
# Ring Oscillator-Based Temperature Sensor in FPGAs

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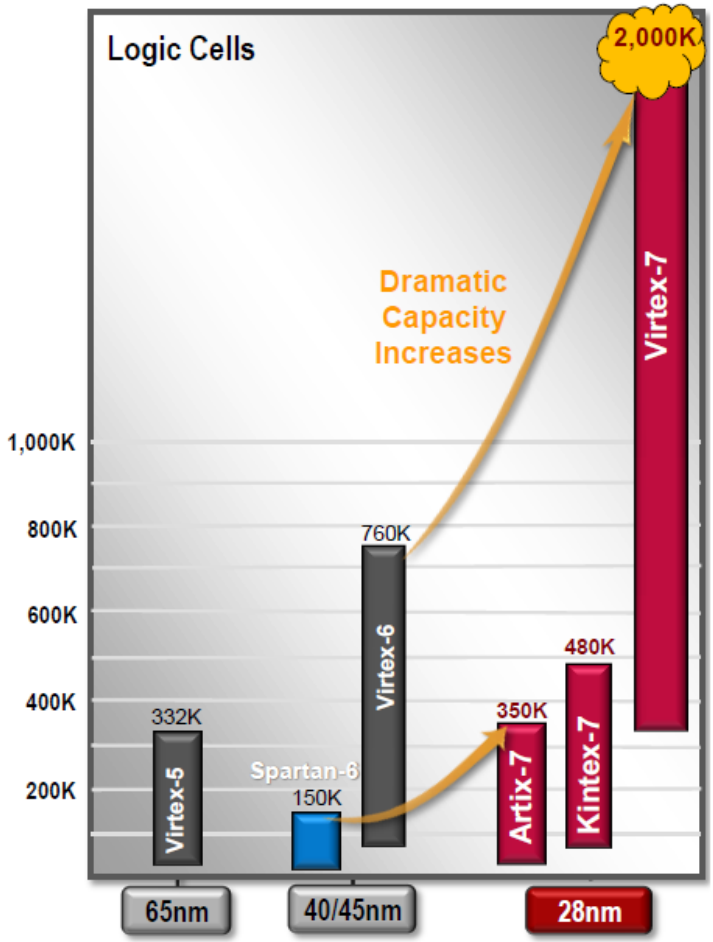
# Presentation Overview

- Introduction
- Thermal Monitoring
- Ring Oscillator
- Ring Oscillator-Based Sensor
- System Monitor
- Conclusion
- References

# Introduction

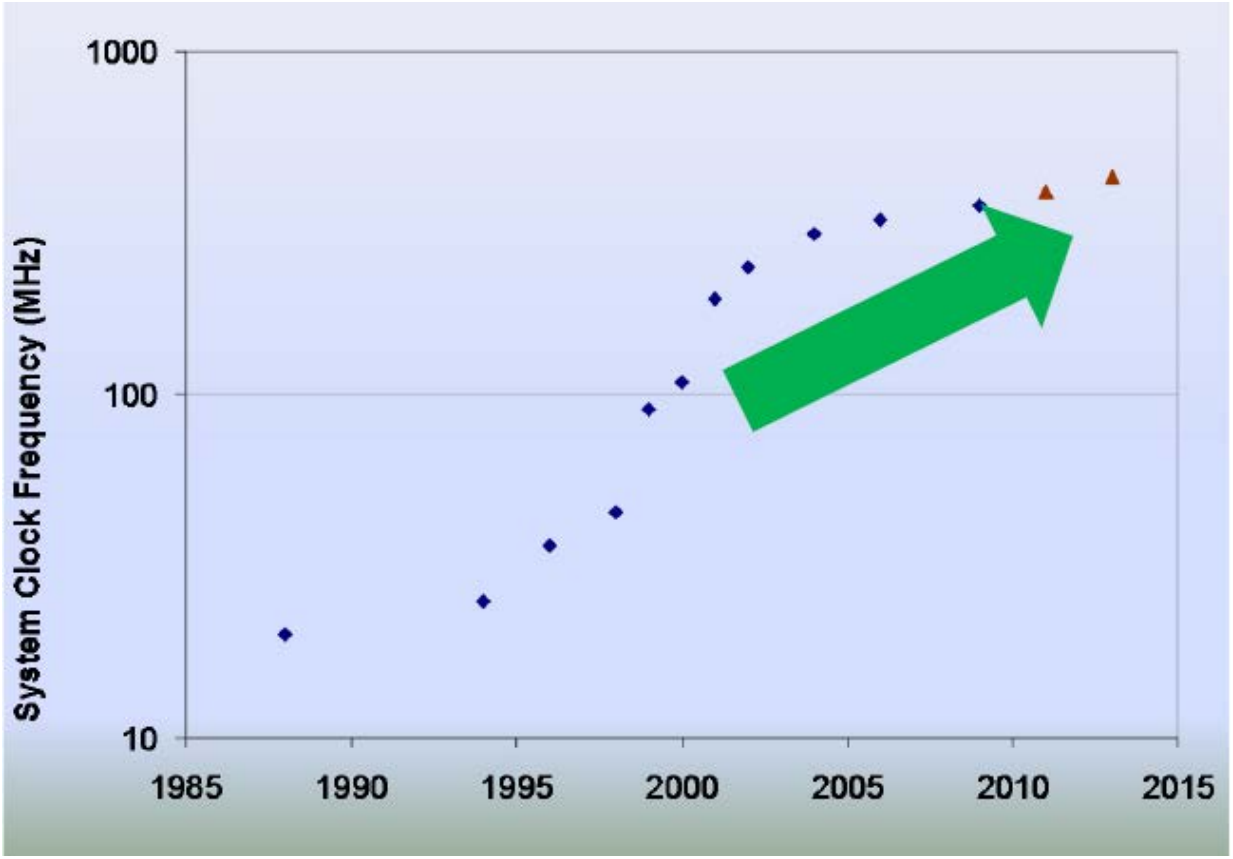
- Field Programmable Gate Array (FPGA): Technology Trend




