Targeting ultra-low power consumption with non-uniform sampling and filtering

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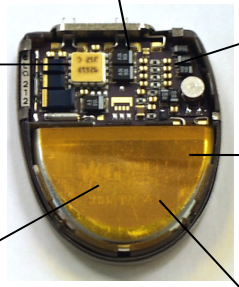
Challenges

Ultra low power consumption
- Non uniform sampling techniques
- Asynchronous logic

Robustness
Fault tolerance

Circuit formal proof



Sensors
Actuators
Electrodes

Safety
Monitoring

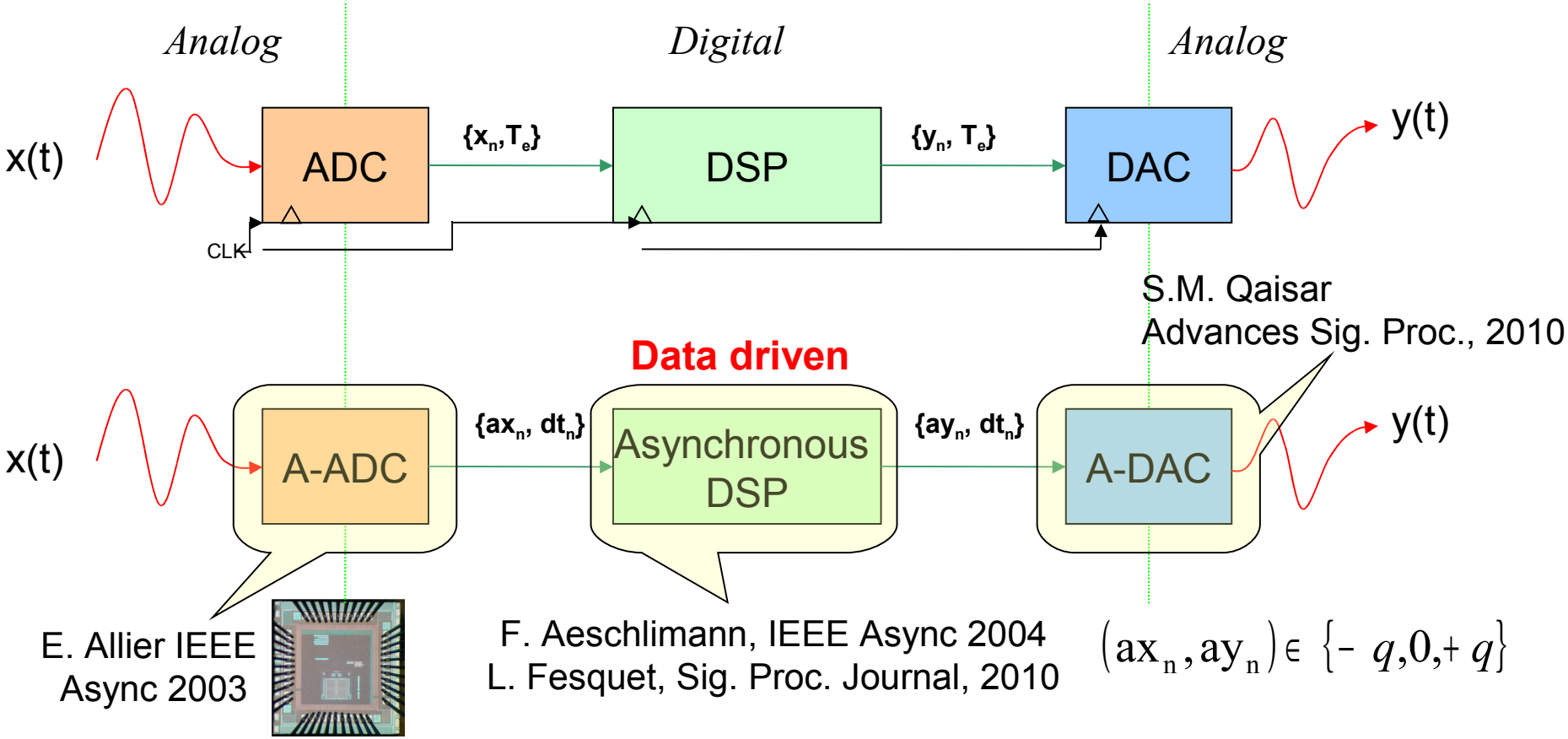
Energy harvesting
Battery

Outline

- Non uniform sampling
- Asynchronous logic
- Signal processing for low-power
- FIR filtering
- Conclusion

