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Design of Wireless Power Transmission System Based on Magnetic Coupling Resonant for the Capsule Endoscopy

Shuxiang Guo[1,2], Peng Zhang[1], Jian Guo[1*], Lili Wang[3] and Gang Sun[4]

1 Tianjin Key Laboratory for Control Theory & Application in Complicated Systems and Biomedical Robot Laboratory
Tianjin University of Technology, Binshui Xidao 391,Tianjin, China
2 Intelligent Mechanical Systems Engineering Department, Kagawa University, Takamatsu, Kagawa, Japan
3 Internal Medicine-Oncology, Tianjin Hospital of ITCWM Naikai Hospital,Three latitude Road 122, Tianjin, China
4 Gastrointestinal Surgery, Tianjin Hospital of ITCWM Naikai Hospital,Three latitude Road 122, Tianjin, China
**Corresponding Author: jianguo@tjut.edu.cn;guoshuxiang@hotmail.com; lpy19920505@gmail.com;nkyywlili@163.com*

Abstract **- In order to solve the problem that the capsule endoscope is limited by energy, it can reduce the volume and weight of the capsule robot by using the external wireless power to replace the button cell. This paper proposed a miniaturized, low-power energy transmission mode based on magnetic coupling resonant WPT(Wireless Power Transmission). Based on the scheme design, we finished the contrasting experiments of the magnetic coupling resonant and magnetic induction coupling transmission in power and efficiency, completed the weighing experiments of receiving coil and button cell(CR3032), and experimental results are obtained through constructing the platform. Through this design, we solved the questions of wireless capsule endoscope battery power restrictions, improved the work efficiency.**

Index Terms – Wireless energy transmission; Power restriction; Magnetic Coupling Resonant; Push-pull circuit of H-bridge; High frequency current transmitter

I. INTRODUCTION

At present, in the medical field, wireless power supply technology are mostly in the stage of research, research institutions and enterprises at home and abroad had made some progress in technology. The intestinal robot used for testing, in the human gut fixed-point repair, the power supply has been the bottleneck of its development[1,2]. The development of WPT technology provides the possibility for us to carry out experimental study. WPT technology in transmission mechanism is different, can be divided into magnetic induction coupling, magnetic coupling resonance, microwave radiation, laser, electric field coupling and ultrasonic method; electromagnetic field source distance according to the distance, can be divided into the near field and far field radiation type coupling. Among them, the magnetic induction coupling, magnetic coupling and electric field coupling are near field coupling, microwave radiation and laser mode are far field radiation WPT [3]. Among the several WPT technologies, the magnetic induction coupling, magnetic coupling, microwave radiation and laser are the main concerns. Among them, the microwave radiation and magnetic induction coupling started earlier, the development of the technology is more mature, and the laser mode and the magnetic coupling resonance although late start, there are still many problems to be solved. Based on the research of the existing literature, the most mainstream WPT -- magnetic induction coupling, magnetic coupling resonance, microwave radiation and laser technology widely, summarizes the research and applications. From this the basic structure and working principle of the key issues, explains the current situation of domestic research on 4 main WPT and need to be solved in the application, based on existing research, discusses the application prospect and development trend of the mainstream WPT.

Based on the problem of insufficient energy supply and high energy consumption, the WPT power transmission system is designed. The energy supply of the button battery is replaced by the coil energy transfer, and the feasibility is verified by experiments.

II. OVERVIEW OF THE PROPOSED SYSTEM

A. Overall Structure

The overall system structure of wireless power transmission device is shown in Fig. 1, mainly is composed of 3 parts: the high frequency current transmitting part and a wireless energy transmission part and a receiving coil power part. The high frequency current emission system is divided into the high frequency oscillation circuit and power amplifier circuit.

The high-frequency oscillation circuit of AC power input into weak sinusoidal alternating current of 100kHz, the current is very small. The power amplifier circuit, the current will increase to 50mA. The another part is the receiving coil which receives the current high frequency alternating current, it can not be directly on the power of the robot. Through a bridge rectifier circuit ,filter capacitor, voltage stabilizing circuit, a combination of these 3 steps, the current will turn into a stable DC transmission to the robot.

