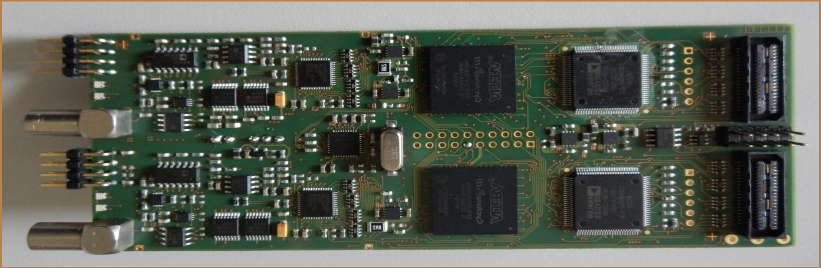


Custom digitizers with on-board pulse shape discrimination

Pietro Ottanelli
INFN Sezione di Firenze

GDS-Topical Meeting
January 30, 2017

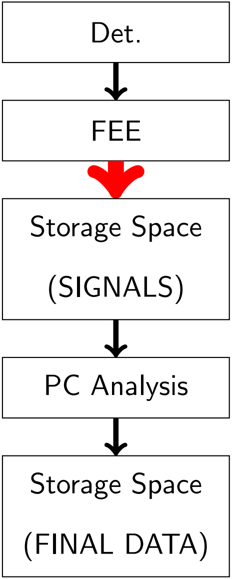
Outline

- Digitizing electronics: the data flow problem;
- GARFIELD+RCo: an overview of the FEE boards;
- Pulse shape discrimination (PSD): an introduction;
- On-board real-time PSD using linear filters;
- Results and conclusions.

Digital Acquisition: Data Flow Problems
Centralized Data Elaboration

Pros:

- reconfigurable analysis;
- elaboration optimized *a posteriori*;
- simple FEE board.



Digital Acquisition: Data Flow Problems

Centralized Data Elaboration

Pros:

- reconfigurable analysis;
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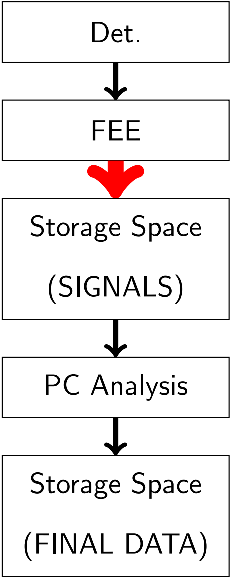
- simple FEE board.

Cons:

- huge throughput required;
- huge storage space for signals;
- slower PC analysis.



Digital Acquisition: Data Flow Problems
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Pros:

- reduced data throughput;
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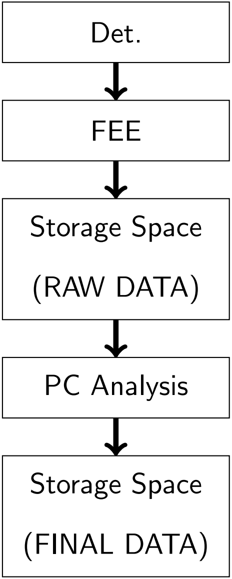


Digital Acquisition: Data Flow Problems

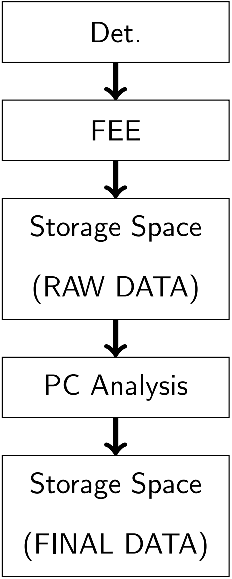
Distributed Data Elaboration

Pros:

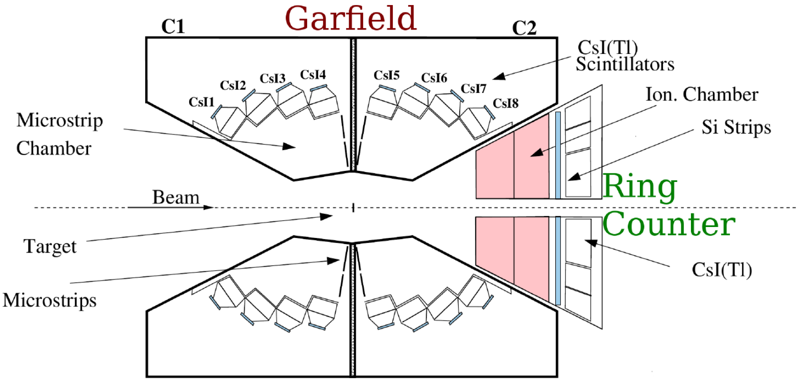
- reduced data throughput;
- reduced storage space for raw data;
- faster PC analysis.

