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**ASync'06**

# A Level-Crossing Flash Asynchronous Analog-to-Digital Converter

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13 March, 2006  
Grenoble, France

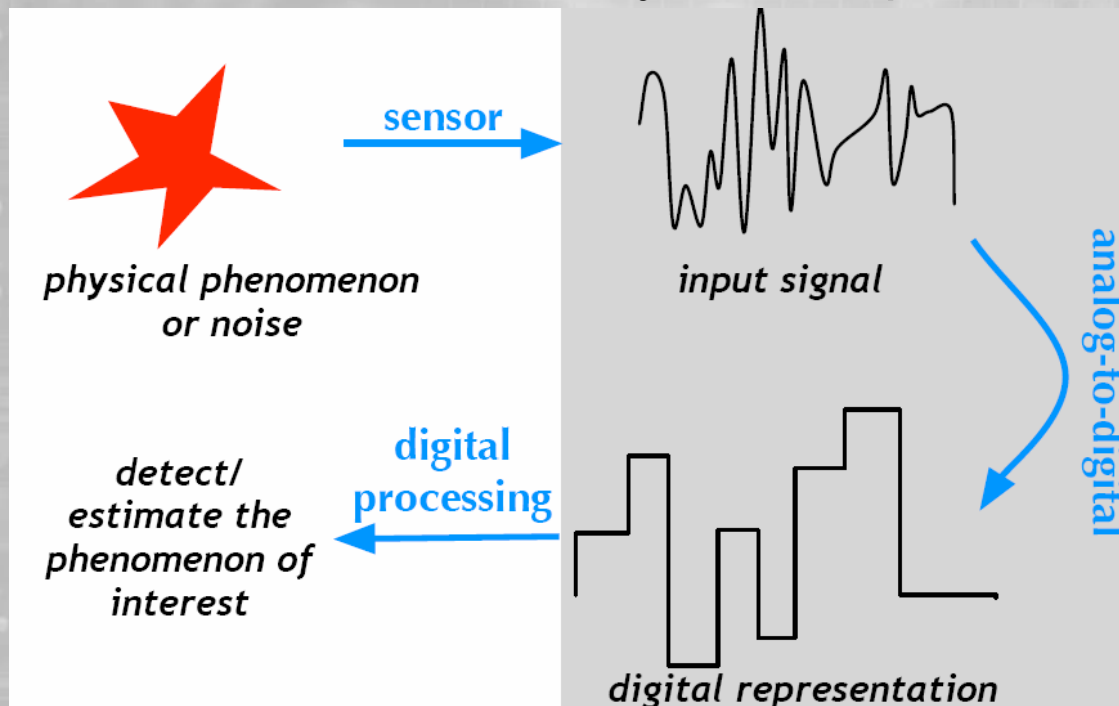
# Motivation

Ultra Low Power ADC will be beneficial in several areas:

- *Signal processing field*
  - data processing in sensor networks
  - increasing lifetime of cell phones
  - temperature, pressure, vibration sensors, etc.
  
- *Biomedical engineering field*
  - low-power implants to monitor human organs
  - process data that reflects changes in the body
  - signal if the body is not functioning properly

# Design Goals

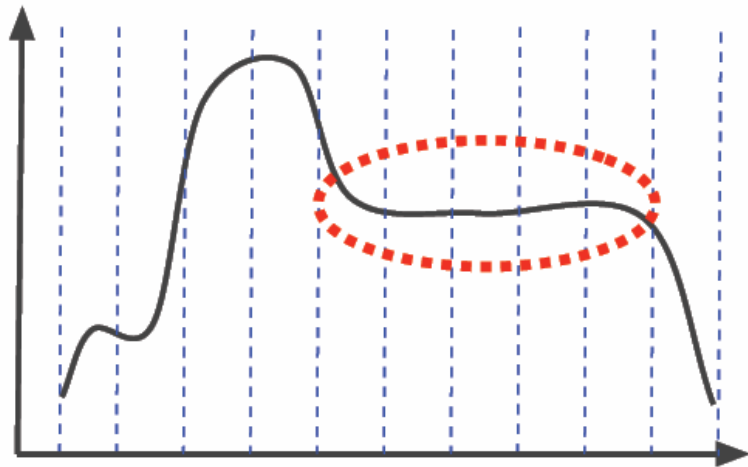
- ❑ Exploit Signal Properties
  - Wide range of input frequencies
  - Real-world signal are often idle
- ❑ Asynchronous Design
  - Circuits adapt to input signal bandwidth (data-driven)
  - System shuts down automatically when input is stable



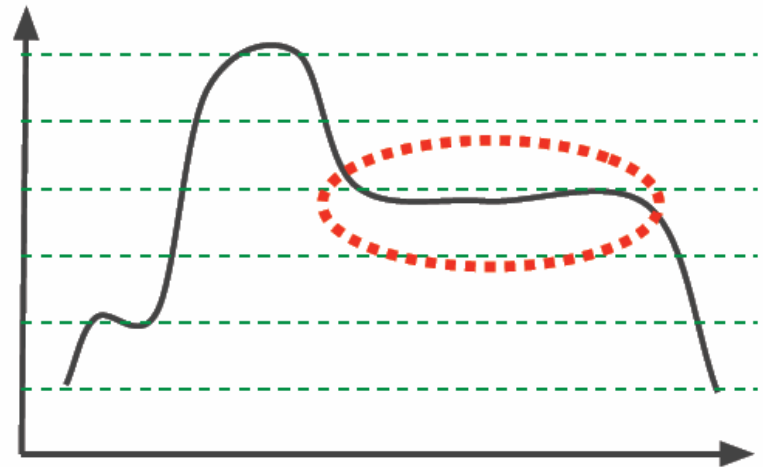
# Asynchronous ADC for Low-Power Applications