B. High Frequency Transmitting Circuit

The high frequency transmitting circuit mainly consists of two parts: high frequency generating circuit and power amplifier circuit. The circuit adopts the integrated function generator ExarXR2206 high frequency power supply voltage, +6 V to +12 V, XR2206 is connected with a capacitor and a resistor to control the frequency and the magnitude of the current. When C=0.001F, covering the frequency range of 500 Hz to 1 MHz. the higher the current frequency is, the fewer the loss of energy in wireless transmission, so we choose the capacitor of C=0.001F. This circuit to convert DC into AC current of high frequency, because the chip itself is not suitable for structure, the current is weak. After the power amplifier, in order to meet the emission needs. Using LM386 chip and feedback structure constitute amplifying circuit can transfer micro electric into large current. Through the multistage micro electric power amplifier, current will increase to 50mA. The emission circuit is to convert DC to 100 kHz, 50mA AC sine wave. We accomplished the physical circuit board welding according to the coil circuit design show in Fig. 2 , the physical map is shown in Fig. 3. After the test, the circuit board can work stably.

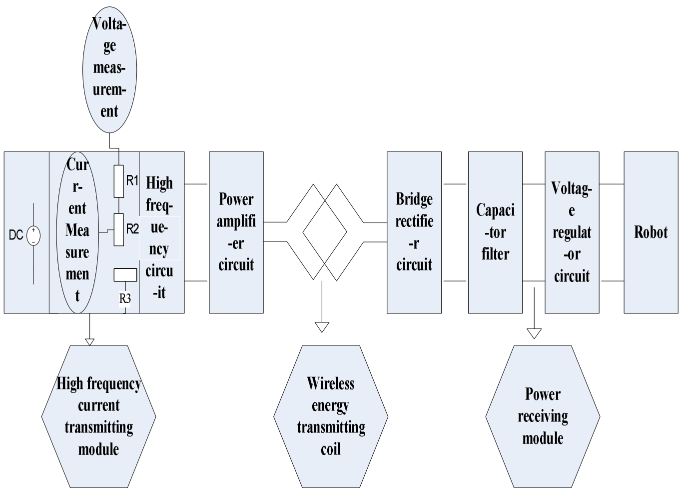

Fig. 1 The structure of experimental system

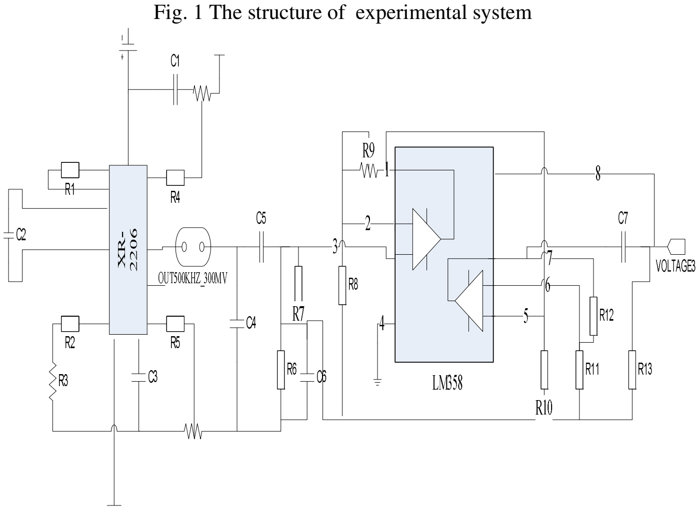

Fig . 2 Circuit diagram of high frequency current transmitter

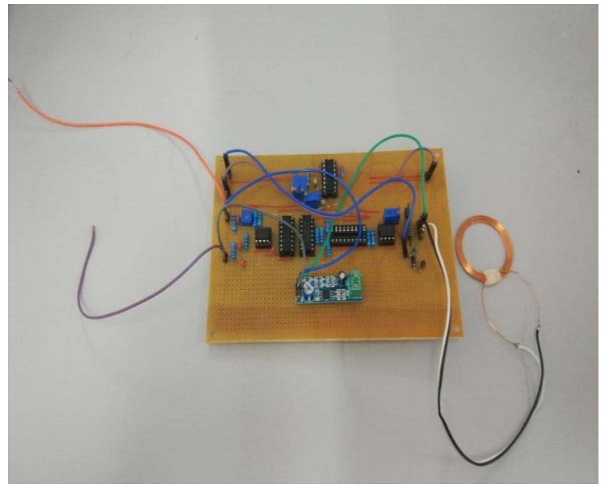

Fig. 3 Transmitter circuit module

C. *Two Patterns of Wireless Transmission*

Relates to magnetic induction coupling, magnetic coupling resonance and microwave radiation application field of medical electronic equipment WPT technology, because of the high degree of microwave electromagnetic radiation harm to human body, so the study of fewer, so the main study of this paper were the magnetic induction coupling and magnetic coupling resonance. In recent years, the research and application of WPT technology in the field of medical electronic equipment mainly in implantable medical devices, the