Design Procedure for Wireless Power Transfer to Integrated Circuit

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***Abstract* - This paper designs wireless power transfer systems using PCB transmitter (Tx) coil and on-chip receiver (Rx) coil. The receiver on-chip coil has 3 mm outer dimension and the receiver assumes 3.3V/100 mA power drawing. The design procedure decouples Tx optimization and Rx optimization, allowing both Tx and Rx can have the highest figure-of-merit. Full wave electromagnetic simulation illustrates the design concept.**

***Index Terms* — Wireless power transfer, resonator design.**

1. Introduction

The wireless power transfer can be conducted to power silicon integrated circuit (IC). In those applications, the IC equips with a power-receiving coil at the outer side of IC. These applications may include wireless biomedical implants or wireless testing/sensing applications. Unlike high power applications, these low power applications generally have very low magnetic coupling between transmitter (Tx) and receiver (Rx). For the low coupling scenario, the method of receiver power susceptibility (Rx-PRS) and transmitter figure-of-merit (Tx-FOM) has been developed [1].

In this paper, a design procedure for IC wireless powering which has low magnetic coupling is illustrated using the Rx-PRS and Tx-FoM developed in [1]. While [1] focuses on the 1mm-sized wire-wound sub-milliwatt biomedical implant, this work designs 3mm-sized integrated circuit coil with higher power (330 mW).

2. Design Procedure

(1) Overall dimension

The load resistance of system is dependent of receiver chip supply voltage and current consumption. For example, 3.3 V supply voltage with 100 mA current drawing is equivalent to the load resistance of 3.3/0.1 = 33 Ω. In this work, we will focus on 33 Ω load resistance.

Fig. 1 illustrates the physical arrangement and dimensions of coils. The transmitter coil is made from PCB pattern and its thickness is 35 um. The outer dimension is 10mm. Its number of turn is determined such that its Q-factor is maximized at the frequency where the receiver Rx-PRS [1] is maximized. The receiver coil outer dimension is restricted within 3 mm. The distance between Tx and Rx is set to 1 cm.

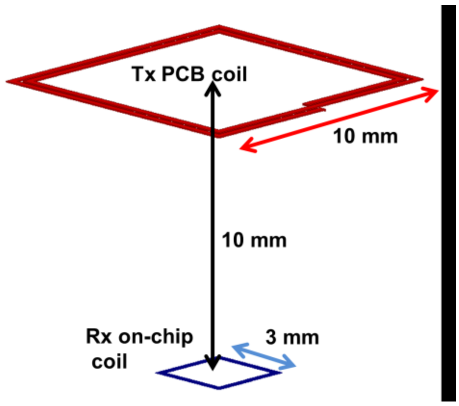

Fig. 1. Overall system structure.

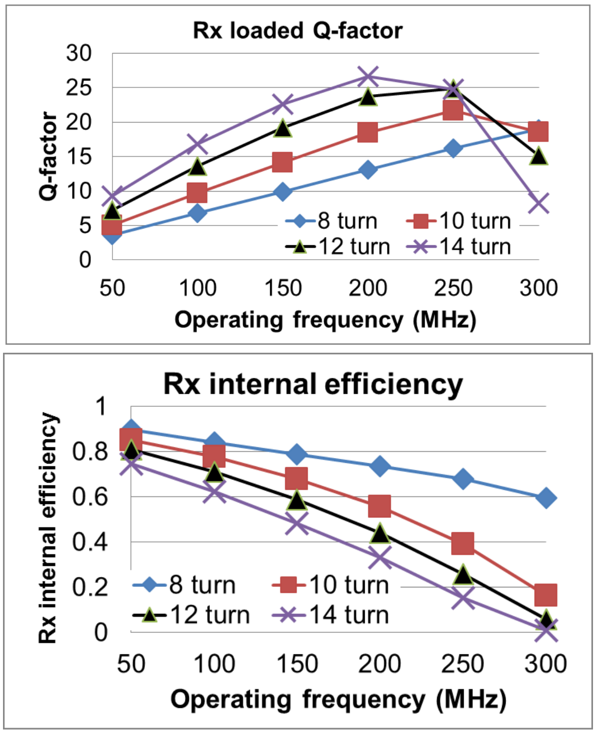

Fig. 2. Receiver loaded Q-factor and internal efficiency

(2) Selection of Receiver Number of Turns and Frequency

The receiver number of turns and the operating frequency range are determined such that receiver power reception susceptibility (Rx-PRS) is maximized. The receiver resonant coil is series-resonant unlike [1] because the load resistance is small and loaded Q-factor can be therefore high. Fig. 2 shows that the loaded Q-factor is high when the

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number of turns is increased. This is due to the fact that Rx loaded Q-factor, Q_{RX} is given by $Q_{RX}=\omega L_{RX}/(R_L+R_{22})$. On the other hand, Rx internal efficiency is reduced as the number of turns are increased. This implies that there exists optimum number of turns of receiver which maximizes Rx-PRS which is the multiplication of loaded Q-factor and Rx internal efficiency.

