Effective Low Voltage Wireless Charging System with an Active Matching Circuit for AIMD's

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Abstract— Power is very important to modern systems. Wireless transmission is useful in cases where instantaneous or continuous energy transfer is needed. Biomedical implants require a clean and medically safe source of power. Earlier medical implants used lithium ion batteries but due to limited battery life, it posed a significant health risk. A wireless power transfer (WPT) system based on magnetic resonant coupling is applied to the implant to recharge its battery. The primary coil is assumed to be on-body, while the secondary coil is in-body. Most existing system require the induced voltage of the receiving coil to be higher than the turn-on voltage of the diodes used in the rectifier for the efficient AC to DC conversion. This requirement results in larger coil size, shorter operating distance or more stringent geometrical alignment between the two coils. So a low-input-voltage wireless power transfer system has been proposed. In this system, the voltage of the induced AC input can be even as low as 500mV, and it has been converted to 5 V DC. Both the output voltage and the power drawn into the receiving coil can be regulated by the duty cycle of a control signal. This allows reduce the size of the receiving coil, increase the operating distance between the transmitting and the receiving coil, and yet to achieve the desired DC output. A real time matching circuit is added between Tx coil and source to improve the coupling efficiency which further increases the power transmitted and operating distance.

Key words: Active Matching Circuit, AIMD's, Low Voltage, Pacemakers, Wireless Power Transfer

I. INTRODUCTION

An active implantable medical device is a medical device with a battery as a source of energy. It is totally or partially inserted into human body through surgical means to provide therapy or to monitor various vital parameters. Pacemakers, implantable cardio defibrillator, ICP devices, LVAD's are some implantable medical devices. The major problem with AIMD's is limited battery life. A surgery has to be performed again to replace the device or device battery. This poses health risk and costly since the whole device has to replaced. In order to overcome this, a simple wireless power transfer system is placed in the AIMD's to recharge the battery. By this power can be sent from transmission coil to receiving coil placed in the device. Short range WPT system use either inductive or resonant coupling to transmit power. The efficiency of such system depends on the coupling co-efficient. In inductive coupling the coils must be positioned such that maximum magnetic flux goes through the receiving coil. It has lower efficiency and operating distance than resonant coupling where the both coils are tuned to same resonant frequency.

Generally wireless power transfer has been implemented in range of few KHz-MHz. One of the important while designing wireless power transfer system for AIMD's is recharging time which must be limited so that they do not heat up the tissues. Presently induced voltage in receiving coil is higher than the turn-on voltage of diode use in rectifiers. This leads to larger coil size, shorter operating distance, requires voltage and clippers, limiter circuits which would further lead to bulkier components, high cost and inefficient conversion. In order to avoid that scenario a low voltage WPT system is designed which would even charge even if the voltage induced in Rx coil is less even of order 500mV. This voltage is converted to 5V DC Lower frequencies below 20 KHz are used for power transmission to comply with EMF standards. A real time matching circuit is added to increase the coupling between the coils which results in higher efficiency and significantly larger operating distance.

II. OPERATING PRINCIPLE

A real-time active matching circuit (MC) is inserted between the signal source and the Tx coil. The MC is electrically controlled by a microcontroller to decrease the mismatch between the signal generator and the transmitting coil. The maximum power to the Tx, is measured by utilizing a directional coupler and an RF detector integrated circuit (IC), which is mainly composed of a detector diode. In this system, a fraction of the reflected signal from the Rx coil is fed through the coupled port of a directional coupler to a detector diode, and the output dc voltage from the diode is measured by utilizing an analogue-to-digital converter (ADC) in the microcontroller module. With this method, the system does not require any RF measurement equipment, which usually increases the system cost and complexity while limiting its applicability. If the output voltage of the detector diode is at the minimum value, it can be assumed that the reflection from the Tx coil is minimized, which equivalently means the highest power transmission in the magnetic resonant Tx–Rx coil network.

