A Multi-Coil Wireless Power Transfer System Utilizing Dynamic Matching for In-Vivo and Biomedical Applications

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Abstract **— Typically, single coil wireless power transfer (WPT) systems which are potential utilized for in-vivo device powering are limited by the total available power at the antenna. To overcome this limitation, a multi-coil system is presented which can greatly increase the power available to the receiver coil by as much as 80% while still remaining within the regulatory limits for total available power from an individual antenna. The effects of matching based on coil separation are presented which demonstrate the dependence of the self-resonant frequency of the WPT system, and a dynamic matching solution is proposed which allows for maximum power transfer efficiency independent of coil separation or changes in body impedance.**

Index Terms — Wireless power transfer, Dynamic matching, In-vivo electronics, Biomedical systems, Implantable systems

I. INTRODUCTION

In recent years, wireless power transfer (WPT) technology has become a major focus of the research community, and has found a wide variety of applications which benefit from the removal of wires and batteries. One of the high-impact applications of WPT technology is a power supply for implantable biomedical products [1]. By developing WPT systems which can power or charge in-vivo medical electronics, it is possible to reduce the pain and risk of surgery which is currently required to replace batteries in implanted electronics.

In this work, a new magnetic resonance coupling WPT system for biomedical application is presented. In this system two transmitting coils are utilized in order to increase received power while using a relatively small amount of power from each transmitting coil. In addition, in order to cancel out the effect of resonant frequency change caused by mutual inductance of each coil and increase the power transfer efficiency at the expected operation frequency of 13.6MHz, a dynamic matching circuit is introduced for each transmitter.

II. SYSTEM OVERVIEW

In this paper, a dual transmitting coil wireless power transmission system is discussed which is intended for use in the powering and re-charging of bio-implantable devices. The block diagram of the WPT system is shown in Fig.1. The system is composed of two transmitting coils which are driven by a main controller (Central Processing Unit and Power Management Unit). The receiver circuit is designed to be mounted inside the human body. The main controller then optimizes the input power level and matching circuit depending on the impedance of receiver circuit and distance between the transmitting coils and the receiver coil. This is critical to maximizing the power transfer efficiency when coil spacing or body impedance varies. The expected operation frequency of this system is 13.6MHz which is the resonant frequency of each coil.

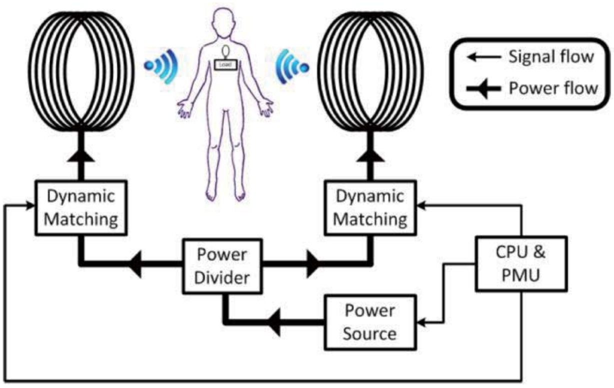

Fig. 1. Block diagram of a dual transmitting coil wireless power transmission system.

III. RESULTS

Preliminary results of the coil design are presented along with a comparison between conventional single transmitter and receiver coil techniques and new multiple transmitter configurations.

A. Single Coil Design

First, both transmitting and receiving coils are designed by utilizing CST STUDIO SUITE 2014. Each coil is a helical antenna, and designed to have self resonant frequency of 13.6 MHz. The coils are made with copper wires. The simulation results yield the following coil dimensions for 13.6 MHz operation; the radius of the coil is 50 mm, the diameter of the copper wire is 1 mm, the gap between each wire is 0.2 mm, and the number of turns is 26. The input reflection coefficient

(S11) of the coil from 10 to 15 MHz is shown in Fig. 2. At the resonant frequency, the imaginary part of S11 is close to 0, and the real part of S11 is 1.53 Ohm. This resistance is assosiated with the conductor loss and the radiation loss.

