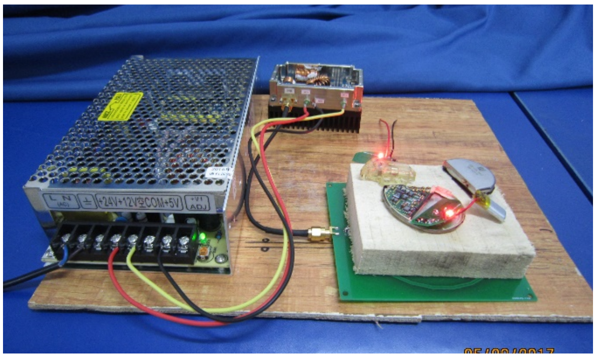
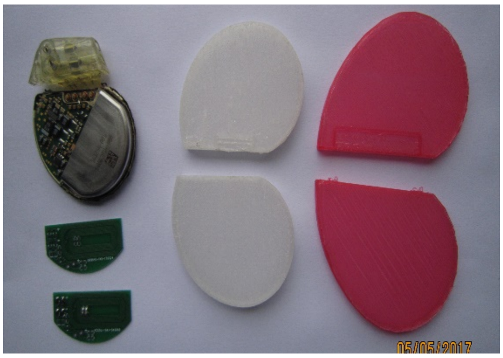
———Research Report———

Study on Wireless Power Transfer Technology Toward the Application for Cardiac Pacemaker





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Abstract

At present, at least 5 million people worldwide rely on cardiac pacemakers to maintain their lives, and this population increases by about 15% per year. But the batteries of pacemakers can generally work for 5~7 years. Therefore, to avoid bringing new pain and economic burden to the patients to replace the batteries for the implanted devices (pacemakers, etc.), there is an urgent need for new technologies that can power pacemakers wirelessly and externally.

A special wireless power transfer (WPT) technology for pacemakers based on magnetically coupled resonance (MR) was designed and fabricated in the present project. And to obtain the fundamental data for future application in the human body with different body sizes (fat or thin levels), the effect of different medium or biological tissue on the WPT performance (WPTP) was explored and quantitatively investigated. This topic has important scientific significance and practical value.

The fabricated special MR-WPT wireless charger for pacemakers includes three characteristics: the resonant transmission frequency is 6.78MHz, we designed special mini coils for pacemakers, and we used non-magnetic transparent organic materials.

The obtained main results are as follows:

(1) Based on the 6.78MHz frequency designed by Alliance for Wireless Power (A4WP) and the limited size of the pacemaker's original battery, a particular wireless charging system for the pacemaker was designed and fabricated. It is made of special mini coils, a non-metallic transparent organic shell, using a protective polymer lithium battery 041120 as a rechargeable battery, an NTP8G202N type GaN transistor as the power amplifier chip, and T-120D as power supply. The maximum WPT distance and efficiency of this MRWPT are 97% and about 12cm. It takes 1 or 1.5 Hrs for the fabricated 6.78MHz WPTS to fully charge 041120 Type polymer LIB (capacity 85mAH, 4.2V).

(2) The fabricated WPTS can implement the charging of LED, bulb lamp, mobile phone, sensor, single or multiple small household electric appliances at the same time. It can charge pass through the air, wood, brick, water, artificial human body, and biological tissue(pork). The WPTS can provide a wireless power supply to electric appliances or sensors under unique environments.

(3) Effect of thickness and conductivity of saline and agar gel on WPT performance is quantitatively studied. It is found that when all other conditions are the same, the WPT efficiency decreases with the increase of transmission side and receiving side (T-R) distance; decreases with the increase of conductivity; increases with the thickness of the medium. Agar has a stronger blocking ability for the magnetic field to pass through. At a smaller T-R distance(10cm), medium thickness and conductivity have a significant influence on the transmission efficiency

These results can provide primary data and a useful reference for the wireless power supply of implantable devices, such as pacemakers, and have important reference value. In particular, at present, there are few reports about the wireless power transmission performance through the human simulated biological tissues (agar) and biological tissue(pork), so the research objects and contents in the present project are innovative.