University of Toronto in Canada Meysam Zargham use the coil which integrated in the FR4 and CMOS structures through the air, muscle and blood of radio transmission experiments [4][5]; Li Xiuhan in Beijing Jiaotong University had a research on application of magnetic coupling resonant WPT in miniature implantable medical sensor[6]; the University of Washington Benjamin H. Waters studied the application of WPT technology in the ventricular assist device wireless power supply[7]. In addition, the design and fabrication of a thin film resonator and a wireless sensor network prototype were carried out by Zhang Fei et al., Pittsburgh, USA. The radio energy transmission device is realized by the law of electromagnetic induction of Ferrari, which is mainly used in the field of wireless transmission of electric energy.

1). Magnetic Induction Coupling WPT

The basic structure and principle of the magnetic induction coupling WPT is shown in fig. 4. The components of the magnetic induction WPT system mainly include rectifier filter, high frequency inverter, the original side compensation, the separable transformer, the secondary side compensation and

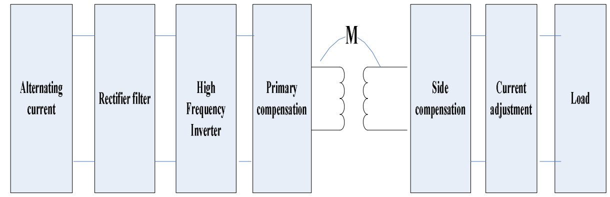

Fig. 4 The basic structure and principle of magnetic induction coupling WPT

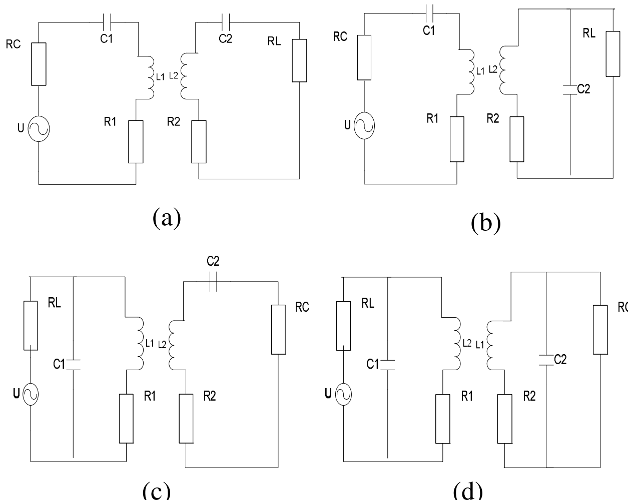

Fig. 5. Equivalent circuit of different compensation topologies:(a) Series capacitor compensation (b) Series –parallel capacitor compensation (c) Parallel-series capacitor compensation (d)Parallel shunt capacitor compensation

current conditioning, etc.. The working principle of magnetic induction is WPT AC power input from the rectifier inverter after converting high frequency alternating current, and input to the primary winding of the isolation transformer, in an inductively coupled high frequency electromagnetic fields of the power transmission to the secondary side of the transformer can be separated, and the high frequency alternating current to current conditioning the circuit converts the load current is needed, in order to achieve the purpose of power supply load.

