, the limitation in energy storage is still hindering its application and durability (Hu *et al.*, 2005). The internal battery has the disadvantages of limited life time, large volume and leakage possibility, hence it is not a preferable solution in this area of interest (Cha *et al.*, 2012; Li *et al.*, 2012; Samad *et al.*, 2006).

Devices such as the implanted extendable rod for the treatment of adolescent idiopathic scoliosis or as growing prosthesis for young patients with bone cancer, it requires several watts of electric power to drive the electric motor (Jiang *et al.*, 2010). For this high power demand device, a more frequent recharging of battery or replacement is required. This increases the risk of operation. Otherwise, a transcutaneous power cord has to be made out from the patient's skin in order to charge the devices. According to a research, there are about 40 percent of patients who are infected due to this opening and require re-hospitalization. In some extreme case, the patients might die from it. In order to reduce the fatality rate of patients, which is the objective of medication, a continuous supply of energy is crucial in order for the devices to operate continuously and reliably (RamRakhyani *et al.*, 2011; Zhu *et al.*, 2011).

As a result, it is a meaningful study in order to power these implanted devices efficiently (Liu *et al.*, 2009b; Si *et al.*, 2007).Moreover, due to the space constraint, real-time energy supplying system can save a lot of space as well Laskovski *et al.* (2009). If these problems can be solved by getting rid of the cable, the human made devices can be a good alternative for the patients to recover.

## 1.2 PROBLEM STATEMENT

As mentioned in the background study, the power supply for the implantable devices can only be obtained mainly through two processes, which are the battery replacement or via external power cord charging.

The energy supply is crucial in the functionality of biomedical devices. Hence, an efficient, continuous and stable supply of energy is required. These devices must receive energy supply externally or harvest the ambient energy. For non-implantable devices, batteries can be easily replaced or recharged. For the patient's benefit, it is also not recommended to do it frequently. One of the examples is the behind-the-ear cochlear instrument which has to be charged everyday. However, the batteries in implantable devices can only be replaced or recharged by surgery. Therefore, an alternative solution such as wireless power charging may be a viable solution (Chandrakasan *et al.*, 2008).

An alternative method to use is transcutaneous power cable. Generally, the percutaneous link across the body skin is used to recharge the internal battery (RamRakhyani *et al.*, 2011). However, it may pose infection risks to the patients and the wire is also somehow entangled and causes restriction in mobility (Samad *et al.*, 2006; Si *et al.*, 2007).The power cord also restricts the patient to peform activities related to water. Since human is an individual which required motion and freedom, the constantly charging also make them have to stick to a place for certain amount of time periodically. These will cause low moblity and not productive for the patients to carry out their works.

So, if the electric supply for the implant devices can be solve, certainly it will make the biomedical implant devices more applicable and help to save more life.

## 1.3 OBJECTIVE

This research has proposed the use of wireless power charging technology to charge the battery of biomedical devices.The objectives for this research are outlined as follow:

1. To develop a mid-range wireless power transmission system to charge the biomedical devices.
2. To design a transformer based wireless power transmission system.
3. To evaluate the safety performance of developed wireless power transfer system.

## 1.4 SCOPE

The area of interest of this research is limited to the following scope:

1. The research focuses on the development of transmitter circuit and receiver circuit. This include the transmitter and receiver coils pair design and the impedance matching for the system.
2. This wireless energy transfer system is only implemented for biomedical applications.
3. The viable range for charging the devices should be within 1meter.
4. The target power of biomedical devices is from 1 watt to 5 watt.
5. The range of frequency used should be lower than 1MHz

## 1.5 IMPORTANCE OF RESEARCH

This system is expected to contribute to the advancement of biomedical technology for more patients to benefit from it especially for those who need the biomedical devices to sustain their life. The increasing usability of cables for charging purposes towards the biomedical devices will limit the mobility of patients during the charging process. In addition, when replacing the batteries of some implantable biomedical devices in human body, it will increase risk of several infection during the operation surgery. Hence, the wireless power charging system is a better solution for those problems.

## 1.6 Thesis Organisation

Chapter 1 introduces the background of the study. It gives a brief introduction on the problems related to the biomedical devices. In addition, it also list out the objectives and the scope of this study.

Chapter 2 presentes the literature review for this research. It includes a history of recent wireless charging technology and its founder. Comparisons between three different techniques of wireless charging technologies, namely inductive transfer, magnetic resonant coupling and radio frequency energy transfer are described. Magnetic resonant coupling technique is used in this research and for further elaboration. The technical review on magnetic resonant coupling for two coil transfer system, four coil transfer systema and resonators are presented in this chapter. A short discussion on mid-range wireless charging system can improve patients life is presented in this chapter. The available evaluation methods are discussed based on the suitability and effectiveness and how the results are statistically compared is also introduced in this chapter.

Chapter 3 present the methodology used in this study. It describes the quality factor of transmitter and receiver coils pair being measured and fabricated, the impedance matching apply to the system to improved efficiency, the system machanism of the system works, and measurement, tabullation and verification of results.

Chapter 4 present the experiment set up for the study. It shows the procedures and preparations for the experiment and equipment used.

Chapter 5 presents the result and discussion section. It shows the quality factor measured for each different transmitter and receiver coils. It also compares the result from the experimental and simulation result and provides some discussions and also compares with the preformance current wireless technologies with others researches.

Chapter 6 summarises the conclusion and the contributions of this research. The future works are also presented at the end of this chapter.

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