ECS Transactions, 52 (1) 1091-1097 (2013)
10.1149/05201.1091ecst ©The Electrochemical Society

An Optimization Procedure for Coil Design in a Dual Band Wireless Power and Data Transmission System

Wuxi Li[a], Hang Yuan[a], Wei Xu[a], Kunling Geng[b], and Guoxing Wang*[a]

[a] School of Microelectronics, Shanghai Jiao Tong University, Shanghai, China, 200240
[b] Department of Biomedical Engineering, University of Southern California, Los Angeles, California, 90033, USA

Biomedical implanted electronic devices such as retinal prosthesis and artificial cochlea commonly use coupling inductive coils for power and data transmission. With many parameters to be considered, exhaustive sweeping of these parameters is impractical in physical verification. This paper presents an applicable optimization procedure for coils design in a dual band transmission system proposed by our group. This procedure focuses on the optimization of two pairs of coils based on an overlapping structure which minimizes power-to-signal interference in the data transmission. We applied the optimization procedure to a practical design case, and the result showed that our semi-automatic optimization procedure can achieve both optimal power transmission efficiency and high signal to interference ratio.

I. Introduction

Biomedical electronic implants have been widely researched for a long time, and some of these devices have been applied clinically(1), (2), (3). These devices are normally powered wirelessly through magnetically coupled coils. With the development of biomedical engineering, data transmission is also required in recent biomedical implanted devices, thus power and data needs to be transmitted simultaneously.

In traditional power and data transmission systems, power transmission and data transmission share the same carrier frequency (4), (5), (6), (7). However, data transmission requires higher carrier frequency and low quality factor (Q) to guarantee wide bandwidth while the power transmission requires high Q and lower frequency to achieve high efficiency (8), thus the performance of traditional transmission systems are limited. To avoid this drawback, we have proposed a dual band architecture for the purpose of wide bandwidth data transmission and high efficiency power transmission simultaneously (9). We separate power and data transmission by using two different frequency bands. However, one of particular challenges associated with dual band transmission system is the power-to-data interference introduced by strong power transmission. To solve this problem, a novel overlapping coil structure was proposed in (10). As can be seen in Figure 1, the overlapping of power and data secondary coils (L_2 and L_4) can minimize the interference from power link to data link. With many parameters of these four coils to be considered, the physical parameters and geometrical structure of them must be carefully optimized for such a wireless transmission system. However, existing design procedures mostly only concentrates on optimizing one pair of coils, thus an optimization procedure for dual band transmission system is necessary and valuable.

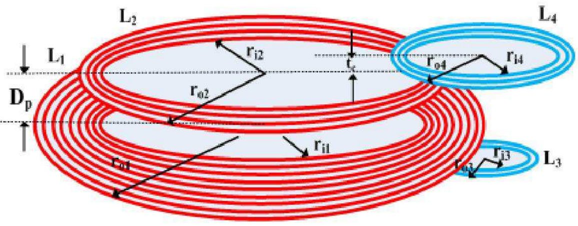

Figure 1. Schematic of the overlapping dual band coil structure

This paper presents an optimization procedure for coil design in a dual band wireless power and data transmission system as shown in Figure 1. With the optimization procedure, such kind of systems can be optimized both quickly and automatically. Based on our procedure, we implement a program that can semi-automatically optimize dual band transmission system with the help of the source code of FastHenry 3.0 (11). We also applied this program procedure to a practical design case, and the results showed that our automatic optimization procedure can achieve both optimal power transmission efficiency and high signal to interference ratio.

This paper is organized as follows. Section II specifically describes the semi-automatic optimization procedure of the dual band transmission system. Section III presents an optimized design case that applied our procedure.

II. Optimization Procedure

The planar structure of an inductive coil is shown in Figure 2. The geometrical parameters in concern are the outer radius r_o (or outer diameter d_o), conductor width w, conductor space s and fill ratio φ. The fill ratio φ is defined in (1). The planar geometrical structure of a coil can be completely determined by r_o, w, s and φ, and our primary goal is to optimize these four parameters of each coil.

