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PSO based Matching Circuit tuning System for Magnetic Resonance Based Wireless Power Transfer in Biomedical Implants

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ABSTRACT

The main challenge behind magnetic resonant based wireless power transfer systems is the frequency splitting which occurs when the separation of the coil distance is reduce to a critical value. As the distance reduces the coupling between the coil will increase which leads to change in the resonant frequency of the WPT system. When the resonant frequency is changed the power transfer efficiency will reduce, which must be avoided in the case implanted biomedical devices.This paper presents a particle swarm optimization technique based tuning algorithm to match the impedance whenever the frequency split occurs in the WPT system.

1. INTRODUCTION

Capsule Endoscope (CE)are the potentialsto give the solutions to gigantic illness of public health, identical to diagnosis and treatment of gastrointestinal (GI) tract diseases. It has been calculated that in a year approximately over $30 billion is required to cure on some form of digestive disorder in United State alone [1]. Because of restricted accessibility by GI endoscopy methods, electronic pills are used since it is more powerful and non-invasive method as desired. Capsule Endoscope(CE) are employed to inspect the small intestine and reduce pain and discomfort as compared with the conventional system. Present CEs devices are normally used as auxiliary diagnostic tools because of their limited battery power and limited distance movement.As the developmentin CE technology a capsule robot (CR) with the active locomotion system has been developed [2]. With theactivelocomotionsystem, the doctors can have the full control over the CR and easy to perform some complicated operations such as biopsy and drug delivery. Apart from this feature some of the CR can walk forward and backward for repetitive diagnostics of doubtful places.On board actuators with magnetically driven methods have been developed for active locomotion.CRs are highly packed and miniaturized devices, consist of a sensing unit to monitor the physiological data of the human body, a signal conditioning circuit, a central processing unit which process the required data, a transmitter used for the communication with a receiver placed outside the body, and a power supply unit [3]- [5].

The intricate human body system and natural constraints on size of the CR presents several restrictions on the design. Even though the CR concept is best to use, the feasible and real time implementation of such a device is a complex task [6]. In the literature, researchers are focusing on size miniaturization, design of respective miniaturized components to produce marketable systems, less internal interferences with low signal-to-noise ratioand biofoulingeffects, small battery size, biocompatible packaging and high frequency wireless telemetry link solutions [7]-[9]. Among all drawbacks, volume, size and required power are the major challenges faced by an electronic pill designer. Miniaturized batteries are the simplest and practical way to attack these issues, but wireless power transmitting through the skin presents itself as a convenient solution. Whereas the complexity added by wireless power transfer to both electronic pill and outside body transmitter, batteries have limited energy budget [10]-[12].

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The energy is transferred between the primary and secondary coils of the WPT system and the capacitors are used to resonate the coil at a desired frequency value to achieve maximum energy transfer. The power transfer efficiency depends on the coupling between the coil and the coupling increases if the separation between the coil reduces [13]. At resonance if the distance between the coil is reduced then the coupling will increase above the critical value, which leads to changes in the self-resonant frequency of the coil i.e. a frequency split will occur in the WPT system. The two resonance frequency are above and below the original resonance frequency [14]. Because of this the power transfer efficiency at original frequency will reduce, this effect is named as “horn effect”. Therefore, a significant challenge in such WPT systems is that of maintaining a high power transfer efficiency with respect to distance variations as well as misalignments between the transmit and receive coils. In the recent literature, many papers are published addressing the re tuning of the coupled coil system at frequency split condition in order to operate the system at maximum efficiency [15]. This paper presents particle swarm optimization based global tuning algorithm to eliminate the effect of frequency split at small distance separation between the coupled coil.

2. SYSTEM DESCRIPTION

The evaluation platform consists of a wireless power transmitter and receiver on a single printed circuit board (PCB), show in Fig. 1. Thus it is possible to evaluate the transmit power and efficiency within a single system. The coils are connected through standard SMA connectors.

2.1. Transmitter

The transmitter is realized by the following main com-ponents, shown in Fig. 2. A direct digital synthesis (DDS) chip is used to provide a sinusoidal source signal up to 37.5 MHz. Two high output operational amplifiers with controllable gain are used to amplify the DDS output signal and drive the transmitting coil. Finally, a digitally controlled capacitor array is used to provide a tunable matching network that allows retuning of the system resonance frequency under variations in the WPT system setup, such as distance variations and misalignments. The transmitter also includes a power monitor to determine the power at the output of the amplifiers.

