Effect of Layer Spacing and Coil Center Distance of PCB Coil on Resonant Frequency

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Abstract. With the development of electronic science and technology, people have entered the information society, a variety of portable electronic products enter people’s lives. A large number of miniature human implantable medical devices applied to clinical fields. The traditional human implantable medical device power supply is implanted battery, its biggest drawback is the treatment problem after the battery power consumption. Whether it is taken to replace the new battery, or deep into the body, there is a huge risk. Therefore, the portable external wireless charging, it becomes the best choice for human implantable medical devices. In this paper, HFSS software is used to simulate, a large number of simulation experiments are carried out on the PCB with 2 layers coils. At the same time, the electrical parameters such as layer spacing, coil center distance and resonant frequency are analyzed. Finally, the conclusion is: in the case of fixed layer spacing, with the increasing of the coil center distance, the resonance frequency is gradually increasing; The increasing trend is becoming more and more obvious. When the coil center distance is fixed, with the growing layer spacing, the resonance frequency value is constantly increasing, the resonant frequency of the growth is also more and more slow.

Introduction

In recent years, the rapid development of resonant coupled radio transmission technology. In the energy transfer system, the transmitting coil and the receiving coil are self resonant coils with the same resonant frequency, and they are the key parts of the system. For a coil, in the design must meet to ensure self resonant frequency accuracy, as far as possible to improve the coil’s quality factor and other requirements. In its design stage, it can accurately simulate and calculate for its characteristics (resonant frequency, quality factor, etc). In the course of the study there are many kinds of coil structure can be selected, which is based on the PCB flat coil due to high precision, high stability, easy to manufacture, and so on. Especially suitable for the human body implantable medical devices, such as a variety of small power occasions. PCB coil has its own electrical parameters, line width, layer spacing, line center distance and so on. No matter which indicators occur change, will have an impact on the resonant frequency and quality factor. The resonant frequency of the system is related to the transmission efficiency. Resonant frequency of a resonant circuit is \( f = \frac{1}{2\pi\sqrt{LC}} \), the resonant frequency of the system changes, which affects the transmission efficiency of the whole system. Therefore, the study of the relationship between the PCB coil center distance, layer spacing and the resonant frequency of the system for the study of energy transfer efficiency has very important significance.

[1][2] introduces the S Wang and Wong C. Ho, they analyzed the inductance value of dual layer and multilayer PCB coil; [3] describes the relationship between inductance value and operating frequency of rectangular spiral inductor based on wire grid method; [4] introduces the new SMD PCB type inductive coil; [5] introduces use Litz wire or silver wire to reduce the skin effect of the method,
at the same time different ways wound coil of the resonant frequency will be affected. The influence for the efficiency of wireless energy transfer system is obtained. Above literature, only studied PCB inductance coil, and no studied the characteristic of resonance frequency. [6] introduced the distribution capacitance of planar spiral coil is changed with the change of frequency; [7] points out that there is a mutual restraint relationship between the system’s frequency wavelength(\(\lambda\)), the transmission distance(D) and the coil radius(r). It is a matter of design wireless power transmission system that must be considered; [8] introduced when the resonance occurs, the resonance frequency of the helical antenna and the geometrical parameters’ empirical formula; [9] introduced for the frequency splitting caused by the change of the transmission distance, ultimately lead to drastic changes in transmission efficiency, and proposed an automatic frequency tracking method; [10] use the mutual inductance circuit model, studied the causes of frequency splitting and the general rules. And the frequency tracking method is used to improve the transmission efficiency. Although the above literature has carried on the research and the analysis to the wireless energy transmission technology’s characteristic of resonance frequency, but they are not based on the rectangular plane spiral PCB coil. It is found that the research on the relationship between the electrical parameters and the resonant frequency of the rectangular spiral coils is still very little.

Specific Design of PCB Rectangular Coil

HFSS (Frequency Structure Simulator High) is the world’s first commercial 3D electromagnetic field simulation software, the industry recognized the three-dimensional electromagnetic field design and analysis of industrial standards. HFSS software is used to carry out simulation experiment. PCB coil design, as shown in figure 1. The plane spiral coil is a square structure, and the bottom layer is a coil bracket which is composed of FR4 material, and a spiral coil is attached to the surface of the medium plate, a total of 8 turns.

PCB electrical coil design parameters with letters: \(w\) is line width; \(s\) is coil center distance; \(L\) is rectangular coil side; \(h_f\) is a layer spacing; \(n\) is the total number of turns of the coil; \(h_c\) is the thickness of the copper; \(h_f\) is the thickness of the substrate FR4. The dimensions shown in figure 2.