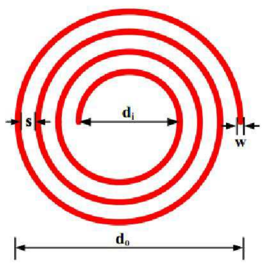

Figure 2. Inductance schematic

$$\varphi = \frac{r_o - r_i}{r_o + r_i} \qquad [1]$$

Step1: Set Design Constraints

A number of constraints of the transmission system must be specified in this step as the beginning of further steps. Various applications will give different constraints of these parameters including the length of the implanted unit (assuming this unit is square), transmission distance and operating frequency. Other parameters such as minimum conductor width, minimum conductor space and minimum conductor thickness are determined by PCB fabrication technology. All parameters set in this step are listed in Table I.

TABLE I. Design Constraints

Parameter	Symbol
Implanted unit length	l
Transmission distance	d_t
Power transmission frequency	f_p
Data transmission frequency	f_d
Minimum conductor width	w_{min}
Minimum conductor width	s_{min}
Minimum conductor thickness	h_{min}

Step2: Optimize Power Link (L_1 and L_2)

Power link optimization aims at maximizing transmission efficiency. The equation for transmission efficiency is listed in [2] (12).

$$\eta = \eta_1 \eta_2 = \frac{k_{12}^2 Q_1 Q_2^{'}}{1 + k_{12}^2 Q_1 Q_2} \cdot \frac{Q_2}{Q_2 + Q_L} \qquad [2]$$

In this step we are concerned with r_{o1}, w_1, φ_1, r_{o2}, w_2 and φ_2. With so many parameters to be optimized, the sweeping procedure is divided into several sub-steps. An iterative procedure is utilized which repeatedly executes these sub-steps. Each sub-step sweeps parameters of one coil, from L_1 to L_2 and then again to L_1, until a converged optimal result is obtained.

Step 2-1. Initialize the geometrical parameters of L_1 and L_2.
Step 2-2. Sweep r_{o1} and φ_1.
Step 2-3. Sweep w_1.
Step 2-4. Sweep w_2 and φ_2. Back to Step 2-2 until the optimization result is converged.
Step 2-5. Set h_1 and h_2.

Step3: Find out Zero-coupling Point of L_2 and L_4

For two overlapping coils, there always exists a zero-coupling point (10), where the coefficient of mutual induction is zero. This step aims to find out the zero-coupling point of L_2 and L_2 in order to minimize the interference from power link to data link.

Step 3-1. Choose w_4, s_4 and φ_4 empirically.

Step 3-2. Set the centre of square implanted unit as Point A, and set the lower right corner of square implanted unit, as shown in Figure 3(a), as Point B.

Step 3-3. Set the centre of L_4 at the midpoint C of line section between Point A and Point B, and set r_{o2} as large as possible without beyond the boundary of the implanted unit as shown in Figure 3(a).

Step 3-4. If the absolute value of k_{24} is smaller than 10^{-3}, we regard it as the zero coupling status and the optimization is done. If not, go to *Step 3-5* and continue optimizing.

Step 3-5. If k_{24} is negative, set the midpoint C as new Point B, and remain Point A unchanged, as shown in Figure 3(b). If k_{24} is positive, set the midpoint C as new Point A, and remain Point B unchanged, as shown in Figure 3(c). Go back to *Step 3-3*.

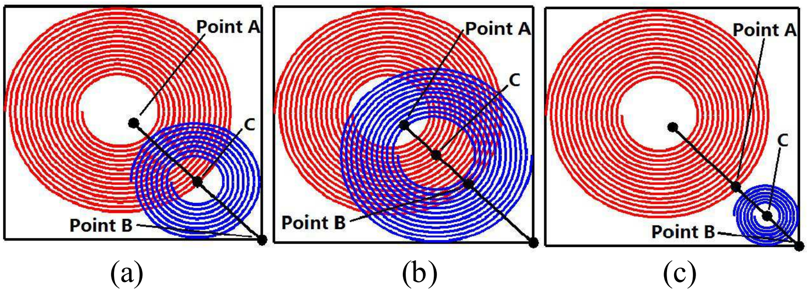

Figure 3. Finding r_{o4} (a) initializing Point A and Point B (b) when k_{24} is negative, update Point B (c) when k_{24} is positive, update Point A

Step4: Optimize the Data Link (L_3 and L_4)

Different from power link, the objective of data link optimization is not to maximize transmission efficiency, but to meet the requirement of the signal to the interference transfer function ratio (SITR).

