A Novel Impedance Matching Approach for Passive UHF RFID Transponder ICs*

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Abstract: This paper presents a novel impedance matching approach for passive UHF RFID transponder ICs, which are compatible with the ISO/IEC 18000-6B standard and operate in the 915MHz ISM band. The passive UHF RFID transponder with complex impedances is powered by received RF energy. The approach uses the parasitic inductance of the antenna to implement ASK modulation by adjusting the capacitive reactance of the matching network, which changes with the backscatter circuit. The impedance matching achieves maximum power transfer between the reader, antenna, and transponder. The transponder IC, whose operating distance is more than 4m with the impedance matching approach, is fabricated using a Chartered 0.35μm two-poly four-metal CMOS process that supports Schottky diodes and EEPROM.

Key words: impedance matching; RFID; passive transponder; backscatter circuit

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1　Introduction

Radio frequency identification (RFID) is a rapidly developing automatic identification technology that is used to identify objects with radio waves[1]. It is replacing traditional barcode technology and encodes data into a monolithic microchip in tags for identifying, gathering, and processing product information or tracking application[1,2]. RFID has gained attention because it can realize ubiquitous computing technology[3].

RFID system uses LF (125kHz, 135kHz), HF (13.56MHz), UHF (860～960MHz) or microwave (2.45GHz). The UHF band is used worldwide for its long read range and low manufacturing cost in the distribution field. In North and South America, the center frequency is 915MHz, whereas Europe, Middle East, and Russian Federation mainly use 866MHz. Asia and Australia use frequencies within the band from 866 to 954MHz. Korea made an allocation from 908.5 to 914MHz (bandwidth 5.5MHz)[1,4].

A typical passive RFID transponder consists of an antenna and an integrated circuit (chip). The chip is usually placed at the terminals of the tag antenna, and both the chip and antenna have complex input impedances. The chip contains the analog front end (AFE) and the control logic. The RFID reader transmits an RF signal, which is received by an antenna of the RFID transponder. The voltage received on the antenna terminals powers up the chip, which sends the information back by varying its input impedance and thus modulating the backscattered signal[5]. Proper impedance matching network between the antenna and the chip is important in RFID tags because it determines the characteristics of the RFID tags, such as the tag reading range[6]. High-efficiency, low-cost impedance matching between the antenna and the chip is the most important goal in the design of the RFID transponder.

Three methods of impedance matching, which are transformer matching, L-type matching, and shunt inductor tuning, can be used to implement high RF to DC conversion efficiency. Transformer matching is cost prohibitive for the retail RFID tag targeted for only a few cents[1,7]. The L-type matching uses a series inductor to resonate out the input capacitance of the transponder chip. This type of match can provide voltage boosting if the antenna impedance is low and the rectifier impedance is high. The shunt inductance tuning method requires a strap inductor[7]. For RFID applications, integrated inductance in the CMOS process is very expensive and has lower accuracy.

This paper presents a novel impedance matching approach for passive UHF RFID transponder ICs with lower power and longer range. This approach uses the parasitic inductance of the antenna to implement ASK modulation by adjusting the capacitive reactance of the matching network, which changes with the backscatter circuit. Also, the impedance matching

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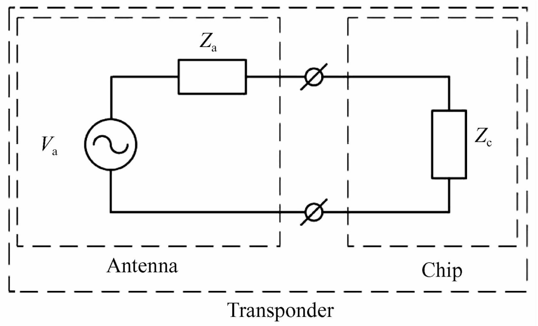


Fig.1　RFID transponder equivalent circuit

achieves maximum power transfer between the reader, antenna, and transponder. The technology is a 0.35μm two-poly four-metal (2P4M) CMOS process with EEPROM and Schottky diodes supported. The operating distance of the transponder IC with the impedance matching approach is more than 4m.

