

An Analog Front-End Circuit for ISO/IEC 14443-Compatible RFID Interrogators

Kyung-Won Min, Suk-Byung Chai, and Shiho Kim

An analog front-end circuit for ISO/IEC 14443-compatible radio frequency identification (RFID) interrogators was designed and fabricated by using a 0.25 μm double-poly CMOS process. The fabricated chip was operated using a 3.3 Volt single-voltage supply. The results of this work could be provided as reusable IPs in the form of hard or firm IPs for designing single-chip ISO/IEC 14443-compatible RFID interrogators.

Keywords: RFID, RFID interrogator, analog front-end circuit, ISO 14443.

I. Introduction

There has been a great interest in radio frequency identification (RFID) using contact-less IC cards in many fields such as E-commerce, credit cards, mobile phones, personal administration, PDAs, ID tags, transportation, fare collection, and so on [1]-[5]. ISO/IEC 14443 is an interface standard between a transponder (RFID) and interrogator (reader) operating in proximity, where the communicating distance is less than 10 cm.

Figure 1 illustrates the signal interface between the transponder and interrogator of the 14443 type-A and type-B system. The system communicates in a half-duplex mode. The interrogator uses a carrier frequency (f_c), 13.56 MHz, of the industrial, scientific and medical band (ISM) for both transferring energy and data. For the type-A interface, the interrogator sends 100% amplitude shift keying (ASK)-modulated data encoded using the modified miller method. For the type-B interface, a 10% ASK-modulated signal of non-return to zero (NRZ)-coded bits shall be transmitted to the transponder.

The inductively-coupled loop antenna of a reader and transponder form a transformer. The transponder can send data by load modulation, which is switching a load in the transponder with a subcarrier frequency. The transponder uses a sub-carrier of 847 kHz, which is $f_c/16$. The bit rate of communication is 106 kbps, or $f_c/128$. For type A, the transponder modulates data by Manchester coding. On the other hand, the subcarrier is binary phase shift keying (BPSK)-modulated for the type-B interface.

There were many publications regarding the design of a single-chip-set solution for RFID [2]-[6]; however, there has been almost no technical papers regarding a design issue of ISO 14443-compatible RFID interrogators [7]. The goal of this work is to provide a reusable IP for the analog front-end circuit of an ISO/IEC 14443-compatible RFID interrogator used in the design

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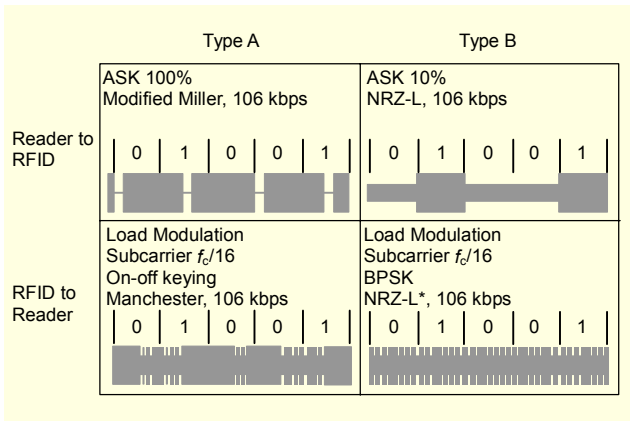


Fig. 1. Example communication signals of ISO/IEC 14443 type-A and type-B interfaces between an interrogator (Reader) and transponder (RFID).

of a platform-based single-chip RFID reader [8].

II. Design of Analog Front End Circuit

Figure 2 shows a block diagram of the RFID reader system. The RFID reader system consists of a digital controller and an analog front-end part. The analog front-end part is composed of a transmitting section for the ASK modulator and antenna driving circuit and a receiving section for demodulating the sub-carrier-modulated input data from the RFID. D_{TX} is the input data to be transmitted to a transponder. D_{TX} is either modified Miller-coded or NRZ-coded data for type-A mode or type-B mode, respectively. R_{X_OUT} is a demodulated output of the receiving circuit.