[Xilinx, 2013]

# Introduction (cont.)

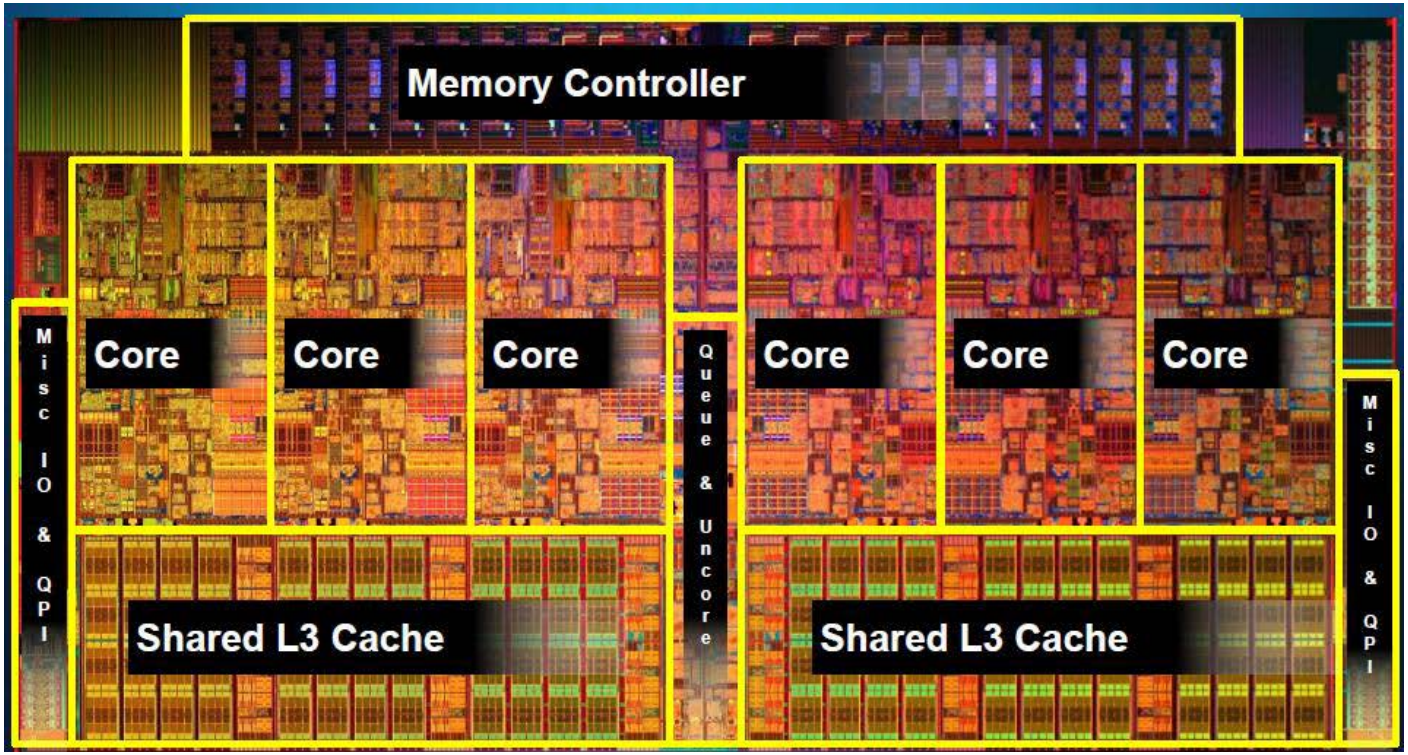
- Field Programmable Gate Array (FPGA): Technology Trend




