Maximum Power Transfer Considering Limited Available Input Power in Ultrasonic Wireless Power Transfer for Implanted Medical Devices

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***Abstract*—Ultrasonic energy harvesting emerges as a leading candidate for clean energy used in implanted medical devices. In implanted medical applications, in order to prevent hot spots, only very low input voltage is allowed, while a high enough output voltage is needed for battery charging. Recent studies use an inductor in either series or parallel to the piezoelectric transducer to boost up output rectifier voltage, sometimes with the price of failing to achieve maximum power transfer. This study provides a method to obtain both maximum power transfer and highly boosted rectifier output voltage for ultrasonic wireless power transfer, considering the limited available input power case, to get enough high output voltage for battery charging in implanted medical applications.**

***Index Terms*—energy harvesting, implanted medical devices (IMD), ultrasound, wireless power transfer (WPT).**

I. INTRODUCTION

In implanted medical devices (IMD), while the CMOS system can have expected lifetime between 20-plus years and 200-plus years, battery lifetime becomes the fundamental limitation of the device lifetime performance. An important example of IMD is the pacemaker which has battery lifetime of about ten years. Hence, patients with pacemaker are expected to have replacement surgery every ten years. Such surgery is not only inconvenient to the patients, but also dangerous to the ones at their old ages. For this reason, wireless power transfer (WPT) becomes a potential solution for future IMD. Among various possible WPT methods, piezoelectric WPT using ultrasound with the capability of deeply penetrating into human body without significant attenuation, while fast attenuating in the air, becomes the leading candidate as a clean energy resource for IMD.

General piezoelectric energy harvesting (PEH) focuses on getting maximum power transfer (MPT) while keeping high power transfer efficiency. To reduce conduction loss, usually the impedance matching technique is used for only the reactance part simply by adding an inductor to the transducer. Then, AC output of such structure is converted into DC voltage by a rectifier. Hence, the maximum power delivered to the load after the rectifier is limited by: 1) the minimum of the extracted power at the 'maximum power theorem' condition; and 2) the amplitude of the AC input voltage of the rectifier at the corresponding load condition. Careless of the latter limitation, traditional PEH only takes the available parasitic capacitance of the transducer into account, then continue to match with a corresponding inductance value or its nearest practical value[1][2][3]. Therefore, the output voltage of this specific matching circuit, which is also the input voltage of the rectifier, will be specified and limited; or the maximum power transfer condition cannot be obtained. In these cases, a higher transducer open voltage is required, which is not suitable for the IMD applications.

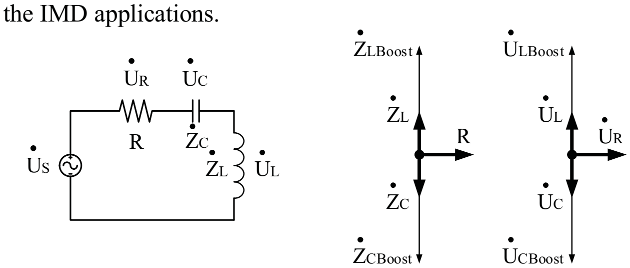

Fig. 1. Series RLC circuit and its phasor diagrams.

In this study, a simple method is proposed to solve the problems above simply by changing the piezoelectric transducer reactance according to the MPT matching condition to a desirable added inductor, which can provide higher output voltage to the rectifier as shown in the phasor diagrams for a series RLC circuit in Fig. 1. Thus, both high output voltage and maximum power transfer condition can be obtained. The proposed method is especially viable to the ultrasonic WPT for the IMD applications with required low output current consumption.

II. MODELING SYSTEM

Shown in Fig. 2 is the overall architecture of the proposed ultrasonic energy harvesting. The piezoelectric transducer is modeled based on the in-vitro experiment result in [1] with the impedance of $700\angle -58^o\Omega$. Since the operation of the piezoelectric energy harvester is only near its switching frequency $f_0 = 1.033MHz$, the ultrasonic transducer (UT) can be modeled as a sinusoidal voltage source in series with a capacitor of 268.1μF and its equivalent series resistance of $370.9435\,\Omega$. To implement the effect of increasing capacitor impedance as in Fig. 1, a small capacitor C_{AddM} of only 43.3pF,