Keywords: wireless energy transmission; magnetic coupling resonance; multi coupling coil; PCB; agar gel; pork

1 Introduction

1.1 Overview

A cardiac pacemaker is an electronic therapeutic device implanted in the body, composed of three parts: a pulse generator, a solid lithium iodine battery, and a wire and electrode [1-10]. At present, at least 5 million people worldwide rely on implantable cardiac pacemakers to maintain their lives. Pacemakers use disposable batteries, and when the batteries have consumed about 85% of power (about 5~7 years), the pacemaker cannot work well anymore. It must promptly replace a new one and implant a new pacemaker. Therefore, the implanted cardiac pacemaker's biggest drawback is the battery's limited life caused by the battery's eventual depletion. The replacement of the pacemaker by surgery adds new physical pain, operation risk, and economic burden to the patients and reduces the cardiac pacemakers' use-value [1-2].

Wireless power transmission (WPT) technology or wireless energy transfer can eliminate the constraints of mechanical connection or space restriction to achieve energy supply by wireless mode. There are three ways to realize wireless power transmission: microwave, electromagnetic induction, and magnetic resonance. Microwave mode can achieve high power and long-distance transmission, but poor orientation, it cannot bypass the obstacles, large loss, easy to heat. Electromagnetic induction mode, which is used in transformers, is easy and straightforward to realize but have a very short transmission distance (usually at the mm level). The magnetic coupling resonance mode has a relatively large transmission distance, a relatively high transmission efficiency, and is almost harmless to the human body.

1.2 Project objectives

This project intends to create a small appliances transducer for wireless charging, to overcome the inconvenience and pain caused by pacemakers' battery replacement. And the means of wireless energy transfer would use the magnetic coupling resonant principle.

Using magnetic coupling resonant principle to realize electromagnetic energy transfer is a new technique proposed in recent years. It has advantages in the following four aspects in our project. Firstly, the energy transmission distance and transmission range are moderate. Secondly, it allows a certain range of movement during charging, which is very flexible. Thirdly, the transmission power can vary from a few watts to several hundred watts, which is easy to adjust to meet the basic needs of common wireless equipment. Lastly, the magnetic field's strong penetrating ability makes the radiation loss small and uninfluenced under many conditions.

However, the current technology still cannot fully meet the practical demands, as it is still laboratory-based. For example, in realizing magnetic coupling resonant, four solenoid coils of manual wire winding were used, resulting in a large and complicated structure and unstable performance. The practical demand needs us to develop a new, miniaturized coil structure. In addition, to achieve a wireless power supply for implantable devices, we need to know the electromagnetic field's performances in penetrating human tissue. But at present, we lack these basic data.

Therefore, aiming at those problems, this paper developed a printed circuit board (PCB) design of coil, manufactured a magnetic coupling resonance energy transfer device, and explored wireless power transmission performance in penetrating different media.

2 Research contents and research process

2.1 Research Contents

The fabrication of WPTS includes four aspects: design and manufacture of the coil, the power amplifier circuit, the selection of the signal generator and the detection of the energy efficiency. The research process includes three stages: design, fabrication, and performance testing.

The research content of this project includes three parts: (1) the exploration research of WPTS; (2) the design and fabrication of special WPTS for pacemaker; (3) the investigation of effects of the medium on the wireless transmission efficiency.

2.2 Research Process

The principle of resonant magnetic coupling radio transmission is shown in Fig. 1. The concept is based on near field coupling, distributed capacitance, and the two resonant coil's inductance. When we generate a high-frequency signal on the transmitting coil A, an alternating magnetic field is produced by near field coupling of coil A with the resonant coil S. Then, the other resonant coil D, which pairs with coil S will pick up the magnetic field, and through another near field coupling with the receiving coil B, transmits the energy to the light-bulb or the load on coil B.

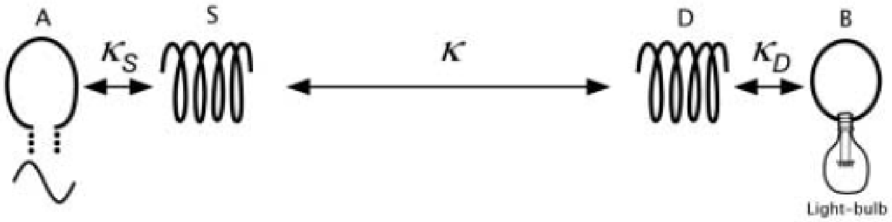


Fig. 1 principle of resonant magnetic coupling radio transmission

Now, to begin our design, we chose the pacemaker by American Medtronic Inc's Vitatron T60DR (DDDR, Model T60A1, IS-1) as a model pacemaker to carry out the work. According to the designated frequency 6.78MHz for wireless charging by A4WP (Alliance for Wireless Power), two kinds of coils have been designed: the planar transmitting coil and the small receiving coil for the pacemaker. The pacemaker's unique coil is designed according to the size of the pacemaker's battery, and the small coil needs to be combined with a rechargeable battery to form a pacemaker wireless charging battery.