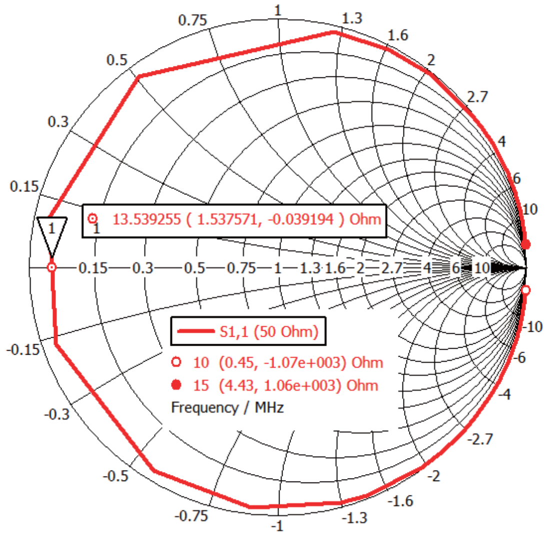

Fig. 2. S11 of helical antenna type coil from 10 to15MHz.

B. Two Coil Configuration

In literature, most of the magnetic resonance wireless power transmission systems discuss about the power transfer between a single transmitter and a single receiver coil [2, 3]. The system block diagram of single transmitter coil configuration is show in Fig.3.

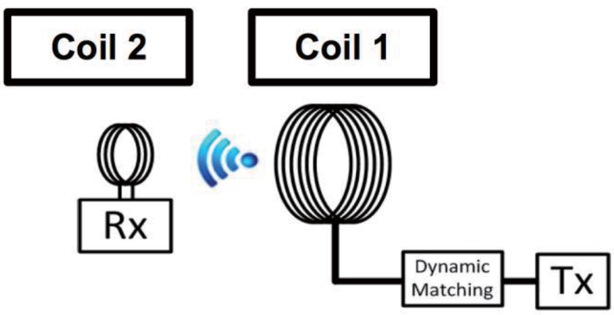

Fig. 3. Block diagram of conventional two coil configuration wireless power transmission system.

As an effect of mutual inductance between two coils, resonant frequency of two coils changes from the self-resonance frequency of each coil. This causes a decrease in the power transfer efficiency at the operation frequency. In order to compensate for the effect of mutual inductance, a matching circuit is connected between the signal generator and the transmitting coil. However, the change in S21 is different depending of the distance between the transmitting and receiving coil as depicted in Fig. 4. The S21 with and without matching circuit when the distance between two coils is 20 cm is shown in Fig.5. Input power to the transmitting coil is 30 dBm. As a result of matching, the power transferred to the receiver increases by 25%.

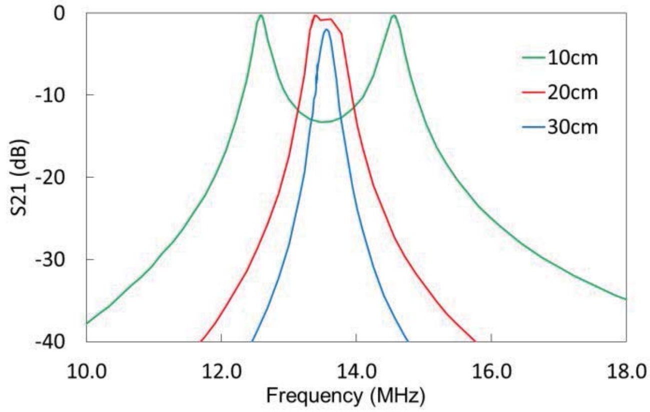

Fig. 4. S21 when distance between transmitting and receiving coil is changed from 10 to 30cm.

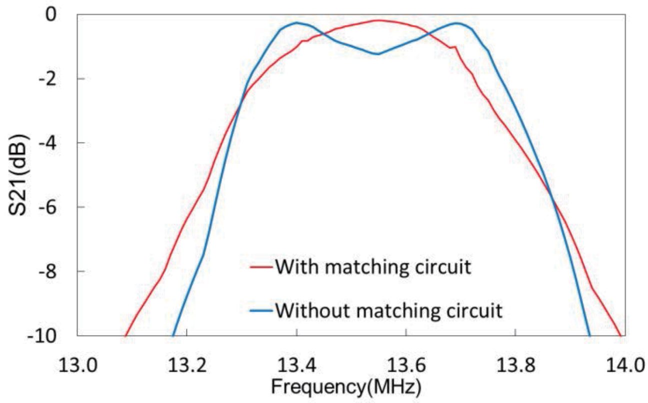

Fig. 5. S21 of the single coil system with and without a dynamic matching circuit at 20cm distance

