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Research Article

Flexible PCB Coils for Wireless Power Transfer System Using Low-Frequency Electromagnetic Induction

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Abstract: A novel flexible coil using PCB（printed circuit board）printing technology was designed. This coil can be used to generate a low-frequency (50 Hz to 10 kHz) magnetic field for wireless charging functions such as lithium batteries. In order to match the flexible coil, a complete wireless charging device is also designed. It was demonstrated the use of the flexible coil to realize the wireless energy transmission function to the lithium battery and other devices within a 2cm distance between the flexible receiving end and the transmitting end. Compared with the traditional coil forming method, PCB printing technology can realize the rapid manufacture of flexible coils with a specific planar structure, which is convenient for application in various flexible electronic devices.

Keywords: Wireless Power Transfer（WPT); Flexible Electronics; Printed Circuit Board; Flexible PCB Coil.

1. Introduction

In order to meet the increasing demands of flexible and wearable microelectronic devices in modern life, various energy storage devices such as supercapacitors, lithium-ion batteries, solar cells, etc. have been realized.

At present, the main shortcomings of various types of flexible electrochemical energy storage systems have three aspects: (1) stability issues: if the external mechanical stress, the energy output will be reduced; (2) low power density issues: it is difficult to achieve a small universal High energy output; (3) Energy supply problem: small energy density and low capacity lead to short battery life [1].

The first two problems can be solved by improving the electrochemical and mechanical properties of electrode materials and devices that withstand various stresses and optimizing the electrodes [2]. The last one can be solved by

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designing a convenient and flexible energy supply strategy that matches the flexible energy storage system. Therefore, the wireless energy transmission method is expected to solve the last problem of the flexible energy storage system.

Because of its non-contact safe and efficient power supply mode, wireless energy transmission technology has a good match for the future development trend of miniaturization, flexibility, and low energy consumption of electronic equipment, so it has become a research hotspot in recent years [3]. The wireless charging technology can well match the system characteristics of small and low power consumption of flexible electronic products, realize the transmission efficiency of mobile electronic devices and miniaturize the volume, thereby greatly increasing the possibility of implementing rich functions of flexible devices. In recent years, in the field of flexible electronics, there have been more and more researches related to the flexible wireless charging function combined with wireless energy transmission technology. Obviously, it has solved the energy supply problem of flexible electronic systems well [4].

In this paper, the author proposes a novel design and manufacturing method of a flexible coil and builds a wireless charging flexible receiving terminal based on this flexible coil. The coil can receive the electromagnetic energy emitted by the alternating electromagnetic field and then the conversion circuit can charge the battery and other devices.

2. Materials and Methods

2.1. Design and experimental setup.

Figure 1 illustrates the design of a double-layer flexible PCB coil. A polyimide substrate is used to achieve flexibility. In addition, in order to enhance the self-inductance of the coil to achieve more excellent power transmission capability, the double-layer coil is designed by connecting the top layer and the bottom layer through the through-holes.

We have extracted from the 3D EM simulation tool to obtain coils with a higher Q factor at 10 kHz using the Qi standard. Table 1 shows the design coil dimensions obtained from the 3D EM simulation. Each layer of the coil has 5 turns to obtain a total of 10 turns. In order to achieve better flexibility, we designed the coil as thin as possible. By following the flexible PCB design rules, we designed the flexible coil thickness to 298.1 μm.

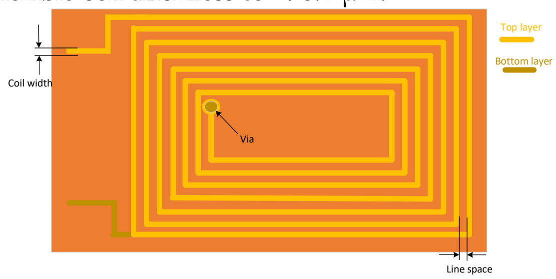

Figure 1. Top view of designed double-layered flexible PCB coil using polyimide substrate.

Table 1. Dimension of the Designed Flexible Coil

Parameter	Value
Coil Turn	6x2（twolayer）
Coil Width (mm)	2.0mm
Line Space (mm)	2.0mm
Coil Dimension (mm ×mm)	70mm ×100mm
Substrate Thickness (μm)	12.7 (μm)
Adhesive Thickness (μm)	110 (μm)
Coil Thickness (μm)	75 (μm)
Toal Thickness (μm)	298.1(μm)

2.2. Design of a wireless power transfer system.

In order to match the above-mentioned flexible coils to achieve a complete wireless charging function, this question has designed a complete wireless charging circuit. The role of each part of the following circuit is briefly explained:

(1) Power generation circuit: By processing 220 V AC mains power, the power source required by the circuit is obtained. Therefore, the function of the power generation circuit is to provide the circuit design of the power supply part for the power supply of the electric equipment. In the wireless charging equipment system based on electromagnetic induction theory in this paper, the role of the power generation circuit is to provide a low-voltage DC power input to the square wave signal generation circuit and power amplification circuit in the system [5].

(2) Square wave signal generation circuit: The role it plays is to use it to realize the output of the square wave signal. The square wave is a non-sinusoidal waveform. The ideal square wave signal has only two levels of high and low-level cycle output. The signal with this waveform is used as a clock signal to trigger the circuit.

(3) Power amplifier circuit: The power amplifier circuit is a circuit structure between the main circuit and the control circuit, which can amplify the control signal generated by the control circuit [6]. In the wireless charging equipment system based on electromagnetic induction theory in this paper, the power amplifying circuit is between the square wave signal generating circuit and the resonant circuit, the square wave signal generating circuit provides the square wave signal to the power amplifying circuit. The power amplifying circuit converts the square wave signal. After power amplification, the amplified signal is passed to the resonant circuit for use.