[Xilinx, 2013]

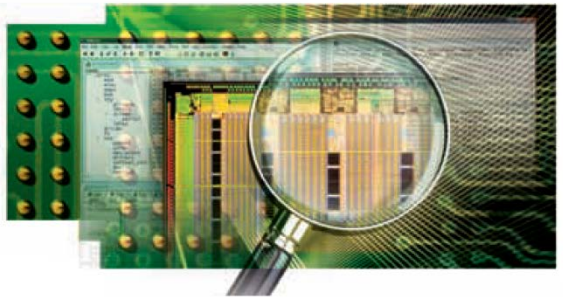
# Introduction (cont.)

- Need for on-chip temperature measurement

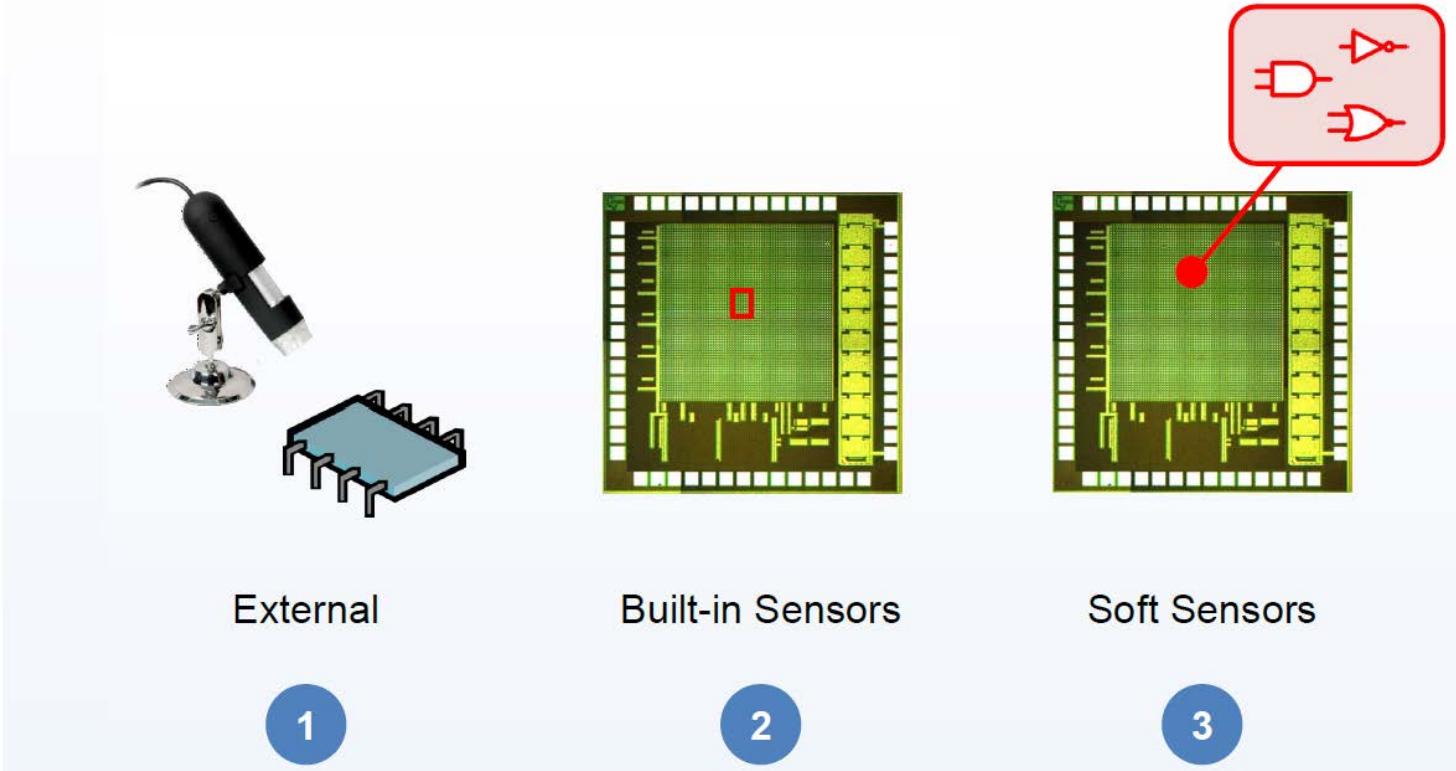



[MPSoC, 2013]

