# Study of Contactless Inductive Charging Platform with Core Array Structure for Portable Products

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***Abstract*—In this research, contactless power transmission technique is applied in the charging of lithium battery for portable electronic products and the concept of common charging platform is proposed. The charging platform is comprised of several pot type cores with array structure, allowing circuit to be charged within a permitted region of displacement on the charging platform. However, a larger air gap exists in contactless structure compared to other contact structures, i.e. poor power transmission efficiency. In order to overcome the weakness, phase-locked loop (PLL) is applied to enable the operation frequency of circuit to be maintained above primary resonant frequency and microprocessor is utilized to improve the transmission efficiency when charging platform is standby. In addition, printed-circuit-board (PCB) is utilized on the secondary to reduce the thickness of the secondary circuit, forming PCB coil. Experimental results show that the transmission efficiency between contactless inductive structures is 55% under the condition of charging current 200mA and air gap 2.5mm.**

***Keywords-contactless power transmission*; *charging platform*; *array structure;*, *PCB coil***

## I. Introduction

In the past decade, electronic products have progressed in a tremendous speed. Portable electronic products, such as multimedia cell phones, MP3, digital camera, notebooks and etc, have almost become a necessity for people of modern age. Accompanying the growing demand for portable electronic products, the demand of rechargeable batteries has also increased.

Despite the fact that rechargeable batteries pollute the environment to a lesser extent, comparing to non-rechargeable batteries, they still have some weaknesses that are not yet overcome. Portable electronic products of different brand require different type of chargers due to different requirements of voltage, current and connector types. Not only the chargers for portable electronic products of different brands are not compatible, but also chargers for portable electronic products with of same brand but different modules. This leads to vast number of battery chargers and thus causing problems. Users with many portable electronic products have to carry a number of chargers is a problem. Besides, the metal and electrolyte components cause environmental problems. According to the survey of research center, IDC, the quantity of cell phone sold globally in 2009 has raised to 1.345 billion, an increase of 22.83% comparing to the quantity of cell phone sold (1.095 billion) in 2007. Therefore, a common charging platform which possesses compatibility of different electronic products becomes rather imperative.

## II. The Framework of Contactless Inductive Charging Platform

Traditional chargers rely on the contact of metals, oxidization or corrosion frequently occur on the contacting point of metals, causing the increase in the resistance between two contacting points and thus causing heat consumption or inefficiency in charging. In recent years, electromagnetic induction theory is adopted to develop contactless inductive power system, and successfully applied on electronic toothbrush, electronic shaver, cell phone, telephone and other portable electronic products [1-6].

The contactless inductive charging technique mentioned in this research aims to provide convenient and uniform charging method for portable electronic products. Upon designing contactless inductive charging system, the analysis of magnetic allocation for inductive structure is the first consideration, relying on the result of analysis to obtain appropriate inductive structure and to consider the impact of current direction of array core on the allocation of magnetic fields. Next, closed-loop control structure is applied, enabling the system to work in the domain of high efficiency. The structure of contactless inductive charging platform proposed in this research is shown as Fig. 1. The primary of Fig. 1 shows that the converter transforms AC into DC, then the inverter again transforms the DC into AC for driving inductive core of the primary. In the secondary, the inductive core picks up power from primary and the power is then rectified in order to charge the lithium battery. The charging scheme utilized in this research is constant current and constant voltage.

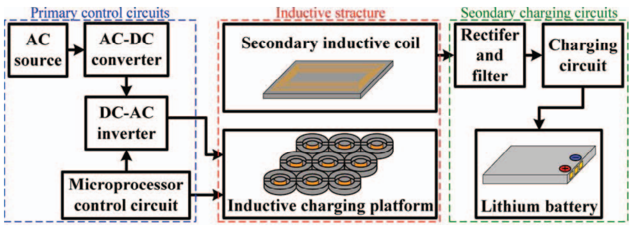


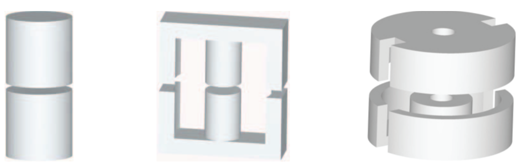

Figure 1. The framework of contactless inductive charging platform.

## III. ANALYSIS OF CONTACTLESS INDUCTIVE STRUCTURE

Contactless inductive charging, using electromagnetic induction for power transmission, can be regarded as a loosely couple transformer. Comparing to the structure of traditional transforms, its contactless inductive structure yields larger gap, causing difficulties for primary inductive coil to establish magnetic circuit and to produce magnetic field. Therefore, this research investigates the influence of different inductive structure on the magnetic allocation based on the analysis of characteristics magnetic allocation for different types of inductive structure.