Figure 2 shows a typical application where the antenna is directly connected to the T_X pin of the driver. The external antenna circuit consists of an electromagnetic coupling (EMC) low-pass filter and an antenna matching circuit. The EMC filter is a low-pass filter composed by L_0 and C_0 , where the cut off frequency of the EMC filter was designed to be 14.5 MHz, which is slightly above the carrier frequency. The resonance frequency of an LC tank composed by C_1 , C_2 , and

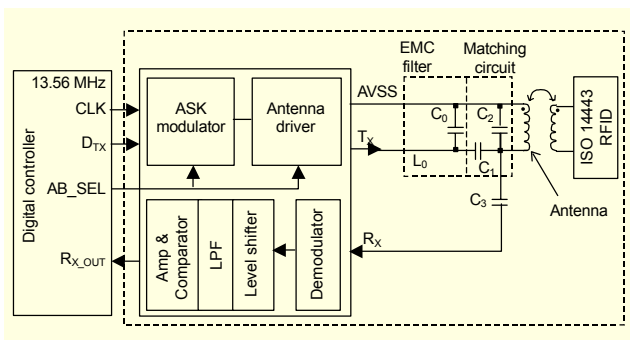


Fig. 2. Block diagram of an RFID reader system.

an inductance of the loop antenna was tuned to a carrier frequency of 13.56 MHz, where C_1 is a stray capacitance of the loop antenna. The value of C_1 depends on the antenna's geometrical properties and the material of the print circuit board.

1. ASK Modulator and Antenna Driver

Figure 3 shows the proposed circuit of the ASK modulator and the antenna driver circuit of an RFID reader for an ISO/IEC 14443 type A/B interface. Signal AB_SEL is the control signal selecting either type-A or type-B mode. MPL should be off by setting AB_SEL to 'low' so that the circuit is operating in type-A mode. Then, the D_{TX} data is ASK-modulated with CLK by the NAND gate $NA1$, while the inverter formed by MPH and MN drives 100% ASK-modulated pulses to the T_X node. The voltage regulator consists of voltage dividers R_1 , R_2 and $OP1$. The voltage of the V_{CAP} is regulated by 90% of V_{DD} since the value of R_1 is determined to be about 9 times the R_2 value. A large external capacitor should be connected to the V_{CAP} node to suppress switching noises during type-B operation.

If the input of AB_SEL is 'high', MPH pulls up the T_X node when both the D_{TX} and CLK levels are 'high', while MPL pulls up the T_X node when D_{TX} is 'low' and CLK is 'high.' The pulse amplitudes of the T_X node are values of either V_{DD} or V_{CAP} depending on the input data D_{TX} . The EMC filter filters high frequency harmonics of the rectangular pulse of the T_X node.

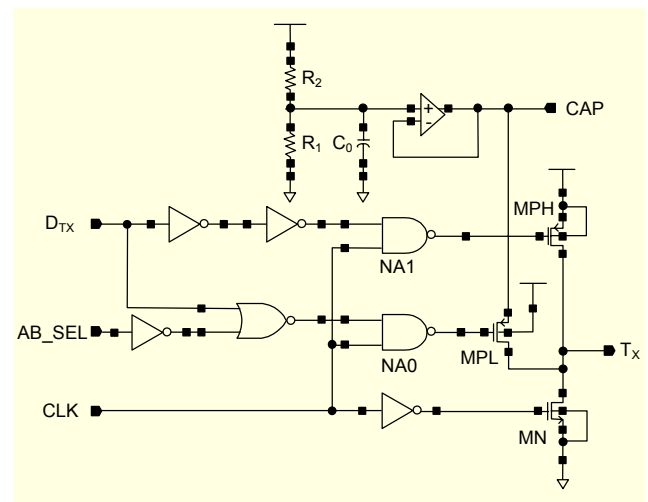


Fig. 3. Proposed ASK modulator and antenna driver of an RFID interrogator for an ISO/IEC 14443 type-A/B interface.

2. Receiving Circuit

Figure 4 shows the proposed circuit for the receiving block.