SITR is a measure that similar to signal to noise ratio (SNR). It indicates how large the signal gain is, compared with interference attenuation. SITR is defined as the ratio of signal and interference gain of the data receiver (L_4), as listed in [3] (8), and its explicit expression is shown in [4] (8).

$$\text{SITR}=\left|\frac{V_4(j\omega_d)}{V_3(j\omega_d)}\right| / \left|\frac{V_4(j\omega_p)}{V_1(j\omega_p)}\right| \qquad [3]$$

$$SITR \approx \sqrt{\frac{L_1}{L_3}} \frac{k_{34}(k_{12}^2 + \frac{1}{Q_1Q_2})}{(k_{34}^2 + \frac{1}{Q_3Q_4})\sqrt{(k_{12}k_{24})^2 + (\frac{k_{14}}{Q_2})^2}} \qquad [4]$$

Normally, smaller r_{o3} could obtain larger SITR. However, a too small r_{o3} is not favorable to the overall performance of data transmission. To avoid a too small r_{o3}, we limit the number of turns of L_3 to be no less than a certain number. In our optimization procedure, we set this number as 7. We design the *Step 4* as follows:

Step 4-1. Set the minimum required value of SITR and L_3.

Step 4-2. Initialize L_3. Set w_3, s_3 and φ_3 same to w_4, s_4 and φ_4 respectively and set the turns of L_3 as the minimum required number.

Step 4-3. If the SITR is not larger than the minimum SITR, the objective of the system cannot be achieved, and go back to *Step 4-1*.

Step 4-4. Store current r_{o3} into r_{old}, and increase r_{o3}.

Step 4-5. If the SITR is larger than the minimum SITR, return to *Step 4-4*. If not, change r_{o3} to r_{old}, and the optimization is done.

Figure 4, Figure 5, Figure 6 summarize the optimization design procedure of power link, zero-coupling sweeping, and data link in three flowcharts.

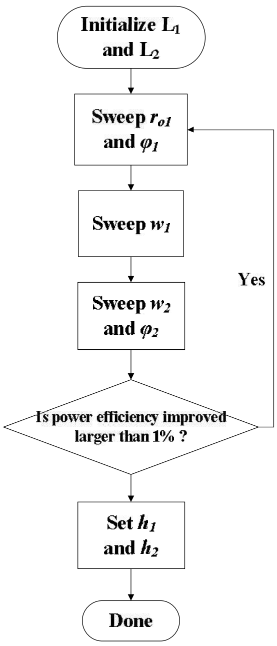

Figure 4. Power link optimization design procedure flowchart

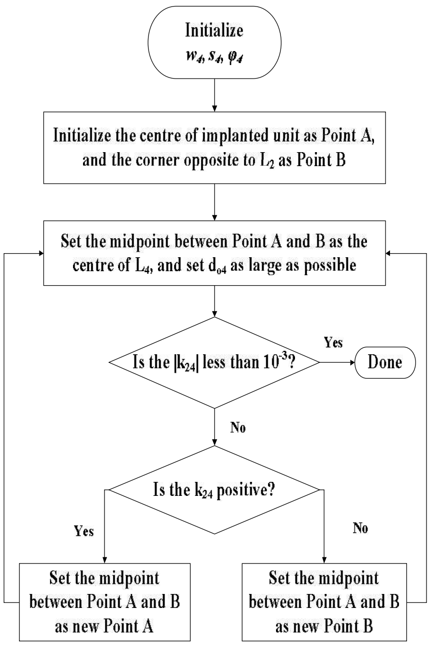

Figure 5. Finding zero coupling procedure flowchart

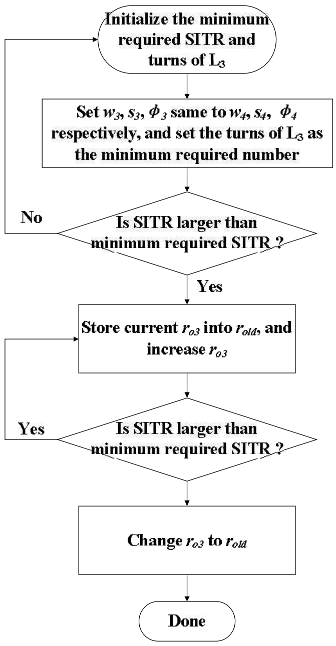

Figure 6. Data link optimization design procedure flowchart

III. Design Example and Discussion

Based on the source code of Fasthenry 3.0, we wrote a program that implements our optimization procedure in C language on FreeBSD operating system. And all the simulation results below are base on this program and our design procedure.

