On-chip RF to DC Power Converter for Bio-Medical Application

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***Abstract*— Wireless power transfer is one of the major challenges in for bio-medical implant. The motivation of this work is to integrate the complete power converter on-chip, eliminating the large off-chip inductors generally used in RF energy harvesting circuits.This paper presents a new architecture of a RF to DC rectifier along with a switched capacitor based DC to DC converter with improved performance over a large range of input power. The post-layout simulation shows an efficiency of 18.5% at input power of 2 dBm. The dimension of the chip is 0.6 mm x 0.26 mm in CMOS 65 nm technology.**

***Keywords* :- Bio-medical implant, RF to DC rectifier, DC to DC conversion, self oscillating switched capacitor (SOSC).**

I. Introduction

Bio-medical implants consist of a electronic circuitry going inside the body which tracks the medical condition of the patient remotely [1]. Power transfer is one of the main challenges for the bio-medical implant design [2]. The bio-medical implants can be powered using implanted battery which limits the lifespan of the implant. Using wireless powering technique gives an advantage of perpetual operation of the implants along with reduction in its size. The block diagram of the RF wireless powering link is as shown in Fig. 1. The architectures discussed in the literature use the off-chip matching components for the rectifier circuitry and a large input inductor for the DC to DC converters. In this paper we present a fully integrated RF to DC power converter operating from 1 mW of RF power (typical power requirement bio-medical circuitry [3]).

II. Proposed RF to DC Rectifier

The circuit diagram for voltage doubler based and cross-coupled RF to DC rectifier is as shown in Fig. 2. Voltage doubler circuit needs minimum input voltage equal to threshold voltage of MOS to effectively transfer charge from input to output. Cross coupled circuit has issue of reverse leakage as soon as the output of circuit crosses threshold of the MOS [4]. The proposed architecture as shown in Fig. 3 prevents the reverse leakage by modifying the dc level of the gate of the rectifying device. Hence a circuit can be designed which can dynamically vary the DC biasing of the gate of the rectifying devices. With help of this circuit, the issue of reverse leakage is solved. Whenever the output dc voltage is less than the threshold voltage of the transistors, the reverse leakage control (RLC) circuit produces a set of DC bias values which makes the topology similar to that of cross-coupled circuit. As the output moves beyond the threshold voltage, DC bias generated turns the topology to conventional voltage doubler circuit. The RLC circuit is shown in Fig. 4.

Fig. 1: Block diagram of RF powering link

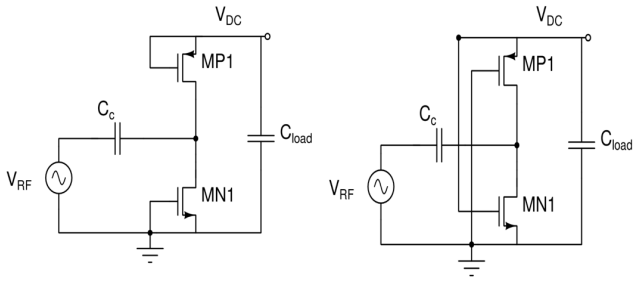

Fig. 2: RF to DC rectifier topologies voltage doubler(left) and cross-coupled (right)

Table I summarizes the operation of the RLC circuit. The circuit uses minimum power as it charges the capacitors with reverse leakage current. In Fig. 4, When the output of the rectifier VDC is less than the threshold voltage of the device, MN1 is turned off and the reverse leakage current through MP1 charges S_n node to V_{DC}. MN2 is partially turned on discharging the node S_p. Here MN1 is High V_t device while MN2 is a low V_t device. On the other hand, when output of rectifier is greater than the threshold voltage of the device, MN1 is turned on discharging node S_n. MN2 is turned off and node S_p charges to V_{DC}. The RLC circuit morphs the rectifier topology from cross-coupled to voltage doubler based V_{DC}. The obtained performance (Power conversion efficiency v/s input power) of this proposed circuit is as shown in Fig. 5. As compared to voltage doubler and cross-coupled topologies, performance is improved for larger range of input power. The typical efficiency characteristics of a rectifier is hill shaped and the output voltage at the maximum efficiency point of the rectifier may not be sufficient to drive the CMOS circuitry of the bio-medical implant. Hence a DC to DC boost converter is used to convert the optimal converted DC power to suitable higher voltage level.