- ❖ Design of the ADC
- ❖ Analysis
- ❖ Evaluation
- ❖ Conclusion

# Level Crossing Scheme



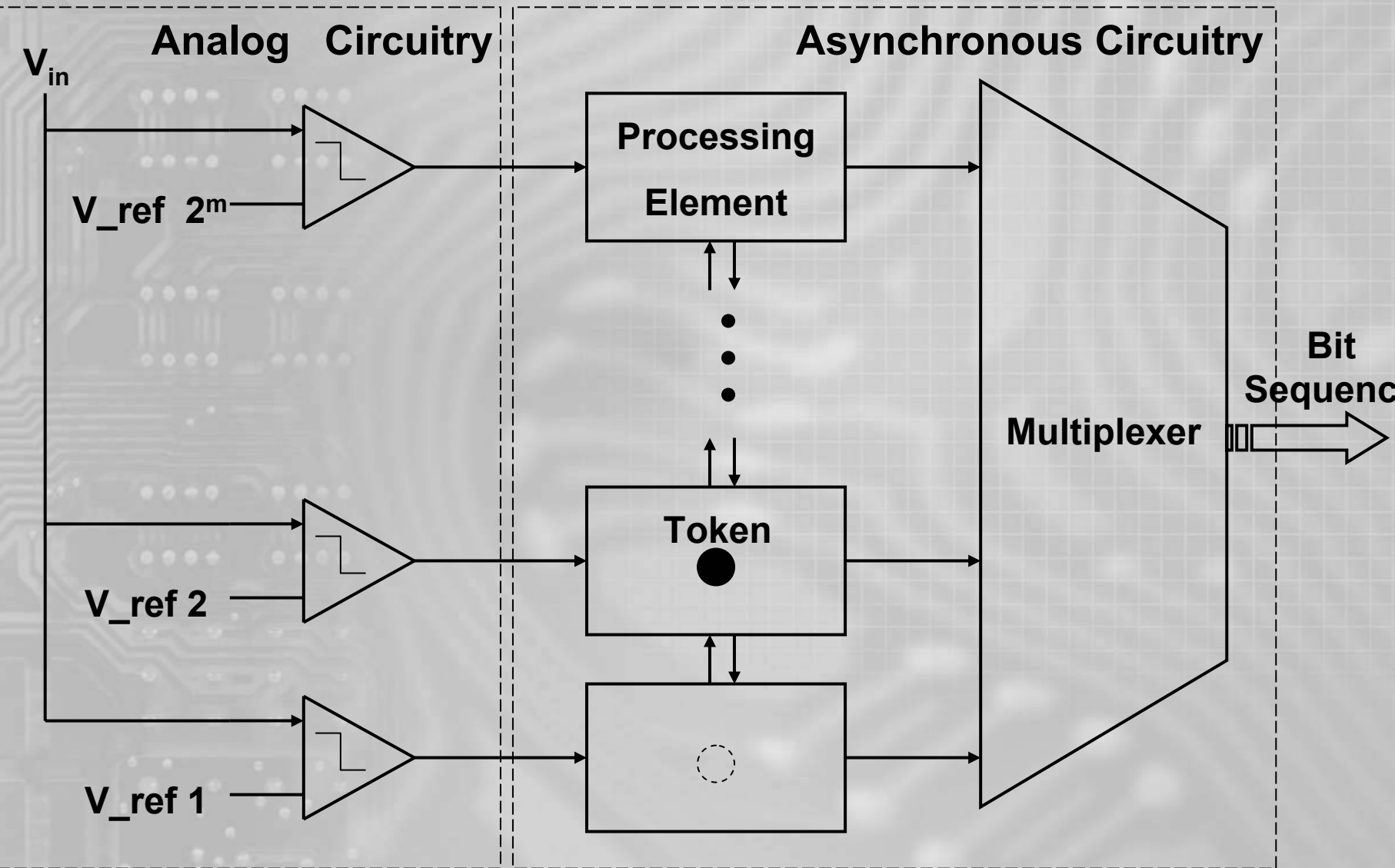
*Conventional uniform Nyquist sampling*



*Non-uniform level-crossing sampling*

- Low power consumption: no activity when signal is not changing
- Bandwidth adaptive: number of samples depends on signal BW

# Proposed ADC Structure

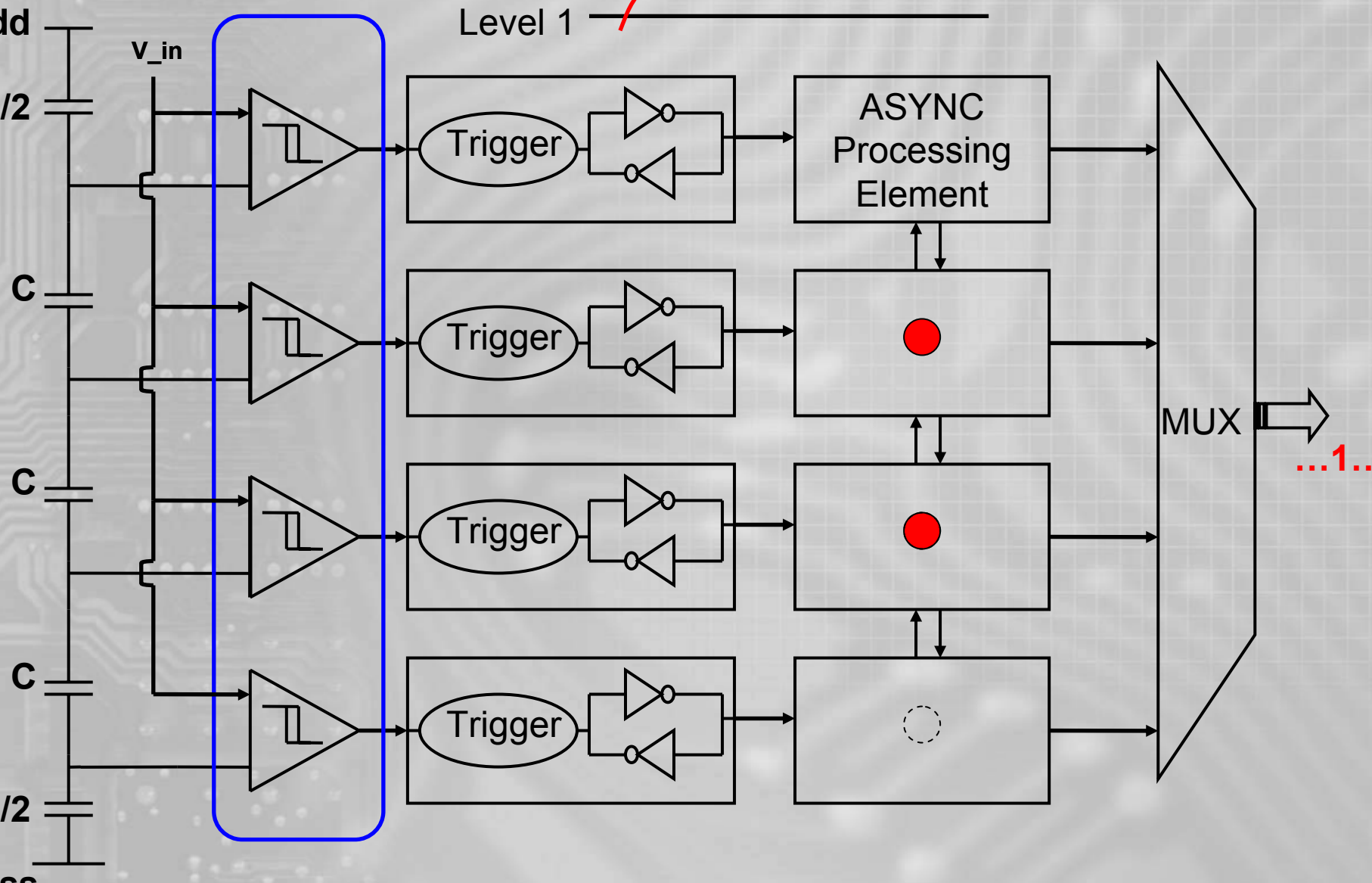


# Design Overview

- Analog circuitry - comparators with hysteresis (for noise immunity)
- CHP (Communicating Hardware Processes) for all asynchronous circuits
- Quasi-Delay Insensitive design style with 4-phase communication protocols
- Data in the ASYNC-ADC is outputted by one channel
- Time is not tracked explicitly

