Developing Efficient RF-DC Converter using Switch-Only Rectifier for Biomedical Applications

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***Abstract*— The implanted biomedical devices require very efficient RF-DC rectified signal, which provides the essential DC voltage, delivered to the implanted device. In this paper, a switch-only rectifier based on CMOS switch controlled by a timing control circuit is used to improve the rectified signal. This rectifier is used instead of the conventional rectifiers such as Full-bridge rectifier, voltage doublers and active rectifiers. The switch- only rectifier may be used to improve the possibility of extracting the power from implanted received coil. The simulation shows that the power output by the Switch-only rectifier is exactly twice than that the output obtained by using the voltage doublers and this give the system more efficient.**

Keywords— RF-DC Converters; implanted devices; rectifiers; inductive coupling link;

I. INTRODUCTION

The rectifiers are very important element in biomedical devise, which used to rectify the RF signal of the implanted coil. This rectified signal should be with minimum drop voltage, minimum rejection ripple voltage and keep the signal as much as possible stable and constant. On other hand to be capable of supporting high voltage typically induced at the receiver coil in the implanted device. Therefore, major challenges are need to integrate the rectifier at a standard CMOS technology used in biomedical applications. The main limitation of the voltage doublers and the full-bridge rectifier is that, most of the charge available from the received coil does not go into the output at high voltages. The charging and discharging of the capacitor, which connected to the received coil is limits the maximum power that can be extracted, taking into consideration that this capacitor is very important for the resonance tuning between the two coils.

There are many methods to conserve power and reduce the interference on nearby electronics by choosing the suitable modulation and suitable design of the modulator and demodulator. However, still there are many drawbacks with the communication systems of the existing designed and developed devices. There are a lot of revew papers [1] and research articales produced by many researchers in the field of wireless low power electronics, such as optical biomedical sensing [2], cochlear implants [3] biomedical wireless sensor networks [4], intelligent biomedical devices [5] and body sensors [6].

In this paper, our aim is to increase the implanted devices efficiency, by reducing the power consumption of the power recovery circuits. The switch-only rectifier will be used instead of full wave rectifier and doubler voltage rectifier. This technique is a good method to improve the power output from the received coil where the output power will be exactly twice that obtained by using the voltage doublers and full-wave rectifiers.

II. THEORETICAL BACKGROUND

One of the main challenges in biomedical devises is the rectifiers due to its voltage dropping and ripple voltage at the output signal. Therefore, very efficient RF signal rectifier is required in circuit design for biomedical applications, which provides a stable DC voltage for implanted devices and sensors with minimum power consumptions. Theoretically, there are many types of rectifiers such as bridge rectifier, voltage doublers, shottky diode rectifier, and active rectifiers. Each one of these rectifiers has its own drawback such as consume power, slow response time and large size. The main rectifiers used in RFID for wireless power transmission system for biomedical applications is the full wave rectifiers and the doubler voltage rectifiers, these rectifiers convert the AC output of the received coil into a DC voltage to powered the implant electronic circuits.

The classic bridge rectifier without voltage doubling is a full-wave rectifier involves four diodes and one stabilizer capacitor, the main disadvantage for this structure it lacks the voltage-doubling effect. During the negative phase, the bridge diodes reverse the coil direction with respect to the load. The secondary dissipation is the power drain in R_{DC} and the diodes as insulated in (1)

$$P = P_{R_{DC}} + P_{diode1} + P_{diode2} + P_{diode3} + P_{diode4} \quad (1)$$

The second full wave rectifier is with a voltage doubling, this structure involves of two diodes and tow stabilizer capacitors. The stabilizer capacitors are connected in series and the DC current (I_{DC}) flows simultaneously through both of them. The rectified DC voltage is twice the amplitude of the rectifier input, minus two diode drops V_{diode}. The secondary power dissipation is the power drain in the resistor $R_{DC.}$ Plus the dissipation in both rectifier diodes as given in (2)

$$P = P_{R_{DC}} + P_{diode1} + P_{diode2} \quad (2)$$

A. Implant electronic circuit

In most implantable microelectronic devices (IMD) and radio frequency identification (RFID), the power transmits via a pair of resonant inductive coupling link. For example, for implanted micro-system the transmitted coil is fixed outside the body and the received coil is mounted inside the body. The transmitted coil produces electromagnetic wave, which linked with the received resulting indicated voltage at the implanted side. This RF signal rectified from RF-DC voltage by efficient rectifier. Fig. 1 shows the bio-implanted micro-system where, the first block after the receiver coil is the waveform rectifier which converts the RF signal into DC voltage, which provides the essential DC voltage for the implanted part [7, 8].