Non uniform sampling

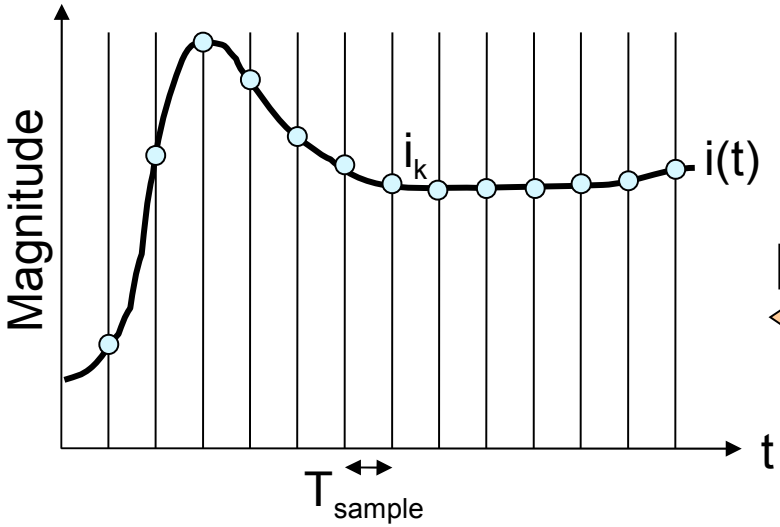
Abaisser la consommation et le rayonnement électromagnétique



$$(ax_n, ay_n) \in \{-q, 0, +q\}$$

Level crossing sampling

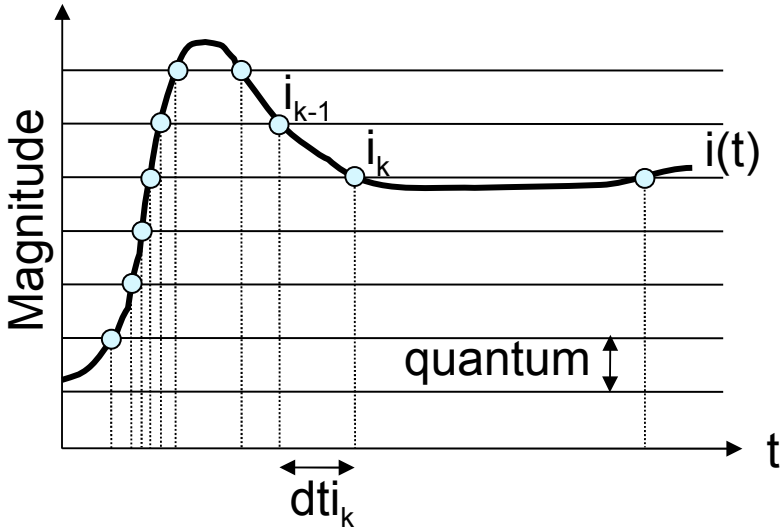
Uniform sampling



- Respect the Shannon theorem
- Instants exactly known
- Information: T_{sample}, { i_k }
- In an ADC: Amplitude quantization
- Many useless samples