Level 4  
Level 3  
Level 2  
Level 1

# Operation

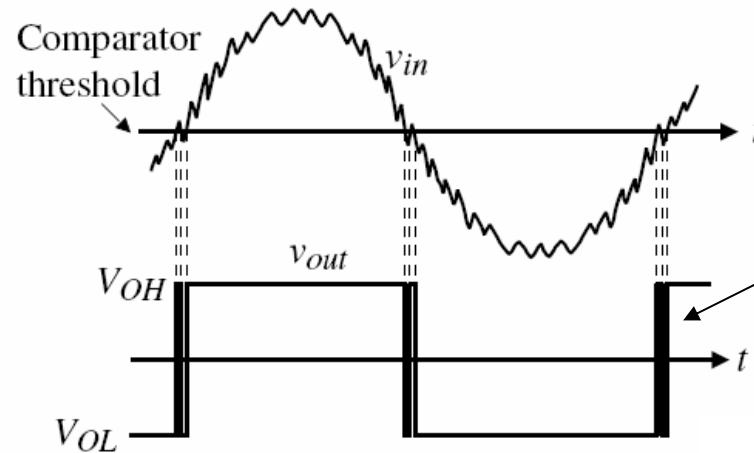




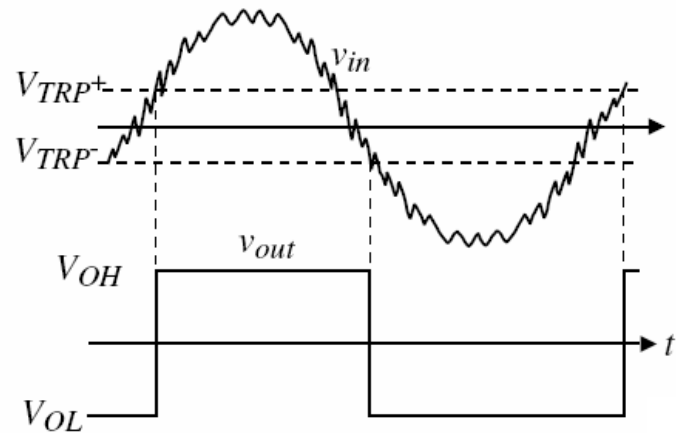
# Analog Considerations

## Influence of Input Noise on the Comparator

Comparator without hysteresis:

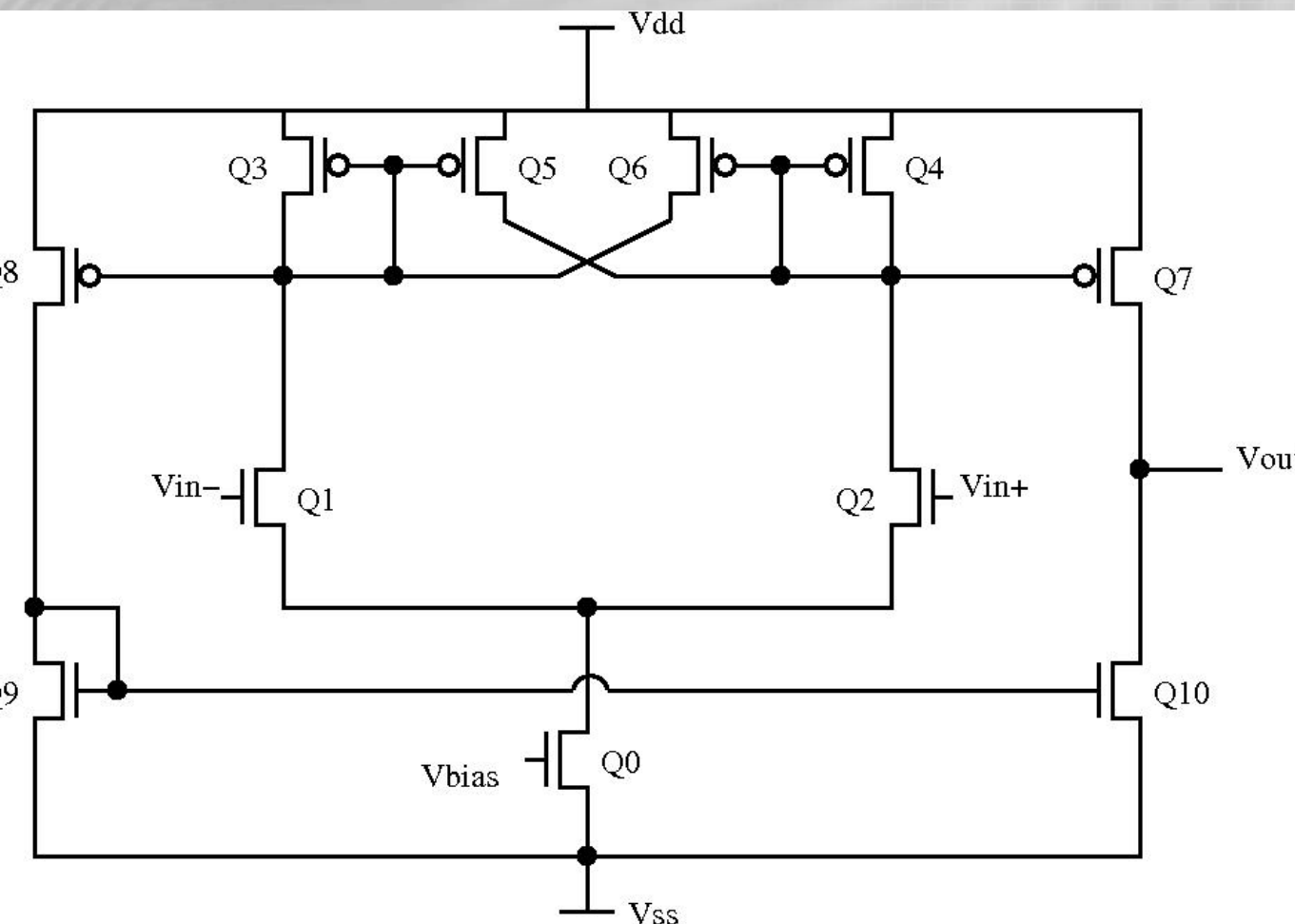


Comparator with hysteresis:



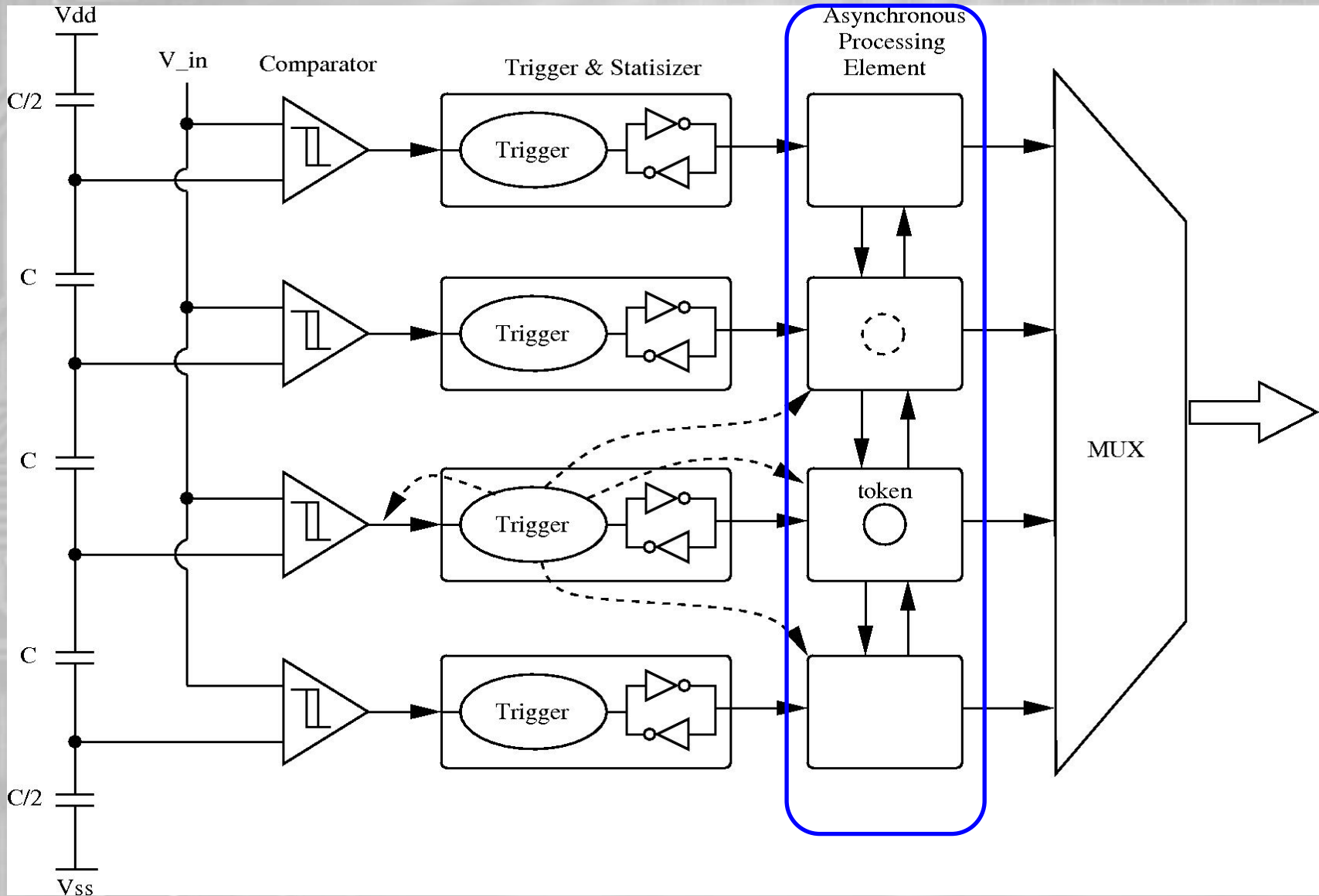
# Implemented Analog Design

## Differential Regenerative Comparator with hysteresis

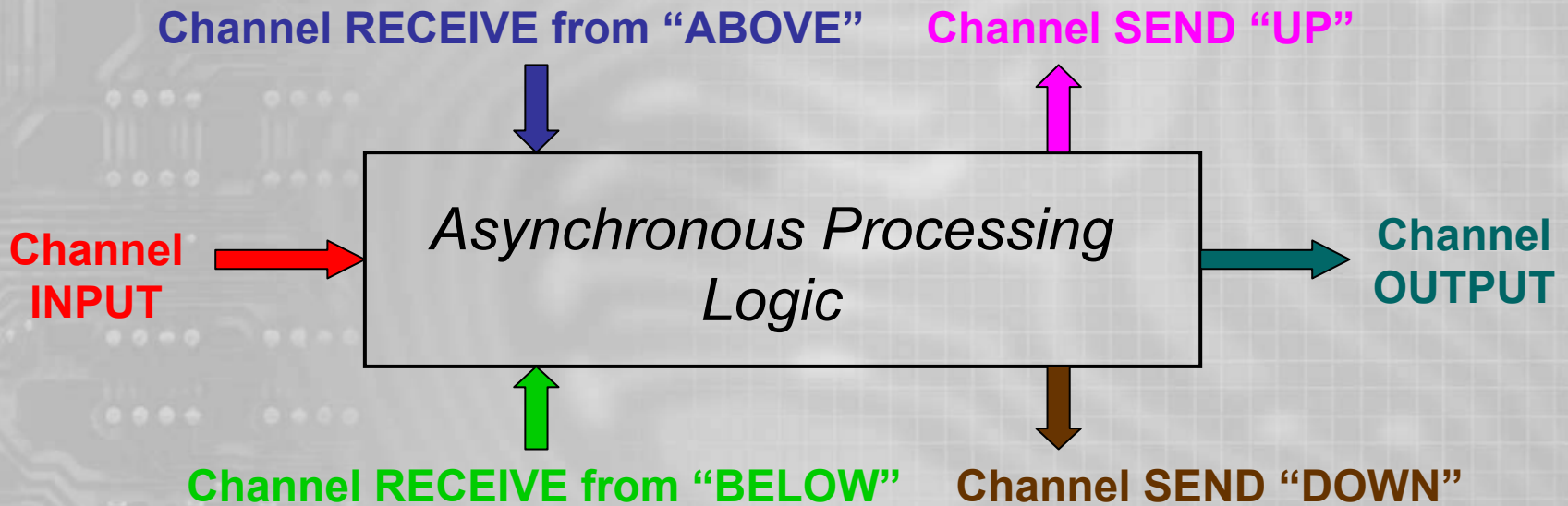
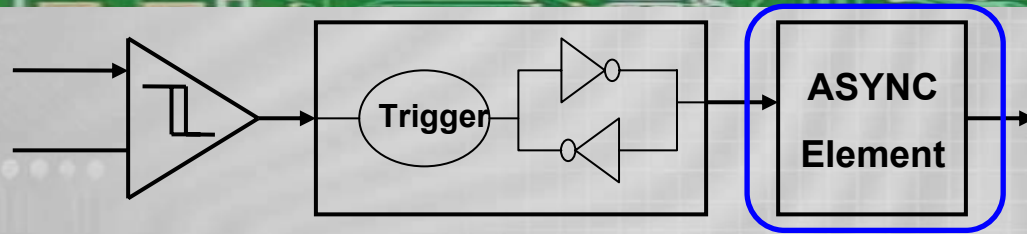