# Thermal Monitoring

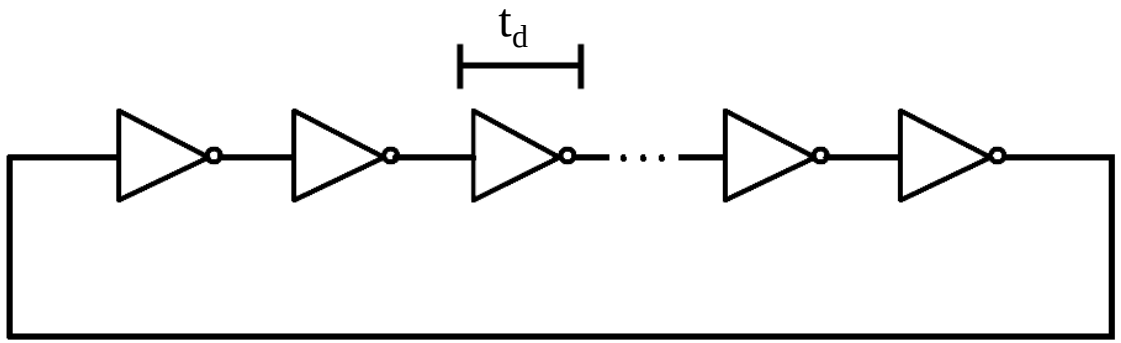


- Thermal sensing in FPGAs



# Ring Oscillator

- A ring oscillator (RO) is formed by connecting an *odd* number of inverters to form a *loop*.




$$T_p = 2 \times n \times t_d$$

$$f = {}^{1}/_{T_p}$$

$T_p$ : period of oscillation

n : number of inverters in loop

$t_d$ : delay of single inverter

# Ring Oscillator (cont.)

- Propagation delay and temperature relationship [1]

$$t_d = \frac{(L/W)C_L}{\mu C_{ox}(V_{DD} - V_T)} ln\left(\frac{1.5V_{DD} - 2V_T}{0.5V_{DD}}\right)$$

$$\mu = \mu_0(T/T_0)^{km} \quad ; \quad km = -1.2 \sim -2.0$$

$$V_T(T) = V_T(T_0) + \alpha(T - T_0) \quad ; \quad \alpha = -0.5 \sim -3\,\frac{mV}{^\circ K}$$

$$\boldsymbol{T \uparrow \Rightarrow \mu \downarrow \Rightarrow t_d \uparrow}$$

# Ring Oscillator (cont.)

- Propagation delay and temperature relationship [1]

If $V_{DD} \gg V_T \Rightarrow \quad t_d = \frac{(L/W)C_L}{\mu C_{ox} V_{DD}} ln(3)$

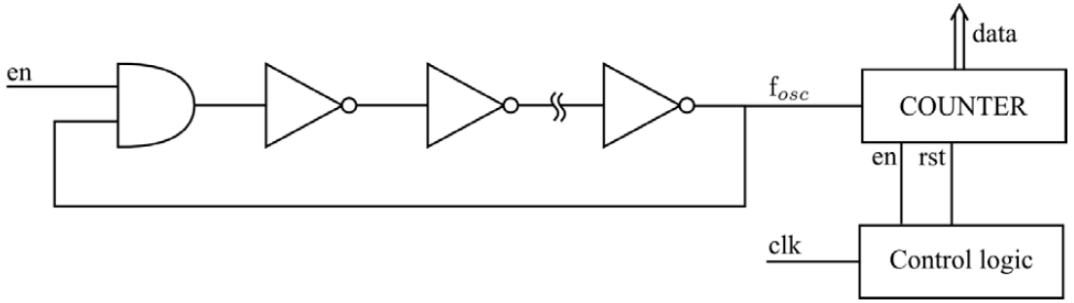
$\mu = \mu_0 (T/T_0)^{km}$ ; $km = -1.2 \sim -2.0$

