Wireless power transmission technology for mobile devices

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Abstract: Wireless power transmission is the new technology that transmits power without electrical connection. There are different approaches to wireless power transmission such as electromagnetic induction, electromagnetic resonance, and microwave power transmission. In this paper, we introduce a mobile phone power charger based on electromagnetic induction, and we built a wireless power charger (the primary side), and a mobile phone battery cover (the secondary side) equipped with built-in planar coils. In experiments, we evaluate the impact of the position and distance between the coils on the primary and secondary sides on performance and the power conversion efficiency of the wireless charger.

Keywords: wireless power, transmission, mobile phone, battery, charger

Classification: Electron devices, circuits, and systems

References

1 Introduction

As wireless information devices such as mobile phone are becoming smarter with many more functions, triggering an increase in frequency of device usage and power consumption, the need to resolve the battery capacity limitations has become pressing. Most current mobile phones use lithium ion batteries. Since the lithium ion battery was introduced about 20 years ago, its energy density has been more than tripled, but we cannot expect further dramatically increases in the near future. Therefore, at this moment, we have no choice but to use lithium ion batteries for mobile phones [1].

The wired connector method, which connects an AC adapter to the mobile phone is the most common mobile phone charging system [2, 3]. Weaknesses of the connector method is that 1) most phones use proprietary connectors and are unable to share chargers, 2) the use of connectors limits the resistance of the phone to water, 3) it also limits the flexibility in designing mobile phone devices. It is considered that wireless power transmission can solve all these issues. It is completely different from the conventional method and its dependency on connectors. Instead it transmits power through the air using media such as electromagnetic induction, microwaves, and laser lights.

In this paper, we explain the concepts of different types of wireless power transmission and the principle of the most realistic, “electromagnetic induction,” its implementation for mobile phones.

2 Concept of wireless power transmission

Wireless power transmission is the technologies that transmit power through free air space without wires or connectors. Table I shows different types of wireless power transmission. Electromagnetic induction transmits power by establishing magnetic flux fields with frequencies of several hundreds of kHz between a pair of coils [4, 5, 6, 7, 8]. Its principle follows that of a high frequency power transformer used for switching power supplies. It realizes “non-contact” status by spatially separating the primary side from the secondary side on high frequency power transformer. This method can be realized with widely spread switching power supply devices. One of the challenges with this method is that if the distance between the primary side and the secondary side exceeds a critical distance, the efficiency of power transmission decreases.
transmission falls dramatically.

Electromagnetic resonance transmits power by using the electromagnetic resonance phenomena between a pair of coils; the frequencies range from several MHz to hundreds of kHz [9, 10, 11]. This technology is fairly new having been introduced in 2007. It can transmit power at high efficiency levels, even if the distance between coils is relatively long. However, it has many difficult issues such as power control methods and circuit design for commercialization.

Microwave power transmission converting power into electric waves (microwave frequencies of several GHz) and converting the microwaves back into power at the receiving element (Rectenna: Rectifying-antenna) [12, 13, 14, 15, 16]. Although it has many restrictions and issues to be resolved because it uses the same band frequency as mobile phones and other mobile communications devices, the principle of this technology has already been verified. One benefit of this technology is that long distance power transmission is possible because of the characteristics of electric waves. Many universities and laboratories are trying to use this technology to transmit power generated by solar-electric power generation stations in space to Earth.

Table I. Types of wireless power transmission

<table>
<thead>
<tr>
<th>Type</th>
<th>Electromagnetic induction</th>
<th>Electromagnetic Resonance</th>
<th>Microwave</th>
<th>Laser light / Visible light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspects</td>
<td>Electric induction (several 100kHz)</td>
<td>Electric resonance (several MHz)</td>
<td>Electric wave (several GHz)</td>
<td>Laser light / Visible light</td>
</tr>
<tr>
<td>Benefit</td>
<td>can be realized with simple circuit</td>
<td>Middle range transmission (about 1m) is possible</td>
<td>Can send long distances</td>
<td>Can use existing photo voltaic technology</td>
</tr>
<tr>
<td>Weakness</td>
<td>Only close transmission (20cm or less)</td>
<td>Stable operation is required</td>
<td>Higher efficiency rate of sending and receiving parts is required</td>
<td>more efficient light resources are required</td>
</tr>
</tbody>
</table>

Laser light / visible light power transmission uses the photo voltaic approach. Light emitting diodes are used to generate visible light and photodiode are used to convert the light back into power at the receiver [17]. One benefit of this method is that it can be realized in a comparatively short period of time with existing technologies. Free space transmission can be replaced by glass fiber and light ducts [18, 19, 20]. Another benefit is that many light sources such as a combination of natural light (sunlight) and interior light can be used. Its weaknesses include limited power transmission levels and low conversion efficiency.

