Optimization of the Circuit Parameter in Class-E Power Amplifier in the Two-coil Wireless Power Transfer System

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Abstract. In this paper, the circuit parameters of the Class-E power amplifier are investigated and optimized to achieve the maximum of output power and efficiency in a two-coil Wireless Power Transfer (WPT) system. The circuit is simulated with software named Saber. Working frequency, the value of capacitors and inductor, which has relationship with the output power and efficiency, are investigated during the simulation. With the simulation results, it is found that the frequency and the shunt capacitor need to be optimized for high performance of the wireless power transfer system.

1. Introduction

The Class-E power amplifier (PA) was proposed by Sokals in 1975, and has the merits of high efficiency and simple circuit. It has been used as the DC/AC (direct current/alternating current) inverter in the Wireless Power Transfer (WPT) system. The efficiency of the Class-E PA has significant influence on the performance of the whole WPT system [1-5].

Casanova, J. used Class-E PA in the WPT with a distance of 10 mm between the transmitter coils and the receiver coils, the system had a maximum transmission power of 3.7 W and a peak efficiency of 66% [1]. Reference [2] presents an open-loop system selection technique based on numerically scanning component values until the drain voltage and impedance meet certain constraints. As switching frequencies are gradually stepping into the megahertz (MHz) region, wide-bandgap devices such as GaN and SiC are employed in the Class E PA [3]. Furthermore, impedance matching and compensation network parameters were theoretically calculated and simulated [4-5].

In this paper, an optimization method of the class-E in the application of WPT system is proposed. The working frequency, values of inductor and capacitors are all investigated with the simulation to achieve the maximum of output power and efficiency.
2. Simulation method

A Class-E power amplifier circuit was simulated and analyzed with the software of Saber. Figure 1 shows the simulated circuit which has a transformer to represent loose coupling coils in WPT system.

![Figure 1. The simulated Class-E circuit in the software of Saber.](image)

In order to achieve the maximum of output power and transfer efficiency, the value of inductor and capacitors had been investigated.

Firstly, the working frequency is considered. As the value of capacitor is much easily changed than the value of inductor, the value of the capacitors varies while the value of inductor is fixed to achieve different frequency. Table 1 shows the value of the capacitors, inductor and working frequency.

| Inductor (Lp, μH) | Capacitor (C3, nF) | Frequency (MHz) |
|-------------------|--------------------|-----------------|
| 3                 | 33.7               | 0.5             |
| 3                 | 8.4                | 1               |
| 3                 | 2.1                | 2               |
| 3                 | 0.94               | 3               |
| 3                 | 0.53               | 4               |
| 3                 | 0.34               | 5               |
| 3                 | 0.23               | 6               |
| 3                 | 0.17               | 7               |
| 3                 | 0.13               | 8               |
| 3                 | 0.106              | 9               |
| 3                 | 0.086              | 10              |

Secondly, the inductor Lp is set as a variable, and the value of capacitor C1 is calculated according to the frequency and Lp in order to maintain the same working frequency. The simulation is carried out with each pair of Lp and C1 to obtain the output power and efficiency.

Thirdly, the capacitor C0 has an important influence on the output power and efficiency. During the simulation, the value of C0 is adjusted to achieve maximum of output power and efficiency, respectively.

3. Simulation results

As described before, the simulation is carried out with different working frequency. Figure 2 and 3 show the simulation result. Since the parameter k of the transformer is set to 0.1 representing that the distance between two coils is 30cm, the output power and efficiency achieve maximum point at the frequency of 2MHz and 1MHz, respectively.
At the frequency of 2MHz, the value of Lp and C1 was adjusted simultaneously to maintain the same frequency. Table 2 presents the value of output power and efficiency as the Lp varying. It is shown that the maximum of output power and efficiency occurs as the Lp equals to 4 μH and 5 μH, respectively.

| Inductor (Lp, μH) | Capacitor (C1, nF) | Output Power (W) | Efficiency |
|------------------|--------------------|------------------|------------|
| 1                | 6.3                | 3.4848           | 5.001%     |
| 2                | 3.15               | 5.767766         | 7.509%     |
| 3                | 2.1                | 6.351048         | 8.657%     |
| 4                | 1.57               | 7.080085         | 9.767%     |
| 5                | 1.26               | 6.589176         | 10.302%    |
| 6                | 1.05               | 6.746934         | 9.755%     |
| 7                | 0.9                | 5.488647         | 9.704%     |
| 8                | 0.79               | 5.4239           | 9.908%     |
| 9                | 0.7                | 5.256579         | 9.516%     |
| 10               | 0.63               | 5.123201         | 9.521%     |

The value of C0 is investigated to achieve the highest value of output power and efficiency. In the simulation, the value of Lp is fixed to 3 μH, and C1 varied from 0.17nF to 33.7nF to set the working
The working frequency, value of $L_p$, $C_1$ and $C_0$ are all investigated with the simulation to achieve the maximum of output power and efficiency in this paper. The simulation results show that, $C_0$ has a significant influence on the output power and efficiency. Considering that the coil in the WPT system is not easily changed, the proposed design procedure of the Class-E PA is in 3 steps. Firstly, the working frequency needs to be chosen. Secondly, the inductor $L_p$ of the coil has to be selected. Thirdly, the capacitor $C_1$ can be calculated from the frequency and inductor, and the capacitor $C_0$ should be optimized for whether high output power or high efficiency.

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