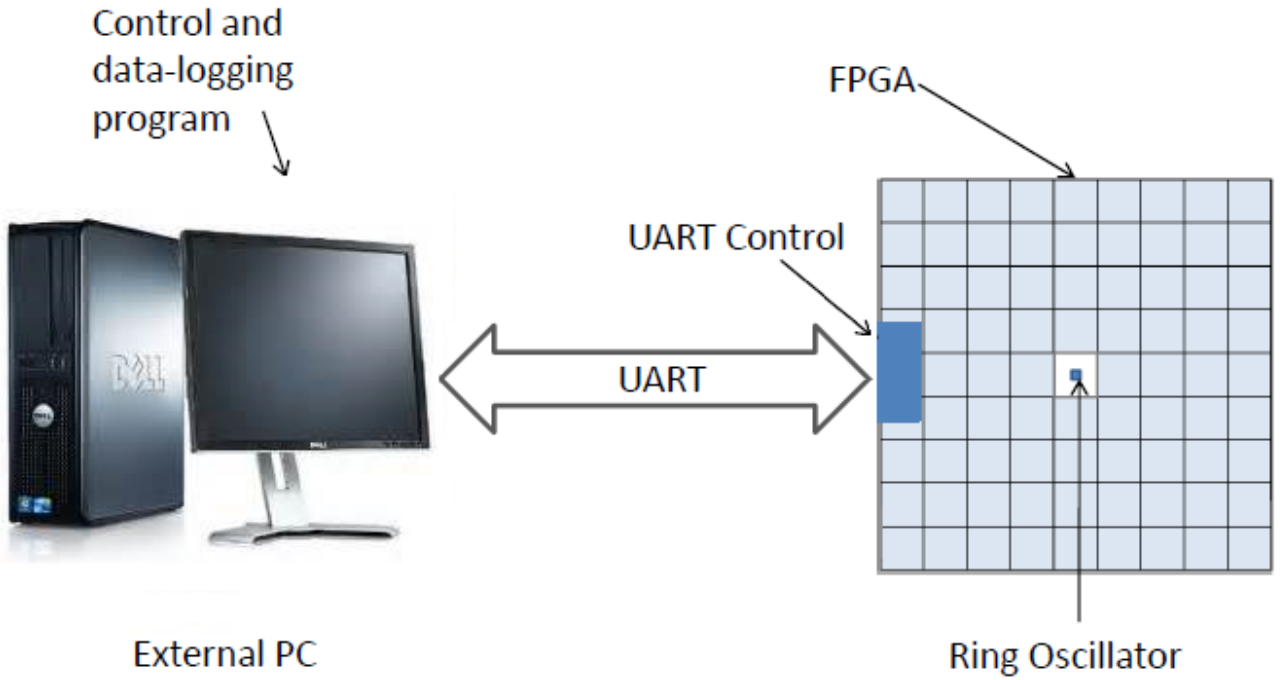
$$\boldsymbol{T \uparrow \Rightarrow \mu \downarrow \ \& \ V_T \downarrow}$$

If $\boldsymbol{V_{DD} \gg V_T}$ then $\boldsymbol{t_d \propto T \Rightarrow T_p \propto T \Rightarrow}$ $\boxed{\boldsymbol{f \propto \frac{1}{T}}}$