Usually we establish energy picking up mechanism of transmitter / receiver equivalent circuit model by using the mutual inductance coupling model method, and analyse the equivalent circuit model with sinusoidal AC, further obtain the transmission characteristic function of magnetic induction coupling WPT system[8]. The equivalent circuit model with different compensation topologies under the condition of magnetic induction coupling WPT system as shown in Fig. 5, so as to establish the equations according to the equivalent circuit, we can get the transmission characteristics of the system function.

2).Magnetic Coupling Resonant WPT

The process is shown in Fig. 6: the high frequency sinusoidal alternating current is flowing in the coil 1, which can arise the change electromagnetic field, cause the strong shock to the induction coil 2, thus induced current is generated, to achieve the wireless transmission of energy from coil 1 to 2. The current frequency of coil 2 is same to coil 1, due to the magnetic field generated by the coil 1 launch all around, the coil 2 cannot be completely received, a part of energy will loss in transmission, so the current amplitude of coil 2 will be slightly smaller than the coil 1[9]. Electromagnetic field can penetrate all non metals, electricity can be transmitted across a variety of non-metallic materials. Therefore, we will design coil 1 placed on the human body outside to provide energy, the coil 2 placed in the capsule robot, through the coil 1 transmit high-frequency signals, coil 2 receives signal to generate electricity through the conversion circuit, which achieves the purpose of wireless power supply[10].

Fig. 7 Us is supply voltage, Zs, C_1, C_2 respectively represent the internal resistance of the power supply, the transmitting and receiving coil tuning capacitor, L_1 and L_2 respectively for transmitting and receiving coil inductance, R_1 and R_2 respectively for transmitting and receiving coil equivalent resistance, Z_L is the resistance of load, M for the mutual inductance between two coils[14].

The power supply frequency is M, and the impedance of the receiving circuit is respectively

$$\begin{cases} Z_1 = R_1 + Z_S + jwL_1 + \frac{1}{jwc_1} \\ Z_2 = R_2 + Z_L + jwL_2 + \frac{1}{jwc_2} \end{cases} \quad (1)$$

Consider the coupling between the two coils, the circuit shown in Fig.4 KVL

$$\begin{cases} U_S = i_1 Z_1 - jwM_{i2} \\ 0 = i_2 - jwM_{i2} \end{cases} \quad (2)$$

Bring (1) (2) (3) into available

$$Z_f = R_1 + jwL_1 + \frac{1}{jwc_1} + \frac{(wM)^2}{R_2 + R_1 + jwL_2 + \frac{1}{jwc_2}} \quad (3)$$

Power output power PS and load reception power P_L are

$$P_S = |i1^2 Z_f| = \left|\frac{(Z_2 U_S)^2 Z_f}{[Z_1 + Z_2 + (wM)^2]^2}\right| \quad (4)$$

$$P_L = |i1^2 R_L| = \left|\frac{(wMU_S)^2 R_L}{[Z_1 + Z_2 + (wM)^2]^2}\right| \quad (5)$$

Wireless power transmission efficiency η for

$$\eta = \frac{P_L}{P_s} = \frac{(wM)R_L}{|Z_2{}^2 Z_f|} \quad (6)$$

The working frequency of the magnetically coupled resonant WPT is generally from several Hz to tens of MHz, and the transmission distance is from several cm to several M. In the reported literatures, the transmission power of WPT system of University of Wisconsin Seung Hwang Le et al designed for 220 W, the working frequency is 3.7 MHz, the transmission efficiency is 95%. The transmission distance is

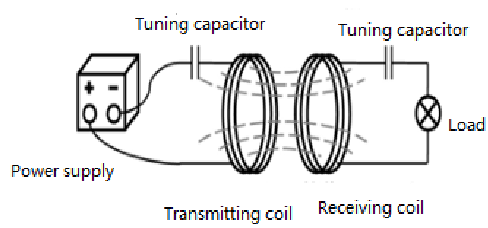

Fig. 6 The basic structure of magnetic coupling resonant wireless energy transmission system