Dual

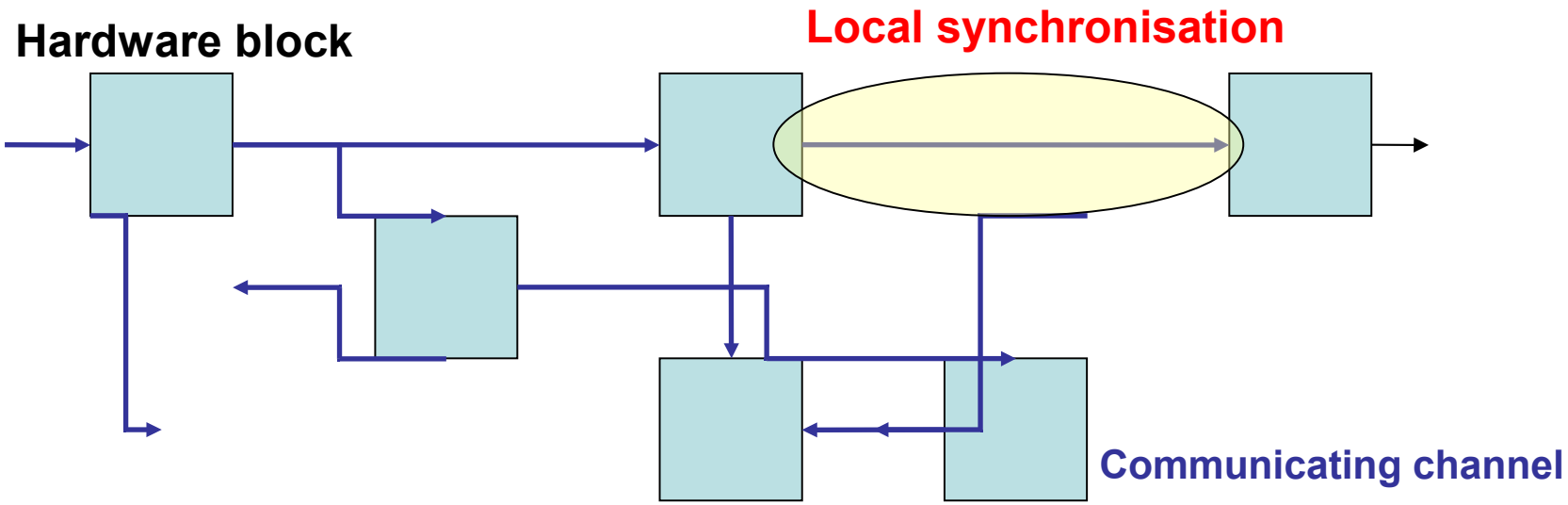
Non uniform sampling



- "Level-crossing sampling"
- Amplitudes exactly known
- Information: quantum, { dti_k }
- In an A-ADC: Time quantization
- Only useful samples

