A 8-µW, 0.3-mm² RF-Powered Transponder with Temperature Sensor for Wireless Environmental Monitoring

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Abstract—We present a RF-powered transponder with temperature sensor for environmental monitoring. The transponder gathers power from ISM (860 – 960MHz) band RF signal. A temperature-compensated ring oscillator and an oversampling synchronizer are proposed for low power and robust system clock generation. The simple structure of temperature sensor is achieved by sharing major reference signals with the ring oscillator. The generated clock frequency has variation less than 5% for 1-V supply voltage and 90°C temperature changes. The temperature sensor has the resolution under 1°C in the range from -10°C to 80°C. The transponder dissipates only 8-µW during active state and occupies 0.3mm² with 0.25-µm CMOS process.

I. INTRODUCTION

The radio-frequency identification (RFID) is being used in a number of applications including supply chain management, access control, public transportation and many more [1]. When the RFID is combined with sensory systems, its application area can be extended to environmental monitoring such as temperature, humidity and pressure sensing. The batteryless and wireless characteristics of the RFID and the ID number assigned to each sensor can support maintenance and field-deployment of multiple sensor units. Recently, a trial to integrate RFID tag and temperature sensor was reported [2]. But it is a combo-chip just placing the two prototypes side by side, and its power consumption is too large to be used in wide space. Also, its die size can still be reduced for low cost.

In this paper, we propose a new type transponder with temperature measuring block reducing power consumption efficiently. Fig. 1 shows the architecture of the proposed transponder. The incident RF signal from the base station is converted to dc supply voltage and stored in a large capacitor. The stored energy provides power to all active blocks on the transponder chip. In most cases, the system clock is extracted from or locked to incident RF signal [2, 3]. But when signal frequency is much higher, these methods are inefficient because of their huge power consumption.

Recent tendency to prefer UHF band for wide operation range and small antenna size brings up power problem to the conventional RF-powered system.

In our transponder, the fully integrated clock generator independent of external RF signal is proposed to reduce power consumption. The proposed clock generator is composed of a temperature-compensated ring oscillator and an oversampling synchronizer. The ring oscillator provides reference current and clock needed in the temperature sensor so that the additional power consumption and area due to the sensor are minimized.

The ROM block and the temperature sensor are enabled exclusively by the command from base-station for power management. The RF interface between the transponder and the reader is based on EPC RFID generation2 protocol [4].

The details of the architecture and circuits will be explained in following sections. Section II describes overall operations of the transponder interacting with base-station. Section III and IV show design of the building blocks and their simulation results. And section V is the conclusion.

II. SYSTEM OVERVIEW

The base station provides RF power in ISM band (860 - 960MHz) to the transponder. Sufficiently high dc supply voltage above 2V is generated from weak RF signal under
400mV amplitude by multistage charge pump to increase transponder’s response range. Schottky diodes are used for efficient charge pumping.

The transponder operates in three states – ready, interrogating and active state. The operation sequence is described in Fig. 2. When the transponder receives an energizing RF field, it enters the ready state in which only internal clock generator is activated. A request from the base-station makes the transponder enter interrogating state. In this state, demodulator and decoder are activated to enable ROM block or temperature sensor. Command data are transmitted with 30% ASK modulation depth. ASK modulation makes input power weak during the interrogating state. For safe operation, commands are always followed by preamble sequence to stop possible activated blocks. The preamble is also the key sequence to synchronize internal clock to input data.

In the active state, the selected functional block is activated and the requested data are transmitted to the base station through backscattering modulation. After the active state, transponder returns to the ready state automatically.

III. DESIGN OF THE BUILDING BLOCKS

A. ASK Demodulator

To obtain full swing bit sequence from ASK modulated RF signal, the envelope of the input signal is compared to average level and then amplified. Typically, average signal is obtained by sending the envelope signal to RC network with large time constant [5]. But this method needs so large resistor and capacitor resulting in the increase of the chip area. Proposed demodulator of Fig. 3 employs diode-connected NMOS pair to obtain the average signal.

When the envelop signal is at Vhigh and Vlow, the NMOS pair limits voltage on node X to Vhigh – Vth and Vlow + Vth. When the difference between Vhigh and Vlow is less than 2Vth, the NMOS in subthreshold acts as a large resistor. We can effectively make average signal while saving much area by removing the large passive units.

B. Internal Clock Generator

Current starved ring oscillator is often used in low power-oriented systems [6]. Most of them focus on robustness against supply voltage variation. However, in the proposed transponder, independence of the reference clock to both of the supply voltage and temperature is mandatory to transmit accurate temperature information to the base-station. Temperature compensated ring oscillator is presented in Fig. 4. The frequency of the ring oscillator is determined by the bias current. Two MOS-based biasing circuits generate complementary reference currents. One (IA) has a positive slope to temperature variation and the other (IB) has a negative slope. By matching the magnitude of the slopes and summing two currents, temperature-independent bias current (IREF) can be supplied to the current starved ring oscillator. To reduce the effect of supply voltage variation and lower minimum operating level, low voltage cascode current mirrors are adopted [7].
Fig. 5 shows frequency – supply voltage characteristics of the proposed oscillator with temperature as a parameter. The frequency varies within 5% from the desired 320-kHz and the oscillator consumes 1-µA at 2-V supply voltage.