A variety of rectifier circuits have been proposed and developed over previous years such as full-wave rectifier, a half-wave rectifier and doubler rectifier with self-threshold cancellation [9-11]. In this work, the switch only rectifier, which is used in piezoelectric energy harvesting [12], is proposed to be used in biomedical applications and portable devices where the output voltages is doubled twice than the conventional rectifiers.

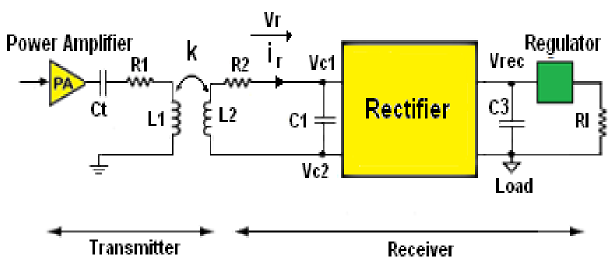


Fig. 1. Simplified block diagram for wireless power via an inductive link for bio-implanted micro-system

B. Full-Bridge Rectifier and voltage doubler

In general the full-bridge rectifiers [13, 14] and voltage doublers [15, 16] are wildly used as rectifier circuits to convert the AC output of the implanted receiver coil into a DC voltage. One of the disadvantages of this technique is that sensitive to time responses (charge time), and the power drops down according to communication distance and load circuit. The typical implementation of above rectifiers circuits are designed using MATLB/SIMULINK as shown in Fig. 2 (a) and (b), respectively. The capacitor C_3 used as a filter to smooth the output DC ripple, and is assumed to be large compared at C_1 for the received coil, and then holds the voltage at the output of the rectifier essentially constant on a cycle-to-cycle basis.

The main disadvantage of the using the full-wave rectifier and doubler voltage rectifier in the implantable devices is that most of the charge available in C_1 does not go into the output at high voltage. Due to charging and discharging of C_1 there is a losses and this limited the maximum power that can be powered the implanted devices and this will be explain as follow, The output power of the full-bridge rectifier (3)

$$P_{rect} = 4C_1 V_{rect} f_r (V_r - V_{rect} - 2V_D) \quad (3)$$

where P_{rect} represents the power rectifier, V_{rect} is the voltage rectifier, V_r is the receiver voltage, C_1 represents the capacitor connected to the receiver, f_r is the operated frequency, which is indicated on the received coil and V_D is the voltage drop across the non-idealities of the diodes when the current from the receiver coil flows through it. The output voltage from the received coil can be observed in (4)

$$V = \frac{I_r}{\omega_r C_{1r}} \quad (4)$$

The full-bridge rectifier offers maximum power as follows

$$P_{\max} = C_1 (V_r - 2V_D)^2 f_r \quad (5)$$

The situation given in (5) can be realized at condition

$$V_{rect} = \frac{V_r}{2 - V_D} \quad (6)$$

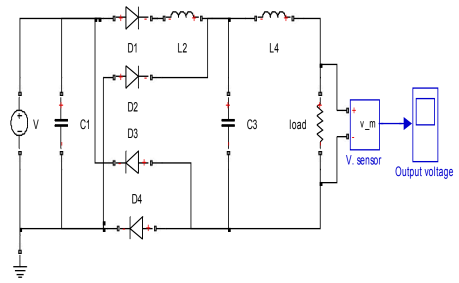
The current flows into the voltage doubler output does not occur every half-cycle. The output power from the voltage doubler rectifier can be calculated as fellow

$$P_{rect} = C_1 V_{rect} f_r (2V_r - V_{rect} - 2V_D) \quad (7)$$

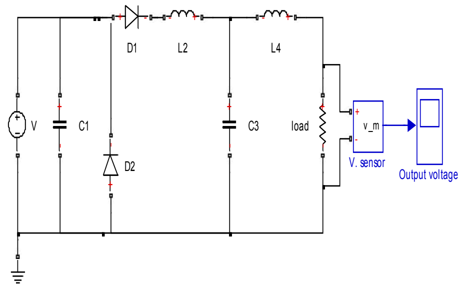
The maximum power (P_{max}) for the voltage doublers rectifier can be achieved when V_{rect}=V_r-V_D then

$$P_{\max} = C_1 (V_r - V_D)^2 f_r \quad (8)$$

The typical implementation of these rectifiers is shown in Fig. 2 (a) and (b). To improve the extraction capabilities from secondary receiver, the switch–only rectifier will be presented in section III.