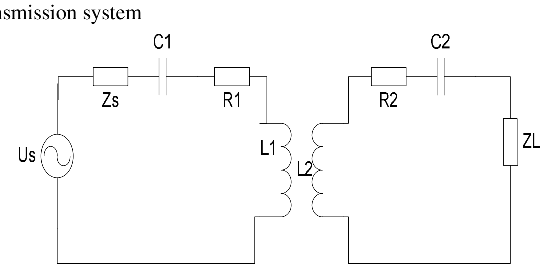

Fig. 7 Equivalent circuit model

3.7 MHz, the transmission efficiency is 95%. The transmission distance is 0.3 m[11]; Tianjin University of Technology Zhang Xian et al design high power radio of the transmission system can achieve the output power is 3 kW, the transmission efficiency 92.5%, the transmission distance is 30 cm, the frequency of 200~400 kHz[12].

D. Receiving Circuit

In order to form a resonant circuit, the emission energy achieve maximum, we design the push-pull circuit of H-bridge shown in Fig. 8. The push-pull principle is two different types of tubes in conduction, namely Q1 and Q4, Q2 and Q3 conducting, so that you can produce alternating current in L_C circuit, the alternating magnetic field near L[13]. Its biggest advantage is the high conversion of output power. Since the two tubes are responsible for the amplification the half of the input waveform, so that in a cycle of their respective conduction once, so that it do not work with no signal input, there is no loss [15]. It can save a lot of electricity when it still in static compare to the original input signal, thereby reducing the static loss of the pipe, the pipe exists only in the dynamic loss conduction, thus greatly improving the power output increased 25%, compared to static tube power.

Just as shown in Fig.9, the current in the coil through the rectifier, voltage regulator and filter, output to the load , this is not only decrease the external magnetic field, voltage instability, but also lower the noise[17].

III. EXPERIMENTS AND RESULTS

A. Coil Energy Transfer

Wireless energy transmission consists of two coils, the choice of the system is copper wire radius of 0.05 mm, the radius of bypass coil is 1.5 cm, winding coil the number of

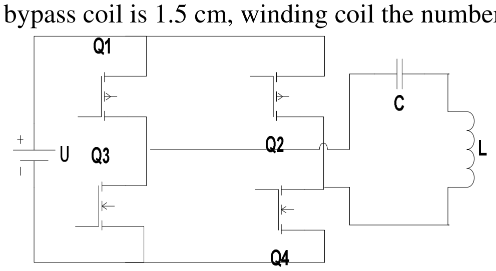

Fig. 8 The push-pull circuit of H-bridge

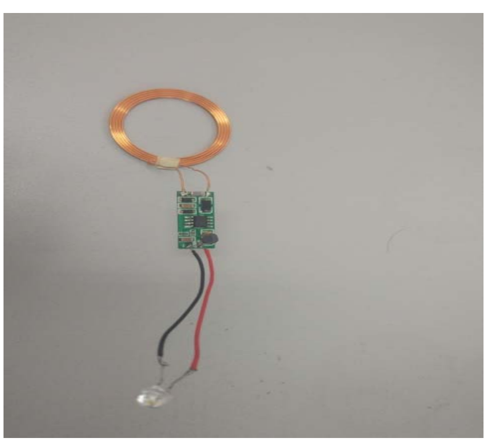

Fig. 9 The physical model of receiving circuit

turns is 20, the wireless transmission of energy to the working process achieve high efficiency, the mutual inductance between the two hollow coil for calculation formula:

$$M=\frac{pi}{2}\frac{\mu 0(N1*N2)^{0.5}r1*r2^2}{D^3} \quad (7)$$

Formula of equivalent inductance:

$$L=N^2 r\mu 0[\ln(8r/g)-2] \quad (8)$$

u_0 for the vacuum magnetic permeability, g for the average distance of the coil cross section

When the transmission distance D increases to 8cm, a critical coupling system state. In fig. 10, P_L of maximum value P_L = 28.2 W. When the system is in critical coupling condition, to make the load to obtain maximum power, must make the transmitter coil natural frequency and natural frequency of receiving coil and power frequency is consistent, namely the f1 = f2 = f3.