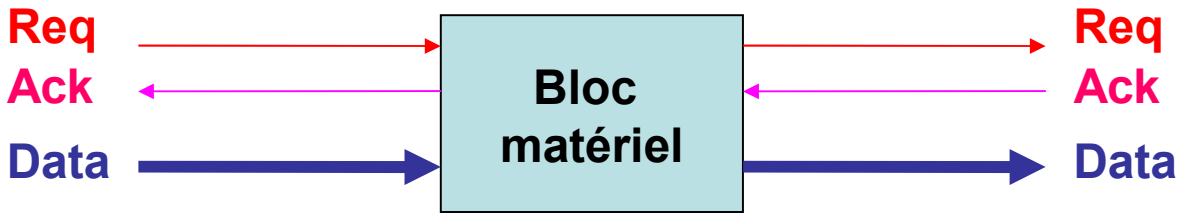
Asynchronous logic

- Relax the timing assumptions ⇨ Robust circuit

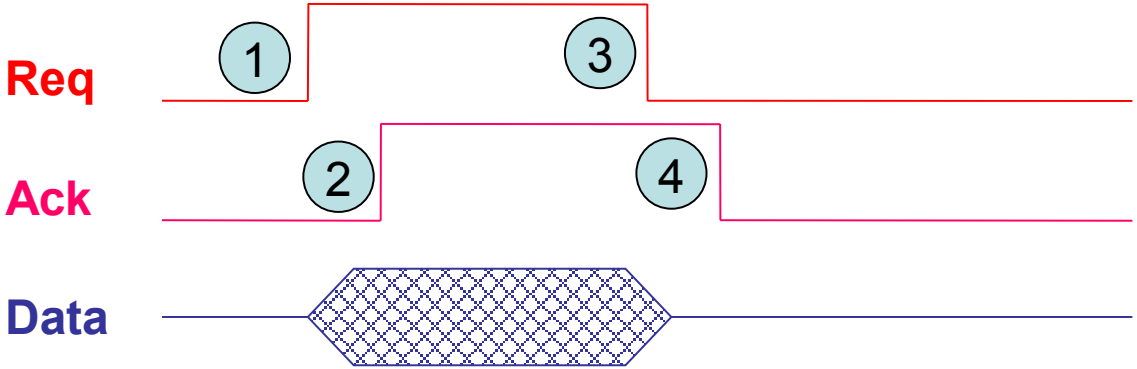


No global synchronization like the synchronous circuits!

Local synchronization based on handshakes

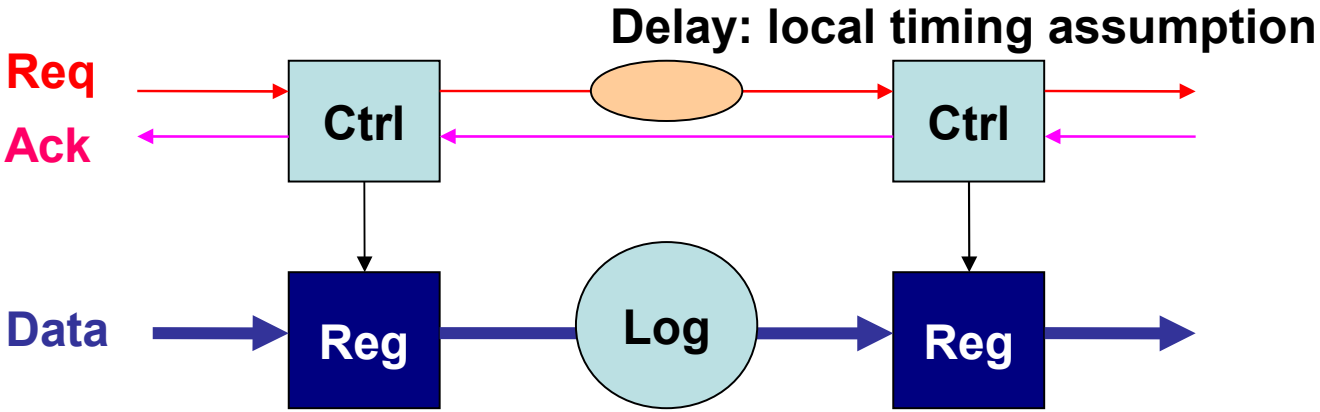


- 4-phase Protocol



Micropipeline circuits

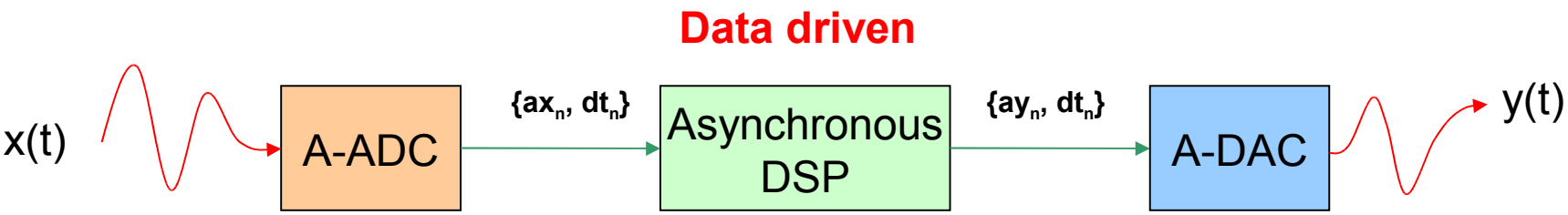
- Data-driven circuits



  - Similar data-path to the synchronous one
  - Data-driven
  - Only consume power when data are processed

Signal processing for low-power

- Only process useful samples (less samples)
- Only computes when data are sampled (data-driven)



- Less activity, less energy consumes
- From 1 to 2 orders of magnitude (signal dependant)
- How to gain more ?

