

A Novel Low-Power Input-Independent MOS AC/DC Charge Pump

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Abstract: This paper presents a novel fully integrated MOS AC to DC charge pump with low power dissipation and stable output for RFID applications. To improve the input sensitivity, we replaced Schottky-diodes in conventional charge pumps with MOS diodes with zero threshold, which has less process defects and is thus more compatible with other circuits. The charge pump in a RFID transponder is implemented in a 0.35 μ m CMOS technology with 0.24 sq mm die size. The analytical model of the charge pump and the simulation results are presented.

Index Terms—AC/DC, charge pump, radio-frequency identification (RFID), low-power CMOS.

I. INTRODUCTION

A charge pump, also called voltage multiplier, converts received AC or DC input voltage to a stable DC output voltage. Depending on the type of inputs, the charge pump can be classified as AC/DC type or DC/DC type. Due to its simple structure and good conversion performance, charge pump circuits have been widely used in EEPROM, Flash memories, Radio Frequency Identification (RFID) and many other applications [1].

Typical AC/DC charge pump circuit used in RFID is comprised of a capacitor-diode network [1][2][3], as shown in Fig.1. In order to increase output voltage and conversion efficiency, Schottky diodes are generally used for its low conduction resistance and low junction capacitance. However, the particularity of manufacturing processes for Schottky diodes and the inconsistency in quality between different product batches often make the integration of Schottky charge pump incompatible with standard CMOS circuits and thus limit its applications.

This paper presents a novel AC-DC charge pump for RFID applications. Instead of using expensive Schottky diodes, the proposed charge pump employs MOSFET diodes with low or zero thresholds (V_{th}) that is compatible with standard CMOS

technologies. With a low-power output regulator, the proposed charge pump converts input radio frequency (RF) signal power into DC voltage with high conversion efficiency and input-independence.

In section II, the novel charge pump circuit is analyzed in detail. The simulation results and layout of charge pump chip design are presented in section III and IV, respectively. Finally, section V gives the summarized conclusion.

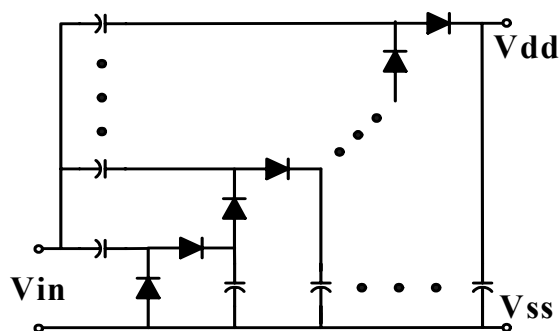


Fig. 1 Conventional Schottky-diode AC/DC charge pump

II. ANALYTICAL MODEL OF THE AC-DC CHARGE PUMP

The presented charge pump mainly consists of two blocks, a basic MOS charge pump and a low power regulator, which are connected in series. The former is to realize the AC/DC energy conversion with high efficiency and the latter is to stabilize output DC voltage with low power dissipation.

A. Basic MOS Charge Pump

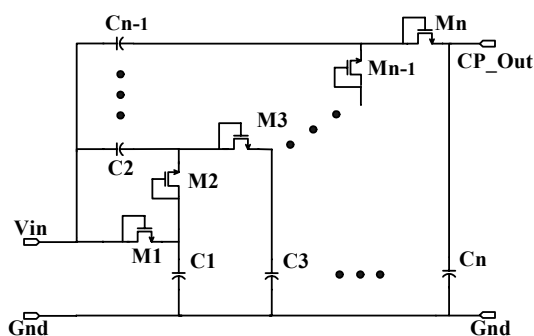


Fig. 2 Schematic of the simplified MOS charge pump

Fig. 2 shows an odd AC/DC charge pump which utilizes ultra-low V_{th} NMOS FETs connected as diodes. Analyzing the initial Unit Voltage Multiplying Cell (UVMC) shown in Fig. 3, multiplying capacitor C_{n-1} and C_n can look like a pair of