Although the oscillator’s output is stabilized, it is not enough to sample demodulated bit stream without error due to its frequency error and synchronization problem. The proposed oversampling synchronizer is shown in Fig. 6. The demodulated data is encoded in Manchester code and all commands are followed by preamble. The preamble is selected as the sequence specified in EPC RFID protocol for generation2 identity tag [4]. The Manchester high violation (01110) in the preamble is used for synchronization. The synchronizer aligns the positive edge of the system clock to the incoming bit’s half width point which is the most resistive point against frequency variation and noise.

C. 128-bit ROM Block

Fig. 7 shows the ROM block to store 128-bit ID numbers. 128 bit block size is selected to store IPv6 address which is sufficient to assign unique ID number to all systems in the world without collision. The ID code can be used to identify the unique position of the transponder in the measured area.

The area of the ROM block is reduced by using only NMOS transistors. The regenerating PMOS can charge up each bit line to full supply voltage level and reduce leakage current caused by threshold voltage drop in NMOS.

D. Temperature Sensor

Fig. 8 presents the integrated temperature sensor. In this circuit, temperature can be measured by capacitor charging time. When the sensor is enabled, large capacitor (Cp) starts to be charged by the reference current. Because the reference current independent of temperature change is already generated in the oscillator, it needs no additional block. The voltage developed on the capacitor is compared to Vbe signal which is decreasing in proportion with temperature. Consequently, the charging time is also linear to temperature. The continuous time information is digitized to pulse counts and sent to the base-station. For accurate AD conversion, the reference clock stable to various conditions should be generated, which is already considered in the oscillator. The temperature sensor requires only two blocks which are the proportional to absolute temperature (PTAT) current source and the comparator. It consumes only 0.8-µA under 2-V supply voltage.

IV. SIMULATION RESULTS

Fig. 9. Synchronization of clock to data

Figure 6. Oversampling synchronizer

Figure 7. NMOS-based ROM block

Figure 8. Temperature sensor
Fig. 9 shows the simulation result on the synchronization of clock to data. When the Manchester high violation is detected, reset pulse is enabled and system clock is set to low. At the next ‘1’ bit signal’s half point, the system clock is regenerated and starts to sample command bits correctly. It can be seen that the clock frequency is stable in spite of fluctuation of supply voltage during the interrogating state.

Output pulse counts of the temperature sensor are presented in Fig. 10 with the temperature as a parameter. The 10-bit binary counter is attached to the sensor’s output port for pulse counting. The simulation result shows the sensor has the linearity of $R^2 = 0.9942$. The resolution of the temperature sensor is 0.8°C within the range from -10°C to 80°C.

Fig. 11 is the chip layout using 0.25-µm standard CMOS technology. The chip area except pads is 0.3mm². The MOS capacitor filled in the empty area acts as not only decoupling capacitor but also energy-storage one.

![Figure 11. Chip Layout (0.5mm x 0.6mm except pads)](image)

### Table I. Power and Size Comparison

<table>
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<th></th>
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<tbody>
<tr>
<td>Carrier Freq.</td>
<td>900MHz</td>
<td>900MHz</td>
<td>2.4GHz</td>
<td>900MHz</td>
</tr>
<tr>
<td>Process</td>
<td>0.5µm</td>
<td>0.25µm</td>
<td>0.18µm</td>
<td>0.25µm</td>
</tr>
<tr>
<td>Size</td>
<td>Not reported</td>
<td>2 mm²</td>
<td>0.1 mm²</td>
<td>0.3 mm²</td>
</tr>
<tr>
<td>Scaled-Size (to 0.25µm)</td>
<td>NA</td>
<td>2 mm²</td>
<td>0.2 mm²</td>
<td>0.3 mm²</td>
</tr>
<tr>
<td>Power</td>
<td>2.3µ<a href="mailto:W@1.5V">W@1.5V</a></td>
<td>2.2mW@2V</td>
<td>40µW@2V</td>
<td>8µW@2V</td>
</tr>
</tbody>
</table>

The power and size comparison with other RF powered systems is shown in Table 1. The proposed transponder is found to have low power consumption and small die area compared to other researches.

V. CONCLUSION

We present a RF powered transponder with temperature sensor for environmental monitoring. The temperature compensated ring oscillator and oversampling synchronizer solved the problem caused by high radio frequency field and integration of temperature sensor. The generated clock signal has maximum 5% variation under 1-V supply voltage sweep and 90°C temperature change. The resolution of 0.8°C is achieved in the temperature sensor with only 1.6-µW power. The chip size is minimized by sharing common blocks and substituting large passive elements with active devices.

The transponder is fabricated in 0.25-µm CMOS process. The chip area is 0.5mm x 0.6mm excluding pads. Total power consumption is 8µW during active state.

REFERENCES


