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A Self-Tuning Inductive Powering System for Biomedical Implants

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Abstract

This paper describes the design and implementation of a self-tuning inductive powering system conceived for biomedical applications. The circuit operates at 1 MHz and delivers 380 mW to the implant with an efficiency of 50%, at a distance of 1 cm. Absorption modulation is used to monitor the circuit parameters allowing the system to deal with distance increases up to 5 cm as well as small coil misalignments. The automatic-tuning system adjusts the configuration of the coil driver depending on the self-monitored coupling, acting on a bank of switchable capacitors with a pattern defined by the received data. It is demonstrated that the implemented tuning strategy boosts the transmitted power by a factor two. In addition, the combination of tuning and smart power regulation was proven to sensibly increase the system efficiency by maintaining a constant energy level at the secondary.

Keywords: transcutaneous energy transfer; TET; inductive powering; self-tuning system; biomedical implant

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1. Introduction

Transcutaneous Energy Transfer (TET) systems are increasingly employed in medical implants as an alternative to batteries [1-4]. These systems typically rely on a well coupled resonant coil pair which, in favorable conditions, can sustain a power transfer of several watts through the skin [3,4]. A common architecture (Fig. 1) consists of a power amplifier, which produces a sinusoidal current through the primary coil. This induces a variable magnetic field that is partially detected by the secondary coil, where it is converted to a voltage and used to sustain the operation of the implanted system. However, a major drawback of TETs is their high sensitivity to misalignments and coils distance variation.

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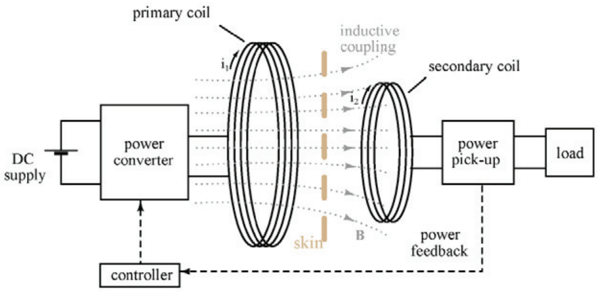


Fig. 1: Block level schematic

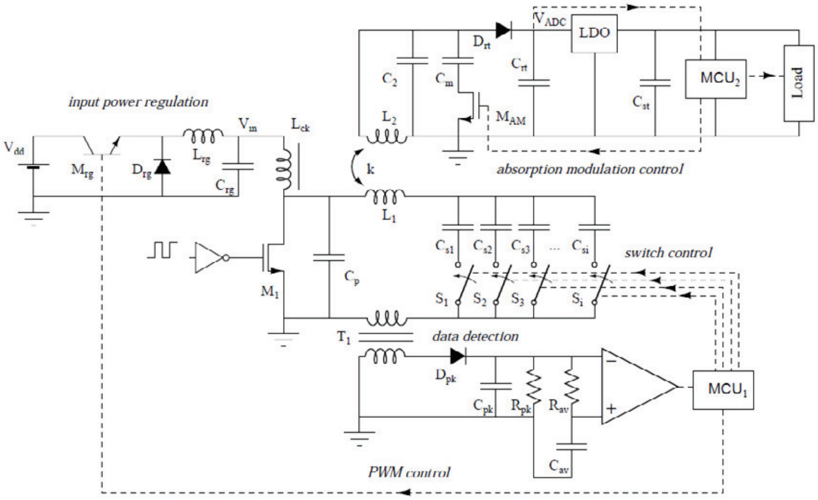


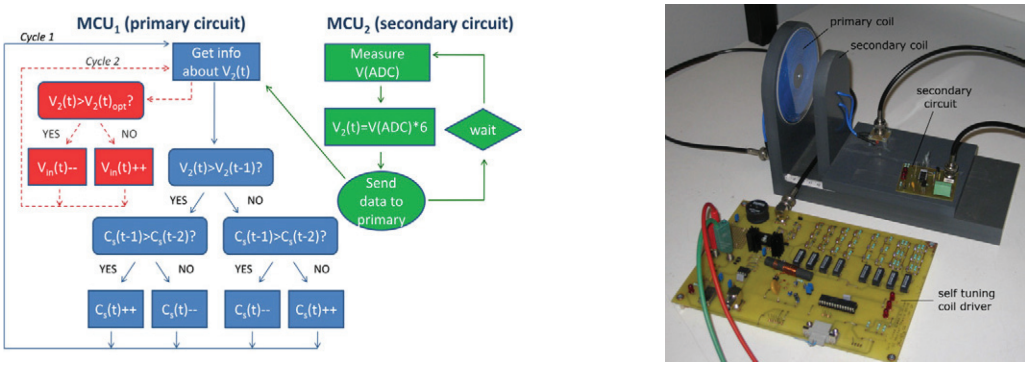
Fig. 2: Circuit level schematic

These can produce instable operation resulting in uncontrolled heat dissipation at the driver side and/or energy black-outs at the implant side [1-6]. In addition, component tolerance and temperature drift can cause frequency shifts up to 20% from the nominal operating frequency. A compensation of these effects is a must in the design of a robust system.