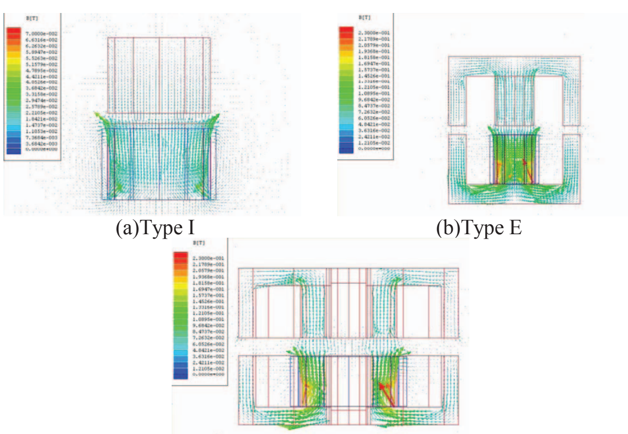
### *A. Primary inductive structure*

Generally, commonly used inductive structures are (a) type I, (b) type E and (c) Pot type, as shown in Fig. 2. Under constant length, inductive coil has to produce enough flux and low leakage flux. Software Maxwell 3D is utilized to analyze the magnetic allocation of different core type and to decide on the core of primary. The simulation of magnetic field for each core is shown as (a) type I, (b) type E and (c) Pot type of Fig. 3. Type I inductive structure, has poor magnetic field closeness and large leakage flux, leading to difficulties in establishing magnetic circuit and a decrease in overall coupling coefficient. Comparing to the inductive structure of type I, the inductive structure of type E has better magnetic field closeness and better coupling effect. However, it's large in size and is easily affected by horizontal displacement, therefore, is suitable for larger and constant load. Pot type has a closer structure, therefore magnetic circuit becomes easily established and produce lower leakage flux comparing to type E. If it is applied in contactless power transmission, the disturbance of leakage flux on surrounding electronic equipments can be reduced.



(a)Type I (b)Type E (c)Pot type

Figure 2. Commonly used inductive structures.



(a)Type I (b)Type E (c)Pot type

Figure 3. The simulation of magnetic field for each core type.

The charging platform of this research is composed of several pot type cores, allowing charging to be done in fixed distance of displacement. The arrangement of array core is shown as Fig. 4, with an area of $100\times70mm^2$. The characteristic of magnetic field allocation for the charging platform is affected by arrangement of core as well as the direction of driving current.

Fig. 5 indicates the allocation of magnetic field of different driving current within a distance of 2.5mm on top of the platform. It is observed that the induced magnetic field for the current of the same direction is smaller near the center of the core. On the other hand, the current of different direction produces larger flux on the outside of the coil and smaller flux in the center of the coil, resulting in a depletion region. However, magnetic field is easily formed in the center of the core, thus, yielding larger induced magnetic field than current of the same direction.

### *B. Secondary inductive coil*

The design of secondary inductive coil is mainly flat and this research adopts the design of PCB coil. As the coupling effect of the PCB coil is poor, a double sided structure is adopted to increase induced current. In addition, the induced field formed by the pot type cores is weaker in the center of the core, resulting in an increase of resistance of PCB coil. Therefore, increase wiring on the outer side of the structure, as shown in Fig. 6. Fig. 7 represents the secondary structure. Plane core is used to cover the surface of the structure, in order to increase the coupling coefficient of the PCB coil and to increase shielding of the magnetic field.

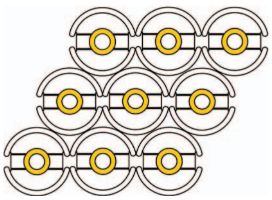
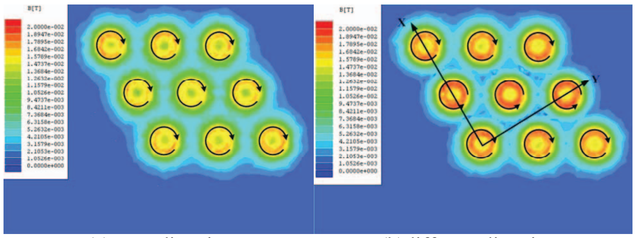


Figure 4. The arrangement of array core.



(a)same direction (b)different direction

Figure 5. The simulation of magnetic field for different direction of current.

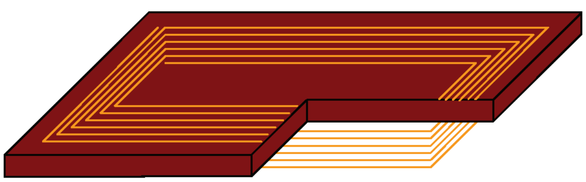


Figure 6. The PCB coil of secondary with double sided structure.

