Design and Analysis of Temperature Sensor using CMOS Technology
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Abstract— This paper presents CMOS temperature sensor which is designed using starved voltage controlled ring oscillator at 180 nm CMOS technology. CMOS temperature sensor also consists a voltage level shifter, a counter, and a register that is designed using d flip flop. Temperature sensor occupies smaller silicon area with higher resolution than the conventional temperature sensor. Used VCRO has full range voltage controllability along with a wide tuning range and is most suitable for low-voltage operation due to its full range voltage controllability. Various parameters of circuits are calculated. Result shows that speed and power dissipation of circuit are directly proportional to power supply voltage. By increasing temperature we see that power dissipation of circuit increases while delay decreases.

Key words: CMOS, VCO, WSN

I. INTRODUCTION

Temperature is one of the most important fundamental physical quantity which is almost common in our daily life and do not depend upon of materials i.e. temperature has intensive property. Nowadays for each & every application new higher performance standard circuits are required. As we know thousands or millions of component are integrated on thin silicon wafers. Before the wafer is scribed and cut into individual chips, they are usually laser trimmed. One popular use of embedded temperature sensors in VLSI implementation is in the emergence of RFID and wireless sensor network (WSN) applications.

For such type of applications, power consumption, instead of sensing range and accuracy requirements, becomes more important. CMOS temperature sensor has been designed for microprocessor application. The advantage of this circuit is no need of any BJT component. One of the popular method is by using the difference between the two outputs of register. These sensors in general achieve good accuracy, less power dissipation.

The temperature sensors have been realized using a ring-oscillator, in a 180 nm technology. Temperature is a physical quantity that is a measure of hotness and coldness on a numerical scale. Output signal generated by the ring oscillator is proportional to the change in temperature. The positive rising edge of voltage level shifter is counted by the counter and then it is saved in register i.e. d flip flop. The difference between outputs of register is taken as temperature. Block diagram of temperature sensor is given below.

II. DESIGN OF CIRCUIT

A. Ring Oscillator:
A voltage controlled oscillator (VCO) is one of the most important building blocks in analog and digital circuits. There are many different implementations of VCO’s. One of them is a ring oscillator based VCO, which is commonly used in the clock generation Subsystem. The ring oscillator is mainly used for its direct consequence of Easy integration. Due to the integrated nature ring oscillators, they have become the main part of many digital communication systems. They are used as voltage controlled Oscillators (VCO’S) in applications such as clock recovery circuits for serial data Communications.

A ring oscillator consists of number of gain stages in a loop in which output of the last stage is fed back to the input of the first. The ring oscillator must satisfy the Barkhausen criteria, which says that it should provide a phase shift of 2π and to achieve oscillation it must have a unity gain. The voltage controlled oscillator is designed using self-bias ring oscillator as shown in figure 2.

B. D Flip Flop
A register is a memory device that can be used to Store more than one bit of information. A register is usually realized as several flip-flops with common control signals that control the movement of data to and from the register. Flip-Flop stores a logical state of one or more data input signals in response to a clock pulse. During recurring clock intervals to receive and maintain data for a limited time period sufficient for other circuits within a system to further process data. Power dissipation is an important parameter in the design of VLSI circuits, and the clock network is responsible for a substantial part of it (up to 50%). When the supply voltage is decreased the speed of the logic circuits

Fig.1: Block diagram of temperature sensor

Fig.2: Voltage Controlled ring oscillator
might be decreased due to reduction in effective input voltage to the transistors. Circuit diagram of D flip flop is shown below in fig 3.

**Fig.3: Schematic Diagram of D Flip- Flop**
It consists 4 nand gate and 1 not gate. D and clk are its input. Clock pulse (clk) is used to control the data moving from input to output.

**C. Level Shifter**
In this temperature sensor the reduced ring oscillator output is extended by voltage level shifter to full-scale so that the counter counts the number of its rising edge. A binary input signal having low voltage level to a binary signal having different output is translated by a level shifter in an integrated circuit. The level shifter is controlled by the low state voltage translation circuits. Schematic diagram of level shifter is shown in fig 4.

**Fig.4: Level Shifter**

**D. Temperature Sensor**
A temperature sensor is a device that gathers data concerning the temperature from a source and converts it to a form that can be understood either by an observer or another device. Schematic diagram of Temperature Sensor is shown above in fig. 5.