The concept of a self tuning inductive powering is not new to the scientific community. Although adjusting the operating frequency is the easiest option [5,6], such an approach significantly affects the power transfer when the system is designed to operate in critical coupling. The only viable option to guarantee stability while maintaining the operating frequency constant, is to act on the driver resonant tank. Systems that adjust the inductance of a class C and a class E amplifier have been proposed by [6] and [1] respectively. However, both implementations require a bulky transductor to be integrated in the driver and are therefore not suitable for wearable systems. Aiming at reducing the circuit complexity and at increasing the portability, this paper explores the feasibility of an automatic tuning system, which adjusts the capacitances of the class E driver depending on the coupling conditions.

2. Design and Implementation

A paramount parameter in the design of an inductive link is certainly the coupling factor (k) which is proportional to the link power transfer potential. Its value is fixed by the geometry of the coil pair: by their cross section, their number of windings and by their mutual position. As coil characteristics depend



(a) (b)

Fig. 3: Tuning algorithm (a) and implemented prototype (b)

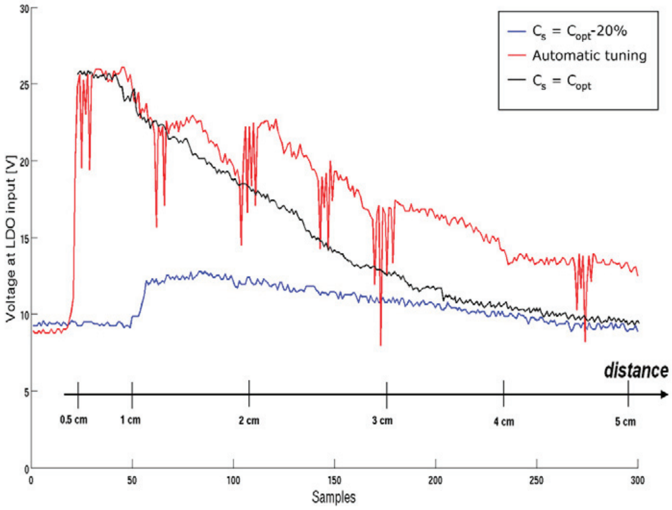


Fig. 4: Measured voltage at the input of the LDO (V_{ADC}) in different working conditions

on the application and are fixed by construction (except for changes due to deformation), the relative position of the coils is the main actor in the variability of k. Besides being affected by lateral and angular misalignments, k decreases with the cube of the distance between the two coils. As this effect is dominant with respect to the others [7], providing robustness against increasing distance also guarantees robustness against small misalignments. Therefore a system was designed which can operate in the 0.5 to 5 cm range, and k comprised between 35 and 8%.

Another critical design parameter is the operating frequency (f_c). Although the higher f_c the smaller the coil cross sections become, a high f_c implies high absorption of the magnetic field by the human body. However, f_c cannot be too low neither as implantable coils are intrinsically bound to small dimensions. Moreover, if data transmission is envisaged through the power link, a low f_c would significantly limit the available bandwidth. The operating frequency was then set to 1 MHz, which allows reasonable coil dimensions and a few kHz bandwidth for data transfer.

A TET provided with feedback-loop allowing misalignment compensation has been developed which is based on a self-tuning class E driver [8]. The system is built around two spiral coils counting 14 and 7 windings of 16 AWG Litz wire, respectively, with 10 and 5.2 cm as cross-sections. The tuning system relies on a controlled bank of switched capacitors (C_s) at the driver side. Although both parallel capacitor (C_p) and C_s play a role in the amplifier operation, it was proven that only the latter has a significant effect in the tuning of the resonant tank, whereas C_p mainly limits the voltage across the switching element

(M_1). Without modifying the carrier frequency, C_s is adjusted with a 100 pF resolution in a ±55% range around its nominal value, depending on the information received from the secondary side (Fig. 2) and interpreted according to the tuning algorithm (Fig. 3, a). The most suitable value of C_s is determined by monitoring and processing the trend of the received DC voltage ($V_{ADC} = V_2(t)/6$), which results from a change in the coupling conditions. A two-step control on $V_2(t)$ and C_s rules the increment/decrement operation. After a fixed number of oscillations, the system selects the combination that results in the highest induced voltage. Absorption modulation is used to transfer data through the uplink and is detected at the primary side by sensing the current in the resonant loop by transformer T_1. Asynchronous PWM modulation is applied and a dedicated protocol has been defined to obtain error-free transmission. Once the optimal C_s has been selected, a second iteration adjusts the input voltage V_{in} to maintain the amount of energy received by the implant, at the desired level. Fig. 3, b shows the implemented prototype. Fig. 4 depicts a comparative measurement of $V_2(t)$ while increasing the coils distance: for a detuned system (blue), for a system optimized to work with fixed coils (black) and our automatic-tuned system (red). It is clear that in the same conditions (load and distance), the TET performance is significantly improved in the last case.

3. Conclusion

A self-tuning TET system was presented that adjusts the driver configuration depending on the coupling conditions. The tuning circuit acts on a bank of series capacitors of a class E power amplifier. The optimal C_s configuration is determined by monitoring the trend of the DC voltage at the implant side and elaborating the result according to the tuning algorithm. The system can overcome small misalignments and variable distance between primary and secondary coils.

Acknowledgements

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