Cons:

- once and for all signal analysis;
- chosen *a priori*;
- more complex FEE board.



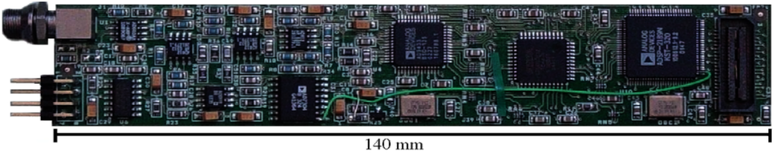
The GARFIELD+RCo apparatus



M. Bruno et al., EPJ A 49(2013)

Distributed Data Elaboration
GARFIELD+RCo old FEE board

- variable gain stage;



G. Pasquali et al.,NIM A 507 (2007)

Distributed Data Elaboration
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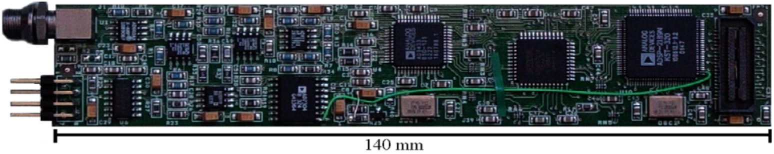
- variable gain stage;
- 12-bit, 125 MHz digitizer, 2V range;



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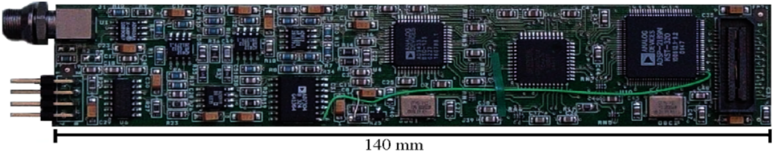

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- variable gain stage;
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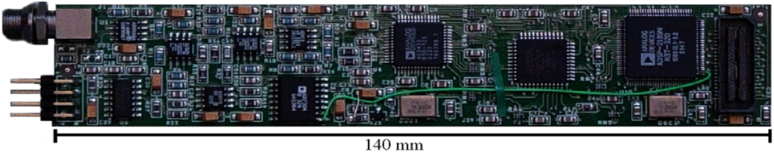
- **NO SIGNAL TRANSMITTED, ONLY FINAL DATA**;
- several publications (http://www.bo.infn.it/nucl-ex/).



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P. Ottanelli, Master Thesis, 2016
http://www.bo.infn.it/rem/tesi.htm

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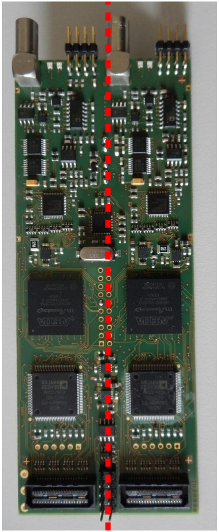

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Distributed Data Elaboration
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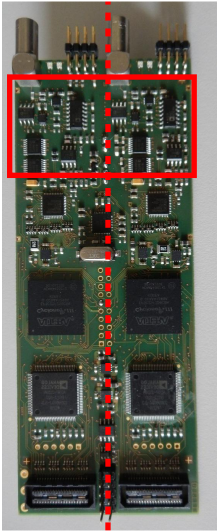

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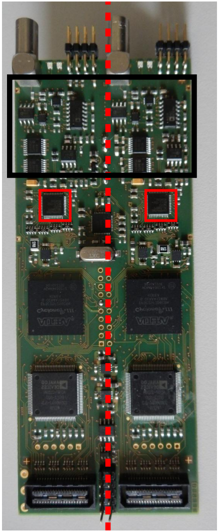

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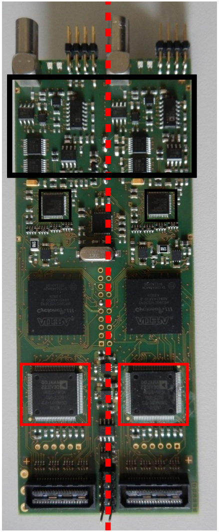

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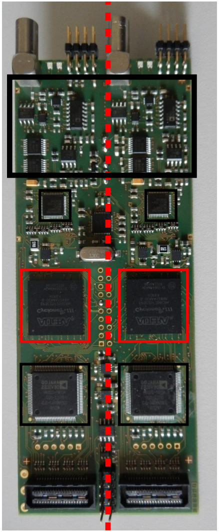