As the coil area becomes smaller, the coil was designed to be double-sided to increase the number of turns and increase the induced voltage. The parameters for the coils are:

(1) The parameters of 6.78MHz planar coil: PCB plate 10*10cm, 4 resonant coil turns, top and bottom each have 2 turns, the linewidth is 1mm, line spacing 0.3mm; outer radius 44mm, inner radius 41mm; transmitting coil 1 turns, radius 47mm, width 1mm. The resonant coil inductance coefficient L=3.066uH, the distribution resistance R=0.127Ω, distribution capacitance 19.74pF, parallel connection 160 pF, the resonant frequency is 6.78MHZ.

(2) The parameters of the small coil for pacemaker: PCB plate 3.5*1.8cm, the resonant coil is rectangular 22*8mm, PCB double-side designed, coil 14 turns, the top and bottom each have 7 turns, the linewidth is 0.175mm, and line spacing 0.175mm; receiving coil is rectangular with 22*8mm, PCB double-side designed, coil 10 turns, the top and bottom each have 5 turns, the linewidth 0.175mm, and line spacing 0.175mm The resonant coil inductance coefficient L=3.819uH, the distribution of resistance R=1.69Ω, distribution capacitance 12.805pF, parallel connection capacitance 131.5 pF, the resonant frequency of 6.78MHZ.

A silica gel shell was also made to compliment the coils for the pacemaker.

The products are shown below in fig. 2, 3, and 4.

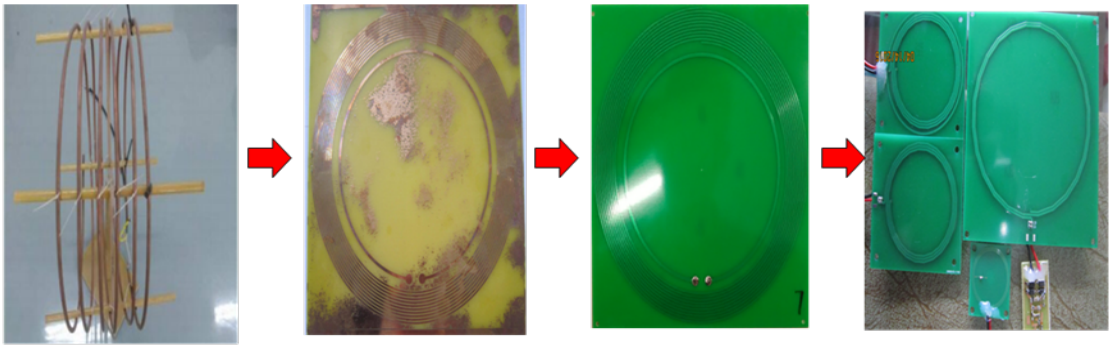
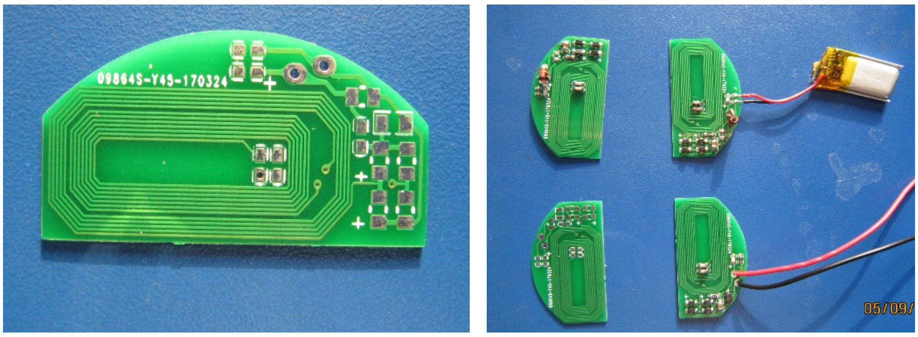
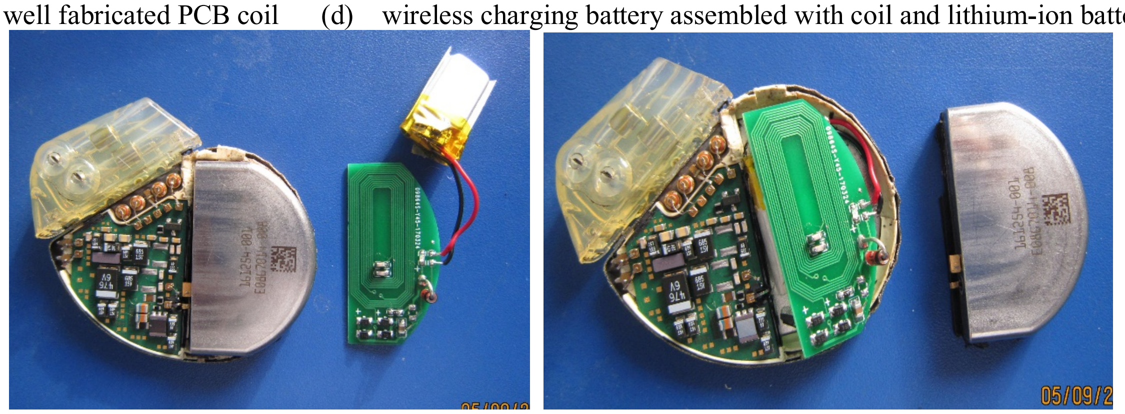