- Positive Feedback
- Tunable Bandwidth
- Variable trip voltage
- High differential gain
- Nonlinearities
- Transistor matching

# Processing Element



# Processing Element

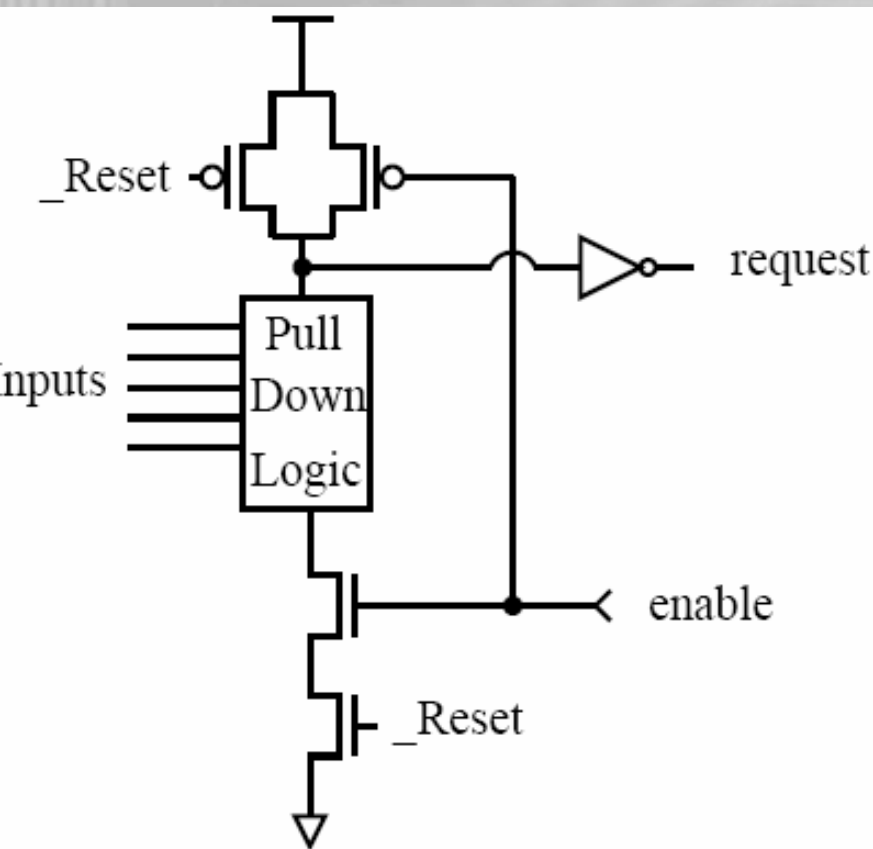
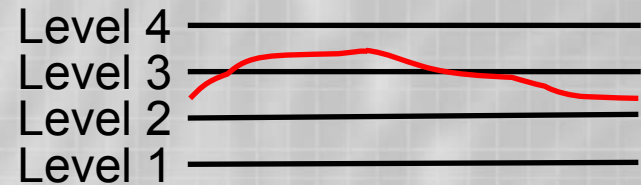
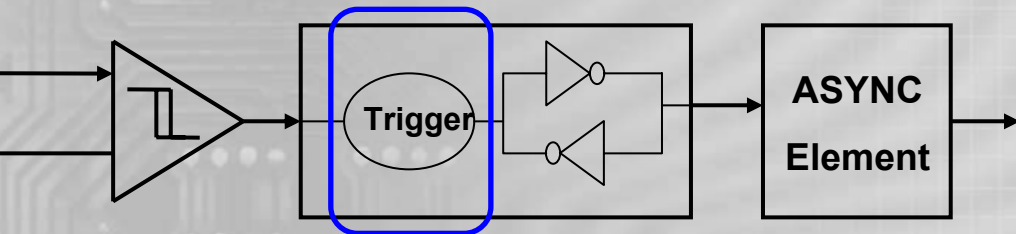


**input** → *TOKEN\_CHECK*; **output** (1) or (0); indicate if signal is above or below

**request from above** → **pass token "above"**; {don't have token}; indicate that token is above

**request from below** → **pass token "down"**; {don't have token}; indicate that token is below

# Digital Design



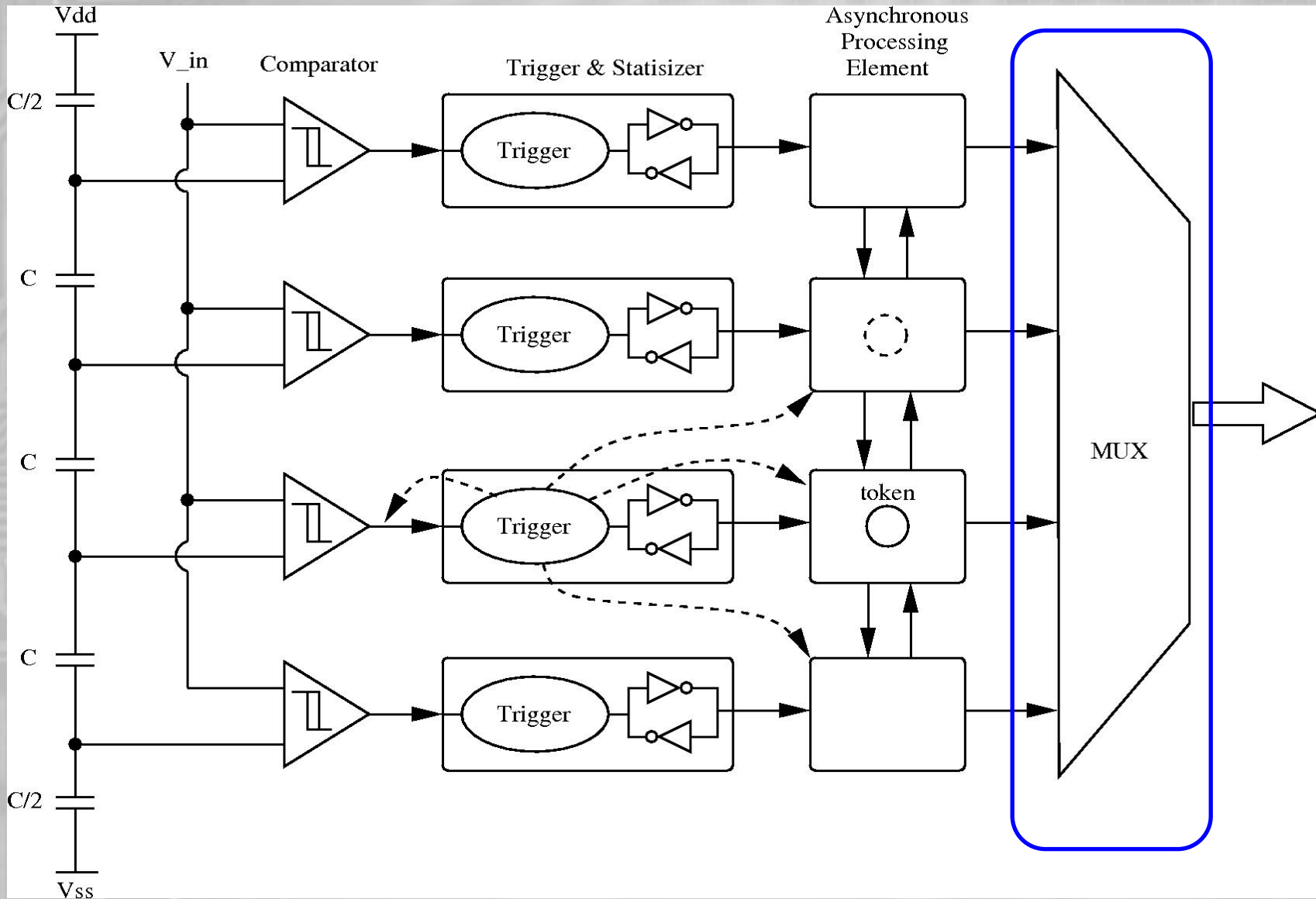
***Trigger becomes active if one of the crossing conditions holds:***