2.2. Receiver

The (equivalent) receiver circuit is shown in Fig. 3. Simi-larly to the transmitter circuit a tunable capacitor network is used in order to re-tune the receiver input matching. The re-ceived RF signal is

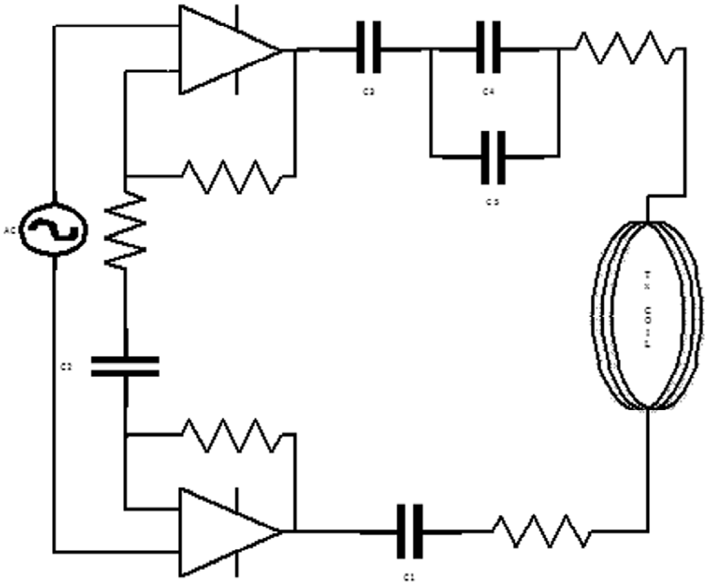


Figure 1: Equivalent circuit of the transmitter

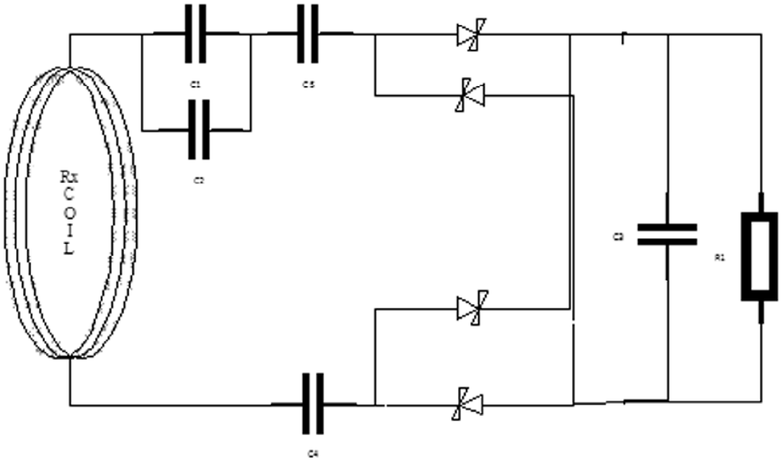


Figure 2: Equivalent circuit of the receiver

rectified by a bridge-rectifier, built by four high speed, low threshold voltage Schottky diodes (Skyworks SMS3923). The obtained DC voltage is then converted by an adjustable buck-boost DC-DC converter and finally connected to the output load. The output voltage of the DC-DC converter is set by a digital potentiometer. In the same way as in the transmitter the receiver also includes three power monitors to measure the power at the input and output of the rectifier stages as well as the output of the DC-DC converter.

3. TX ANDRX COIL DESIGN

An open type helical coil structure has been considered for the analysis of coupling between the coil in small separation range. The operating frequency or the self-resonant frequency is considered to be 13.56 MHz with the coil diameter of 10 cm. For the simplicity of design and analysis the transmitter and receiver coil is considered with the same number of turns, diameter and inductance. In the simulation the gap between the coil was optimized in order to reduce the radiation loss and integral solver is chosen to reduce the simulation time. The simulation result is listed in the table.1, for the coil radius of 50mm, diameter of the copper wire is 1mm, air gap between the consecutive turns of the coil is of 0.2mm and the number of turns is 26 to maintain the operating frequency as 13.56 MHz.