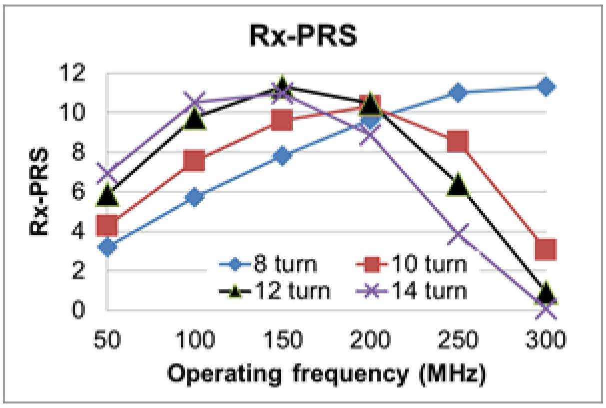

Fig. 3. Rx-PRS, the multiplication of two quantities in Fig. 2

Fig. 3 shows that Rx-PRS is maximized when Rx number of turns is 12 at the frequency range of 100~200 MHz.

(3) Selection of Transmitter Number of Turns

The transmitter number of turns is swept and optimum turn number is found. Recall that the operating frequency range is roughly specified by the receiver design process. In other words, Fig. 3 specifies that the best operating frequency range is between 100~200 MHz using 12-turn receiver coil. The 300 MHz point also has high Rx-PRS when the number of turn is 8. However, practical power conversion circuits exhibit low efficiency at such high frequency.

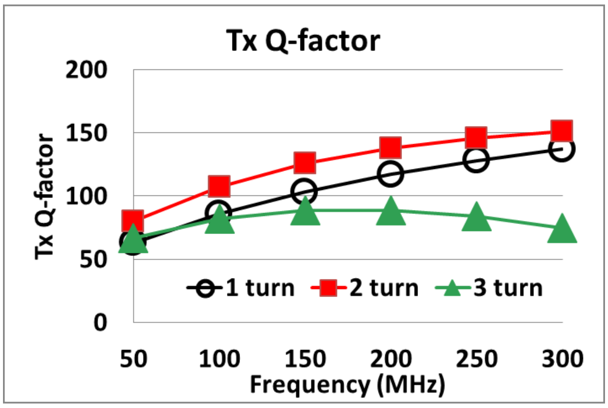

Fig. 4. Tx coil Q-factor. The 2-turn Tx coil is selected due to its high Q-factor at the 100~200 MHz range where Rx-PRS is high.

Fig. 4 shows that the 2-turn Tx coil shows the highest Q-factor across the target frequency range of 100~200 MHz where Rx-PRS is high. Therefore, the 2-turn Tx coil is selected as a final design.

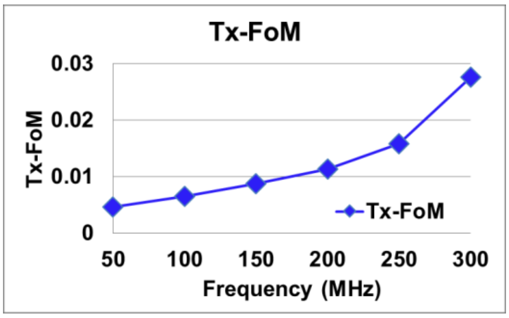

Fig. 5. Tx-FoM with 2-turn Tx coil.

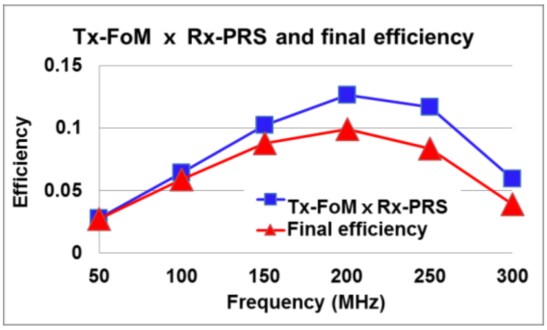

Fig. 6. The multiplication of Tx-FoM and Rx-PRS. Also compare the multiplication with final efficiency.

(4) Final Frequency Selection

In this step, the final operating frequency is selected. The Tx-FoM found in Fig. 5 and the Rx-PRS in Fig. 3 are multiplied to produce the final efficiency value. It is shown that the product of Tx-FoM and Rx-PRS is equivalent to power transfer efficiency when the coupling coefficient is very small [1]. Fig. 6 exhibits slight discrepancy between the multiplication (blue square) and final efficiency (red triangle). This is due to the rather strong coupling coefficient. However, this discrepancy level is acceptable and will be removed for the applications of lower coupling coefficient. Since the product of Tx-FoM and Rx-PRS is maximized at 200 MHz, it is selected as the final operating frequency.

3. Conclusion

The receiver optimization takes place first and produces the number of turns of receiver and rough operating frequency range. Within the frequency range, Tx Q-factor is maximized. Final frequency is selected by the product of Tx-FoM and Rx-PRS

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References

[1] D. Ahn and M. Ghovanloo, “Optimal Design of Wireless Power Transmission Links for Millimeter-Sized Biomedical Implants,” *IEEE Trans. Biomed. Ckt. Syst.*, vol. 10, no. 1, pp. 125—137, Feb. 2016.