Through the power calculation can be concluded that the value of P_L ,We measured and calculated power and efficiency value under the magnetic induction and magnetic coupling resonance respectively, and obtained by MATLAB simulation, then the relation between coil distance and power can be shown in Fig. 11

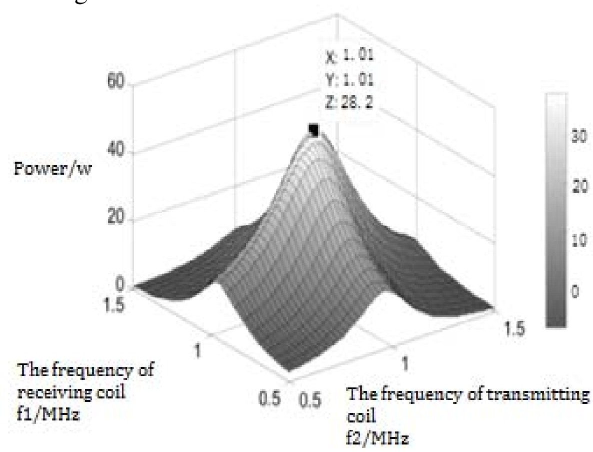

Fig. 10 Load power variation in critical coupling

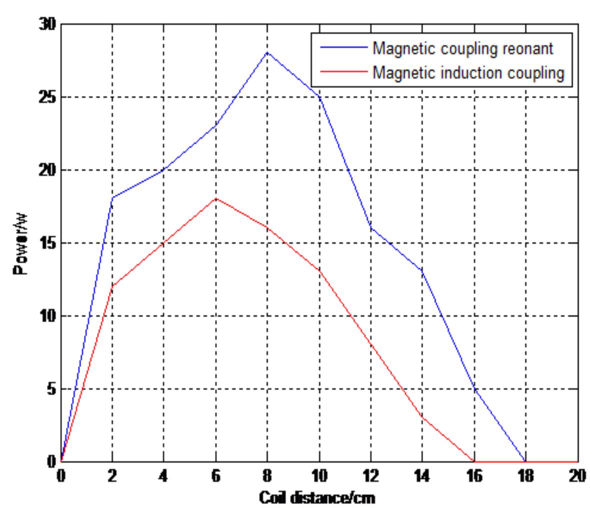

Fig. 11 The relationship between coil distance and power

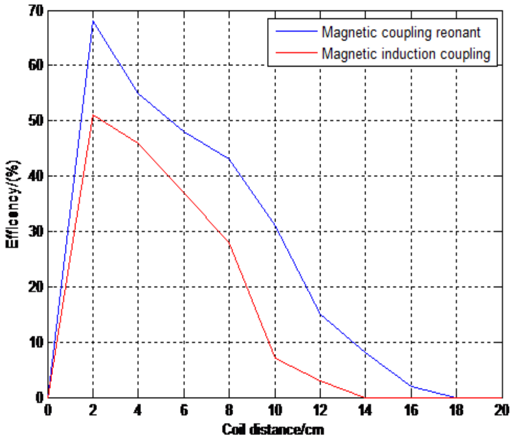

Fig. 12 The relationship between coil distance and efficiency

From the Fig. 11, the load reception power of magnetic coupling resonant no matter from the transmission distance or amplitude are more than magnetic induction energy transfer mode. When the transmission distance to the 8cm, the system is in the critical state of coupling and the power can get biggest. The maximum value of the magnetic induction coupling is 18w in 6cm[16],which is lower than magnetic coupling resonant.

According to the formula of efficiency:

$$\eta = \frac{P_L}{P_s} = \frac{(wM)R_L}{|Z_2{}^2 Z_f|} \quad (9)$$

Through Fig. 12,with the increase of the distance between the coils, the efficiency decrease. So, we can draw the conclusion: The farther the coil distance is ,the more the energy losses. When the transmission distance surpass 18cm, transmission power verge to 0, two coil distance within the 2cm, transmission efficiency is higher. So for the intestinal robot is also close to transmit power in this paper.

