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High Performance Smart Temperature Sensor Using Voltage Controlled Ring Oscillator

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Abstract— *In the broadest definition, a* ***sensor*** *is an electronic component, module, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. Temperature is most-measured process variable in the industrial automation. The most commonly, temperature sensor was used to convert the temperature value to the electrical value. The temperature sensors are the key to read the temperatures correctly and to control the temperature in the industrials applications. Such "smart" temperature sensors combine a sensor and interface electronics on the single chip, and are preferably manufactured in a low-cost standard CMOS process.*

Keywords—CMOS, Sensor, Temperature.

I. INTRODUCTION

Temperature sensors are widely applied in measurement, instrumentation, and control systems. In many applications, it would be attractive to use the temperature sensors which generate a readily interpretable temperature reading in the digital format.

Temperature is unique of the supreme significant important physical quantities and is almost common in our day-to-day life and which is autonomous of the amount of material i.e. temperature is having intensive property. CMOS temperature sensor which is designed using self-bias differential voltage controlled ring oscillator at 180 nm TSMC CMOS technology to achieve low jitter operation. Temperature sensor and its various components Used VCRO has full range voltage controllability along with a wide tuning range from 185 MHz to 810 MHz, and with free running frequency of 93 MHz. Power dissipation of Voltage controlled ring oscillator at 1.8V power supply is 438.91µW.There are different types of smart sensors used in many fields of the industry like, biomedical application, control systems, security systems etc. These Microsystems combine sensing, accuracy and signal processing in a microscopic scale. Examples of smart sensors include

- Temperature sensors
- Pressure sensors
- Accelerometer sensors
- Optical sensors
- Humidity sensors
- Gas sensors

II. TEMPRATURE SENSOR

Temperature is one of the most important fundamental physical quantities that are a measure of hotness and coldness on a numerical scale. Temperature sensors are widely used in measurement, instrumentation, and control systems. In many applications, it would be attractive to use the temperature sensors which produce readily interpretable temperature reading in the digital format [2]. Such "smart" temperature sensors combine a sensor and interface electronics on the single chip, and are preferably manufactured in a low-cost standard CMOS process. Block diagram and Circuit diagram for temperature sensor is shown below in fig 2.1.

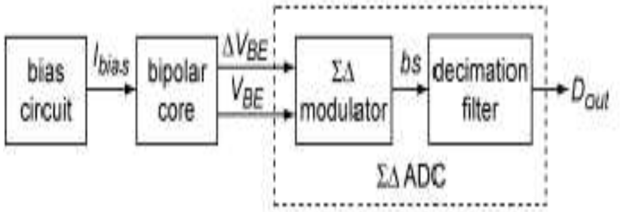

FIG 2.1 (A) BASIC BLOCK DIAGRAM OF TEMPERATURE SENSOR

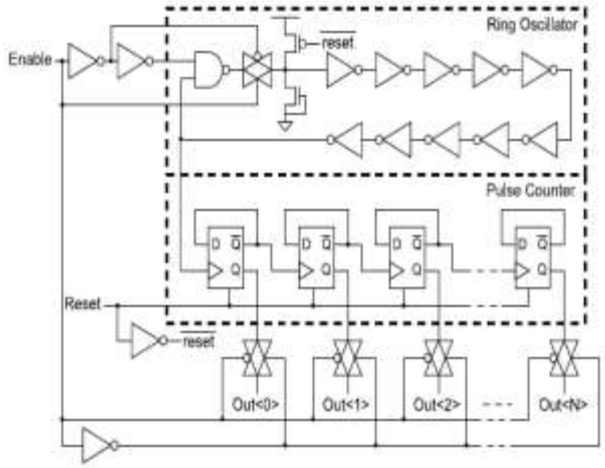

FIG 2.1 (B) SCHEMATIC OF TEMPERATURE SENSOR COMPONENT

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It consist ring oscillator [1], transmission gate and pulse counter circuit. Pulse counter circuit is designed using d flip flop. The oscillation period (1/*f*) is converted in to a number of oscillations by applying enable signal of fixed pulse width (PW), and the number of oscillations is stored in the counter to produce the digital output [3]

III. VOLTAGE CONTROLLED RING OSCILLATOR

The voltage controlled ring oscillator is used to generate a signal of specific frequency. This VCO is designed using self-bias differential ring oscillator as shown in figure 3.1. A ring oscillator device is composed of odd number of NOT gates and whose output is oscillates between the two voltage levels, representing logic '1' and logic '0'.

In this figure 3.1, the MOSFETs M7 and M13 operate as inverter while MOSFETs M2 and M18 operate as current sources. The current sources are used to limit the current available to the inverter or it can be said that the inverter is starved for the current. So this type of oscillator is called current starved voltage controlled oscillator. Here the drain currents of MOSFETs M1 and M12 are the same and are set by the input control voltage. The other transistors are added just to form the 5-stages of ring oscillator because the 5-stage ring oscillator gives better VCO characteristic and frequency range.