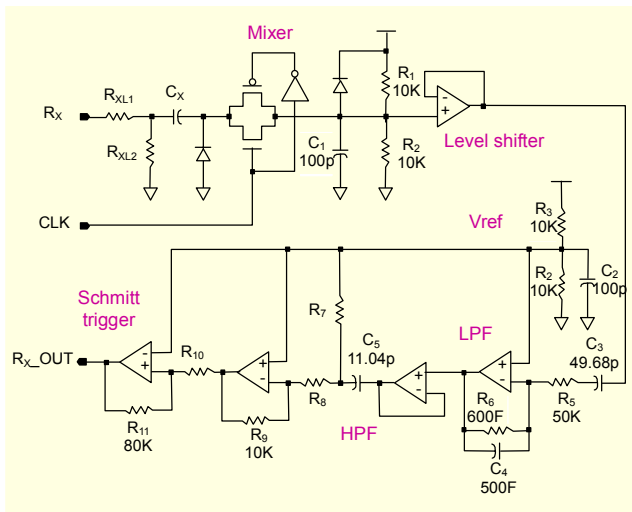


Fig. 4. Circuit diagram of the receiving block.

The basic function of the receiving block is to demodulate load-modulated data in the R_X input so that it reproduces a subcarrier-modulated pulse signal, R_{X_OUT} , and feeds it to the digital controller. The binary data received can easily be produced in the digital controller [7], [8]. The voltage level of the R_X input is adjusted by the voltage divider formed by R_{XL1} and R_{XL2} , and an offset voltage is added by a clamper circuit so the negative input level is shifted to the ground. The maximum amplitude of the antennal signal is larger than 30 V. The main purpose of the voltage divider is to protect the mixer from a high voltage signal from the antenna. The designed ratio of the voltage divider is about 1/5. Negative input is not acceptable inside of the circuit because we only use a single positive supply as a VDD. Moreover, since process migration is important, we have been aiming for a reusable IP for an SoC solution of an RFID interrogator so that a complicated technology such as the triple-well process is not necessary for analog IP design.

The mixer made of a CMOS transmission gate multiplies CLK and the incoming RF signal. The R_X input is a signal from the antenna, so the carrier of the R_X signal is synchronized with CLK by itself. The DC offset level of the mixer output is adjusted to half VDD in the level adjustment circuit before feeding to the filter and comparator circuitry. The low-pass filters in the receiving section suppress high-frequency noise where the cut off band is about 800 kHz. A high-pass filter with a cut off frequency of about 1.6 MHz formed by C_5 , R_7 and R_8 is used to eliminate the low-frequency spurious signal. The mid-band gain of the low-pass filter is about 10, and the gain of the inverting amplifier composed by R_8 and R_9 is about 10, so the overall gain of the receiving circuit was designed to be about 100. A Schmitt trigger is used for the comparator.

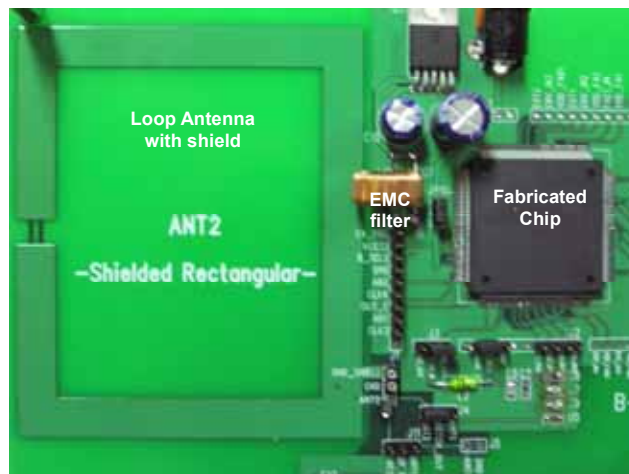
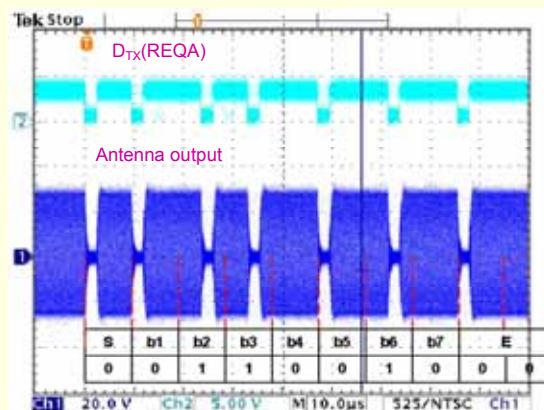
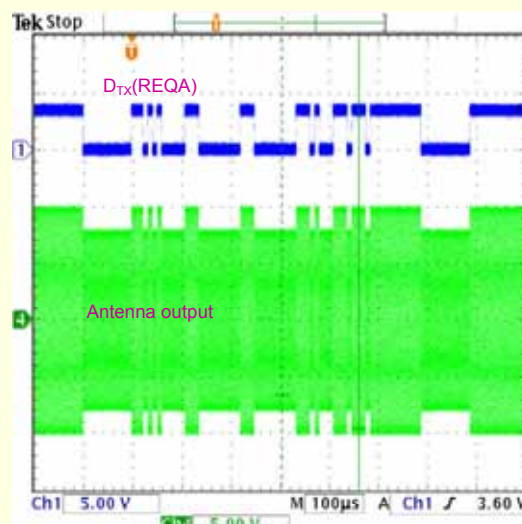