TABLE II. Geometrical Parameters

	r_o (mil)	r_i (mil)	w (mil)	s (mil)	h (mil)	N	φ
L_1	905	121	10	6	1.4	50	0.76
L_2	524	76	8	6	1.4	33	0.75
L_3	180	26	8	6	1.4	12	0.75
L_4	328	48	8	6	1.4	21	0.74

TABLE III. Geometrical Structure

Transmission Distance (mil)	Central Distance between L_2 and L_4 (mil)	Size of implanted board (mil×mil)
393.7	464	1181×1181

TABLE IV. Electrical Parameter

	freq (MHz)	L (μH)	Rs (Ω)	Q
L_1	1	50.59	7.945	40.01
L_2	1	12.86	3.757	21.55
L_3	13.56	0.525	0.634	70.76
L_4	13.56	3.153	2.134	125.886

TABLE V. Coupling Coefficient

k_{12}	k_{34}	k_{14}	k_{24}
0.22	0.04	0.07	2.84e-06

TABLE VI. System Performance

Power efficiency	SITR (dB)
70.14%	58

The dual band transmission systems in the case above are implemented based on the structure shown in Figure 1. Table II and III summarize the optimized geometrical parameters and structures of the two systems. Table IV and V summarize the electrical parameters and coupling coefficients. Table VI shows the transmission efficiencies of power link and the SITR of the two systems.

The case demonstrates a power transmission efficiency of 84.91%, and an overall SITR of 62.58 dB. As shown in Table V, base on our optimization procedure, k_{12} is very large and k_{24} is negligibly small (almost zero), this is why the case shows very high power transmission efficiency and good SITR performance. This case can be applied to some certain applications. For example, it can be used as the power and data transmission system for retinal prosthesis (9).

IV. Conclusion

We have designed an optimization procedure for dual band power and data transmission system. This procedure could optimize the geometrical and physical parameters of two pairs of coils used in implantable electronic devices to maximize the power transmission efficiency and reduce the interference to data transmission. Unlike other design procedures which mostly only concentrated on the optimization of one pair of coils, our procedure can optimize data link and power link simultaneously and achieve both optimal power transmission efficiency and high signal to interference ratio at the same time.

Acknowledgments

The authors would like to thank the financial support provided by the National Basic Research Program of China (Grant No. 2011CB707505)) and by Shanghai Committee of Science and Technology (Grant No. 11441900400).

References

1. C. Graeme, *AIP series in modern acoustics and signal processing by Beyer RT (editor in chief) Springer, New York* (2003).
2. D. B. Shire, S. K. Kelly, J. Chen, P. Doyle, M. D. Gingerich, S. F. Cogan, W. A. Drohan, O. Mendoza, L. Theogarajan and J. L. Wyatt, *Biomedical Engineering, IEEE Transactions on*, **56**, 2502 (2009).
3. R. E. Isaacs, D. Weber and A. B. Schwartz, Rehabilitation Engineering, IEEE *Transactions on*, **8**, 196 (2000).
4. C. M. Zierhofer and E. S. Hochmair, *Biomedical Engineering, IEEE Transactions on*, **37**, 716 (1990).
5. D. C. Galbraith, M. Soma and R. L. White, *Biomedical Engineering, IEEE Transactions on*, 265 (1987).
6. P. R. Troyk and M. A. K. Schwan, Biomedical Engineering, IEEE Transactions *on*, **39**, 589 (1992).
7. W. Liu, K. Vichienchom, M. Clements, S. C. DeMarco, C. Hughes, E. McGucken, M. S. Humayun, E. De Juan, J. D. Weiland and R. Greenberg, *Solid-State Circuits, IEEE Journal of*, **35**, 1487 (2000).
8. G. Wang, P. Wang, Y. Tang and W. Liu, *Biomedical Circuits and Systems, IEEE Transactions on*, **6**, 208 (2012).
9. G. Wang, W. Liu, M. Sivaprakasam, M. Zhou, J. D. Weiland and M. S. Humayun, in *Engineering in Medicine and Biology Society, 2006. EMBS'06. 28th Annual International Conference of the IEEE*, p. 4392 (2006).
10. P. Wang, Y. Tang, H. Wang and G. Wang, in *Circuits and Systems (ISCAS), 2012 IEEE International Symposium on*, p. 2191 (2012).
11. FastHenry 3.0 [Online]. Avaliable: http://www.fastfieldsolvers.com/links.htm.
12. U. M. Jow and M. Ghovanloo, *Biomedical Circuits and Systems, IEEE Transactions on*, **1**, 193 (2007).