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Power Management Circuit for Semi-Passive UHF RFID Transponder

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***Abstract*—This work develops a power management system that switches between RF rectified power and internal battery to power RFID transponder operating at ultra-high frequency band (860-915 MHz), with operating voltage of 1.8V circuit. The proposed design employs a single stage full wave rectifier, 4-stage Dickson charge pump and a novel switching circuit. The power management unit is able to sustain the operation of 1.82V, 15uA at 120KΩ load. This is comparable with the performances of previously published works, but with less transistor counts due to the efficient design.**

Keywords—RFID, power management unit, semi-passive.

I. INTRODUCTION

Current semi-passive tag in the market operates such that the on-board power supply (battery) provides energy to the tag for its operation. For data transmit, semi-active tag uses the reader's emitted power. The combination of battery and induced reader's power enable semi-passive tag to have the best characteristics of both active and passive transponders, however it requires complex power management system in order to generate sufficient current (at least 15uA) to voltage regulator (2V) to sustain the RFID tag full operations. The previous works mostly employ multistage rectifier, as much as 16-stages [1], and one work employed Schottky diode in the threshold detector for the power switching circuit [2]. Che *et al.* [3]-[4] implemented highly efficient charge pump and low power wake-up circuit, where the latter controls the power switch for the tag core. The wake up mode is designed to be power sensitive, where it will be waked-up only when it is located in the interrogating field. Najafi *et al.* [5] used elaborated clock gating and operand isolation techniques.

Based on the literature survey, there are plenty of innovative designs on the RF rectifier, power management (switching) system and overall power consumption, however, these advances need many additional components i.e. transistors, capacitors, and diodes, which will increase the die size of the RFID tag. As it is, the analog portion of the RFID tag can easily takes up 40 to 50% of the die size. Therefore, the objective of this paper is to reduce the component count of the semi-passive RF power management system, but at the same time, is able to deliver 1.8V at a minimum of 15uA for the RFID tag operation. The details are provided in subsequent sections.

II. CIRCUIT ARCHITECTURE

Figure 1 illustrates the high-level block diagram of the semi-passive RFID tag. It consists of antenna, semi-passive power management system (in light blue box), demodulator, modulator, controller, and read only memory (ROM). The semi-passive power management block is the focus of this paper. The proposed design employs a single stage full wave rectifier, 4-stage Dickson charge pump, battery charger and switching circuit, and voltage regulator.

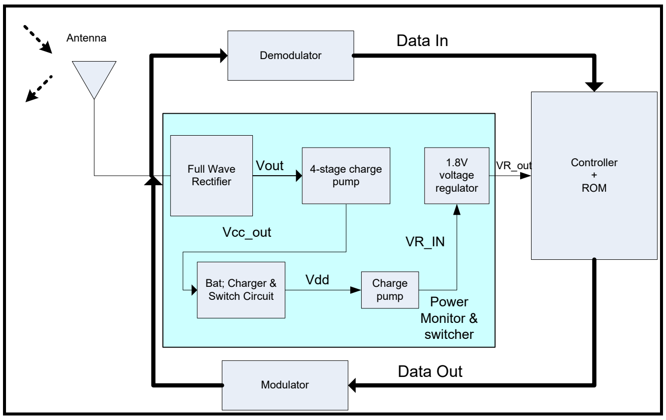

Fig. 1 Top level block diagram

The theory of operation is as follow: when transponder detects emitted power from the antenna, other than power on internal circuit and supply to data transmission, it will rectify the signal and charges it to the internal battery using the 4-stage Dickson charge pump. When the switching circuit detects no emitted power, it will trigger battery to power the transponder. In both scenarios, voltage regulator is used to provide constant 1.8V output. This mechanism helps preserve battery life while maintain semi-passive RFID tag's fast response time advantages. The operations of the key modules are explained in the sub-sections.

A. Rectifier

The full wave rectifier is used to rectify the RF signal made of ac components from the antenna, before passing it to the charge pump. The circuit comprises a full wave rectifier formed by two NMOS and 2 PMOS. The PIN diodes are used for ESD protection. The detailed operation is referred to [6].

B. Charge Pump

In order to pump up voltage level of RF rectifier output, which is less than 1V, a Dickson charge pump is employed. The equation for Dickson Charge pump is given as:

$$V_{OUT} = NV_{\phi} + V_{in} - (N+1)V_D \quad (1)$$

Where V_{in} is equal to input voltage of the charge pump, V_D is the MOSFET's threshold voltage and is a function of the source voltage and will gradually increase as the charge pump is ramping up. Even though the zero bias Vt is close to 0.69V, the actual Vt in the last few stages of the pump will rise close to 1.8V or higher. Assuming N=4, V_ϕ = 3V (battery source), V_{in} = 0.8V (from RF rectifier), V_D = 0.7V (assume zero bias first). V_{OUT} of the charge pump is equal to 9.3V, which is sufficient to regulate 1.8V for the operation of the RFID tag. The initial pump frequency is set at 25 MHz, and C is 200 pF. We used a gate width of 400×l and a gate length of 2×l where l is equal to 0.12u. Based on all the described parameters, the 2 four-stage charge pump were designed to pump up RF rectifier voltage output V_{OUT} and pump up battery switching (charging) circuit source voltage level V_{dd}, respectively.