B. The Experiment for Weighing

In the Fig. 13 and Fig. 14, the weight of receiving circuit is much lighter than the button cell(CR3032), so the design is available. Through power connection , the LED is bright. It verify the feasibility of this experiment. To improve the receiving circuit is divided into 2 parts: the first is using H-ridge module to replace the diode combination, save vast space, a corresponding increase in the receiving coil volume; the second is the separation of filtering and voltage stabilizing circuit, its integration to the load and the overall shielding, minimize electromagnetic interference, effectively improve the energy conversion efficiency.

C. Experimental Results

Just as shown in Fig. 15, the design based on magnetic coupling resonant wireless power transmission system can work normally. The transmit circuit into 9V voltage, after high frequency transmission circuit and amplification circuit to a resonant coil, and then transmit to the receiving circuit, the completion of the energy transfer is proved by LED light. By adjusting the distance between two coil, the distance is 3cm, the LED lamp brightness is the largest, with the increase of distance until the distance to 17 cm, LED out, coil transfer energy close to 0. It can realize the wireless capsule robot power supply, also verify the feasibility of the design

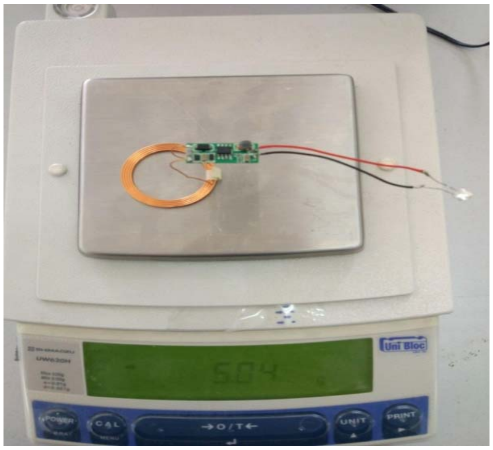

Fig. 13 The weight of receiving circuit

Fig. 14 The weight of button cell

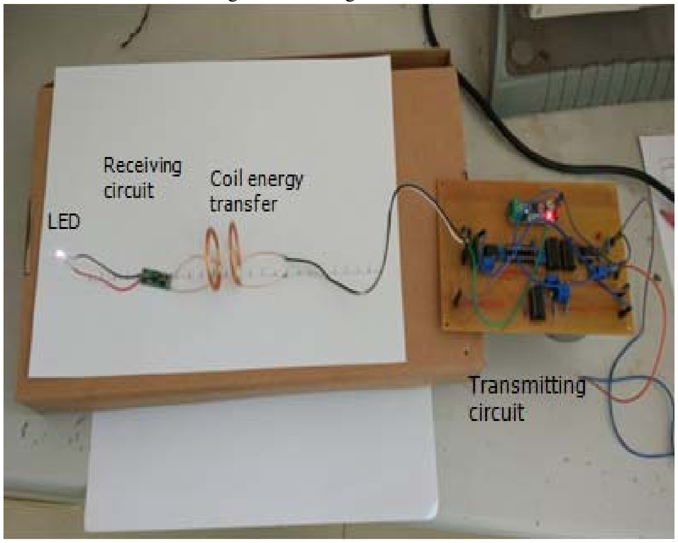

Fig. 15 Experimental result

IV. Conclusions

This paper proposed a miniaturized, low-power energy transmission mode based on magnetic coupling resonant WPT(Wireless Power Transmission).Through analysis of the data transmission device of WPT , proved that the wireless power supply device can meet the design requirements of power supply, high efficiency, small current fluctuations, wireless transmission long time stability, and reduce the volume and weight of the capsule robot, so as to promote the robot in the gastrointestinal tract more flexible. In this paper, we design wireless transmission coil replace the button battery, it also can provide capsule robot with power through the wireless transmission, make them more efficient and work longer hours. It can also supply the capsule robot, on hearing aids, heart pacemaker, and portable communication equipment and other areas with electrical power supply. Power supply mode of this innovation, greatly simplifies the process of power supply line complex, the problem of power supply equipment, medical equipment, military equipment and all kinds of waterproof of implantation in the human body resolved.

Acknowledgment

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