2　Architecture

2.1　Impedance matching

An equivalent lumped circuit of an RFID transponder is shown in Fig. 1[5,8]. $Z_c = R_c + jX_c$ is the complex chip impedance, which does not contain the parasitic capacitance and inductance of the bonding pads and wires because they are less than several femtofarads and one nanohenry, respectively, and $Z_a = R_a + jX_a$ is the complex antenna impedance. The voltage source represents an open circuit RF voltage developed on the terminals of the receiving antenna. Both Z_a and Z_c are frequency dependent. In addition, chip impedance Z_c may vary with the power consumption of the chip. The antenna is usually matched to the chip at the minimum threshold power level necessary for the chip to respond[5]. Furthermore, the impendence of the antenna and chip must be conjugate matched in order to achieve maximum power transfer.

If an antenna has minimum scattering, the amplitude of the backscattered power is:

$$P_{BS} = \frac{P_{EIRP}}{4\pi r^2} A_e \frac{4R_a^2}{|R_a + jX_a||R_c|^2} \quad (1)$$

where P_{EIRP} is the effective isotropic radiated power, R_a is the antenna resistance, R_c is the chip resistance, and A_e is the effective radar-cross-section (RCS) area. The reflection coefficient of the transponder is given by

$$s = \frac{Z_c - Z_a^*}{Z_c + Z_a} \quad (2)$$

The power reflection coefficient is given by

$$|s|^2 = \left|\frac{Z_c - Z_a^*}{Z_c + Z_a}\right|^2 \quad (3)$$

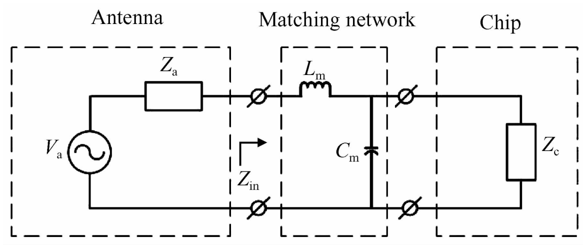


Fig.2　RFID transponder equivalent circuit with L-type matching network

In the case of ASK modulation, the input impedance of the transponder is real ($X \gg R$) and is modulated by the data signal between two values (logic 0 and 1). When the impedance of the antenna and chip is conjugate matched, the reflection coefficient will be zero and the received energy will achieve maximum power transfer. If the impedance of the transponder is changed, a part of the energy transmitted by the reader will be reflected, which is the mechanism of ASK modulation.

2.2　Matching network circuit

For maximum power transfer and hence better performance of the transponder, the impedance of the antenna should be matched with the impedance of the chip, and an impedance matching network is usually necessary to obtain an appropriate match. In practical applications, a reasonable impedance match must be achieved. The impedance matching network is shown in Fig. 2. Since integrated inductance in the CMOS process is expensive and has lower accuracy, in order to reduce the chip size and facilitate the integration, the equivalent inductance L_m of the antenna is put into the L-type matching network.

The equivalent input impedance of the antenna is designed to be approximately 73 + 247j. ASK modulation depends on different input impedances, which represent different reflection coefficients. Assuming that the input impedances are Z_1 and Z_2, respectively, the input power is given by[8]

$$\begin{aligned} P_{RF,in,1,2} &= \frac{1}{2}\mathrm{Re}(v_{in}^* i_{in}) \\ &= \frac{1}{2}\mathrm{Re}\left[\frac{v_0^2 (R_{1,2} - jX_{1,2})}{|R_{1,2} + R_{ant} + j(X_{1,2} + X_{ant})|^2}\right] \\ &= \frac{1}{2} \times \frac{v_0^2 R_{1,2}}{(R_{1,2} + R_{ant})^2 + (X_{1,2} + X_{ant})^2} \\ &= \underbrace{\frac{v_0^2}{8R_{ant}}}_{\text{available power}} \times \Bigg(1 - \underbrace{\left|\frac{Z_{1,2} - Z_{ant}^*}{Z_{1,2} + Z_{ant}^*}\right|}_{\text{ratio of power reflected}}\Bigg) \end{aligned} \quad (4)$$