C. Power Management Circuit

The circuit of Figure 2 is the power management circuit, and is the new contribution out of this paper. This circuit requires an oscillator to operate continuously from Vbatt.

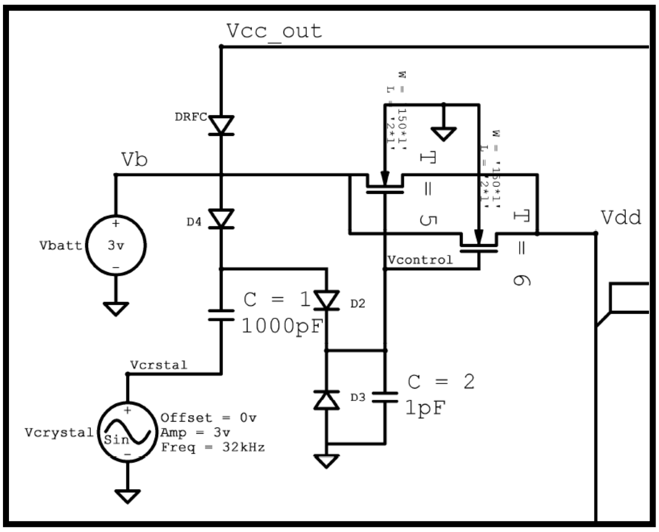

Fig. 2 Power management circuit

When the reader is ON, as long as the voltage coming from the dipole antenna is large enough, the battery Vbatt is charged through diode DRFC and the RFID IC load gets its power mostly from the reader as desired.

When the reader is OFF and the battery Vbatt is charged up, transistors T5 and T6 turns on. This provides Vdd power to the CMOS tag protocol and permits data logging functions. In this case transistor T5 is turned on because the oscillator drives a voltage doublers circuit (C1, D2, C2, and D4), causing Vcontrol to increase to a high enough level to turn on T5 and T6. The oscillator serves as charge pump signal to double the voltage from battery (DC source). The oscillator signal is not required when the power comes from RF, as RF itself is an oscillating source. Diode D4 is required to charge C1 during the half cycle. Diode D3 is reversed-biased and it only serves to discharge C2 when the oscillator stops and force transistor T5 into cutoff.

When the battery is removed and the reader is ON, transistors T5 and T6 will not turn on. When the reader is OFF, and the battery Vbatt is powering the oscillator, voltage is doubling Vcontrol from the combination of C1, D2, and C2, which turns on transistors T5 and T6. Diode D3 acts only as a very large resistance bleeder to discharge C2 when the oscillator stops. When the oscillator stops oscillating (with no battery voltage), Vcontrol is pulled up through diode D4, and transistor T5 and T6 is turned off.

D. Voltage regulator

A voltage regulator design is employed using op-amp to provide an output of 1.8V. Figure 3 shows the Vref circuit, which is adopted from [7].

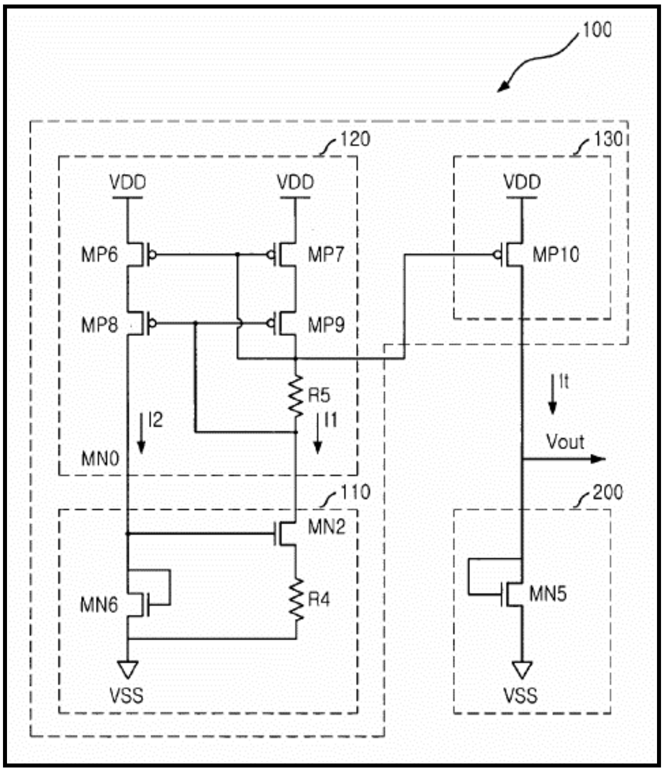

Fig. 3 Schematic of fixed voltage regulator [7]