# Ring Oscillator-Based Sensor

- Thermal Monitor Architecture



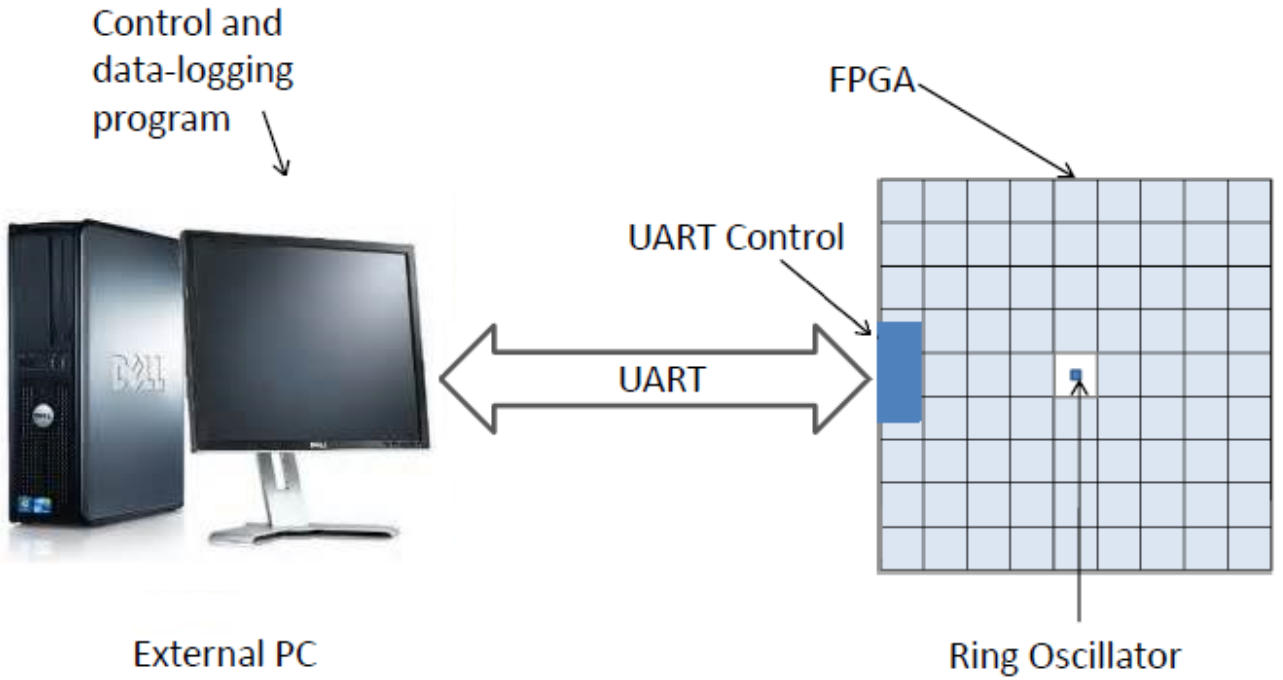




[2]

# Ring Oscillator-Based Sensor(cont.)

- Thermal Monitor Architecture

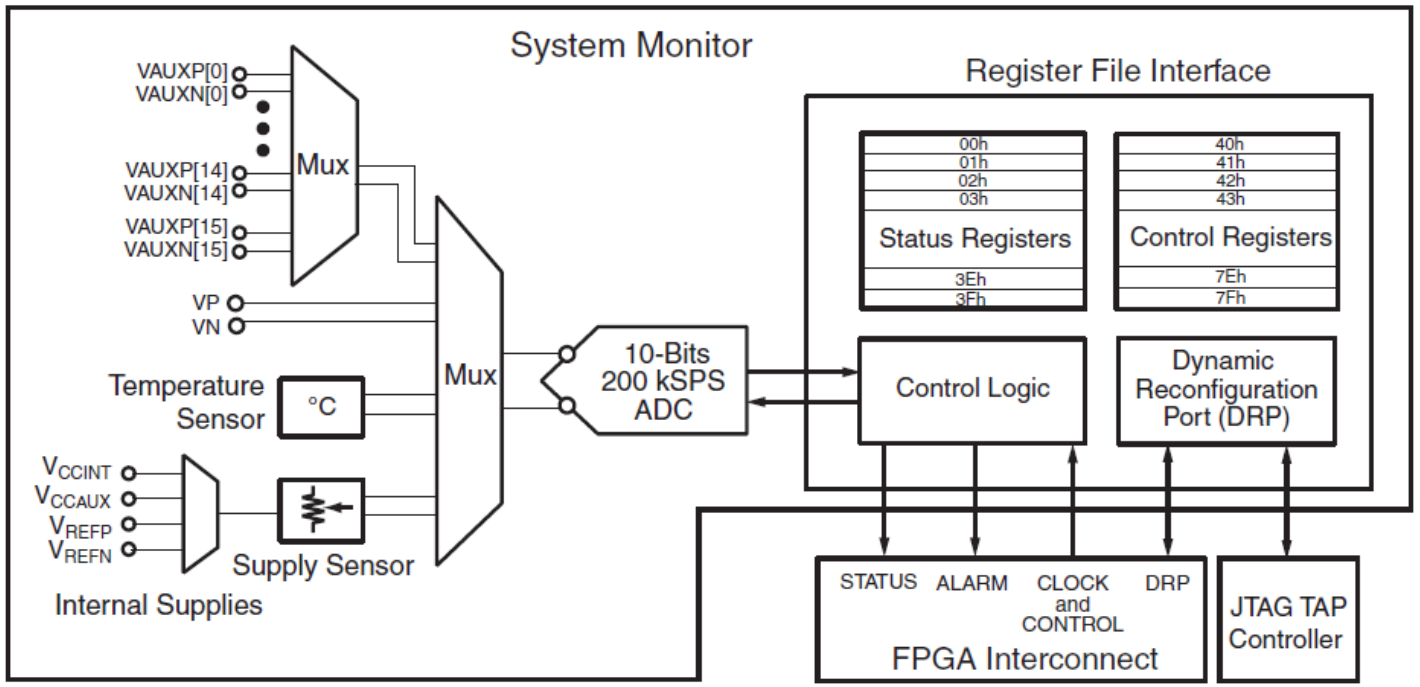
$$Temperature = -0.000234(Count - 69420)^2 + 0.2476(Count - 69420) + 6.3231 \quad [2]$$