where v_{in} is the peak voltage of the transponder, i_{in} is the peak current of the antenna and chip, and v_0 is the peak voltage of the voltage source V_a, when the antenna is open. If the equivalent input impedance Z_{in}

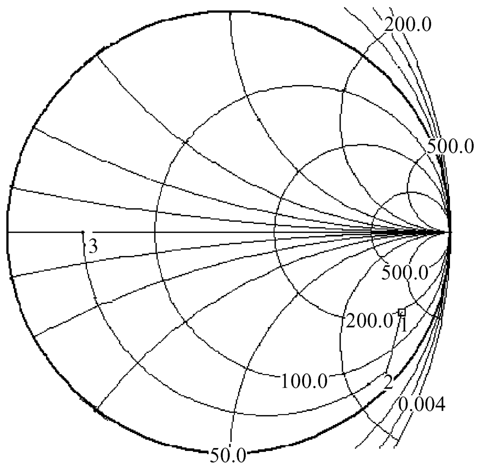


Fig. 3 Impedance Smith chart of conjugate match between the antenna and chip

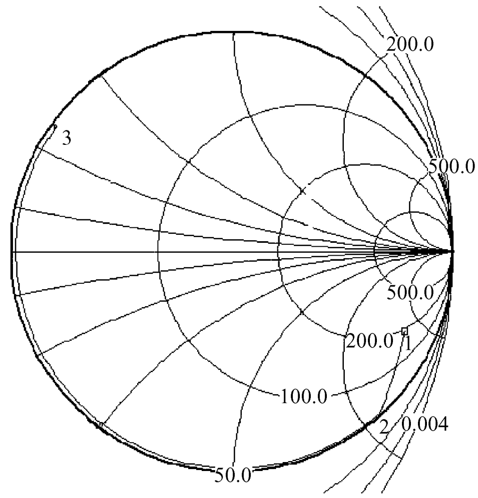


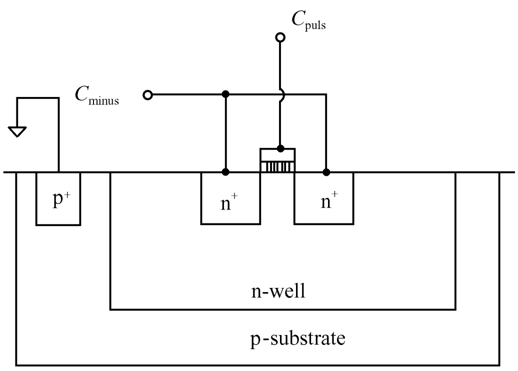
Fig. 4 Impedance Smith chart of 30% reflection coefficient between the antenna and chip

of the matching network is 73 − 247j, the impendence of the antenna and chip will be conjugate matched to achieve the maximum power transfer. If the reflection coefficient of the transponder is 30%, the value of Z_{in} will be 51 + 32j.

