# A CMOS Complementary Bridge Rectifier for Driving RFID Transponder Chips

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In this paper, a CMOS complementary bridge rectifier for driving RFID transponder chips is presented. The proposed RFID CMOS complementary bridge rectifier is designed with two NMOSs at the input, which are configured by cross-connected gate structures, and two PMOSs and two NMOSs at the output, which are configured by diode-connected MOS structures. Output characteristics of the proposed rectifier are analyzed with the high frequency small-signal equivalent circuit and verified with SPICE for RFID operating frequencies of 13.56 ㎒ HF for ISO 18000-3, 915 ㎒ UHF for ISO 18000-6, and 2.45 ㎓ microwave for ISO 18000-4. Simulation results show well-rectified and high enough DC output voltages for driving the low power microchip in the RFID transponder for the frequency range from HF to microwave. DC output voltages are dropped by only around 0.7 V from the input peak-to-peak voltages.

*Keywords* : RFID, CMOS, Complementary, Bridge rectifier, UHF, Microwave

## 1. INTRODUCTION

In recent years, as the submicron CMOS technology is progressed, the field of CMOS application is enlarged to RF band in ㎓ and many commercial RF products are used in highly integrated RF CMOS communication systems. Especially, because of features of the high speed and the high integration, the RF CMOS technology becomes a most necessary technology for the implementation of single chip RF system ICs[1]. In addition, it is an essential technology in the field of Auto-ID system for the recent realization of ubiquitous environments[2,3].

Until now, there has been considerable interest in Auto-ID systems. Auto-ID systems have become commonplace in many manufacturing and service industries such as securities, purchasing and distribution logistics, material flow systems, and so on. Especially, the Radio Frequency Identification (RFID) system has been used mainly in Auto-ID applications, which is able to transfer the data and the power required for operating the transponder by the contactless technology[4-7].

The RFID system consists of RF tags (or transponders), RF tag readers (or transceivers), and host computers. The transponder, which represents the actual data carrying device of the RFID system, normally consists of a silicon-based microchip that stores data and a coupling element, such as a coiled antenna, used to communicate via radio frequency communication. The use of silicon-based microchips enables a wide range of functionality to be integrated into the transponder[8-10]. The passive transponder obtains all of their operating power from the interrogation signal of the reader and either reflect or load modulate the reader's signal for communication.

The transponder incorporates a rectifier circuit to convert the coupled AC continuous electro-magnetic carrier waveform to a DC voltage and to serve as a power supply for the rest part of the chip circuits. Therefore the rectifier is treated as one of essential parts of RF interface circuits in the RFID transponder[10].

In past few years, some rectifier structures for RFID transponders are published, which are made with Schottky diodes or NMOSs or PMOSs. However, they are not compatible with the current CMOS process, or rectified DC output voltages obtained by them are not high enough for driving the microchip in the transponder. Further more, in recent, various RFID systems operated at widely differing frequencies, ranging from 135 ㎑ longwave to 5.8 ㎓ microwave, have been developed for various applications. Therefore, the generic rectifier for supplying the well rectified and high enough DC output voltage has been required. And it is very important to implement the rectifier on a single chip using the same CMOS process with the microchip in the transponder for the realization of low price transponders.

In this paper, a CMOS complementary bridge rectifier for driving RFID transponder chips is proposed and analyzed theoretically with the high frequency small-signal equivalent circuit, which supplies the well rectified and high enough DC output voltage to microchips for the frequency range of 13.56 ㎒ HF(for ISO 18000-3), 915 ㎒ UHF(for ISO 18000-6), and 2.45 ㎓ microwave(for ISO 18000-4).

## 2. CMOS COMPLEMENTARY BRIDGE RECTIFIER CIRCUIT

One of the major challenges of the RFID rectifier is the implementation of the circuit with the current CMOS process. Because of the high speed and the low power dissipation features, the CMOS is commonly used on most integrated circuits. These features of CMOS are very suitable to design the microchip in the low power passive transponder of RFID systems. Therefore, it is essential for the rectifier circuit to be designed with CMOS for minimizing the power dissipation of elements and for implementing the single chip transponder incorporated the rectifier circuit into the microchip[11].