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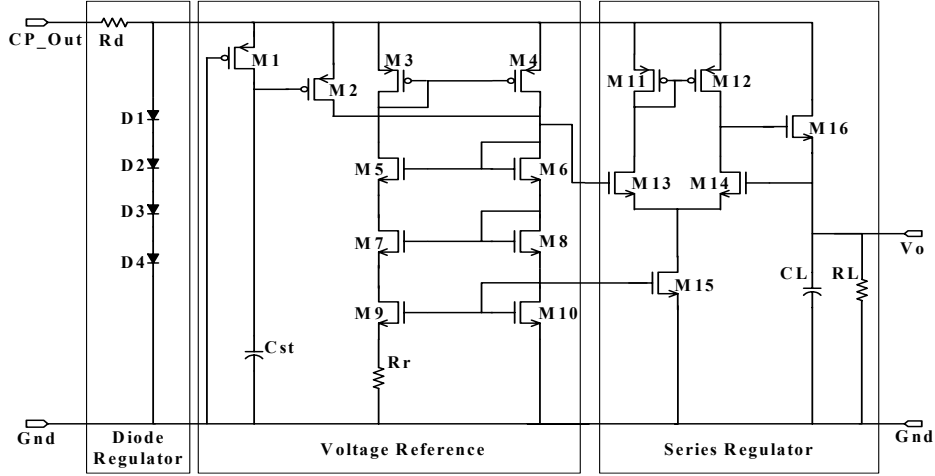


Fig. 5 Complete schematic of the low-power regulator

It is evident that $P_{nmos,loss}$ is smallest and η is largest when

$$R_c = \frac{1}{\omega C_p}. \quad (10)$$

In saturation region,

$$R_c = \frac{1}{g_m} = \frac{V_{gs} - V_{th}}{2I_o}. \quad (11)$$

Therefore, as shown in Fig. 4, there is a given output current I_o that corresponds to the largest conversion efficiency.

B. Low-Power Regulator For Charge Pump

Due to the variance between V_i , RF input signals with different power levels, modulation indexes and modes will generate quite different and even unstable output voltages through the charge pump, which is not desired for a steady DC supply in RFID transponder. For stabilizing output voltage, Fig. 5 presents a low power regulator that includes a diode regulator, a voltage reference and a series regulator.

The diode regulator simply utilizes four series diodes to provide an elementary regulating strategy, which only confines large output swing to a comparatively low but still apparent and unfavorable degree. For two following portions, such pre-regulation is necessary and makes them properly work in an appropriate and acceptable supply swing range to produce more precise and stable output.

To reduce power dissipation, the required high reference voltage, for example 1.5V, is directly generated through a β self-biasing voltage reference instead of the conventional way to accurately amplify a pre-generated low reference voltage. As shown in Fig. 5, M_5 — M_{10} build up triple cascode connection to increase output resistance and all operate in the subthreshold region for reduced power consumption. In

subthreshold region, the drain-source current [5] approximately is

$$I_{sds} = I_{do} \frac{W}{L} e^{q(V_{gs} - V_{th}) / (nkT)} \quad (12)$$

where

$$I_{do} = \mu_n C_{ox} \left(\frac{kT}{q} \right)^2 e^{1.8}. \quad (13)$$

If the W/L of M_9 is made Q times larger than that of M_{10} and both have the same L , V_{gs} of M_9 and M_{10} can be rewritten in terms of the current I_{sds} as

$$V_{gs10} = n \frac{kT}{q} \ln \left[\frac{I_{sds} \cdot L}{I_{do} \cdot W} \right] + V_{th} \quad (14)$$

and

$$V_{gs9} = n \frac{kT}{q} \ln \left[\frac{I_{sds} \cdot L}{I_{do} \cdot Q \cdot W} \right] + V_{th} \quad (15)$$

In addition, we have

$$V_{gs10} = V_{gs9} + IR_r \quad (16)$$

Solving for the subthreshold current I_{sds} using Eq. (12), (14) and (15), we have

$$I_{sds} = \frac{n \cdot kT}{qR_r} \ln Q \quad (17)$$

which is independent of DC supply source and is much smaller, only in the order of magnitude of several dozen nA, than the current operating in typical saturation region. With

such a constant and small current, the voltage on the drain of M_6 can be also stable and independent of power supply. Moreover, for minimizing the RF input power, since such reference is expected to work under a power supply as low as possible, the current mirror load M3—M4 utilize the low V_{th} PMOS FETs to reduce requisite V_{ds} voltage drops as well.