[2]

# System Monitor

- System Monitor block diagram

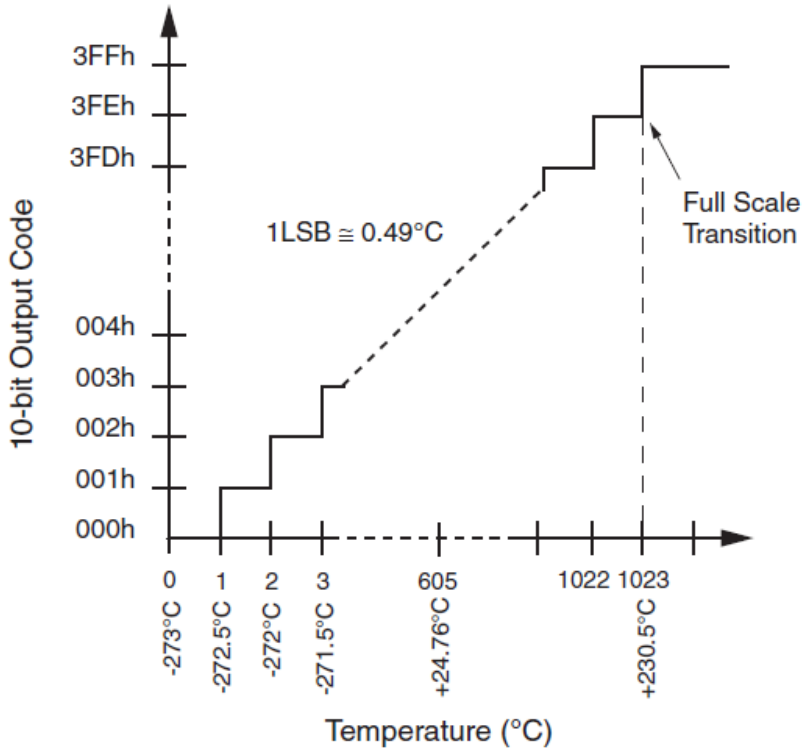



[3]