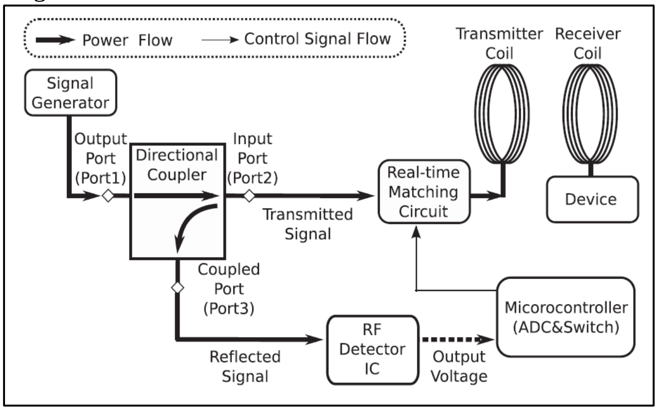

Fig. 1: Block diagram of the WPT system

Unlike a traditional boost converter the described circuit operates only at 2x, instead of 50x-100x, of the input frequency. The reduction of the control signal's frequency makes the system possible to process the AC power at the radio-frequency and also unlike a regular DC to DC boost converter; the circuit shown in Fig. 1 is started by the induced voltage's rising or falling edge. In a positive charging cycle as labelled in Fig. 1, the rising edge of the input is first detected by an edge detector (a low power comparator) which consequently triggers the control circuit. At this moment, the main switch (S0) is turned on. A large current is shorted.

After a controlled time delay (shorter than the input's half cycle's period), S0 is turned off. The abrupt current change of the receiving coil produces a large voltage. Then, the boosted voltage pulse is rectified to a high voltage DC by a regular bridge diode rectifier, as depicted in Fig. 1. In the consequent negative charging cycle, S0 operates in the same manner. Thus, the induced time-varying AC power at both positive and negative charging cycle are boosted and rectified to DC.

III. Implementation and Design

The implementation and characterization of the low input voltage wireless power transfer are described in this section.

A. *Circuit Design*

The transmission side consists of a RF detector IC, matching circuit, Tx coil and a microcontroller. AD8306 is used for RF detection and MSP 430F2101 microcontroller is used which has an integrated ADC. A discrete value impedance MC with p-i-n diode switches is designed because of its fast switching speed, small feature size, and robustness. The MC topology is based on the cascading of a unit cell consisting of an L-type series inductor and shunt capacitor. The L-type topology was chosen to make the unit-cell configuration simple. Ideally, the range of impedance values created by the variable MC unit increases as the number of stages increases. The loss associated with the lumped circuit components increases as the number of stage increases. Therefore, the number of stages was limited to six. Each capacitor can be grounded through a p-i-n diode, which acts as the switching element. The p-i-n diodes are controlled by a microcontroller unit to choose the best configuration for the MC by changing the combination of "on" and "off" states of the p-i-n diodes. In receiving side, the low-input-voltage wireless power transfer is implemented on a printed circuit board (PCB). The switch (S0) in is an n-type trench MOSFET with the turn-on resistance of 0.4 Ω. The diode (D+ and D-) is a regular silicon pn junction diode with 0.72 V turn on voltage. The power consumption of the edge detector (LTC1540) used in this experiment is about 1 µW.

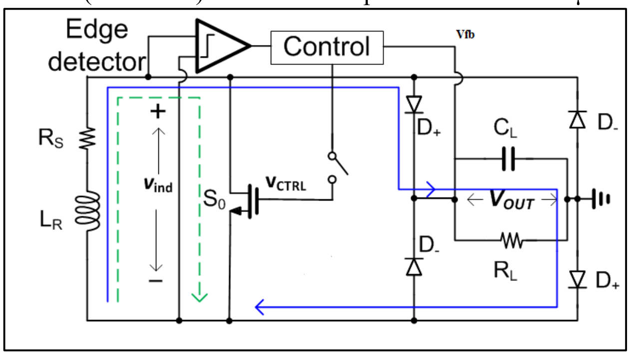

Fig. 2: Receiving Side Circuit Design

The control in Fig. 1 is established based on an XOR Gate1 One input of the XOR is connected to the output of the edge detector directly, and the other input is connected to the output of the edge detector through a RC delay whose delay time is controlled by VFB. Thus, S0 is always turned on when the edge detector changes its output, and turned off after a controlled delay.