Series regulator simply utilizes a differential amplifier and a negative feedback NMOS FET to make the output fixed on the given reference voltage. In order to achieve low-dropout regulation and ensure that M16 operates in saturation region, the native transistor with nearly zero V_{th} same as the one in basic charge pump and greatly large W/L are employed.

By far, through the multiplying of basic charge pump and the regulating of low-power regulator, input RF signals are converted into a stable and input-independent output, which can be used as the power supply for passive RFID tag with good efficiency.

III. SIMULATION RESULTS

Fig. 6 shows the simulation result of output voltage of proposed charge pump with different input signals. Based on the practical design demands, the output needs to reach 1.5V with a 1Mohm load resistor. Our simulation shows that when input 900MHz RF power changes from -19.25dbm to 13.22dbm, the deviation of the output V_{out} from 1.5V is less than 15mV. In addition, with a -19.25dbm input power, the obtainable largest conversion efficiency is still 18.56%, which is higher than the reported result in [1]. These simulation results have indicated that the presented novel AC/DC charge pump is capable to provide efficient, stable and input-independent power supply for RFID transponder tags.

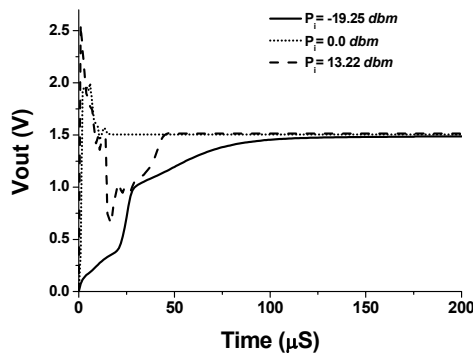


Fig. 6 Simulated output versus time for an MOS AC-DC charge pump

IV. IMPLEMENTATION OF THE CHARGE PUMP

We have implemented the proposed charge pump in a $0.35\mu\text{m}$ CMOS offered by Chartered Semiconductor. The chip layout of the low-power input-independent AC/DC MOS charge pump is shown in Fig. 7, which includes the different subcircuits such as basic charge pump, diode

regulator, voltage reference and series regulator. The size of whole chip is only $570\mu\text{m} \times 420\mu\text{m}$, which can be easily fitted into RFID transponder chips and other passive wireless chips. Meanwhile, it also provides good compatibility with various CMOS digital or analog integrated circuits.

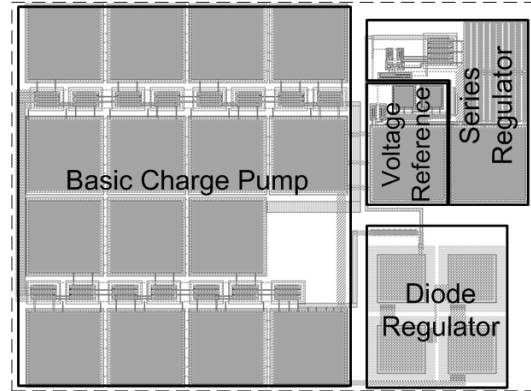


Fig. 7 Complete proposed layout of presented charge pump

V. CONCLUSION

A novel AC/DC charge pump implemented with MOS FETs has been presented for low power applications. Based on our theoretical analyses and circuit simulations, this charge pump circuit demonstrates the capability of generating a stable and input-independent DC voltage as the power supply for RFID tags.

Using more stable and compatible MOS FETs, this new charge pump structure eliminates the process defects existing in the conventional Schottky diode based charge pump. The proposed charge pump is hence more compatible with other CMOS circuits and can be used in many areas where a passive power supply is needed.

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