(a)



(b)

Fig. 2. Circuit diagram (a) A full-bridge rectifier and (b) voltage doublers

III. PROPOSED SWITCH-ONLY RECTIFIRE PERFORMANCE

Figure 2 (a) and (b) shows the full-bridge rectifier and voltage doubler rectifier circuits, both provide the same amount of maximum output power. However, the voltage doubler supplies current to the output only during the positive half-cycle of current i_r. Whereas, during the negative half-cycle, the parallel diode D_2 helps in pre discharging the capacitor C_1. This way during the positive half cycle, i_r only needs to do half the work to charge up C_1 to V_{rect} before it can flow into the rectifier output. To overcome this surveillance, the design of the switch-only rectifier is a good and suitable choice due its simplest (only one active device) and supplies power to the implanted devices twice higher than conventional rectifiers.

The design of switch-only rectifier is shown in Fig. 3 where a simple switch NMOST (S_1) is connected across the output of the received coil (secondary coil) controlled with timing control circuit. Assume that the transistor switch S_1 is turned ON for a brief time at every zero crossing of the secondary received current. When the switch is ON, it discharges the capacitor C_1. Once C_1 has been discharged, the switch S_1 is turned OFF. This operation makes the rectifier to conduct during both the half-cycles of the input current. Figure 4 shows the input signal and the rectified output waveform signal for the full wave rectifier and doubler rectifier. Fig. 5 shows the voltage and current waveforms for the full rectifier, doubler rectifier and switch-only rectifier, respectively. The explanation of the switch-only rectifier operation is as follows; at every half-cycle, when i_r changes of the direction wave, the switch S_1 is turned ON briefly to discharge the voltage across the capacitor C_1. Now, the secondary current only has to charge up from [0 *to* $\pm (V_{rect}+2V_D)$] before it can flow into the output. The switch-only rectifier combines the advantages of full-bridge rectifier and the voltage doubler rectifier by conducting current in both the half-cycles as in a full-bridge rectifier while charging the capacitor C_1 up from only 0 *to* $\pm (V_{rect}+2V_D)$ every half-cycle similar to that in a voltage doubler. Equation (9) explains the power delivered to the output by the switch-only rectifier.

$$P_{rect} = 2C_1 V_{rect} f_r \left(2V_r - V_{rect} - 2V_D\right) \quad (9)$$

The maximum power (P_{max}) can be achieved at condition $V_{rect}=V_r-V_D$ then

$$P_{\max} = 2C_1\left(V_r - V_D\right)^2 f_r \quad (10)$$

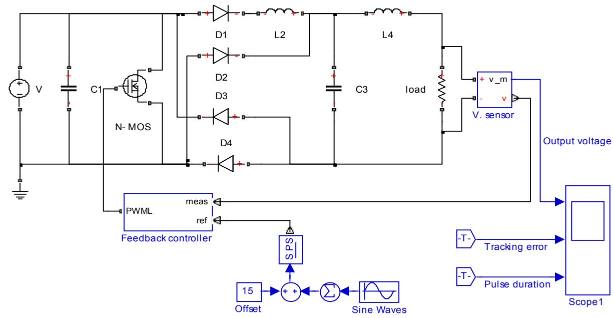


Fig. 3. A developed switch-only rectifier circuit

IV. DISCUSSIONS AND SIMULATION RESULTS

The design of the implanted biomedical devices has many limitations such as power consumption, data rate transmission, size and feasibility. The development for each part of electro-circuit design helps to improve the overall device efficiency. One of the main challenges in design implanted is the rectifiers, which usually integrated off-chip. The function of the rectifier is to convert the RF signal to DC signal, this RF signal in biomedical applications should be converted to DC signal with minimum power loss and with maximum output voltage due to sensitive of the bio-medical implanted devices. As given in section II, there are several types of rectifiers.

