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# A power conversion chain with an internally-set voltage reference and reusing the power receiver coil for wireless bio-implants

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ABSTRACT

In this paper, a power conversion chain (PCC) with an internally-set voltage reference is presented. It is comprised of a power receiver coil, an active rectifier and a novel buck-boost converter. The output voltage of the PCC is set by using the parameters of a new buck-boost converter control unit in order to avoid utilizing an extra voltage reference circuit. Furthermore, the proposed PCC reuses the power receiver coil to facilitate the realization of the buck-boost converter. This way, the efficiency of the proposed PCC gets almost independent of the receiving coil voltage amplitude. In addition, the proposed buck-boost converter significantly reduces the size of the PCC and makes it suitable for wireless power transfer via inductive links in bio-implant applications. It should be noted that employing an active rectifier followed by the proposed buck-boost converter enhances the PCC end-to-end efficiency. The proposed PCC is simulated for the input received signal with a frequency of 10 MHz and an amplitude variation within 3–7 V. The simulation results show that the efficiency variation is less than 2.6% and the achieved maximum efficiency is 80.4% and 63.4% for the proposed converter and PCC, respectively. For further verification of the proposed idea, a proof-of-concept prototype is implemented and experimental results are provided.

## 1. Introduction

Nowadays, power transmission via inductive links for implantable medical devices (IMDs) considerably becomes important and pervasive. The reason is that it is an alternative option for the battery-powered cases that can decrease the total size of the IMD and reduce the probability of infection. Power transmission via inductive links can be used for applications such as cochlear implants [1], visual prosthesis [2] and invasive wireless neural recording [3]. Significant challenges in today's IMD design are related to the size of IMD and the power consumption [3,4].

Fig. 1 shows a typical power conversion chain (PCC) which is used in IMDs. The PCC converts the input AC voltage to a DC output voltage. After rectification, there should be a voltage regulator to maintain the output voltage at a certain level, by comparing it to a voltage reference. Thus, this voltage can be used as a supply voltage for other parts of the implant. The conventional structure used in bio-implants is the linear regulators [5,6]. In power transfer via inductive links, the amplitude of the received voltage may vary a lot due to the variation in the distance or the angle between the power transmitting and receiving coils. Moreover, the other parameters such as the moisture of the path between these two coils would be able to have influence on the received voltage amplitude.

In linear voltage regulators, the output voltage level is constant. As a result, the variation in the input level can increase voltage drop across the regulator. This can significantly decrease the regulator efficiency. The considered problem would be diminished using two methods. The first method reduces the power loss by controlling the power transmitter gain in the driver of the outer coil [7]. Using this method, when the received voltage level is decreased, the power transmitter gain increases and the transmitter coil transmits higher power to compensate for the received voltage. In return, when the received voltage level is increased, the power transmitter gain is decreased to compensate. This method needs a variable gain power transmitter in the primary side of the coil. In addition, an analog-to-digital converter, and also, a data transmitter in the implant side are needed to gather the received voltage level information and send them for the power transmitter. Besides, imposing an additional reverse path to send the received voltage level information for the power transmitter from the implant can significantly increase the size of the implant, which is critical in the bio-implant applications.

The second method in order to get rid of the efficiency degradation by input voltage variation is the use of nonlinear voltage converter as introduced by the previous work of the authors in Ref. [8]. In the mentioned reference, by employing a buck-boost converter instead of a

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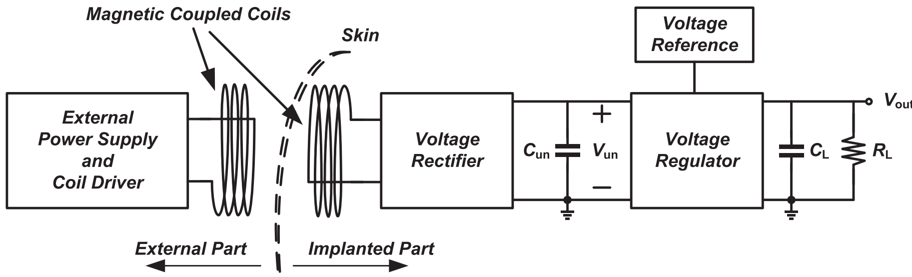


**Fig. 1.** Power conversion chain structure in bio-implant systems.

linear regulator, the efficiency variation is decreased from 35% to less than 8% for input amplitude voltage variation of 3–6 V [8]. The designed converter achieves an output current range of 10 μA to 4 mA without the problem of instability. Moreover, the output DC voltage level could be higher or lower than the amplitude of the received input voltage. The main problem in the nonlinear converters is the existence of a large bulky inductor that is inevitably off-chip and considerably increases the size of the implant. Reusing the inductor of the power receiver coil not only resolves the problem of the large off-chip coil but also gives a very small converter by adding just four power switches and a control circuit as well. This is the main idea of the previous work of the authors [8].