A simple FIR filter

- Digital convolution product

$$y_n = \sum_{k=0}^{N} h_k . x_{n-k}$$

⇨ Well-suited to the synchronous paradigm (sampling and circuits)

- Analog convolution product

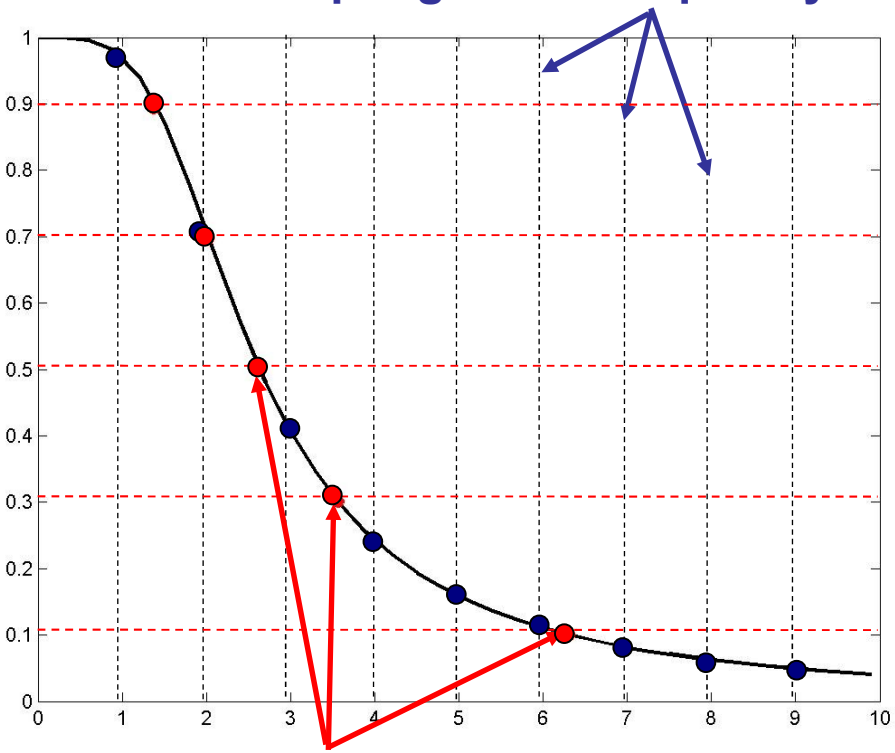
Non uniform sampling in time

$$y(t) = \int_{-\infty}^{+\infty} x(\tau) h(t-\tau) d\tau \Rightarrow y(ty_n) = \int_{-\infty}^{+\infty} \hat{x}(\tau) \hat{h}(ty_n - \tau) d\tau$$

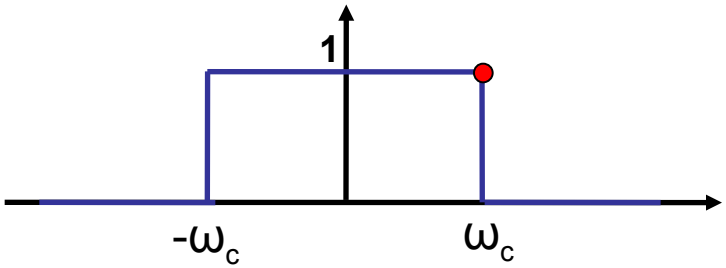
⇨ Interpolations: $ty_n = tx_n$ ($dty_n = dtx_n$)