With the help of simulation results the Transmit and receive coil prototypes were designed with 1mm diameter of copper wire using laser cut acrylic board for support purpose. For different ranges of center to center coil distances the measured value of coil efficiency as listed in table 2. Because of the conductor loss in the copper wire, dielectric loss due to acrylic board support and radiation loss due to design error, higher loss will occur in the measurement. The open helical coil structure can be approximated to an equivalent series RLC circuit. Considering the resistance, inductance and capacitance of the coil as R, L and C, then the impedance Z of the coil is given by (1) and the imaginary part of the impedance is given in (2). In practice, the self-capacitance and self-inductance of the coil remains constant over the operation range of frequency, then the imaginary part of the coil impedance ca be derived at two different frequency points. The mutual inductance L_m between the two coil can be derived from the self-resonance frequency of the single coil and upper and lower resonance frequency of the two coupled coil.

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right) \tag{1}$$

$$X = \omega L - \frac{1}{\omega C} \tag{2}$$

$$L_m = \left(\frac{f_u^2 - f_l^2}{f_u^2 + f_l^2} \right) L \tag{3}$$

Table 1
Open Helical Coil Parameter

Parameters	*Values*
Radius of the coil	50mm
Diameter of the wire	1mm
Gap between the loop	0.2mm
Number of turns	26
Height of the coil	60mm
Self resonance frequency	13.56MHz

4. EVALUATION

In this paper, a PSO is used to tune the transmit and receive matching networks of the evaluation platform automatically to achieve a maximum power transfer at a frequency of 13.56 MHz, independent of coil distances and misalignments. The integration of this evaluation platform in a real operating solution will require certain communication between the transmitter and receiver to read out the received power and send the optimum capacitance conûguration, similarly to [4]. Alternatively, the evaluation platform allows one to tune a different set of parameters such as for example the operation frequency.

4.1. Cost function

The measured RMS power at the receive coil (before the rectiûcation) is used as the cost function of the PSO optimization. This function depends on the distance of the coils and experiences the frequency splitting phenomenon when coupling between the coils is strong. Fig. 4 shows measurements of the cost function that were made with the evaluation platform under several coil distances. The cost functions are normalized to the maximum achievable power at a certain distance and the capacitors are normalized to the tuning range of the system.

4.2. PSO setup

For this particular optimization problem some PSO strategies where emperically found to work properly. Bouncing is used as outer and round half up (to the next valid capacitance conûguration) as inner bound handling strategy. The particles are not initialized uniformly over the sample space but by a Gaussian distribution N(0.5,0.2) because the border values are not likely a good choice for an optimum solution as seen in Fig. 4. The swarm parameters bglob and bloc are set to a mutual value b. The use of 3-5 particles is likely a good trade-off between convergence to the global maximum and the median number of particle evaluations required to converge.

4.3. PSO-based tuning and convergence

The convergence of the PSO for many swarm parameter values a and b = bglob = bloc was evaluated. Fig. 5 shows the median number of required particle evaluations to converge to an optimum solution versus the swarm parameters a and b. It can be observed that the algorithm converges faster in the case of critical and strong coupling. In the case of weak couplingthe algorithm is more sensitive to the proper choice of the swarm parameters. There is no single optimum solution but it is rather a trade-off which case is more likely and should be optimized faster. Based on the results of Fig. 5a the selected values for the evaluation is a = 0.25 and b = 1.7.