TABLE I: Working of RLC circuit

Output Voltage (V_{DC})	S_n	S_p	**Topology**
$V_{DC} < V_{th}$	V_{DC}	0	Cross-coupled
$V_{DC} > V_{th}$	0	V_{DC}	Voltage doubler

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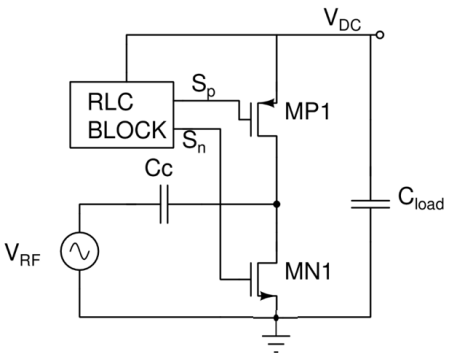

Fig. 3: Proposed RF to DC rectifier

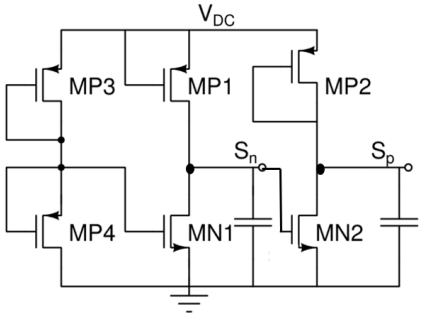

Fig. 4: Reverse Leakage Control circuit

III. Self Oscillating DC to DC Boost Converter

The different types of boost converter such as LC based, switched capacitor based have their own characteristics. LC boost converter has better efficiency as compared to the switched capacitor converter. When on-chip integration is considered, switched capacitor based converter has an edge. The self oscillating switched capacitor (SOSC) DC to DC boost converter eliminates the overhead of the clock generation and the level shifter as required by the switched capacitor based topologies with nearly same efficiency. Fig. 4 shows the schematic of SOSC DC to DC converter [5]. It consists of two stacked ring oscillator. In each stage either

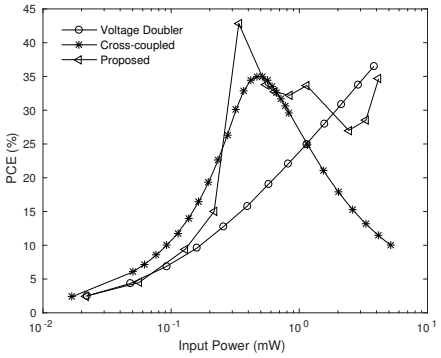

Fig. 5: Results - PCE v/s Pin for different architectures

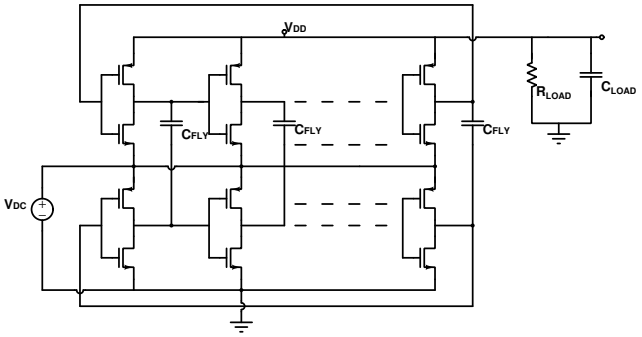

Fig. 6: Self Oscillating Switched Capacitor DC to DC Converter

the top or bottom inverter charges the flying capacitor. This self oscillating structure does not need any kind of external clock for operation as they generate their own clock. The architecture is also able of self start-up regardless of its initial state. As soon as V_{DC} is applied to the circuit, both the inverter chain starts to oscillate. For every stacked inverter cell, charge is transferred to load resistor and load capacitor from input source in one phase and stored on flying capacitor in other phase. The value of oscillation frequency is decided by the input impedance which DC to DC converter has to offer to the rectifier.

IV. Post Layout Results

Simulation result for the overall efficiency of the RF to DC converter system over a certain power range across process corners and temperature is 18.5%. On chip LC leg impedance matching network is used to match RF input source to the rectifier circuit. To improve efficiency, custom designed antenna having input impedance as large as 600Ω can be used. This will further reduce the value of on-chip matching inductor required improving the quality factor. This reduces the loss in matching network improving the overall efficiency of the converter.

V. Conclusion

In this work, an on-chip RF to DC power converter is designed for implantable bio-medical devices. A switched capacitor DC-DC converter is used to address issue of large off-chip inductor. To improve efficiency over the range of input received power, an improved rectifier has been implemented eliminating reverse leakage associated with cross-coupled topology. The post layout simulation shows overall efficiency of 18.5% at 2 dBm of input power.

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