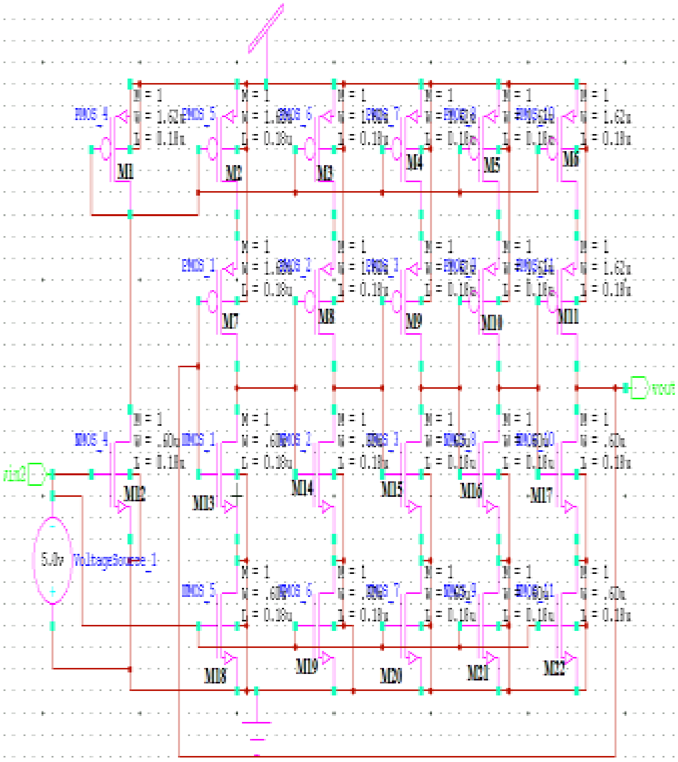

Fig 3.1: Voltage Controlled Ring Oscillator

This VCO characteristic also depends on the width and length parameters. So the width and length of each MOSFET is chosen very carefully according to the used technology. Specification table for ring oscillator is shown in table 3.1. Length and width of MOS transistor is set according to technology.

Table 3.1: Specification for Ring Oscillator

S.No.	Parameter	Values	
1.	Technology	180nm	
2.	Threshold Voltage	0.37V	
3.	Minimum Operating Voltage	1.8 V	
4.	NMOS	Length=0.18u	Width=0.60u
5.	PMOS	Length=0.18u	Width=1.62u

IV. TEMPERATURE SENSOR COMPONENT AND SENSOR

The temperature sensor component is shown in fig 4.1. It consists of a ring oscillator and a pulse counter circuit. The oscillation period (1/*f*) of voltage controlled ring counter is converted to a number of oscillations by applying enable signal of fixed pulse width, and the number of oscillations is stored in the counter to produce the digital output. Additional circuitry between the enable input and the ring oscillator is used to remove synchronization problem, and the sensor outputs are connected to transmission gates to avoid unnecessary toggling [4]. The reason of synchronization problem is the oscillator frequency which is temperature-dependent [6].