Fig. 2 PCB coils



(c) well fabricated PCB coil (d) wireless charging battery assembled with coil and lithium-ion battery



(e) the comparison of wireless charging battery and cardiac pacemaker (f) the position of the wireless charging battery in the cardiac pacemaker.

Fig.3 PCB mini coils for wireless charging device for cardiac pacemaker(6.78MHz)

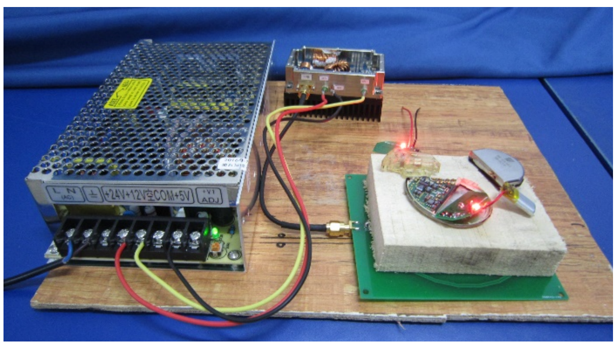
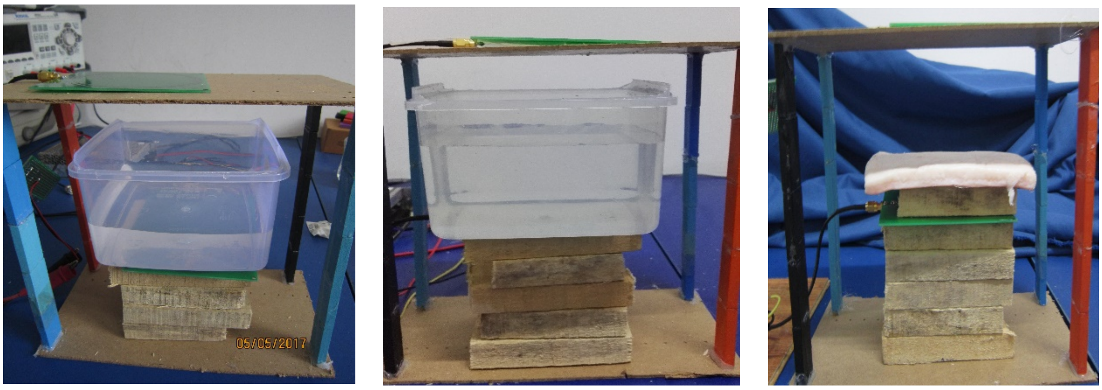


Fig. 4 The physical picture of the assembled 6.78 MHz wireless charging device for pacemaker (Transmitting and receiving PCB board are placed horizontally)

Then, we adopted two of the dielectric mediums, including salt solution and agar gel (to mimic human bionic tissue), to quantitatively study the effects of different dielectric mediums on the WPT efficiency.

A signal generator (RIGOL DG4162) equipped with a power source (GWINSTEK GPS-4303C) is used to produce a signal source with a frequency of 0.833MHZ, an amplitude of 20 VPP, an offset of 0 VOC, and a phase of 0 degrees. The input power is calculated from the DC voltage and current values of the input source detected by a power source (GWINSTEK GPS-4303C). The DC current at the output side is detected by connecting a multi-meter to the load in series. Similarly, the DC voltage at the output side is detected by connecting another multi-meter to the load in parallel. Subsequently, the output power is calculated from the DC voltage and current values of the output source. Finally, we can calculate the WPT efficiency of the whole system. The system is shown below in fig. 5.