## IV. PRIMARY CONTROL SCHEME AND CHARGING CIRCUIT

### A. Control scheme

The control circuit of primary is controlled by PLL, enabling the system to be operated in resonant frequency. However, when secondary inductive coil is removed from the charging platform, operating under resonant frequency would cause quality factor of charging platform to increase, leading to the increase of primary voltage. In addition, due to the removal of secondary, loadless condition leads to unnecessary consumption of power rate and heating of the inductive coil. In order to solve the aforementioned problems, this research replied on PIC16F876A microprocessor as a remedy and the control circuit is shown as Fig. 8. The removal of secondary would lead to changes in the voltage of primary inductive coil, therefore, can be detected by the level of voltage. Feedback voltage, $V_F$ connects to analog input of microprocessor, AD converter transfers feedback voltage into digital signal for control processing. If the voltage exceeds the upper limit of default value, microprocessor defines that primary is removed and send out low- level signal to switch off the optocoupler. Aforementioned produces a voltage into a control circuit of PLL, leading to the offset enlargement of phase, in order to remove operating frequency from resonant frequency to reduce the consumption of power.

The primary inductive array core is comprised of several pot type cores, i.e. magnetic field locates mainly in the center of the core. Besides, the primary is driven by different direction of current, resulting in poor magnetic field in the connecting region between core and core. This connecting region leads to insufficient energy supply for the secondary. The control scheme proposed in this research includes a function to show the coupling effect, for the purpose of misplacing secondary in the connecting region. Fig. 9 illustrates the flow chart of the control scheme.

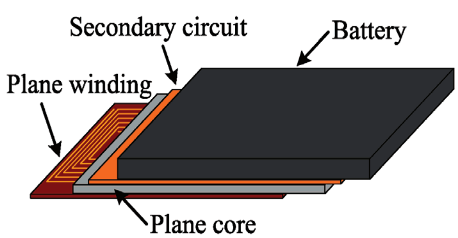



Figure 7. The structure of secondary.

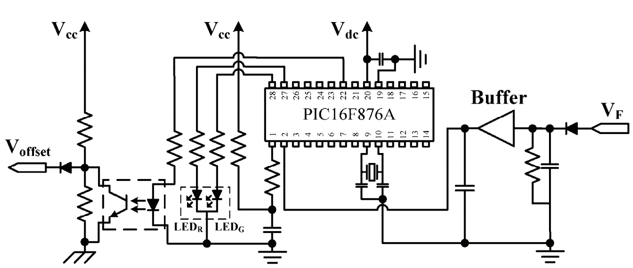



Figure 8. The diagram of micropocessor control circuit.

### B. Charging circuit

As it is desirable for secondary to be as thin as possible, charging management IC (BQ2057) produced by company TI is utilized to implement charging circuit. The charging scheme adopts constant current and constant voltage. The process of charging includes three steps: pre-charged mode, constant current mode and constant voltage mode. At the start of charging, BQ2057 would switch to the pre-charged mode to charge the battery with constant current if the voltage of battery is too low. In the process, the voltage of the battery increases gradually to the default value. When default value is reached, BQ2057 would switch to constant current mode to charge the battery with current of default value. At the end of charging process, constant voltage is utilized to charge the battery and the charging current decades along with time. If the charging current reduced to the lowest value of the set current, BQ2057 would terminate charging and switch to standby mode. Fig. 10 illustrates the charging circuit of BQ2057.

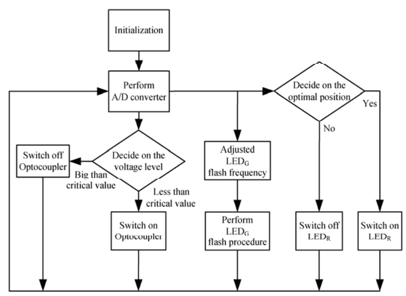



Figure 9. The flow chart of the control scheme.

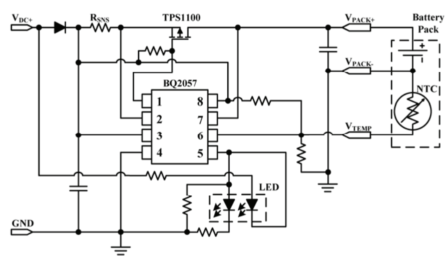



Figure 10. The charging circuit [7].

## V. EXPERIMENTAL RESULT

Fig. 11 is the contactless inductive charging platform structure proposed by this research. The main structure is class D inverter, which drives the contactless inductive structure to transfer energy to secondary. Next, the battery is charged by the charging circuit. As the charging current decades along with the process of charging, the system equivalent impedance alters. Therefore, the system can be adjusted by the feedback circuit.