On the other hand, the rectifier circuit for generating the DC output voltage is constituted with a full wave bridge structure, in general, because of the reduced ripple voltage. Then the MOS transistor can be used to form a diode to fulfill a bridge rectifier structure. However, the diode-connected MOS transistor has around 0.7 V built-in voltage. Thus the rectified DC output voltage is dropped by around 1.4 V from the input peak-to-peak voltage, which was shown in our previous paper[11]. Because the minimum voltage drop is around 1.4 V, the input voltage level should be more than 2.5 V for the considerable output voltage. This voltage drop can be reduced significantly by changing the diode-connected NMOS configuration to the NMOS current source configuration at the rectifier input, and the substrate of each NMOS is connected on a chip ground. Then the DC output voltage is dropped by only around 0.7 V from the input peak-to-peak voltage.

The designed CMOS rectifier circuit is represented in Fig. 1 and the high frequency small-signal equivalent circuit for (+) half period is represented in Fig. 2.

In Fig. 1, the input consists of two cross-connected NMOSs. The gates of NMOS M1 and PMOS M3 are connected to antenna 1, and the gates of NMOS M2 and PMOS M4 are connected to antenna 2. Substrates of M1 and M2 are commonly connected to the chip ground and

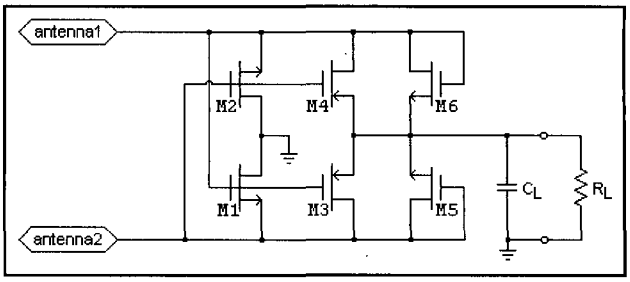


Fig. 1. Designed CMOS complementary bridge rectifier circuit.

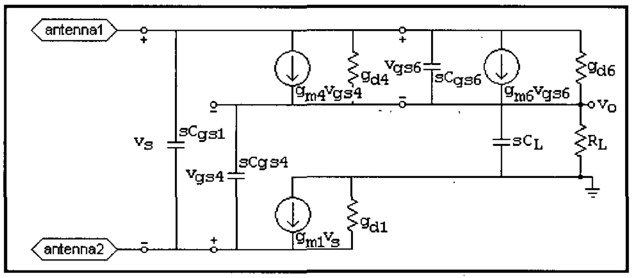


Fig. 2. High frequency small-signal equivalent circuit for (+) half period.

substrates of M3 and M4 are connected to their sources. Therefore, the body effect by substrate bias in M3 or M4 is eliminated. The gate and the drain of each NMOS M5 and M6 are commonly connected to antenna 2 or antenna 1, respectively. So they are configured to the diode-connected NMOS structures. The RF input voltage source is directly added onto two antenna ports. $C_L$ is the capacitor of rectifier, and $R_L$ represents the equivalent resistance of the microchip in the transponder

The operating principle of the designed CMOS rectifier is as follow. During the positive half period of RF input voltage source, NMOS M1, M6, and PMOS M4 are turned on. Then the current flows through M1 → RF input voltage source → M4 and M6, and charges the capacitor $C_L$. However, the charge current is reduced by the leakage current due to the capacitive coupling effect on the two NMOS cross-connected gates. This leakage current can be compensated by the diode-connected PMOS M4. In this positive loop, the voltage drop in NMOS M1 is small. And the parallel diode-connected two transistors, M4 and M6, drops around 0.7 V. Thus, only around 0.7 V dropped DC output voltage from the input peak-to-peak voltage can be obtained at the rectifier output. During the negative half period of RF input voltage source, NMOS M2, M5, and PMOS M3 are turned on. Then the current flows through M2 → RF input voltage source → M3 and M5, and charges the capacitor $C_L$. Therefore, the designed CMOS rectifier operates complementarily as a full wave rectifier.