Fig. 5. Manufactured test board of an RFID interrogator.



(a)



(b)

Fig. 6. Measured waveforms of DTX and output voltage on the antenna for (a) type-A mode and (b) type-B mode.

III. Experimental Results and Discussions

The chip was designed in full custom and fabricated by using Dongbu's 0.25 μm double-poly CMOS process. A test board of an RFID interrogator was manufactured as shown in Fig. 5. Since the size of an antenna is related to the read range [9], the size of the antenna is about $7 \times 7 \text{ cm}^2$, which was designed to cover 10 cm of the read range. Figure 6 shows a measured waveform of D_{TX} and the output of the loop antenna. The data of D_{TX} are the frame data of the request-A command (REQA) encoded by a modified miller for type-A mode and request-B (REQB) for type-B mode [1]. The measured waveforms show that the RF outputs on the antenna meet the ISO/IEC 14443 type-A and type-B specifications for rising and falling time, overshoot and undershoot, and AM modulation index under a supply voltage of 3.3 V.

Figure 7 shows a subcarrier-modulated signal on the antenna and the corresponding $R_{\text{X_OUT}}$ signal output of the receiving circuit. The ripple voltage on the antenna with a subcarrier of 847 kHz is a response of an RFID to a request command. The R_{X} signal was demodulated so that each ripple voltage was converted into a corresponding pulse signal. The proposed analog front-end circuit was operated in a 3.3 V single-supply voltage. Since the proposed circuit is designed using standard CMOS with a single-supply voltage, it can be integrated with the digital part for a single-chip design of an RFID interrogator using a standard digital CMOS process.

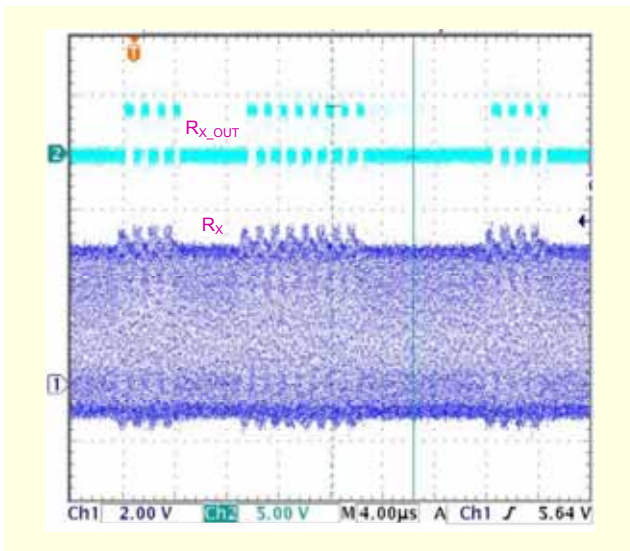


Fig. 7. Measured waveforms of load-modulated antenna voltage (R_{X}) and demodulated $R_{\text{X_OUT}}$ voltage.

IV. Conclusion

An analog front-end circuit for an ISO/IEC 14443 type-A- and type-B-compatible RFID reader has been designed in full custom

and fabricated by using 0.25 μm double-poly CMOS process. The measured results demonstrated that the circuit has met the standard specifications. The final goal of this work is to provide reusable analog IPs for an SoC solution of ISO/IEC 14443-compatible contact-less card readers by integrating both analog and digital parts into a single chip. The proposed circuit can be easily migrated to other CMOS processes for the IP-based design because the proposed circuit was designed and silicon-proved using a 0.25 μm CMOS process with a single-supply voltage of 3.3 V, which is available for most foundry companies.

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