## 1. Upward Crossing

- the comparator output is high
- + the current level indicates that the signal was below before
- + the previous level indicates that the signal is above
- + the previous element has completed processing its request and sending its output

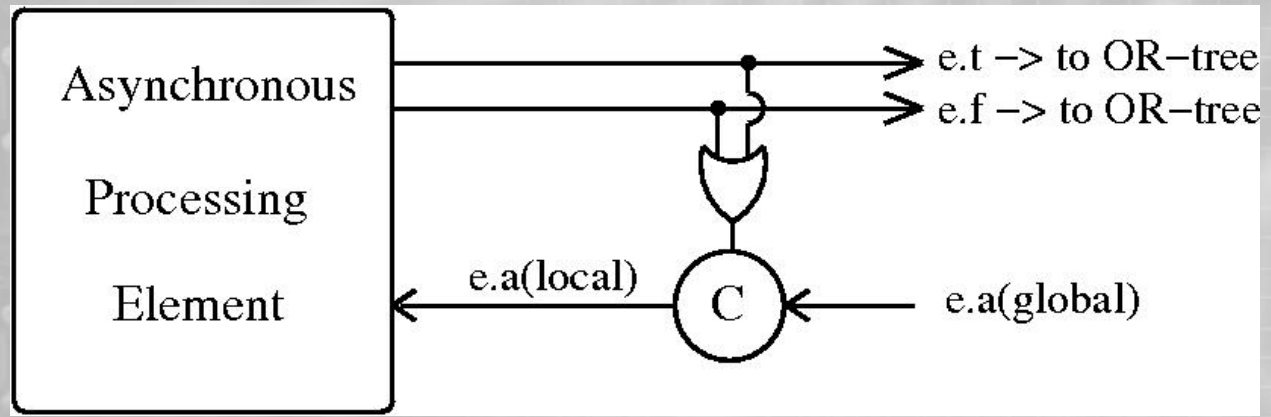
## 2. Downward Crossing

# Multiplexer

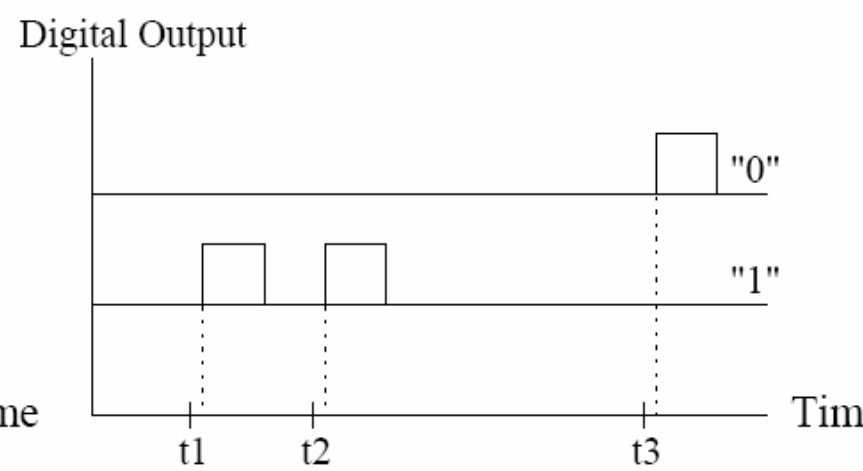
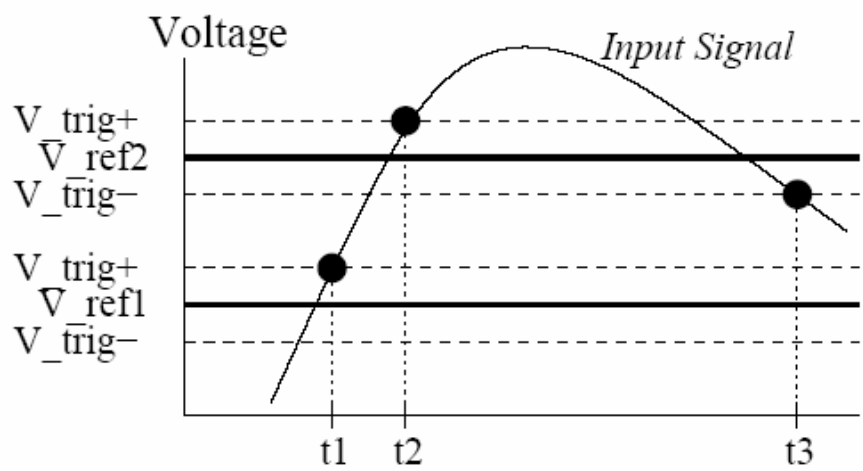