3 Circuit design

The input impedance of the chip without the matching network circuit is approximately 200 − 400j with the minimum input power. Therefore, if the inductance L_m and capacitance C_m of the matching network circuit are 44nH and 280fF, the impendence of the antenna and chip will be conjugate matched to achieve the maximum power transfer with the rectifier circuit, which uses the structure of a Dickson charge pump[9,10]. The impedance Smith chart of the conjugate match between the antenna and chip is shown in Fig. 3, where $P_{oint\,1}$ is 200 − 400j, $P_{oint\,2}$ is 73 − 247j, and $P_{oint\,3}$ is 73Ω. $P_{oint\,3}$ is matched to the impedance of the antenna. If the inductance and capacitance of the matching network circuit are 44nH and 400fF, the value of Z_{in} shown in Fig. 4 will be 51 + 32j with a reflection coefficient of 30%, where $P_{oint\,1}$ is 200 − 400j, $P_{oint\,2}$ is 51 − 220j, and $P_{oint\,3}$ is 51 + 32j. Consequently, ASK modulation is implemented by changing the imaginary part of the chip between 280 and 400fF. In other words, the value of Z_{in} is modulated by adjusting the capacitive reactance of the backscatter circuit.

By changing the capacitance of the MOS varactor, the bi-state amplitude modulated backscatter is implemented. With the standard CMOS process, the MOS varactor is fabricated by the voltage controlled capacitor between the MOS gate and substrate, as shown in Fig. 5[11,12]. With modulation, high power efficiency for DC supply voltage generation and high modulated backscatter power for the backward link are achieved simultaneously. The schematic of the backscatter modulation circuit is shown in Fig. 6[9].



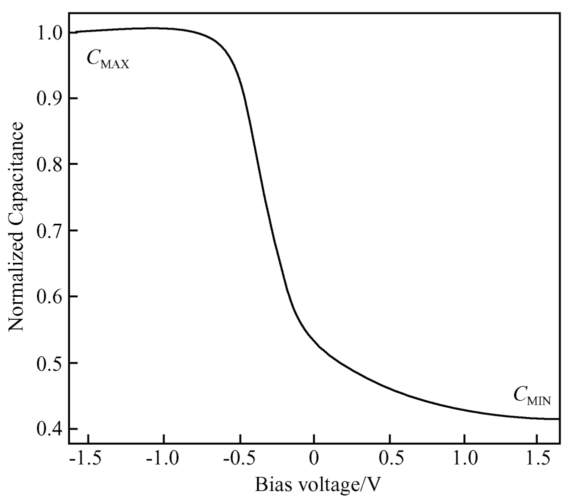


Fig. 5 Characteristics of the MOS varactor

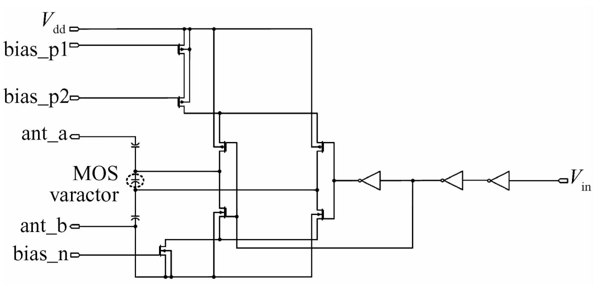


Fig. 6　Schematic of the backscatter circuit

4　Experimental results

A novel impedance matching approach for a passive UHF RFID transponder IC is presented. This approach uses the parasitic inductance of the antenna to implement ASK modulation by adjusting the capacitive reactance of the matching network, which is changed with the backscatter circuit. Furthermore, the maximum power transfer is achieved between the reader, antenna, and transponder. The technology is a Chartered 0.35μm two-poly four-metal CMOS process with EEPROM and Schottky diodes supported.

A die photograph of the chip is shown in Fig. 7. The matching network and backscatter circuits are labeled. In normal applications, only two bonding wires are required to connect the antenna to the transponder. The other bonding PADs in Fig. 7 are used for the testing purposes. The die photograph only shows the AFE of the transponder and a small part of the logic control circuitry. The rest, which is not shown here, contains the other logic circuits and EEPROM. Figure 8 shows the testing results of the transponder with the impedance matching approach. The demodulated waveform is shown with an Agilent 54642A oscilloscope by the UHF RFID reader of Model THM6BC1-915 (Tongfang Microelectronics Company, Beijing), which is compatible with the ISO/IEC 18000-6B standard. With 4W EIRP at 915MHz and 0dB transponder antenna gain, the operating distance of the transponder is more than 4m.