(4) Resonant circuit: The essence of the resonant circuit is that the electric field energy in the capacitor C and the magnetic field energy in the inductance L flow to each other [7]. The electric field energy increases, and the magnetic field energy decreases. It can keep the sum unchanged during the process of mutual conversion and achieve complete compensation. For the resonance circuit in the transmitting end, after the power amplification circuit, the power amplification circuit transmits the amplified control signal to the resonance circuit. The resonance circuit oscillates, thereby converting the DC control signal into a high-frequency AC signal. For the resonance circuit at the receiving end, it resonates with the resonance circuit at the transmitting end, generates electromagnetic induction, and receives electrical energy in the magnetic field. Complete the wireless transmission of electrical energy between the transmitter and the receiver.

(5) Rectifier circuit: The rectifier circuit is generally mainly composed of rectifier diodes[8]. The unidirectional continuity of the diode is used to achieve the purpose of rectification.

(6) Filter circuit: Since the voltage after passing through the rectifier circuit is not a pure DC voltage, to obtain a more ideal pure and stable DC voltage, a filter circuit is needed to filter out the AC voltage components.

In order to explain each part of the above wireless charging device from the circuit principle, the article gives the LCL-S type magnetic resonance wireless energy transfer equivalent circuit model, as shown in Figure 2. The circuit model is composed of self-inductance (L) and capacitance （C).

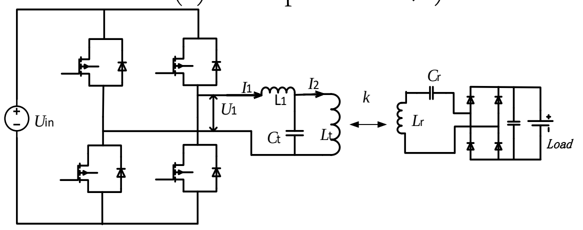

Figure 2. The equivalent circuit model of mutually coupled flexible coils in 10 kHz.

2.3. Experimental setup.

The construction of the experimental device is connected to the power supply, battery load, external oscilloscope, voltage collector, and other devices to form a measurement platform.

At a specific frequency (10kHz), the wireless power transmission coil, and the capacitor need to be matched under resonance conditions. According to the circuit design, the secondary AC output is first connected to the D20XBS6 Schottky rectifier bridge. To the voltage drop (= 0.08V-0.1V), the smaller diode voltage drop can significantly reduce the efficiency loss of the balanced system. Use an electronic load device to simulate the lithium battery charging process. The experimental setup is shown in Figure 3.

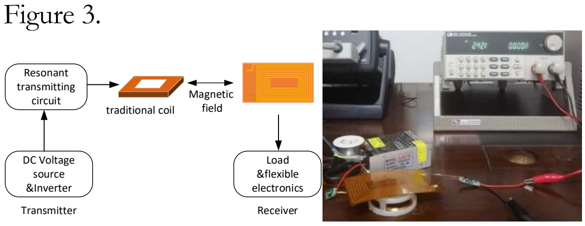

Figure 3. The wireless power transfer device using flexible printed coils.

3. Results and Discussion

3.1. Flexible coil and WPT device test.

It can be seen from the circuit topology in Figure2 that the main structure of the circuit is the series and parallel resonance of the inductor and capacitor. In this experiment, the coil with a specific inductance value is first designed and determined, so it is necessary to make a matching capacitor to make it Its resonance.

Connect the inductor and capacitor in series to the AC output of the inverter. When resonating, the voltage and current are in the same phase. The characteristic waveform of resonance current and voltage is shown in Figure 4.

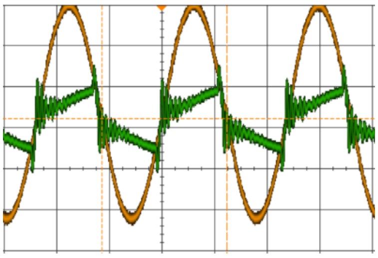

Figure 4. Current and voltage waveforms at resonance.

3.2. Battery wireless charging test.

Then we tested the wireless energy transmission system built using flexible PCB coils to charge the lithium battery. According to the LCL-S circuit topology used in Figure2, the output voltage is constant, so the relationship between battery voltage and charging current when charging the battery is shown in Figure 5.

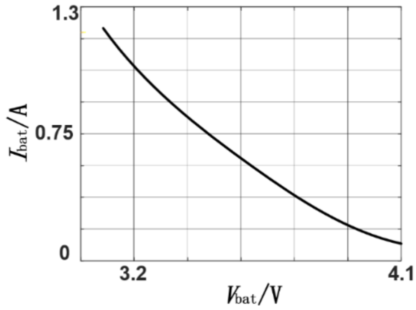

Figure 5. Flexible coil WPT system to charge the battery.

As shown in the figure above, the electrical energy obtained by the inductive transformation of the flexible coil is constant in voltage. Hence, as the charging process proceeds, the battery voltage rises, the charging current decreases, and the charging is completed after a while. The maximum output power can reach about 3W.

4. Conclusions

In this work, a flexible coil using a polyimide base material was designed and built a complete wireless energy transmission system and a flexible receiver circuit. This flexible coil can easily and quickly form different shapes and sizes according to the needs of the load, so it can well match the mechanical characteristics of the load and supply power to the load through wireless energy transmission. The charging experiment of the manufactured wireless charging device proves that this flexible coil can output stable power and is suitable for various flexible electronic systems.

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Conflicts of Interest

The authors declare no conflict of interest.

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