# System Monitor (cont.)

- Output voltage of the temperature sensor

$$voltage = 10 \times \frac{kT}{q} \times \ln(10)$$

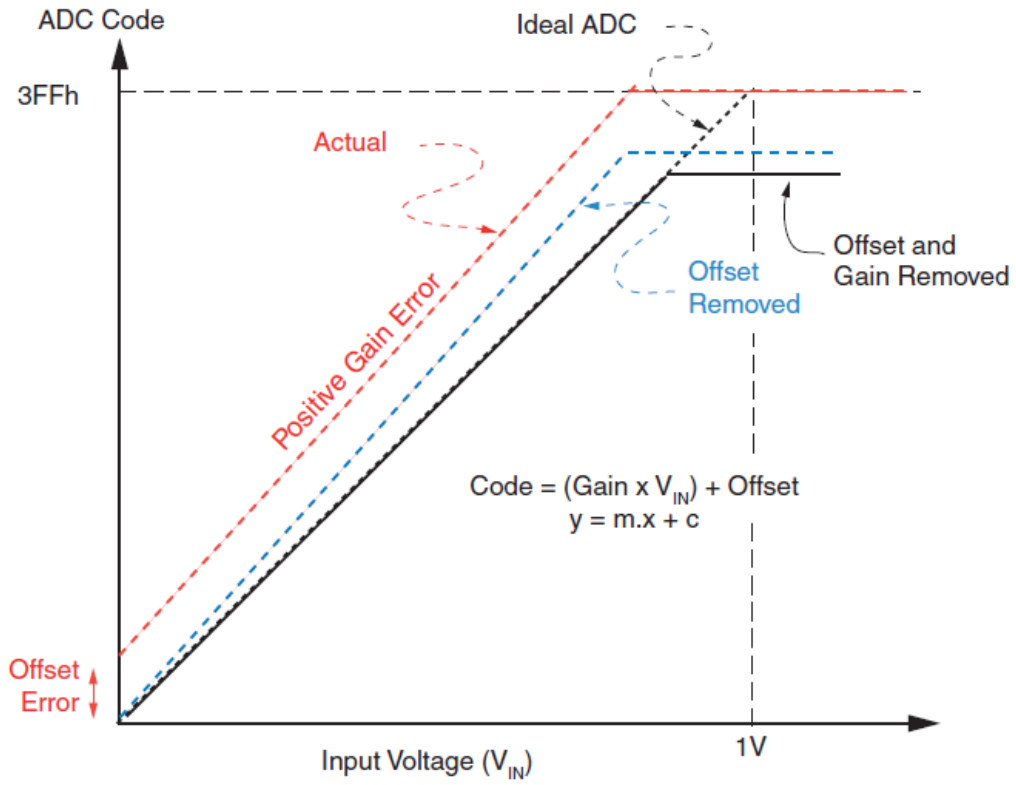



[3]

# System Monitor (cont.)

- The temperature sensor plus the ADC transfer function

$$Temperature(°C) = \frac{ADCcode \times 503.975}{1024} - 273.15$$




[3]

# Conclusion

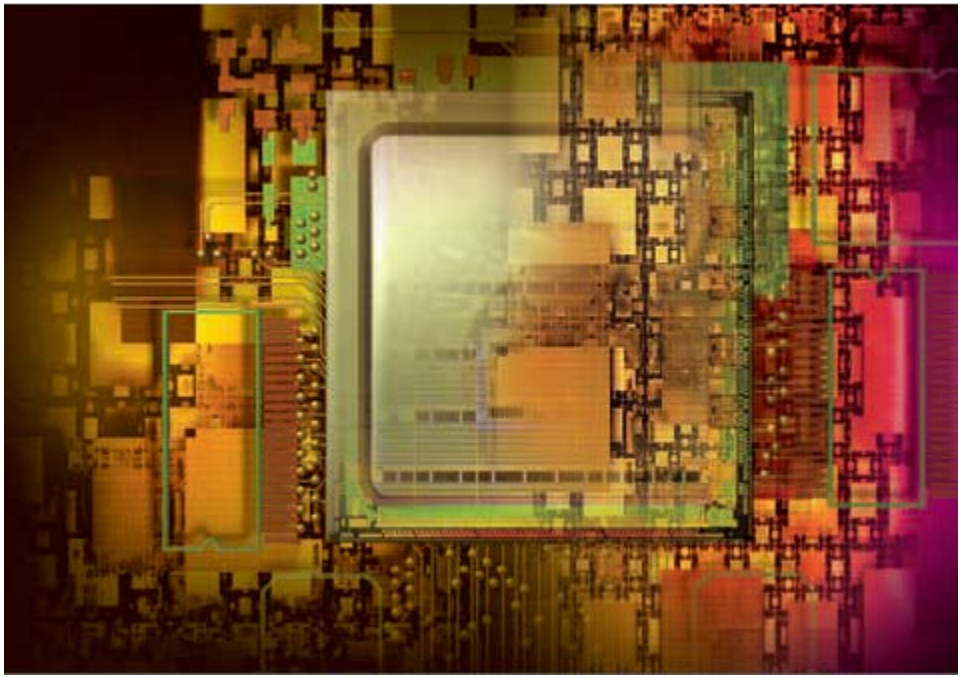
- ✓ Need for on-chip temperature measurement
- ✓ Temperature measurement techniques in FPGAs
- ✓ Ring oscillator theory
- ✓ Mechanism of RO-based temperature sensor
- ✓ A complete hardware-software solution to log measurement data from the FPGA to an off-chip computer in real time
- ✓ Describe Xilinx System Monitor

# References

[1] Poki Chen, Chun-Yan Chu, Mon-Chau Shie, Zi-Fan Zheng, and Zhi-Yuan Zheng. "A Fully Digital Time-Domain Smart Temperature Sensor Realized With 140 FPGA Logic Elements," IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 54, no. 12, pp. 2661-2668, Dec. 2007.

[2] Franco, J., Boemo, E., Castillo, E., and Parrilla, L. "Ring oscillators as thermal sensors in FPGAs: Experiments in low voltage," In Programmable Logic Conference (SPL), 2010 VI Southern, pages 133 –137.

[3] System Monitor (2011). ug192 Virtex-5 FPGA System Monitor User Guide. Xilinx Inc.



Thanks!

Any questions?