From the high frequency small-signal equivalent circuit shown in Fig. 2, the output voltage of designed rectifier is obtained as eq. (1) by node analysis.

$$v_o = \frac{g_{m1} + \frac{g_o}{g_\alpha} g_{d1}}{g_L(1+\frac{g_{d1}}{g_\alpha}) + g_{d1}} v_s \tag{1}$$

where,

$$\begin{aligned} g_o &= sC_{gs6} + g_{m6} + g_{d6} + g_{d4} \\ g_\alpha &= sC_{gs4} + g_{m4} + g_{d4} + sC_{gs6} + g_{m6} + g_{d6} \end{aligned} \tag{2}$$

$C_{gs}$ is the gate-source capacitance of NMOS, $g_m$ is the transconductance, $g_d$ is the drain conductance, and $g_L(=sC_L+1/R_L)$ is the load conductance. For simplifying the analysis, other parasitic capacitances are not included in the equivalent circuit. If $g_{d1}$ is small ($\approx 0$), the output voltage of eq.(1) is simplified to eq.(3).

$$v_o \approx \frac{g_{m1}}{g_L} v_s \tag{3}$$

Therefore, we can see that the output voltage of designed rectifier varies in linear for the input voltage. It can be increased by high $g_{m1}$ (high W/L ratio of M1) or low $C_L$. However, the lower the capacitance $C_L$ is, the larger the ripple of rectified output voltage is. Thus the capacitance $C_L$ should be fitted in the allowable ripple range.

## 3. CIRCUIT SIMULATION AND RESULTS

Using the standard CMOS 0.5 ㎛ process parameters, the designed CMOS complementary bridge rectifier shown in Fig. 1 is simulated with SPICE. If 1.5 V DC voltage is required for driving the microchip in the transponder and if the power consumption of the microchip is 50 ㎼, then the equivalent load resistance for the microchip is calculated around 45 ㏀. Therefore the load resistance $R_L$ in Fig. 1 is set to 45 ㏀ for simulation. The capacitance of MOS transistor is proportional to the size of MOS transistor. Actually, the capacitance is usually determined by processes for given MOS transistor sizes. The larger the transistor size is, the larger the capacitance is, and the larger the capacitance leakage current is. This causes the unstable operation for microwave frequencies. So it is important to optimize the transistor size for normal operation of the CMOS complementary bridge rectifier. The optimized component values of devices for simulation are summarized in Table 1. Using these component values, the proposed rectifier is simulated for RFID operating frequencies of 13.56 ㎒ for ISO 18000-3, 915 ㎒ for ISO 18000-6, and 2.45 ㎓ for ISO 18000-4, respectively.

Table 1. Component values(W/L, ㎛).

| Component | Value | Component | Value |
|---|---|---|---|
| M1 | 10/0.5 | M5 | 1.0/0.5 |
| M2 | 10/0.5 | M6 | 1.0/0.5 |
| M3 | 1.0/0.5 | $C_L$ | 500 pF for 13.56 ㎒<br>10 pF for 915 ㎒, 2.45 ㎓ |
| M4 | 1.0/0.5 | $R_L$ | 45 ㏀ |

The simulation results for DC output voltages are shown in Fig. 3, 4, and 5, respectively. Figure 3 shows the DC output voltage and the capacitor current for the frequency of 13.56 ㎒ where the capacitance $C_L$ is 500 pF. Figure 4 shows the DC output voltage and the capacitor current for the frequency of 915 ㎒ where the capacitance $C_L$ is 10 pF. And Fig. 5 shows the DC output voltage and the capacitor current for the frequency of 2.45 ㎓ where the capacitance $C_L$ is also 10 pF. The maximum capacitor current of about 0.8 mA is obtained at 4 V peak-to-peak input voltages $V_{p-p}$ for above three simulation frequencies.

These simulation results show well-rectified high DC output voltages and full wave complementary operations for 0.5 V ~ 4 V peak-to-peak input voltages $V_{p-p}$ stepped by 0.5 V peak-to-peak. For the better understanding, the diagram for the rectified DC output voltage vs 13.56 ㎒ peak-to-peak input voltages $V_{p-p}$ is shown in Fig. 6, where circles are the result of proposed rectifier, triangles are the result of nmos rectifier, and rectangles are the result of our previous paper[11]. This Fig. 6 shows the minimum input voltage level for working the designed CMOS complementary bridge rectifier is less than 1 V. In addition, it shows 1.33 V DC output voltage for 2 V peak-to-peak input voltage and 3.18 V DC output voltage for 4 V peak-to-peak input voltage, respectively.