3 Electromagnetic induction

3.1 Operating principle and demonstration

We start with an example of a wireless power charger for mobile phones. Figure 1 shows its concept. This technology is based on the high frequency
Fig. 1. Outline of wireless power system for mobile phone

Fig. 2. Types of transfer

(a) Core transfer method
(b) Planar coil method

power transformer, which is used for switching power supplies, where the primary side coils are set the charger and the secondary side coils are mounted on the phone. Figure 2 shows that the high frequency power transformer. The conventional transformer use the core transforming method (a), while the wireless power charger uses the planar coil method (b). In this experiment, the primary side coil is built into the mobile phone holder, while the secondary side coil is built into the battery case cover of the mobile phone. The system can be realized by the common electronic components used for switching power supplies. However, one issue that must be addressed is that the primary and secondary side coils cannot be widely separated.

Figure 3 shows the circuit of wireless charger. The holder uses switch $Q_1$ for high frequency switching and the primary side coil, while the mobile phone has the secondary coil together with a rectifier diode and smoothing capacitor. As the secondary load, the charging circuit is connected, in series, to the battery and the secondary battery (lithium ion battery). Figure 4 shows the operating waveform (voltage and current) of the circuit in Figure 4. Now, when we set the switching frequency, circuit switch $Q_1$ al-
ternates between ON and OFF at “f (Hz)”; the ON and OFF periods, “T” are the inverse (1/f) of switch Q1’s switching frequency “f”. Within “T”, if we say the time duration in which switch Q1 is ON is given by the product of “T” and “D” (duty cycle D takes a value between 0-1). Since switch Q1 is ON for some period between “0” and “DT”, current I_{L1} flows from direct current voltage E_i to coil L_1, alternating magnetic flux is generated in the coil on the primary side. Following that, during the period between DT and T, because switch Q1 is OFF, coil L_1’s alternating magnetic flux flows to coil L_2, and electromotive force is generated in coil L_2, which yields alternating current I_{L2}. Since switch Q1 alternates between ON and OFF, alternating current I_{L2} passes through the rectifier diode and smoothing capacitor, and is converted into direct current voltage “V_0”. By inputting V_0 in the charging circuit, we can charge the battery.

Figures 5 and 6 shows an image of planar coils and coils placed on the primary side and secondary side, respectively. Table II shows the main specification of or experimental wireless charger. We mounted very thin planar coils using Litz wire. The coils were formed by winding and have about 5 mm margins on both ends of coils’ diameters of the primary side (40 mm in diameter) and the secondary side (30 mm in diameter). The planar coils
are linked by an alternating magnetic flux, and the alternating magnetic flux is transmitted through the air to the secondary side coil. On the backsides of the primary side and secondary side coils, thin magnetic shield sheets are placed. These sheets are particularly important since there under the battery cover lies a lithium ion battery in an aluminum case, and the guard minimizes the temperature increase that would otherwise be created by eddy currents across the battery’s aluminum surface.

We implemented the above mentioned circuit and planar coils on a mobile
Fig. 7. Wireless charger prototype

The concept of this wireless charger is that it has a built-in coil. The planar coil is built into the mobile phone’s battery cover. This mounting arrangement avoids the need to change the mobile phone itself. Input power to the holder is about 3.8 W (5.4 V, 700 mAh), while output power to the battery cover is about 2.2 W (5.5 V, 400 mA) at rated duty time. Issues to be resolved with this prototype include improving the power conversion rate, coil thinness, and reducing the influence of location and usage environment.

3.2 Power conversion rate of prototype wireless charger

In wireless power transmission, the distance between coils is not fixed, and changes in separation distance can lower the power transferred power or the power conversion rate.