The fixed Vref voltage circuit it is formed by a temperature and input voltage independent MOS circuit. Part 100 is the temperature-compensated current generating circuit for reducing a supply current It (current through drain MP10 to Vout) provided to an output terminal in response to an increase of temperature, and a diode 200 receiving the supply current It thought the output terminal Vout. The reference voltage generator constructed as above outputs a constant reference voltage Vout regardless of a change in temperature and input voltage. The diode 200 is configured with a NMOS transistor MN0 having a gate connected to one terminal thereof. The diode 200 receives the supply current It thought one terminal and transfers it to a ground terminal Vss connected to the other terminal.

III. Simulation Results

With extraction of layout SPICE model, the following three scenarios were simulated.

A. Constant RF Incoming Signal to Tag

The first scenario is depicting the situation when the transponder is receiving constant RF incoming signals at 1V 910MHz, PSK-modulated. Figure 4 shows the simulation of battery power charging and discharging, which is depending on 32MHz oscillator. When there is a signal coming from the RFID reader, it is rectified to generated 0.881 V (the output is denoted as Vdd) and subsequently passes through charge pump circuit (the output is denoted as Vcc_out pump) to increase the voltage up to 3V. This voltage is used to charge up the battery and providing power to tag controller and memory operation. The battery is charged at max 12.4W and is discharges at 1.18mW when the current supply reaches 4mA from RF signal.

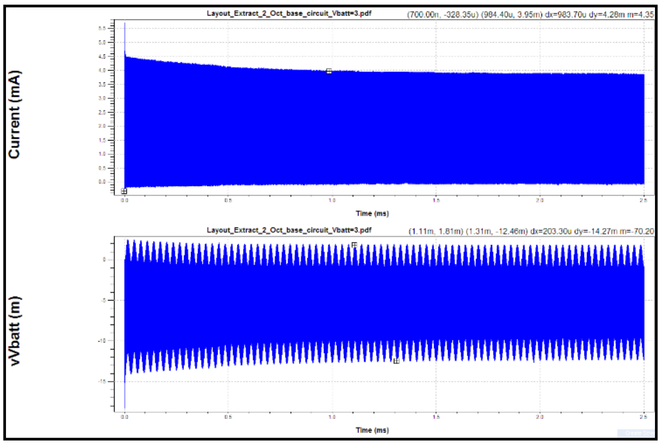

Fig. 4 Simulation of Scenario A.

B. No incoming RF signal, battery operation

As incoming signal equal to 0V, battery management circuit starts to take over. As shown in Figure 5, the measured Vbatt output max is 1.92mW, with an average power of 0.5mW. The Vdd output of battery management circuit reads 2.06V. Based on these data, we can derive the RFID tag circuit power consumption as follow: 1.82V output voltage multiples by 15uA = 27.3uW load; Therefore the circuit power consumption = 0.5mW -27.3uW = 0.47mW.

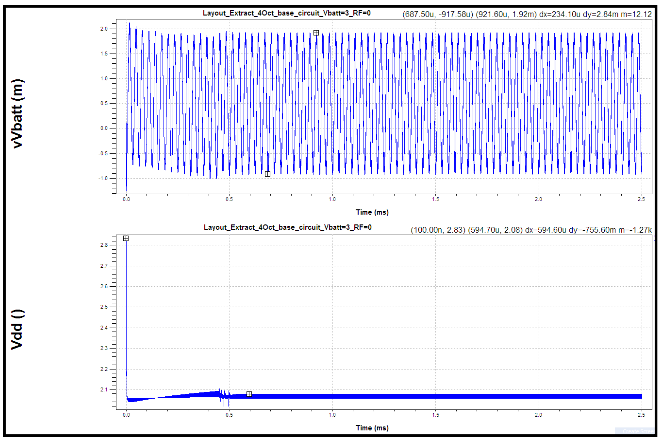

Fig. 5 Simulation of Scenario B.

C. Switching from RF signal to battery

The most important test for the proposed system is when the RF signal suddenly stops. In this case, the system needs to immediately switch to battery. This situation is demonstrated in Figure 6. To simulate this situation, RF signal is turned off at 0.8ms gradually step down to zero at 1.3ms. Hence Vout of RF rectifier steps down from 0.8V to 0V. As shown in Figure 6, during the step down of Vout, Vdd fluctuates 2.0V to 2.1V and VR_IN (the charge pump output of Vdd battery management system output) has sudden step down to correspond to the change of Vout. VR_OUT however still regulate steadily at 1.82V.