Fig. 12 is the waveform of the experiment. Fig. 12(a) shows the complementary of signals of gate (i.e. $v_{gs1}$ and $v_{gs2}$). This is to avoid short circuit of switches. Fig. 12(b) represents the waveform of $v_{gs2}$ and $v_{ds2}$. When the voltage of $v_{ds2}$. decreased to zero, $v_{gs2}$ would be triggered, resulting in inverter possessing the effect of ZVS. Fig. 13 illustrates the charging procedure of the contactless inductive charging platform, with a voltage of 3.1V under the pre-charged mode. When the voltage of battery is lower than 3.1 V, BQ2057 would start the pre-charged mode automatically. The largest charging current is set as 200mA and terminating current is set as 30mA. Fig. 14 represents the 3D distribution diagram of energy transfer efficiency of the charging platform, with a highest transfer efficiency of 55% and the lowest transfer efficiency in the connecting region of the core. The lowest transfer efficiency is resulted from current of the different direction.

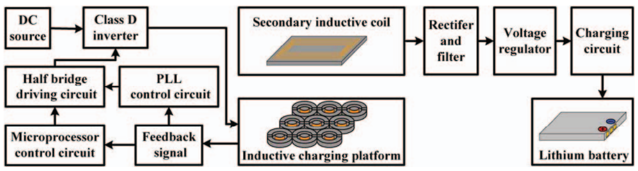
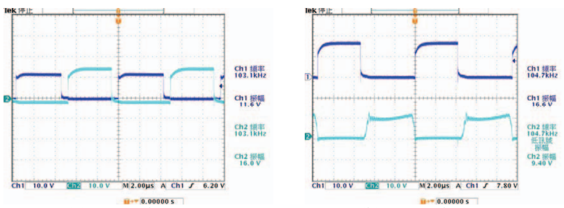



Figure 11. The structure contactless inductive charging platform.



(a)$v_{gs1}$ and $v_{gs2}$ (b)$v_{gs2}$ and $v_{ds2}$

Figure 12. The waveform of the experiment.

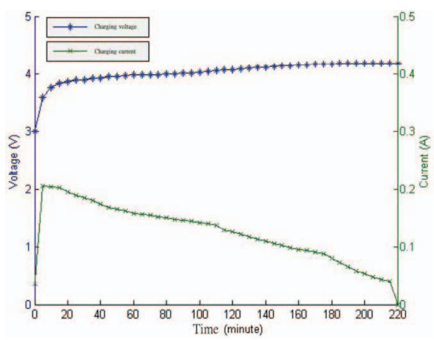



Figure 13. The charging procedure of the inductive charging platform.

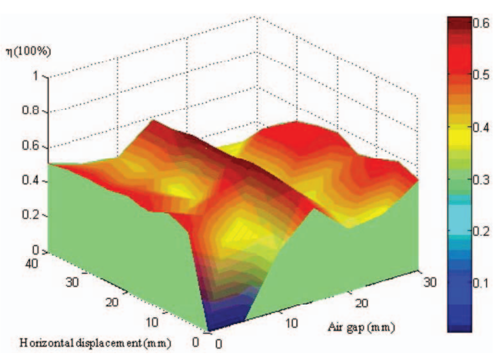



Figure 14. The 3D distribution diagram of efficiency of the charging platform.

## VI. Conclusion

Firstly, this research analyzes the magnetic field allocation of different core and considers the impact of induced magnetic field on other electronic equipments. From the result of analysis, the charging platform is designed by several pot type cores with magnetic enclosure. Secondly, the influence of current direction of the coil on the allocation of magnetic field is investigated to choose appropriate induced structure and current direction of the coil. Primary control circuit adopts PLL control to reduce resonant frequency offset caused by loading effect, to reach the goal of high transfer efficiency. Thirdly, microprocessor control circuit is utilized to adjust input power when the secondary is removed from the charging platform, and to reduce energy depletion. The coupling effect of each part of the charging platform is shown to provide the best position to place the secondary.

As for part of secondary, constant current and constant voltage charging schemes are implemented by charging management IC. In addition, the induced structure is implemented by PCB, leading to plane circuit. Finally, the result of experiment shows that the contactless inductive charging platform is able to charge a battery with charging current of 200mA under the condition of a gap 2.5mm between the secondary and the charging platform. The highest transfer efficiency is 55% between primary and secondary, and is able to work normally within a large enough displacement. Part of energy is lost in leakage inductance of induced structure. Therefore, transfer efficiency can be improved if the above weakness can be overcome and other type of induced structure and magnetic material are added to increase the coupling coefficient.

## Acknowledgment

This work was partially sponsored by the National Science Council, Taiwan, under awards number NSC 98-2221-E-006-248.

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