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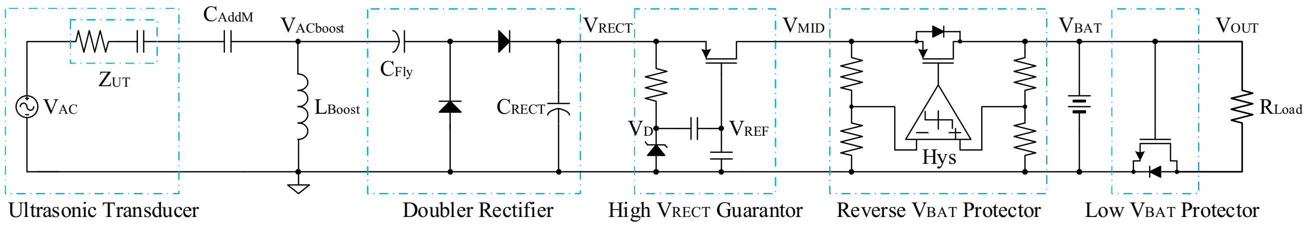

Fig. 2. Proposed ultrasonic energy harvesting architecture.

which can be made on-chip, is added in series with the transducer in order to allow larger L_{Boost} to be matched:

$$L_{Boost} = \frac{1}{(2\pi f_0)^2}\left(\frac{1}{C_{UT}} + \frac{1}{C_{AddM}}\right) \quad (1)$$

Taking into account that IMD power is very small (10µW for pacemaker) and the battery is charged only when V_{RECT} is already high enough, the equivalent resistance seen from the rectifier input to the load is also very high with small effect on the matching condition. As a result, both higher $V_{ACboost}$ voltage and maximum power transfer condition can be obtained.

III. Simulation Results

Shown in Fig. 3 is the plot of V_{Boost} when the load seen from the rectifier input changes, all in the maximum power transfer condition for the same V_{AC} of the transducer input. This result corresponds to the theory in that, V_{Boost} is linearly proportional to L_{Boost} without the presence of R_{Load} (R_{Load} is infinitive). For a practical inductor used at ultrasonic frequency for IMD, inductor with small size and high resonant frequency should be considered. In this experiment, the inductor coil SRR6028-681YTR-ND from Bourns Inc. with inductance of 680µH, equivalent series resistance of 3.1Ω, and self-resonant frequency of 8MHz are chosen.

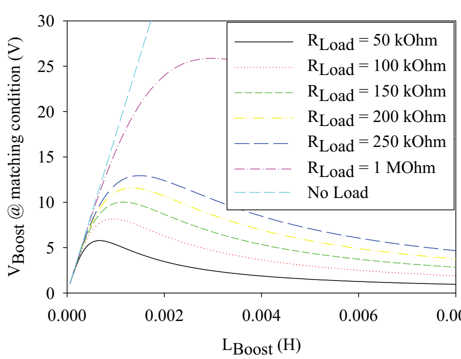

Fig. 3. V_{Boost} profile at matching condition for different load.

In order to compare the performance of the proposed ultrasonic EH to the conventional one, the same AC voltage magnitude of 1V is applied to the proposed EH system (matching with C_{AddM}) and the conventional EH system (matching without C_{AddM}) using both doubler and full bridge rectifier under open circuit condition (R_{Load} is infinitive). As shown in Fig. 4, voltage doubler results double of rectifier voltage output compared to the full bridge rectifier under the same test system. In addition, the proposed EH system results as twice as the rectifier voltage output of the conventional one. The drawback of the proposed system is slower charging time due to larger time constant L_{Boost} / Z_{RECT}.

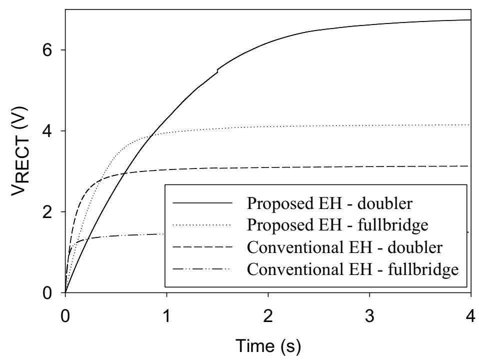

Fig. 4. Rectifier voltage output V_{RECT} at open circuit load condition.

IV. Conclusions

A simple enhanced output boosting voltage with maximum power transfer ultrasonic energy harvesting for IMD was proposed and verified using simulation, using the ultrasound transducer based on the experiment result from previous study.

Acknowledgment

This research was sponsored by Samsung Electronics. The simulation tool was supported by the IC Design Education Center (IDEC), KAIST.

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