B. *Measurement Setup*

The transmitting coil has the diameter and the inductance of 57 mm and 40.2 mH, respectively. The receiving coil is wound on a 5 mm ferrite rod. Four coils whose inductance ranging from 0.48 to 5.73 mH are made for this experiment .The low-input-voltage wireless power transfer system is a low-Q system, thus, the distance or the geometrical alignment between the transmitting and the receiving coil, are not as critical as in a high-Q system.

Receiving coils			OC Input		Duty Cycle %
No.	L mH	R Ω	Vin mV	Fin KHz	
1	5.73	5.5	720	1	78
2	2.22	4.6	220	1.6	75
3	.73	2	200	4.8	65
4	.48	1.5	190	5	63

Table 1: Measurement Setup

C. *Voltage Boosting and Rectification*

The DC output of this low input-voltage wireless power transfer is always targeted at 5 V over a 25 KΩ load resistor (Pout =1mW). The induced open-circuit voltage of the receiving coil is minimized by reducing V_{dd} of the transmitter. The frequency of the input is optimized by comparing its half period (1/2fin) with the time constant of the receiving coil. The duty cycle of VCRTL is maximized. With 1 mW output power at 5V DC, the induced open-circuit voltage of each coil is listed in Table I. The input open-circuit voltage, especially of Coil #2 to Coil #4, is far below the rectifier's turn-on voltage (i.e., 0.72 V). The design enables the wireless power transfer with a very low voltage input. This design provides a viable alternative to achieve the low input-voltage wireless power transfer.

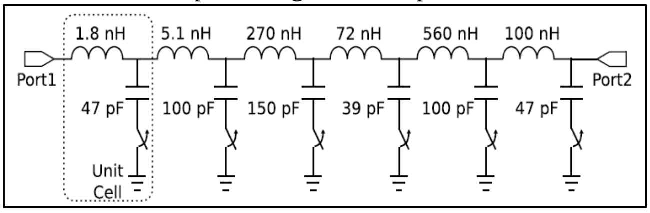

Fig. 3: A Real time matching circuit diagram

D. *Duty Cycle*

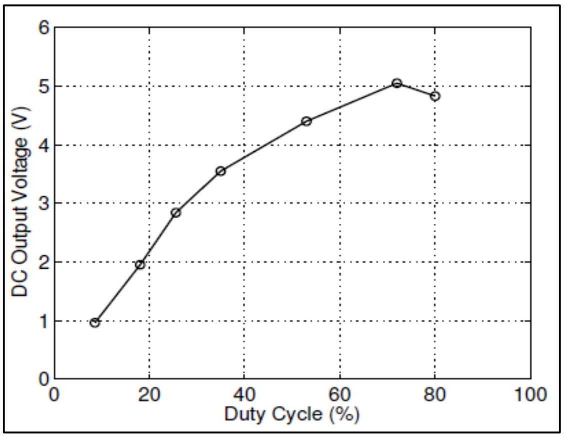

Fig. 4: The DC output voltage at various duty cycles

The duty cycle of VCTRL at the gate of switch S0 can effectively regulate the DC output voltage. To demonstrate this feature, VFB, is manually altered to achieve various duty cycle of VCTRL. With the change of VFB, the DC output voltage across RL and VCTRL at the gate of S0 is measured by an oscilloscope. The voltage DC output is plotted versus the duty cycles of VCTRL which indicates that there is a monotonic increase of the DC output voltage versus the duty cycle. Similar to a regular DC to DC boost converter, the duty cycle of VCTRL is able to regulate the DC output, as well as the power drawn into the receiving coil.

IV. CONCLUSIONS

A low-input-voltage wireless power transfer has been designed for powering medical implants. By synchronizing the switching signal with the induced voltage of the receiving coil, effective AC to DC rectification, voltage boosting and voltage/power regulation can be achieved. In the circuit also can be started up by a random, high-frequency clock instead of edge detector to further power consumption .The low-input-voltage wireless power transfer could lead to a miniaturized power harvesting device that can be widely embedded with various implants. Also the proposed real-time automatic MC system improve transfer co-efficient in the range of 10–16-cm coil separation distance automatically in about very short duration in ms range.

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