IV. ANALYSIS

The simulation results from section III demonstrate that the proposed system is performing as expected, that is to sustain the output voltage of 1.82V and to provide a continuous current of 15uA to the RFID.

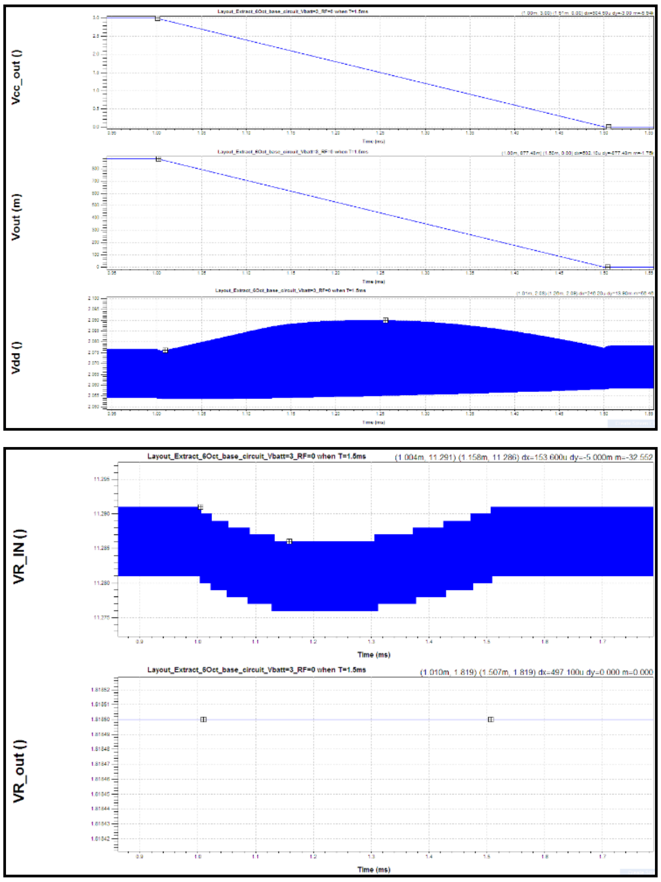

Fig. 6 Simulation of Scenario C

The voltage regulator performs well at 1.8V. There is no significant voltage drop when operating in either cases of battery or RF incoming source. Most importantly, even when the power source is switched from one to another, the output is not affected.

However, the circuit is not without a weakness. In comparison to 180mV RF input voltage design from [1], this design is only able to take the minimum input of 500mV peak to peak. The limitation is because there is a voltage drop across each MOSFET, whereas [1] compensated by using 16-stage rectifier. The former however required more components count: 32 transistors and 32 capacitors as opposed to 8 transistor, 4 capacitors and 2 diodes for both RF rectifier and Dickson charge pump circuit.

For battery management circuit and output voltage/current performance, the proposed design performs on par with [2]. Their design shows their battery switching circuit required 15 transistors, 3 capacitors and 1 diode in order to deliver 2 V and 15 uA. This design achieves 1.8 V and 15 uA with 6 transistors, 4 capacitors and 4 diodes.

Another critical comparison is the power consumption. For this design, the power consumption is equal to 0.47mW. This is relative high as compare to [5], but the latter employed very complex power optimization techniques such as clock gating and operand isolation to achieve 0.22 mW.

One of the major issues with the proposed design is the oscillator that is used in the power switching circuit. The high and low oscillation is turning on and off the gate transistors T5 and T6. This means that at any single clock cycle, only half of the cycle pass through the transistors, and another half of the cycle of the power was wasted. Another major drawback of the design is due to the implementation of a single stage of rectifier, some of the power is wasted due to lower efficiency of the RF to DC rectification. Table 1 shows the summary of the performance comparison with previous works.

TABLE I: COMPARISON WITH OTHER WORKS

Parameters	**Previous works**	**This work**
RF rectifier circuit	32 transistors and 32 capacitors [1]	8 transistors, 4 capacitors, 2 diodes
Battery management circuit	15 transistors, 3 capacitors, and 1 diode [2]	6 transistors, 4 capacitors, 4 diodes
Capability of handle input voltage	As low as 180 mV [1]	500 mV
Output voltage	2V [2]	1.82V
Output current	15 uA [2]	15.16 uA
Power consumption	0.22 mW [5]	0.47 mW

V. CONCLUSION

This paper proposes a power management circuit for a semi-passive UHF RFID transponder. The main contribution is in the reduction of transistor and capacitor counts as shown in Table I, while retaining the same performances as cognate circuits that have been published in literature. This next generation power management unit will be needed for future RFID systems [8]-[9], in particular when it is integrated with micro-sensors [10].

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