# Multiplexer Design

## Deterministic Merge



## Sample Output

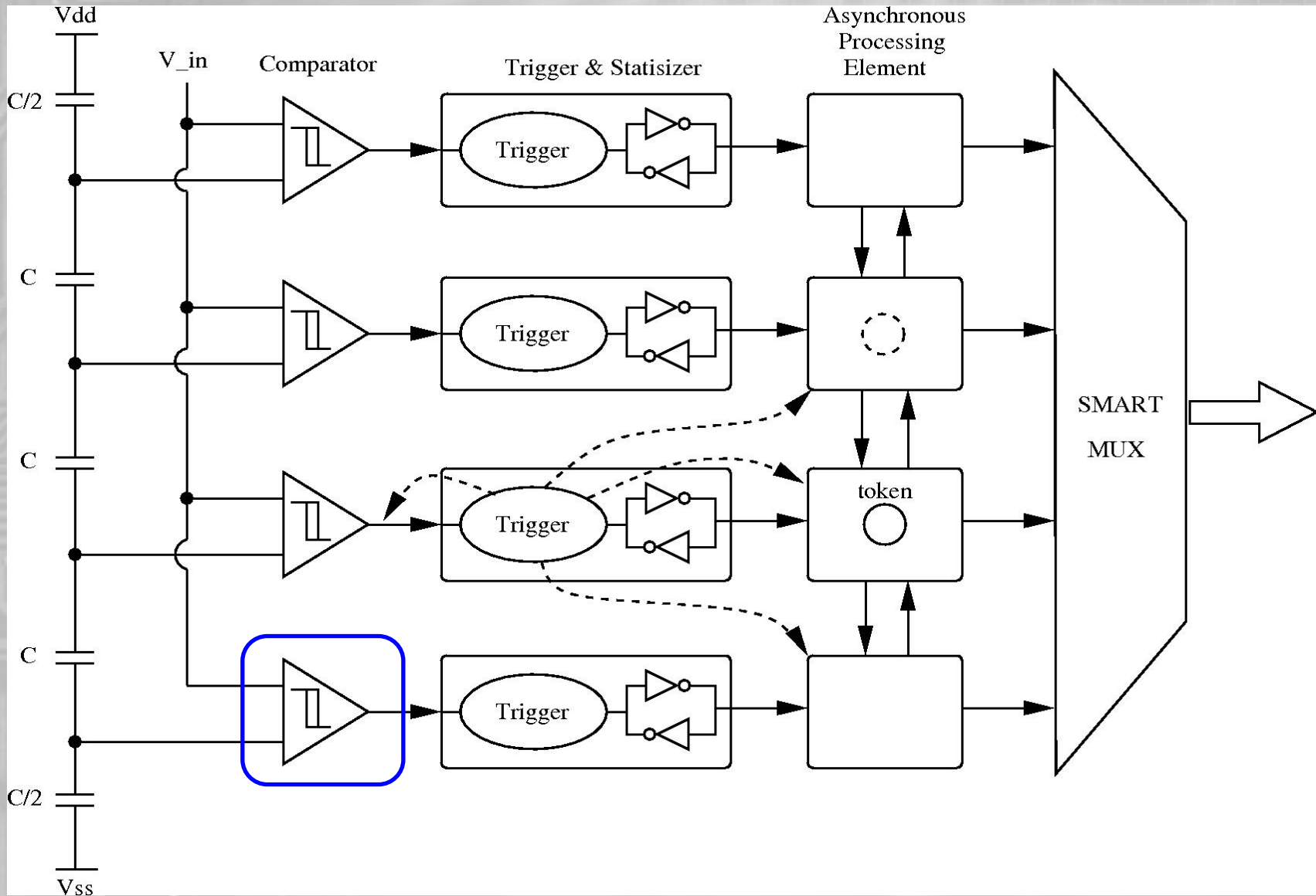


# Asynchronous ADC for Low-Power Applications

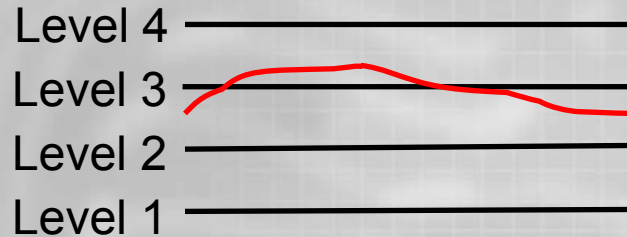
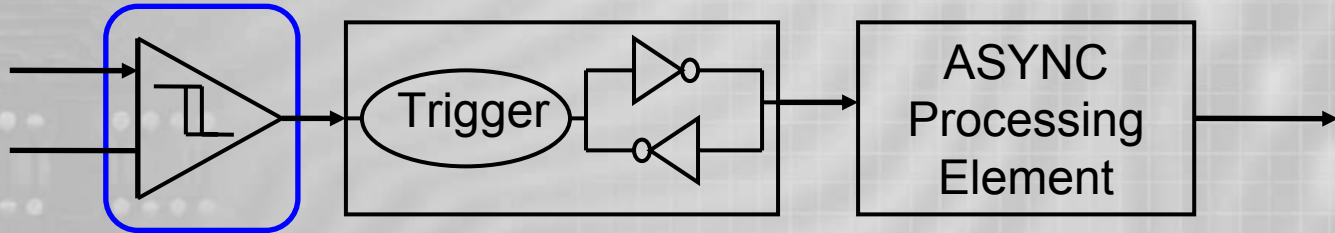
- ❖ Design of the ADC
- ❖ **Analysis**
- ❖ Evaluation
- ❖ Conclusion