**III. RESULT AND DISCUSSION**

**A. Ring Oscillator**
The voltage controlled oscillator is used to generate a specific frequency signal. The VCO is designed by 3-stage ring oscillator which gives better VCO

**Fig. 6: Voltage Controlled Ring Oscillator**

**Fig. 7: Characteristic of VCO**
characteristic and frequency range. The simulated waveform of VCO and the characteristic is shown above in fig 6 and fig 7.Power dissipation and delay of ring oscillator at different power supply voltage is shown below in table 1 when W/L ration of PMOS transistor is equal to 3 times of NMOS W/L ratio.

**Table 1: Power Dissipation & Delay of Ring Oscillator at different Voltage**

<table>
<thead>
<tr>
<th>Vdd(V)</th>
<th>Delay ($10^{-12}$s)</th>
<th>Power(µW)</th>
<th>PDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3130</td>
<td>15.83</td>
<td>20.784</td>
</tr>
<tr>
<td>1.2</td>
<td>1.1896</td>
<td>67.14</td>
<td>99.869</td>
</tr>
<tr>
<td>1.4</td>
<td>1.0662</td>
<td>83.38</td>
<td>88.899</td>
</tr>
<tr>
<td>1.6</td>
<td>0.9428</td>
<td>92.60</td>
<td>87.303</td>
</tr>
<tr>
<td>1.8</td>
<td>0.8194</td>
<td>92.42</td>
<td>75.728</td>
</tr>
</tbody>
</table>

Here we see that by increasing power supply voltage delay of the circuit decreases while power dissipation increases as power dissipation of circuit is directly proportional to square of power supply voltage.

**B. D Flip Flop**
Waveform of D flip flop is shown below in fig 8. When input D is low & clock pulse is 0, then Qb will be low & Q will be high. If input D is high & clock pulse is 0. Then Qb will be low & Q will be high. Simulated waveform of D flip flop is shown below in fig 8.

**Fig.8: Simulated waveform of D flip flop**
### C. Level Shifter

Waveform of voltage level shifter is shown below in fig 9. When the input signal $V_{in}$ is low then output will also low & if input signal $V_{in}$ is high then the output will be high.

![Waveform voltage level shifter](image)

**Fig.9:** Waveform voltage level shifter

### D. Temperature sensor

Ring oscillator-based temperature sensors provide a good indication of circuit speed. Its waveform is shown below in fig 10.

![Waveform voltage level shifter](image)

**Fig.10:** Waveform voltage level shifter

Power dissipation & delay of temperature sensor at different threshold voltage and at different temperature is shown below in table 2 and table 3.

#### Table 2: Delay and Power at different $V_{TH}$

<table>
<thead>
<tr>
<th>$V_{TH}$ (V)</th>
<th>Delay ($10^{-15}$s)</th>
<th>Power(µW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.37</td>
<td>199.43</td>
<td>227.585</td>
</tr>
<tr>
<td>0.47</td>
<td>200.17</td>
<td>161.83</td>
</tr>
<tr>
<td>0.57</td>
<td>199.91</td>
<td>146.41</td>
</tr>
<tr>
<td>0.67</td>
<td>198.57</td>
<td>44.22</td>
</tr>
<tr>
<td>0.77</td>
<td>195.88</td>
<td>75.74</td>
</tr>
</tbody>
</table>

#### Table 3: Power, Delay and PDP at Different Temperature

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Delay ($10^{-15}$s)</th>
<th>Power(µW)</th>
<th>PDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>37º</td>
<td>1.3130</td>
<td>40.35</td>
<td>53.003</td>
</tr>
<tr>
<td>47º</td>
<td>1.1896</td>
<td>112.08</td>
<td>133.33</td>
</tr>
<tr>
<td>57º</td>
<td>1.0662</td>
<td>241.175</td>
<td>257.13</td>
</tr>
<tr>
<td>67º</td>
<td>0.9428</td>
<td>245.175</td>
<td>231.15</td>
</tr>
<tr>
<td>77º</td>
<td>0.8194</td>
<td>344.39</td>
<td>282.19</td>
</tr>
</tbody>
</table>

### IV. Conclusion

A ring oscillator-based CMOS temperature sensor has been presented. Temperature sensor occupies smaller silicon area with higher resolution than the conventional temperature sensor based on band gap reference. Extremely low power consumption is achieved through charge recycling. Ring oscillators are basic building blocks of complex integrated circuits. They are mainly used as clock generating circuits. Used VCRO has full range voltage controllability along with a wide tuning range and is most suitable for low-voltage operation due to its full range voltage controllability.

### REFERENCES