Voltage reference is an essential block in both linear and nonlinear converters. The bandgap reference is mostly employed for this purpose. The quiescent current of the bandgap voltage reference degrades the total power efficiency of the PCC. Recently, many researches have been done to solve this drawback [9,10]. Nowadays, many efforts have been done to replace the bandgap circuit by a completely CMOS reference [9,11]. However, CMOS references most often could not be a suitable alternative since they would bring up various problems causing different challenges for designers. For example, the CMOS reference which is introduced in Ref. [11] and is used in Ref. [8], begins to oscillate with a little change in the value of its elements. Furthermore, two off-chip resistors have been used in order to compensate for the variations in different process corner cases resulting in enlarged size of IMD [8].

Drawbacks of using a bandgap voltage reference encouraged the authors to have more attention to the voltage reference matter in PCC. Therefore, a new structure has been suggested that completely removes the voltage reference from the PCC. The proposed structure is according to the matter in which there is a control circuit similar to the feedback in nonlinear converters. Thanks to the feedback circuit, the output voltage of the converter can be regulated due to the loop parameters. Thus, this method provides a situation in which no voltage reference block is required. Removing the voltage reference not only enhances the efficiency of PCC by omitting its quiescent current but also improves the circuit behavior against the process corner cases, temperature variations and device mismatches in comparison with the other CMOS voltage references.

Therefore, the effect of temperature and process variations on the output voltage is negligible. In this way, the quiescent current of the voltage reference is removed and the converter output voltage could be regulated at any desirable value provided by the converter. Furthermore, by eliminating the voltage reference, the size of the IMD is further decreased.

The proposed power receiver chain introduced in Ref. [8] has been implemented by a passive rectifier. Although this converter has a high efficiency that is almost independent of the input voltage, the total PCC efficiency is low due to the passive rectifier. In this paper, an active rectifier is employed in the PCC structure to remedy this issue. The new structure not only improves the total efficiency significantly, but also shows a very better consistency of the converter efficiency against the variations of the input voltage. Using this structure, the efficiency variation is decreased from 8% for the input voltage range of 3–6 V to less than 2.6% for an input range of 3–7 V.

To validate the simulation results, the suggested PCC structure has

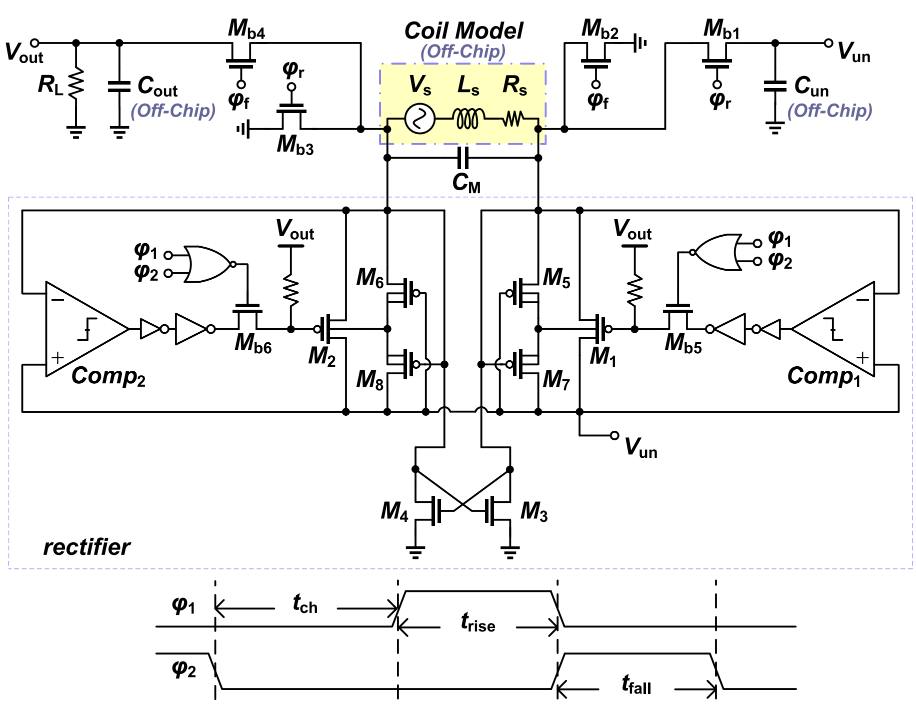


**Fig. 2.** Proposed inductor-reused buck-boost converter with an active rectifier.