![Figure 1. plane graph.](image1)

![Figure 2. Dimensioning.](image2)

Its specific electrical parameter settings are shown in table 1:

| Electrical parameters | Settings |
|----------------------|----------|
| \(n\)                | 8        |
| \(s\)                | 30-75mil |
| \(l\)                | 40mm     |
| \(h_f\)              | 0.1mm-0.8mm |
| \(h_f\)              | 0.33mm   |
| \(h_c\)              | 0.035mm  |
| \(w\)                | 20mil    |
Result Analysis

After setting, the software will automatically be simulated. In this paper, the experimental results are based on a large number of simulation experiments. The simulation data shown in table 2. The data in this table indicates that hf is 0.1mm-0.8mm, the corresponding s is 30mil to 75mil, the value of each resonance frequency.

Table 2. Simulation data.

| s    | 30  | 35  | 40  | 45  | 50  | 55  | 60  | 65  | 70  | 75  |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.1  | 13.63 | 14.74 | 16.9 | 18.6 | 20.2 | 21.33 | 22.73 | 24.06 | 25.54 | 27.14 |
| 0.2  | 21.95 | 22.56 | 23.87 | 24.88 | 26.07 | 27.76 | 29.42 | 30.9 | 32.13 | 34.52 |
| 0.3  | 25.64 | 26.5 | 27.47 | 28.51 | 30.08 | 31.15 | 32.99 | 34.77 | 37.02 | 39.2 |
| 0.4  | 28.37 | 29.44 | 30.65 | 31.65 | 33.29 | 34.61 | 36.48 | 38.63 | 40.31 | 42.9 |
| 0.5  | 30.71 | 31.72 | 33.02 | 34.41 | 35.84 | 37.3 | 39.32 | 41.11 | 43.68 | 46.81 |
| 0.6  | 32.59 | 33.83 | 35.18 | 36.57 | 38.1 | 39.9 | 41.59 | 43.93 | 46.42 | 48.86 |
| 0.7  | 34.58 | 35.66 | 37.07 | 38.49 | 40.03 | 41.96 | 44.07 | 46 | 48.85 | 51.53 |
| 0.8  | 36.12 | 37.46 | 38.85 | 40.16 | 42.06 | 43.83 | 46.02 | 48.35 | 50.74 | 53.83 |

According to the measured data, can draw the figure 3, it shows that the relationship between the coil center distance, layer spacing and resonant frequency.

Can be seen that from the figure 3, with increasing the coil center distance, the resonant frequency is also increasing. The value of the previous point is larger than that of the latter point. To set up a function:

\[ f(i) = \frac{f_i - f_{i+1}}{f_i} \]

\( f_i - f_{i+1} \) is the difference between the first and last two resonant frequencies, this function represents the rate of change of the resonance frequency. Take the point(s, hf) = (50,0.4) and (s, hf) = (55,0.4) corresponding to the resonance frequency value into the function \( f(i) \), we can be
obtained: $\Delta_1 = \frac{34.61 - 33.29}{34.61} = 3.8\%$. Then take $(s, hf) = (55,0.4)$ and $(s, hf) = (60,0.4)$ corresponding to the resonance frequency value into the function $f(i)$, we can be obtained: $\Delta_2 = \frac{36.48 - 34.61}{36.48} = 5\%$.

By comparison: $\Delta_2 > \Delta_1$. Found that the increasing trend of resonant frequency is more and more obvious.

For example, draw the relationship diagram: $s=30\text{mil}, s=35\text{mil}, s=40\text{mil}, s=45\text{mil}$. as shown in figure 4, 5, 6, 7:

Figure 4 and 5. $s=30\text{mil}$ and $s=35\text{mil}$, the relationship between the layer spacing and the resonant frequency.

Figure 6 and 7. $s=40\text{mil}$ and $s=45\text{mil}$, the relationship between the layer spacing and the resonant frequency.

By observing the curve, we can be obtained: When the coil center distance is fixed, with the growing layer spacing, the resonance frequency value is constantly increasing, the resonant frequency of the growth is also more and more slow.

Summary

This paper mainly studies the PCB coil used in the human implantable wireless charging system. By using HFSS simulation software, using the method of observation and analysis, focus on the relationship between the PCB coil center distance, layer spacing, and the resonant frequencies were analyzed and summarized. Finally, the conclusion is: in the case of fixed layer spacing, with the increasing of the coil center distance, the resonance frequency is gradually increasing; The increasing trend is becoming more and more obvious. When the coil center distance is fixed, with the growing layer spacing, the resonance frequency value is constantly increasing, the resonant frequency of the growth is also more and more slow. This understanding on the development of the human implantable wireless charging system of our future is very helpful.
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