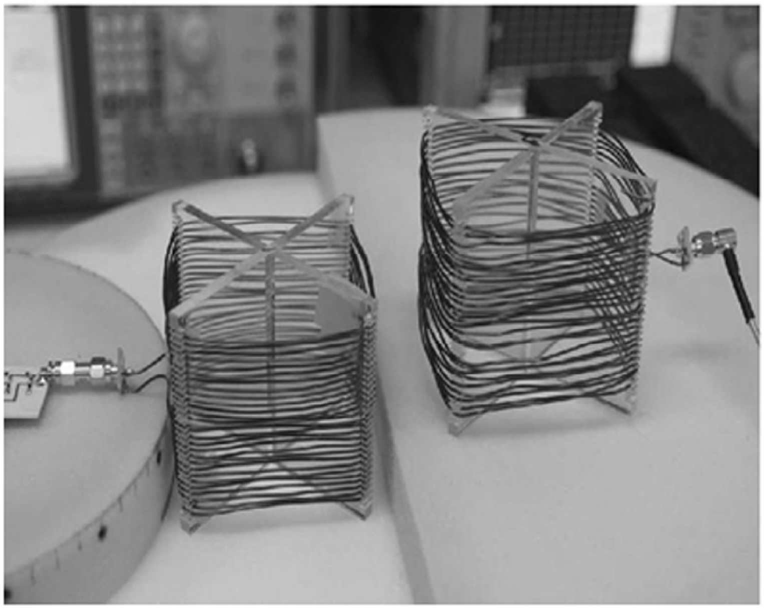
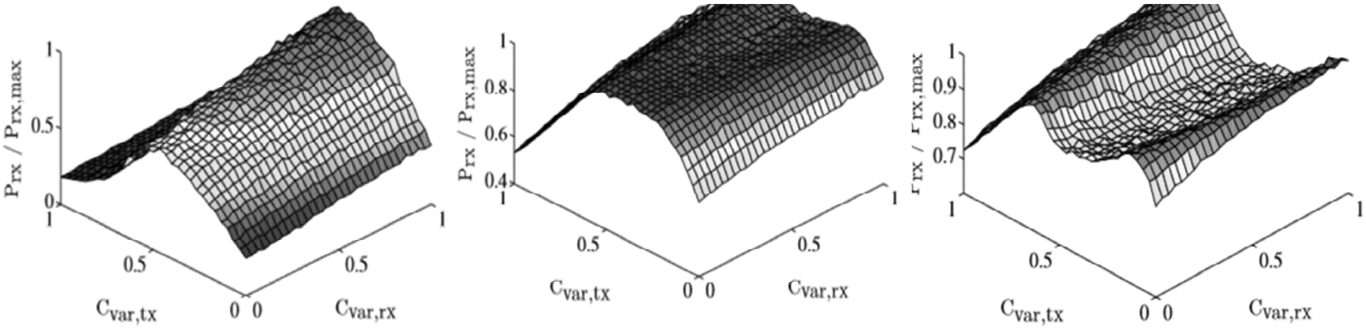
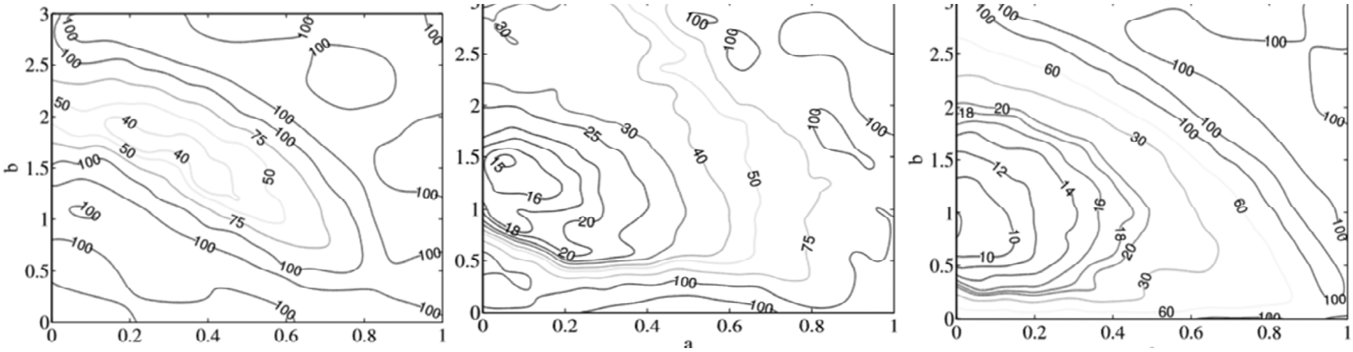


Figure 3: Experiment Setupt



(a) Weak Coupling **(b) Critical Coupling** **(c) Strong Coupling**

Figure 4: The normalized measured power



(a) Weak Coupling **(b) Critical Coupling** **(c) Strong Coupling**

Figure 5: The median mean power transfer

5. CONCLUSION

This paper addressed the challenge behind magnetic resonant based wireless power transfer systems is the frequency splitting which occurs when the separation of the coil distance is reduce to a critical value. As the distance reduces the coupling between the coil will increase which leads to change in the resonant frequency of the WPT system. Also the demonstrated experimental results matches with the simulation results.

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