LOW POWER CAPACITIVE HUMIDITY SENSOR READOUT IC WITH ON-CHIP TEMPERATURE SENSOR AND FULL DIGITAL OUTPUT FOR USN APPLICATIONS

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Abstract— In this paper, a low power CMOS integrated capacitance-to-frequency converter with on-chip temperature sensor and fully digital output designed for humidity sensor interface is newly proposed, which is manufactured by using a standard 0.35um 2P/3M CMOS process. This ROIC(Readout IC) consists of on-chip PTAT temperature sensing circuit, low power temperature-to-frequency converter, low power C-F converter, digital compensation circuit, OTP memory, control logic and serial I/O circuits. Capacitance interfacing capability of the circuit is ultra-wide, up to 350pF, which is higher than previously reported works. At a clock speed of 1MHz, the average power dissipation is as low as about 150uW with one humidity measurement per one second, which is lower than ever reported works. And the minimum detectable capacitance is as low as about 4.5fF.

I. INTRODUCTION

Recently, low cost, low power transducers have been an attractive research for ubiquitous sensor network(USN) applications. The USN sensor interface integrated circuits have gone towards the direction of battery-operated and portable systems, where the sensing elements and the processing circuits can be integrated on the same chip or package to realize multi-function intelligent USN sensors.

In order to fit the demands of commercial market on USN sensor transducers, the proposed converter, which is implemented as a capacitance-to-frequency converter, has the low cost feature. It is due to that a digitized signal is produced without realizing the analog to digital converter. Hence, the hardware cost could be reduced. Besides, the output signal of the proposed transducer is a pulse stream, it could be easily sent and received over a wide range of transmission media, such as radio, optical, IR, ultrasonic, and etc. Until now, several achievements have been developed. However, the power consumption of these chips are 895uW and 270uW respectively. To reduce power consumption of the circuit, a novel design of a CMOS integrated capacitance-to-frequency converter with power saving circuit designed for USN applications is thus inspired and designed.

II. CIRCUIT DESIGN

The simplified block diagram of the designed capacitive type humidity sensor interface circuit with on-chip PTAT temperature sensor is shown in Figure 1. The main block of the chip consists of C-F converter, reference timer, PTAT temperature sensor and oscillator, counting logic, OTP memory and digital interface logic circuits.

The chip has digital calibration logic for sensor offset and gain trimming. Under various ambient temperature, the chip provide actual humidity data with digital calibration logic. Due to the process and ambient temperature variation, there could be some fluctuation of the output pulse frequency of the C-F converter and reference timer circuit. However, all of the pulse signal of the chip has simultaneous timing derived from the same original reference pulse signals.

Figure 2 explains how the humidity counting logic works with respect to the ambient relative humidity, Figure 3 also shows how the temperature counting logic works with respect

![Figure 1. Simplified block diagram of the proposed ROIC for humidity and temperature sensors](image-url)
to the ambient temperature. To reduce power dissipation, the power saving circuit was applied to the analog and digital blocks which is major power consuming circuits. The capacitance to frequency converter block and reference timer block consists of optimized size of CMOS Schmitt trigger circuits without power-consuming operational amplifiers is shown in Figure 4. And all the circuit blocks have individual on/off power saving circuits which can be controlled whenever the actual operation is needed. Figure 5 shows the temperature controlled oscillator circuit.

III. CHIP TEST RESULTS

The total chip size is 1.8 mm by 1.9 mm, output resolution is 14bit for temperature sensor and 12bit for humidity sensor. The photograph of the chip layout, fabricated chip and hybrid sensor module are shown in Figure 6. Figure 7 shows the measured results of output pulses for humidity mode. Different pulse counts could be observed low humidity and high humidity mode. Actually 34 pulses observed at low humidity and 42 pulses observed at high humidity.

Figure 2. Humidity counting logic works with respect to the ambient relative humidity

Figure 3. Temperature counting logic works with respect to the ambient temperature

Figure 4. Reference timer circuit with CMOS Schmitt trigger

Figure 5. Temperature controlled oscillator circuit

Figure 6. Photograph of the chip layout(left), fabricated ROIC (right)

Figure 7. Measured results of output pulses for humidity mode : (a) 34 pulses observed at low humidity and (b) 42 pulses observed at high humidity
Figure 8. Measured results of output pulses for temperature mode: (a) 34 pulses observed at room temperature and (b) 39 pulses observed at high temperature.

Figure 8 shows the measured results of output pulses for temperature mode. Obviously, some different pulse counts could be observed under the low temperature and high temperature mode respectively. Actually, 34 pulses were observed at room temperature and 39 pulses were observed at high temperature.

Figure 9 shows an experimental final output digital code of the proposed circuit at various relative humidity, from 20%RH to 80%RH. The linearity of the data is about 99.775% and standard deviation is about 814.8 code. In this case, the humidity resolution is estimated as about 0.00245%RH. The humidity gain (slope) is calculated as 408 code per unit % of relative humidity change.

The proposed ROIC was designed with gain adjustable circuit structure. Figure 10 shows output code at various relative humidity with different gain setting.

Figure 11. Output digital code at various relative humidity with different ambient temperature.

The relationship between humidity output code and ambient temperature is shown in Figure 11. The plots describe the humidity output code decrease as temperature increase with the slope of about 200 code per unit degree Celsius. Figure 12 shows the frequency change of the temperature oscillator output pulse at various ambient temperature. As shown in Figure 12 output frequency increase as ambient temperature increase. Figure 13 shows the summarized relationship between temperature change and frequency of the temperature oscillator output pulse. Figure 14 shows an experimental output digital code of the proposed circuit at various temperature, from -40°C to 120°C.
Figure 12. The frequency change of the temperature oscillator output pulse at various ambient temperature.

The linearity of the data is about 99.394% and standard deviation is about 1346 code. In this case the temperature resolution is estimated as about 0.0058 °C. The temperature gain(slope) is calculated as 172 code per unit degree of ambient temperature change.

IV. CONCLUSIONS

In this paper, a low power CMOS integrated C-F converter with on-chip temperature sensor and fully digital output designed for humidity sensor interface is newly proposed, which is manufactured by using a standard 0.35um 2P/3M CMOS process. Capacitance interfacing capability of the circuit is ultra-wide, up to 350pF. The average power dissipation is as low as about 150uW with one humidity measurement per one second. And the minimum detectable capacitance is as low as about 4.5fF. The total chip size is 1.8 mm by 1.9 mm, output resolution is 14bit for temperature sensor and 12bit for humidity sensor. The temperature resolution of the chip is about ±0.0058 °C at 25 °C and the humidity resolution is ±0.00245 %RH at 25 °C. Also, the proposed ROIC have programmable gain and offset trimming circuits for humidity/temperature signal calibration.

ACKNOWLEDGMENT

This work was supported by the IT R&D program of MKE/IITA, Republic of Korea [2006-S-054-03].

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