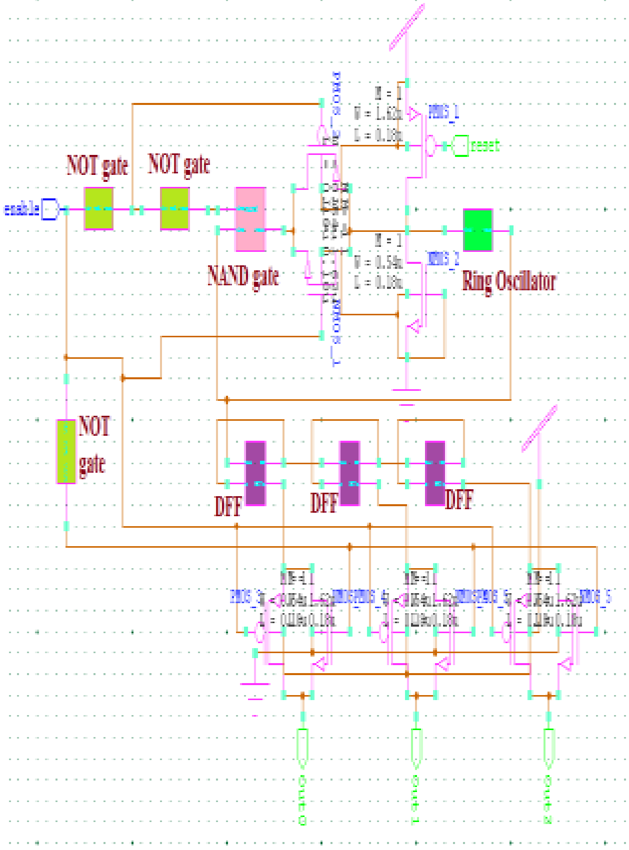

Fig 4.1: Temperature Sensor component

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The complete diagram of temperature sensor contains two temperature sensor components, level shifter, two buffers, two comparator circuit, three XOR gate and one AND gate. Temperature sensor component is used to take readings simultaneously at given temperature readings V_{KT} and operating voltage (V_{OP}) of system. These readings ($T_{KT,t}$ and $V_{OP,t}$) is taken at time t. Low-voltage up level shifters convert the lower voltage, taken from output of temperature sensor component 1 to higher voltage. Comparator compares each temperature reading with previous temperature reading to produce output [5]. Previous temperature readings are stored in buffer circuit. The two comparator outputs are then passed into an XOR gate circuit, which determines if the temperature(V_{KT}) sense by temperature sensor component 1, depends at operating voltage V_{OP} (same as V_{OP}) of temperature sensor component 2 or not. If both V_{KT} and V_{OP} are same then XOR gate gives logic zero output and if different then gives logic '1' output. Circuit diagram of temperature sensor is shown in fig 4.2.

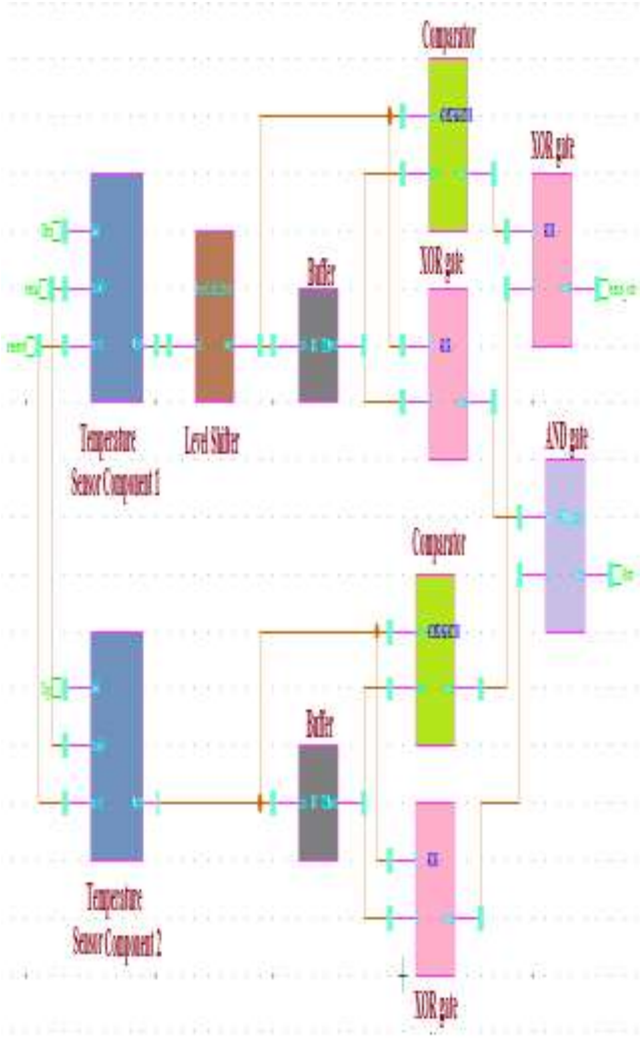

Fig 4.2: Temperature Sensor

V. RESULT AND ANALYSIS

Delay and power dissipation of temperature sensor component is given in table 5.1.

Table 5.1: Delay & Power Dissipation at different V_{DD} of sensor Component

Vdd(V)	**Delay (nS)**	**Power Dissipation (mW)**
1.8	1.528	2.1465
1.6	3.442	1.437
1.4	5.379	0.810
1.2	6.962	0.548
1.0	8.047	0.263

Table 5.2: Delay and Power Dissipation of Temperature sensor at different Temperature

Temperature (ºC)	**Delay (nS)**	**Power Dissipation (mW)**
27	7.656	80.88
37	6.923	83.235
47	5.357	89.56
57	3.514	102.35

Table 5.3: Delay and Power dissipation of Temperature sensor at different V_{TH}

V_{DD} (V)	**Delay (nS)**	**Power Dissipation (mW)**
0.37	7.656	80.88
0.47	9.534	76.475
0.57	10.916	65.32
0.67	12.546	60.44

VI. CONCLUSION

A voltage controlled ring oscillator-based CMOS temperature sensor has been designed at 180 nm CMOS TSMC technology. The proposed temperature sensor occupies smaller silicon area with higher resolution than the conventional temperature sensor based on band gap reference. Various parameters like delay and power dissipation of other circuits are also calculated with respect to different power supply & threshold voltages. Result shows that speed and power dissipation of circuit are directly proportional to power supply voltage. Power dissipation and delay of VCRO based temperature sensor at 5V power supply is 80.88mW and 7.656 nS respectively.

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