C. Three Coil Configuration

In order to increase the received power and remain within the limitations of power available from the transmitter, a WPT system consisting of two transmitting coils is investigated [4, 5]. The block diagram of three coil configuration is shown in Fig. 6. To cancel out the effect of mutual inductance between the coils, a matching circuit is attached to each coil. The S31 and S32 with and without the dynamic matching circuit are plotted in Fig. 7. Input power to each transmitting coil is 30dBm. Output voltages of 50 ohm terminal connected to the receiver coil in each system after matching are shown in Fig. 8. By introducing a dual coil system with dynamic matching networks, the transferred power is increased by 80%

compared to a single coil system with a dynamic matching circuit.

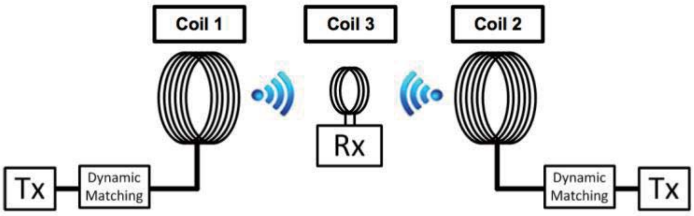

Fig. 6. Block diagram of a dual transmission coil configuration wireless power transmission system.

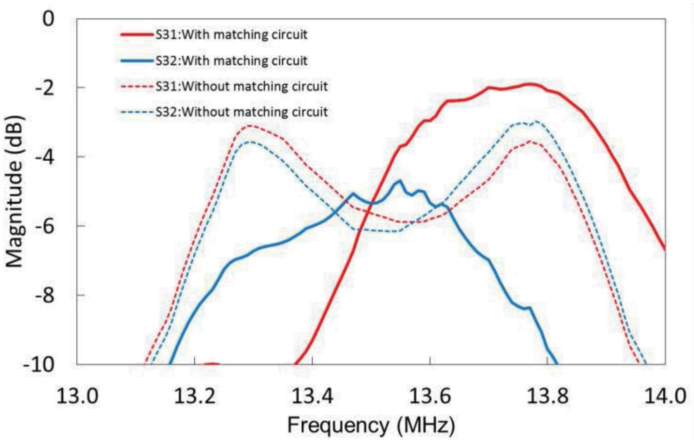

Fig.7. S31 and S32 with and without matching circuit when distance between each transmitting coil and receiving coil is 20cm.

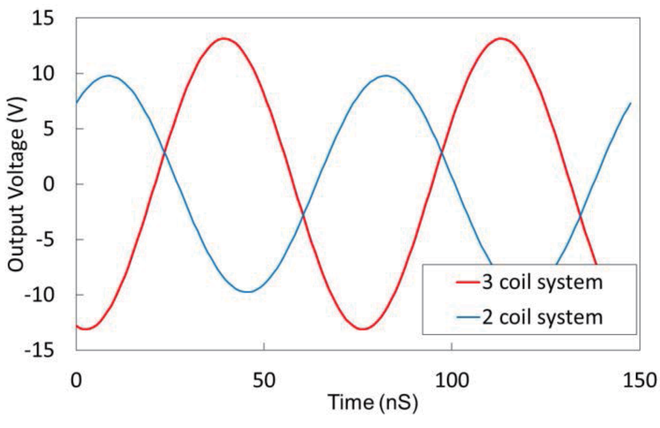

Fig. 8. Output voltage of 50 ohm terminal connected to receiver coil at 3 coil and 2 coil system.

CONCLUSION

In this paper, a novel dual transmission coil magnetic resonance wireless power transmission system for biomedical application is discussed. Compared with a conventional single transmission coil WPT system, it is suggested that the transferred power can be increased by 80% with two transmitting coils utilizing dynamic matching circuitry to account for the variation in mutual coupling due to variance in the coil spacing. From this result, the possibility to increase in available power by introducing multiple transmitting coils without exceeding the limited transmitting power from each transmitter is demonstrated.

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