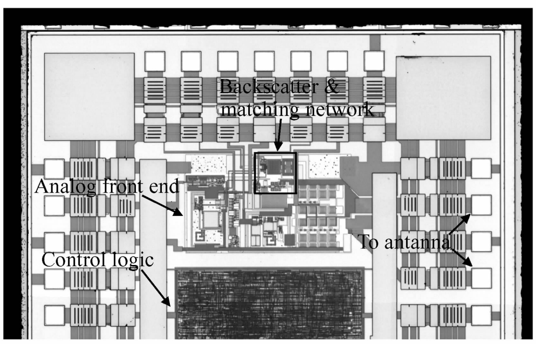


Fig. 7　Die photomicrograph of the AFE

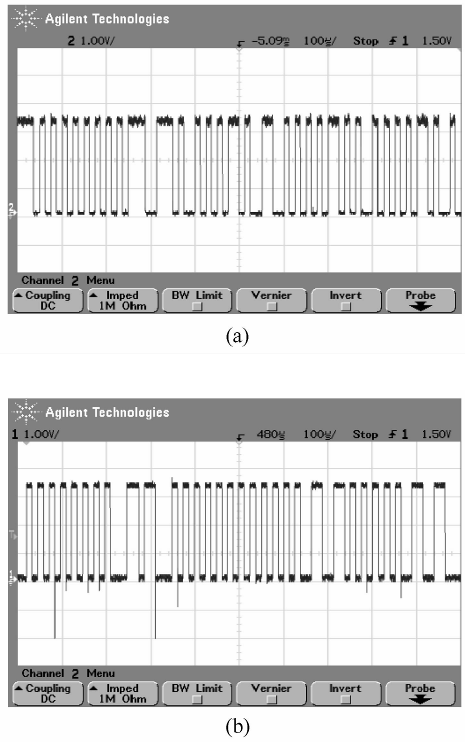


Fig. 8　(a) Demodulated waveform of the transponder; (b) Backscattered signal waveform of the transponder

5　Conclusion

This paper presents a novel impedance matching approach for passive UHF RFID transponders, which are compatible with the ISO/IEC 18000-6B standard and operate at the 915MHz ISM band with lower power and longer range. This approach uses the parasitic inductance of the antenna to implement ASK modulation by adjusting the capacitive reactance of the matching network, which is changed with the backscatter circuit. Simultaneously, maximum power transfer is achieved between the reader, antenna, and transponder because of the conjugate match between the antenna and chip. Theoretical analysis used for the design optimization has been proposed. The whole chip has been fabricated with a Chartered 0.35μm two-poly four-metal CMOS process with Schottky diodes and EEPROM supported. The operating distance of the transponder with the impedance matching approach is more than 4m with 4W (36dBm) EIRP base-station transmit power at 915MHz, and the measurement results meet the specification of the proposed system.

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一种用于无源 UHF RFID 应答器的阻抗匹配方法*

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摘要： 提出了一种可以在 915MHz ISM 频带下工作的、符合 ISO/IEC 18000-6B 标准的无源 UHF RFID 应答器的阻抗匹配方法. 该 UHF RFID 应答器具有复数阻抗并从射频电磁场接收能量. 该阻抗匹配方法利用天线的寄生电感，通过调整反向散射电路的电容来改变匹配网络的容抗，从而实现 ASK 调制. 而且，该阻抗匹配方法在阅读器、天线与应答器之间达到了最大的功率传输. 采用该阻抗匹配方法的应答器芯片通过支持肖特基二极管和 EEPROM 的 Chartered 0.35μm 2P4M CMOS 工艺进行流片，经测试其工作距离约为 4m.

关键词： 阻抗匹配；RFID；无源应答器；反向散射电路

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