# Power Analysis



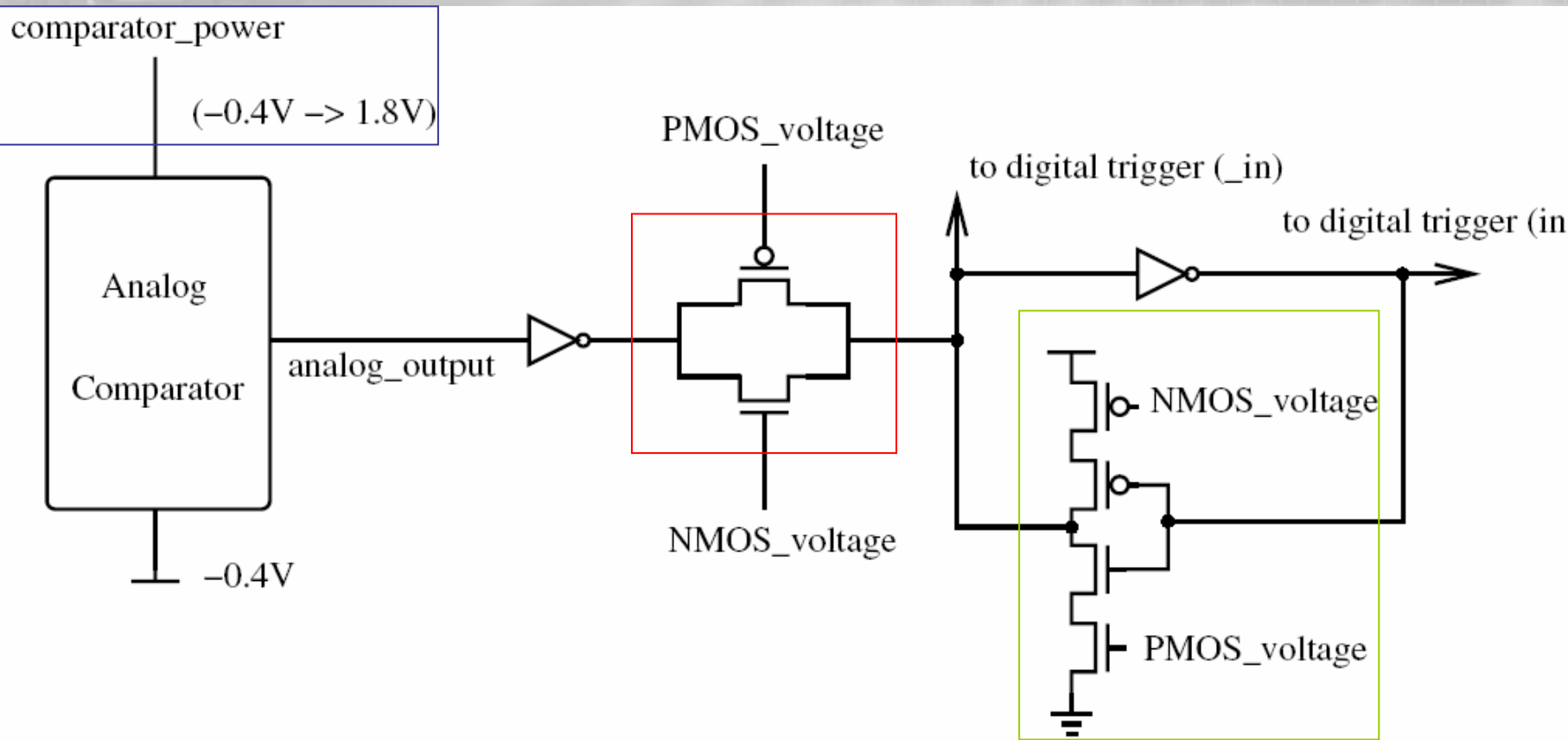
# Power Analysis



Comparator power is **turned on** if one of the following holds:

- The signal is above  $i$  processing element and below  $i+1$  processing element
- The signal is above  $i-1$  processing element and below  $i$  processing element
- The request is being processed by the current ( $i$ ) element

# Power Analysis



**Components added:**

- *Transmission Gate*
- *Gated Staticizer*

Variable "Comparator power" voltage source

# Asynchronous ADC for Low-Power Applications

- ❖ Design of the ADC
- ❖ Analysis
- ❖ Evaluation
- ❖ Conclusion

# Simulation Setup

- 4-bit converter (16 levels)
- Input: sinusoids of various frequencies
- Transistor models for TSMC 0.18 micron process
- Minimal transistor sizing
- The capacitive divider was simulated as a resistive divider ( $R = 1 \text{ MOhm}$ )
- $V_b$  on the comparators set to 0.25V
- No explicit time tracking

# Simulation Data

LCF-ADC Simulation Data

Signal BW	Power ( $\mu\text{W}$ )	Energy/sample (nJ)
1 kHz	34.41	34.4
100 kHz	42.48	0.42
114 kHz	43.57	0.38
160 kHz	46.84	0.29
1 MHz	114.14	0.11
5 MHz	437.81	0.087

❖ Much lower power consumption than previous designs

# Input Signal Consideration

Maximum number of crossings that can be correctly interpreted:

$$BW \cdot \frac{\text{number of crossings}}{\text{cycle}} \leq f_{\max}$$

$f_{\max}$  - maximum throughput of the asynchronous circuitry

$BW$  - input signal bandwidth (in MHz)

Periodic input with  $2n$  crossings in one period:  $BW \cdot 2n \leq f_{\max}$

$f_{\max}$  for minimal power consumption is 220MHz  
Maximum number of levels:

$$n \leq \frac{110}{BW}$$

1 kHz	110000 levels	( $\sim 2^{16}$ )
100 kHz	1100 levels	( $\sim 2^{10}$ )
1 MHz	110 levels	( $\sim 2^6$ )
5 MHz	22 levels	( $\sim 2^4$ )

# Asynchronous ADC for Low-Power Applications

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# Conclusion

- Applications: sensor networks, biomedical implants
- Level-Crossing Flash ADC approach
- Very low-power consumption
- Low-complexity design and ease of increasing precision
- Differential output on one dual rail channel

# A Level-Crossing Flash Asynchronous Analog-to-Digital Converter

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# QUESTIONS

## FURTHER READING

Click any one of the following links to be taken to a website which contains the following documents.

The following are some recent examples of Asynchronous ADC activity off the web.

[6 bit Asynchronous December 2006](#)  
[Asynchronous ADC In CAD Mentor Graphics](#)  
[Asynchronous Data Processing System](#)  
[ASYNCHRONOUS PARALLEL RESISTORLESS ADC](#)  
[Flash Asynchronous Analog-to-Digital Converter](#)  
[Novel Asynchronous ADC Architecture](#)  
[LEVEL BASED SAMPLING FOR ENERGY CONSERVATION IN LARGE NETWORKS](#)  
[A Level-Crossing Flash Asynchronous Analog-to-Digital Converter](#)  
[Weight functions for signal reconstruction based on level crossings](#)  
[Adaptive Rate Filtering Technique Based on the Level Crossing Sampling](#)  
[Adaptive Level-Crossing Sampling Based DSP Systems](#)  
[A 0.8 V Asynchronous ADC for Energy Constrained Sensing Applications](#)  
[Spline-based signal reconstruction algorithm from multiple level crossing samples](#)  
[A New Class of Asynchronous Analog-to-Digital Converters](#)  
[Effects of time quantization and noise in level crossing sampling stabilization](#)

Here is some more background information on Analog to Digital converters.

[A 1-GS/s 6-bit 6.7-mW ADC](#)  
[A Study of Folding and Interpolating ADC](#)  
[Folding ADCs Tutorials](#)  
[high speed ADC design](#)  
[Investigation of a Parallel Resistorless ADC](#)

Here are some patents on the subject.

[4,291,299 Analog to digital converter using timed](#)  
[4,352,999 Zero crossing comparators with threshold](#)  
[4,544,914 Asynchronously controllable successive approximation](#)  
[4,558,348 Digital video signal processing system using](#)  
[5,001,364 Threshold crossing detector](#)  
[5,315,284 Asynchronous digital threshold detector](#)  
[5,945,934 Tracking analog to digital converter](#)  
[6,020,840 Method and apparatus for representing waveform](#)  
[6,492,929 Analogue to digital converter and method](#)  
[6,501,412 Analog to digital converter including a quantizers](#)  
[6,667,707 Analog to digital converter with asynchronous ability](#)  
[6,720,901 Interpolation circuit having a conversio2](#)  
[6,850,180 SelfTimed ADC](#)  
[6,965,338 Cascade A D converter](#)  
[7,133,791 Two mean level crossing time interval](#)

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