(c) Salt solution (d) agar gel (f) Biological medium (pork)

Fig 5 Experiment set- up to measure WPT efficiency at different medium: brine, agar and pork

3 Research Results

The effect of salt solution and agar gel on the WPT efficiency is shown in figure 6, which shows the following basic rules:

(1) For the same medium, when the media height is the same, the WPT efficiency decreases with the increase of conductivity.

(2) When the T-R distance is 10cm, the WPT efficiency increases with increasing media height for the same medium with the same conductivity. WPT efficiency is higher when there are media than no medium.

(3) When the T-R distance is 12cm or 14cm, the WPT efficiency is mainly affected by the conductivity of salt solution and agar gel, which is relatively small by the change of salt water and height.

(4) For different media types, the WPT efficiency through the salt solution is higher than that of the agar gel when the conductivity is similar. Namely, agar gel possesses a stronger ability to block the passage of magnetic fields.

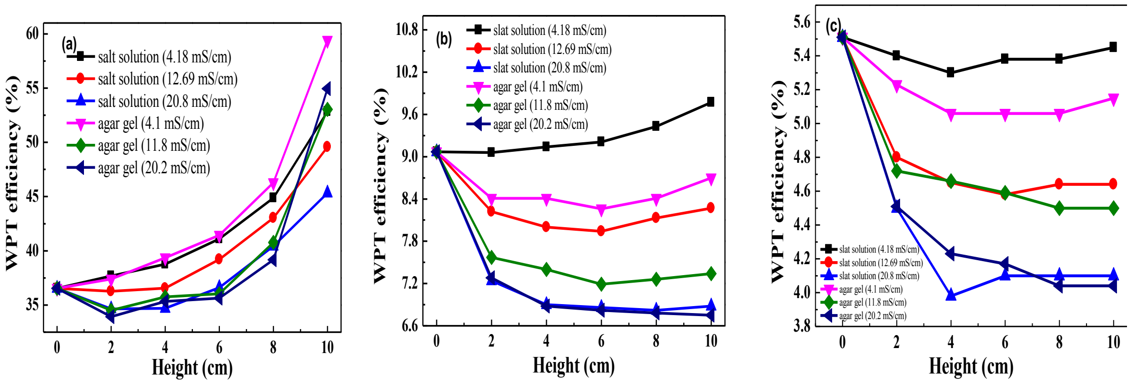


Figure 6 the effect of dielectric mediums with different conductivities on WPT efficiency: (a) the T-R distance of 10cm; (b) the T-R distance of 12cm; (c) the T-R distance of 14cm.

As presented in the experimental results above, magnetic resonance wireless transmission efficiency is affected by transmission distance, dielectric conductivity, and thickness. In addition, conductivity leads to different eddy currents, and dielectric thickness leads to different parasitic capacitance.

4 Conclusions

(1) Based on the 6.78MHz frequency designed by A4WP and the limited size of the original battery of pacemaker, a special wireless charging system for pacemaker was designed and fabricated, which is made of special mini coils, non-metallic transparent organic shell, using protective polymer lithium battery 041120 as a rechargeable battery, a NTP8G202N type GaN transistor as the power amplifier chip, and T-120D as power supply. The maximum WPT distance and efficiency of this MRWPT are 97% and about 12cm. It takes 1 or 1.5 Hrs for the fabricated 6.78MHz WPTS to fully charge 041120 Type polymer LIB (capacity 85mAH, 4.2V).

(2) The fabricated WPTS can implement the charging of LED, bulb lamp, mobile phone, sensor, single or multiple small household electric appliances at the same time, and can pass through the air, wood, brick, water, artificial human body, and biological tissue (pork). The WPTS can provide wireless power supply to the electric appliances or sensors under special environments.

(3) It is found that WPT efficiency decreases with the increase of the T-R distance. At a smaller T-R distance (10cm), medium thickness and conductivity greatly influence transmission efficiency.

(4) Effect of thickness and conductivity of saline and agar gel on WPT performance is studied. The general rule is: when all other conditions are the same, the transmission efficiency decreases with the increase of transmission distance; decreases with the increase of conductivity; increases with the medium's thickness. Agar has a stronger blocking ability for the magnetic field to pass through.

These results can provide the basic data for the wireless power supply for the devices working underwater or in vivo implanted in the body. There are few reports about the research object and research content, so our project is novel.

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Appendix:

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