Obtained DC output voltages show only around 0.7 V dropped voltages from various input peak-to-peak voltages, which are around 0.7 V higher than those of

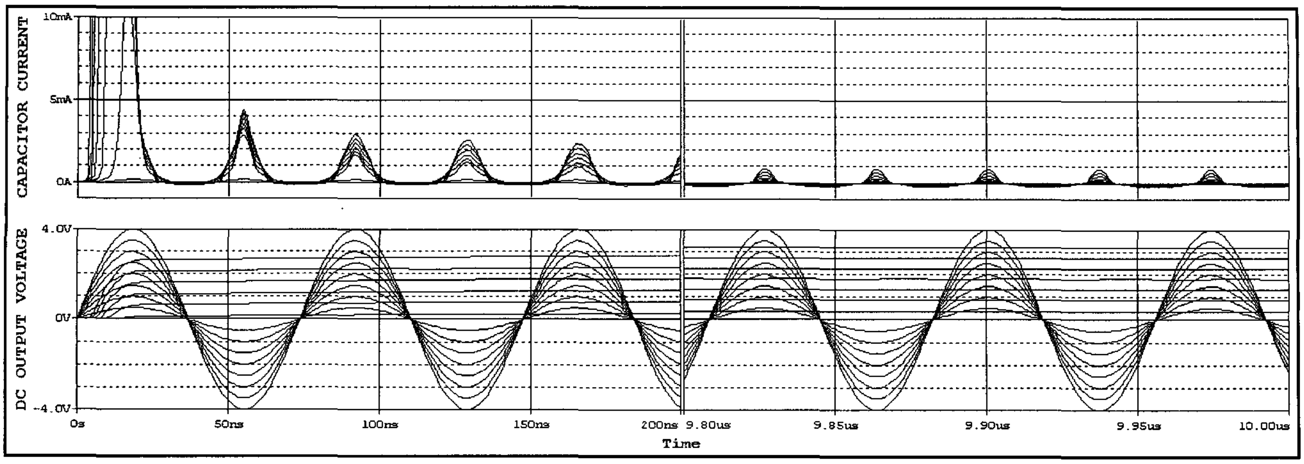


Fig. 3. DC output voltage and capacitor current for 13.56 MHz.

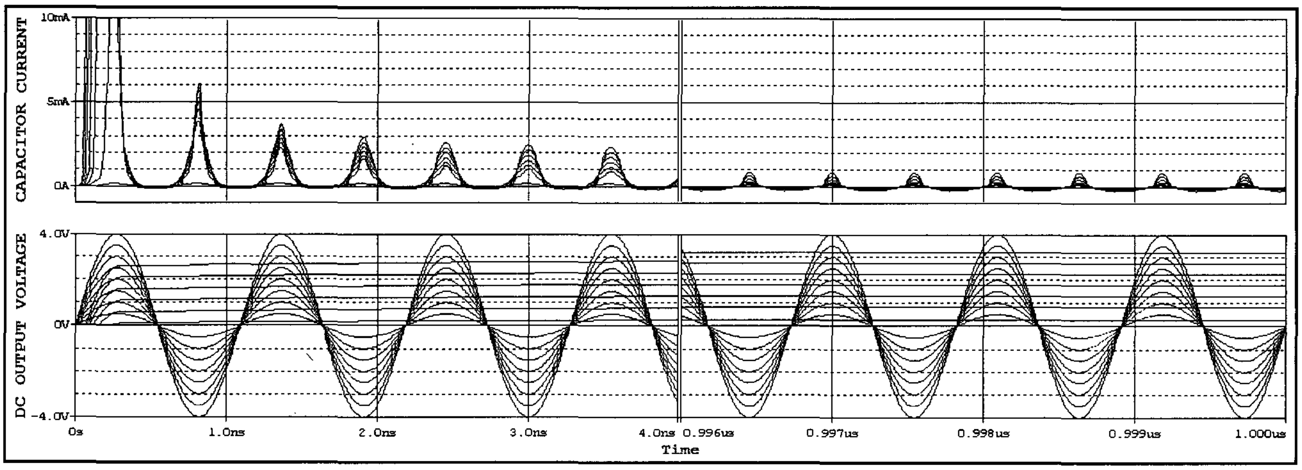


Fig. 4. DC output voltage and capacitor current for 915 MHz.