In this study, we investigated two types of rectifiers, the full-wave and voltage doubler rectifiers, and then we proposed the switch only rectifier based on smooth and fast N-MOS switch, which is a good solution to be used in the implanted devices. Figure 6 shows the power output and the performance of the conventional rectifiers comparing with the switch-only rectifier. We assumed that the received voltage on the coil L_2 is 5 V, then this voltage rectified by the rectifiers to produce approximately 4 V, which is meet many of implanted devices requirements such as implanted micro-system. The output power obtained by the switch only rectifier has better performance than others rectifiers.

From the comparison among (5, 8 and 10), it is very clear that the maximum rectified power $P_{rect.max}$ for the switch–only rectifier is exactly twice that obtained by using the voltage doubler and full-rectifier. In addition, this gives the biomedical implanted devices more efficient.

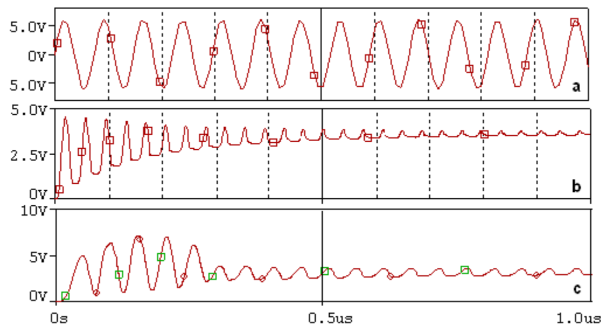


Fig. 4. (a) The input signal (b) full wave rectifier output waveform signal (c) the doubler rectifier output waveform signal

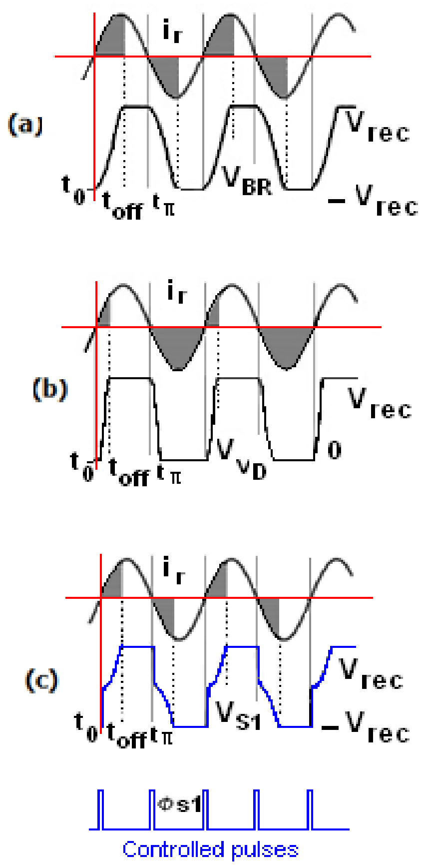


Fig. 5. The output voltage for three methods (a) full-bridge rectifier and (b) voltage doubler (c) switch-only rectifier circuit with controlled pulses

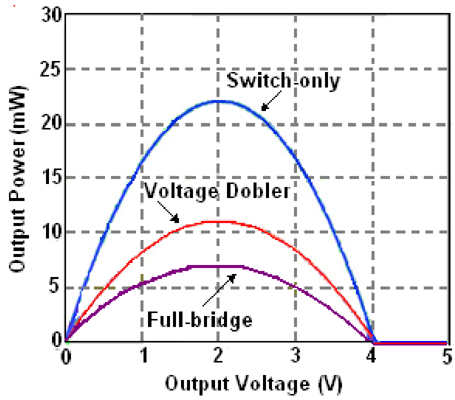


Fig. 6. Comparison among full-bridge rectifier, voltage doubler and switch-only rectifier output power

V. CONCLUSSION

Biomedical implanted devices Efficient are very important challenge in medical field. The RC-DC converter, which is located inside the human body play important rule to supplies power to the implantable devices. Most of the implantable devices used the full-wave rectifier, voltage doubler, schottky diode and active rectifiers. In this paper the switch-only rectifier is presented and used to powered the implanted devices, and achieve output power exactly twice that obtained by using the voltage-doubler and full-wave rectifier and this give the biomedical devices and portable devices more efficiency.

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