Figure 8 shows the positioning of coils on the primary side and secondary side of each test device. We measured the power transfer when the coils were moved on the horizontal plane, X axis, and vertically, the Z axis.

Figure 9 shows the measured input/output powers and the transmission efficiency rate for coil movements on the X axis. From the Figures 9, the transmission efficiency rate falls rapidly when the coils are offset by 4 to 5 mm. This is due to the 5 mm difference in coil radius on the primary side and secondary side; offset beyond 5 mm yield large leakage of magnetic flux. As for the output power, since at least 1 W or so is required for mobile phone
charging, power transfer halts when the offset is more than 5 mm. Thus, our prototype has a lateral offset limit of only 5 mm. Figure 10 shows the measured power transfer values with Z direction offset. The figure shows that if the coils are separated by 2 mm or more, the transmission efficiency rate sharply decreases. This result suggests that the acceptable Z axis offset is 5% of coil radius. If the coils separate by even a little, electric flux leakage will increase and the transmission efficiency rate will decrease. Vertical separation of 3 mm or more drops the power to under 1 W, the requirement for mobile phone charging, and charging operation will stop. Thus, we can say that the flexibility in terms of Z direction offset is about 3 mm. From the above results, our prototype wireless charger with planar coils has acceptable coil separation distances of 5 mm horizontally and 3 mm vertically.

3.3 Impact on the time required for charging
When examining the performance characteristics of wireless power charging systems, the time required for charging is another important issue. We compared the time required for mobile phone charging with the prototype
Fig. 11. Comparison of wireless charging circuits

wireless charger and with a conventional AC adapter. Figure 11 shows that charging took longer with the prototype. Due to the lower power conversion rate, less electric power is available yielding longer charging times.

3.4 Relationship between location and the efficiency rate

The charging environment may also influence wireless charging performance. In this chapter, we placed the prototype wireless charger holder on two different materials, a wooden table and a steel (iron) table, and compared the difference in current, power and temperature (inside the battery cover) when the prototype wireless charger was used on a wooden table and on a steel table. Figure 12 shows that charging on the wooden table took about 140 minutes, the electric current was 430 mA and the temperature was about 20 degrees Celsius. On the other hand, used on the steel table, see Figure 13, the charging time was about 160 minutes, the current was 370 mA and the temperature was about 13 degrees Celsius.

From these results, the steel surface increased charging time by 14 percent, compared to wooden. We consider that the electric flux that leaked from the
wireless charger was absorbed by the steel table, which reduced the power transferred and thus increased the charging time. The result confirms that the materials on which the charger used influence charging efficiency.

### 3.5 Power conversion efficiency at wireless power transmission

Figure 14 plots the electric current and voltage of the wireless charger and the efficiency rate at each point. It starts at charging point A (voltage: around 5 V, phones, we current: 0.5 A) and finishes at point B (voltage: around 5.2 V, current: 0.1 A). The power conversion efficiency rate is relatively high, about 70 percent, at the start of charging (around 5 V, 0.5 A), however, the rate falls sharply to 50 percent or less in the low load range (around 5.2 V, 0.1 A) near the end of charging. From values in Figure 16, we can calculate that the average conversion efficiency rate of wireless power transmission is about 68 percent about 38 percent of the loss is due to heat generation.

![Fig. 13. Temperature, electric current and power (Steal table)](image)

![Fig. 14. Efficiency rate of wireless charger](image)
4 Conclusions

In this paper, we explain the concepts of different types of wireless power transmission and the principle of the most realistic, “electromagnetic induction,” its implementation for mobile phones, and examined the efficiency and practicality of wireless power transmission and discussed results of tests made on our prototype mobile phone charger using electromagnetic induction technology. We can show the characteristic of the alignment vs. power efficiency at the time of charge, and we can calculate that the average conversion efficiency rate of wireless power transmission is about 68 percent.

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He was graduated from Kyushu University with a master’s degree in nuclear engineering technology in 1990. He joined an NTT Laboratory in the same year and was engaged in the research into power supply systems for telecommunications networks. In 1998, he transferred to NTT DOCOMO Laboratory where he is actively engaged in the development of batteries and power system for mobile phone and wireless base station. While working for NTT DOCOMO, he received his Doctor of Engineering form Kyushu University in 2005.