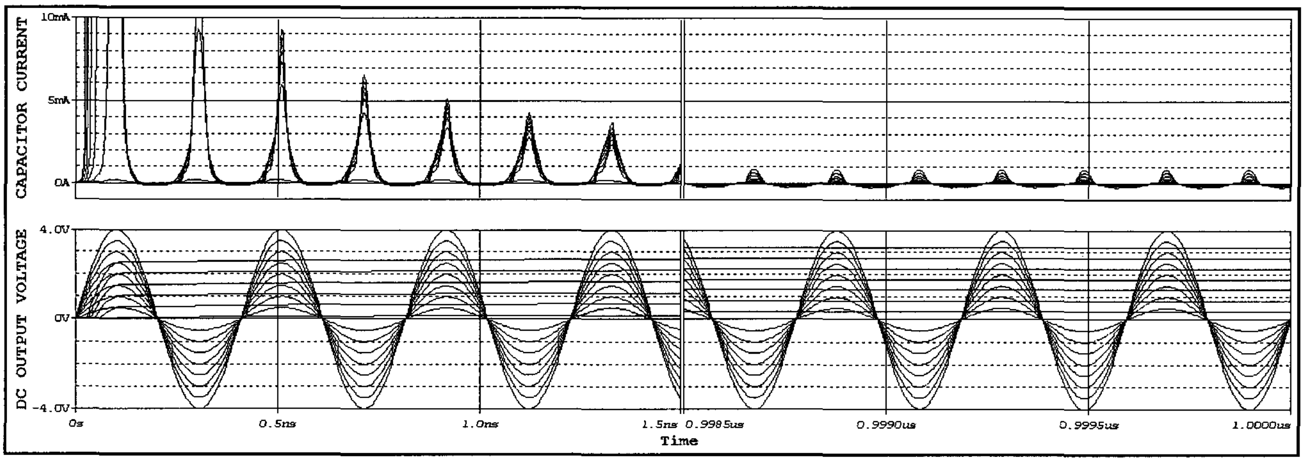


Fig. 5. DC output voltage and capacitor current for 2.45 GHz.

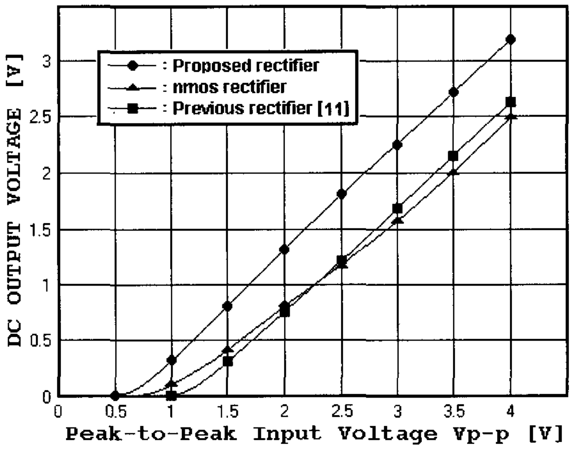


Fig. 6. DC output voltage vs 13.56 ㎒ peak-to-peak input voltage $V_{p-p}$.

our previous paper or those of existing nmos rectifier. These DC output voltages are sufficiently high for driving the low power microchip in the RFID transponder at the frequencies of 13.56 ㎒ HF for ISO 18000-3, 915 ㎒ UHF for ISO 18000-6, and 2.45 ㎓ microwave for ISO 18000-4.

## 4. CONCLUSION

A CMOS complementary bridge rectifier for driving RFID transponder chips is presented. Output characteristics of the proposed rectifier are analyzed theoretically with the high frequency small-signal equivalent circuit and verified with SPICE for RFID operating frequencies of 13.56 ㎒ HF for ISO 18000-3, 915 ㎒ UHF for ISO 18000-6, and 2.45 ㎓ microwave for ISO 18000-4. Then, it shows the minimum input voltage level for working less than 1 V and shows 1.33 V DC output voltage for 2 V peak-to-peak input voltage and 3.18 V DC output voltage for 4 V peak-to-peak input voltage, respectively. Simulation results show well-rectified and high enough DC output voltages for driving the low power microchip in the RFID transponder. These high DC output voltages which are dropped by only around 0.7 V from the input peak-to-peak voltages, could be obtained by CMOS cross-connected gate structures and by making them act as current sources. Therefore, the designed CMOS complementary bridge rectifier may be used as a generic rectifier for driving high voltage transponder chips of various RFID systems.

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