FIR filter synthesis

Uniform sampling in the frequency domain



- Non uniform sampling in frequency
- Less filter coefficients

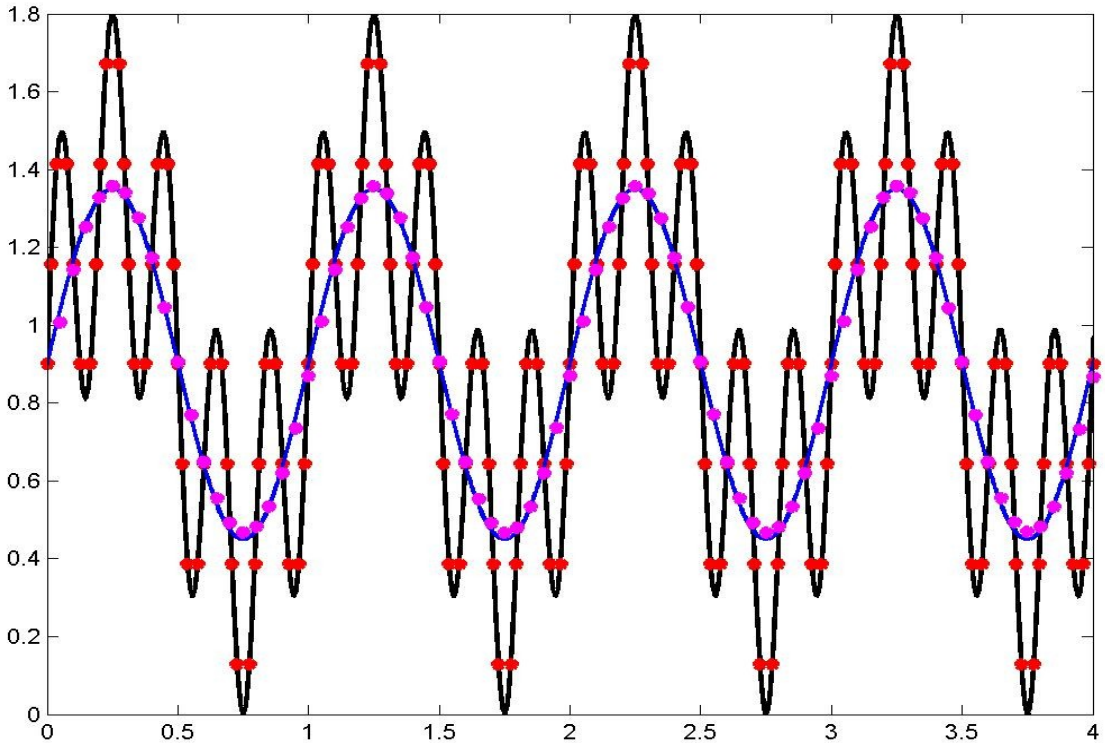


Non uniform sampling in the frequency domain

$H_1=\omega_c/\pi \ \mathrm{sinc}(\omega_c t)$

FIR filter: non uniform in time non uniform in frequency

- Similar results to the classical filters



Errors:

N. bits	Piecewise constant	Piecewise linear
2	6.08%	5.84%
3	0.76%	0. 46%
4	0. 52%	0. 45%
5	0. 46%	0. 45%

Conclusion

- Less samples, less coefficients
- 1 to 2 orders of magnitude activity reduction
- Few bit resolution ADC
- FIR filtering is simple
  - Non uniform data samples
  - Non uniform filter coefficients

- IIR filtering [Fesquet, Sig. Proc. Journal, 2010]

Perspectives for the ultra low power

- Rethink signal processing for low power
  - Analyze the signal characteristics (temporal and spatial)
  - Choose the appropriate sampling scheme
  - Improve SNR with a low resolution quantizer

- Implement asynchronous logic
  - Data driven (no data, no power)
  - Robust to PVT variations (especially QDI)
  - Safe (formal proof)
  - LEGO

And many others …

Questions?