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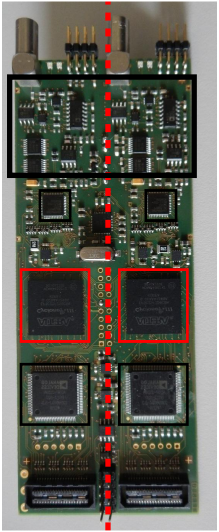

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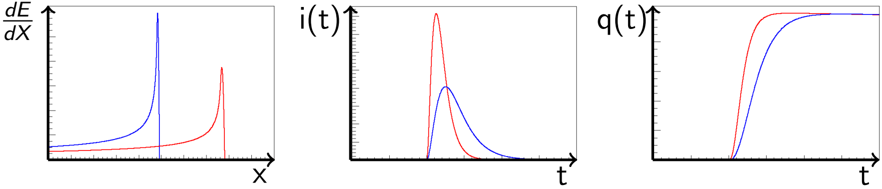
Pulse shape discrimination (PSD)
Working Principle



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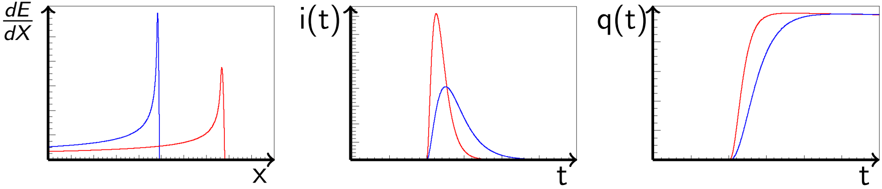

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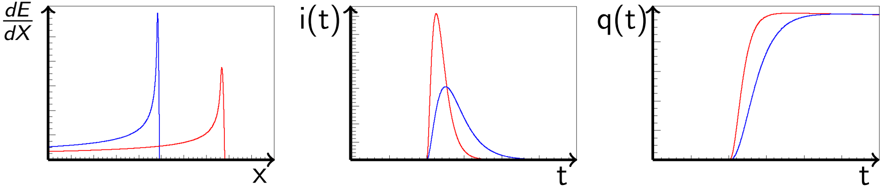

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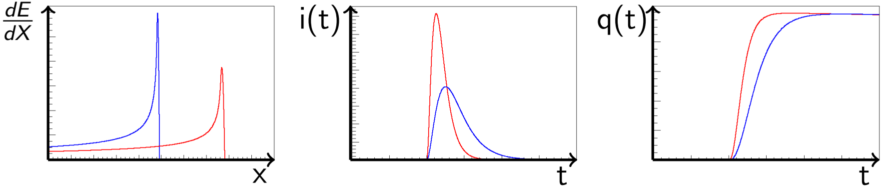

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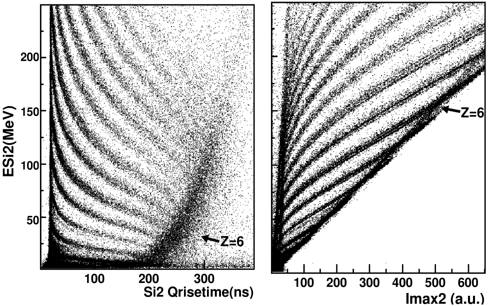
Pulse shape discrimination (PSD)
Working Principle

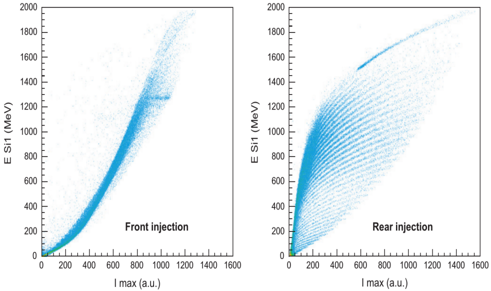
G. Pasquali et al.,EPJ A 50 (2014)



- different distributions→ different shapes for $i(t)$ and $q(t)$;
- info on A and Z can be extracted from signal shape;
- measure shape-sensitive parameters (e.g. Q_{rise},I_{max});

Pulse shape discrimination (PSD)
Working Principle

N. Le Neindre et al.,NIM A 701 (2013)



- different distributions$\rightarrow$ different shapes for $i(t)$ and $q(t)$;
- info on A and Z can be extracted from signal shape;
- measure shape-sensitive parameters (e.g. Q_{rise},I_{max});
- better performances with rear injection.

PSD: the need for interpolation

- Measure of shape sensitive parameters$\rightarrow$ shape reconstruction;
- Samples not always sufficient to achieve a good measure$\rightarrow$ interpolation.(G. Pastore et al.,accepted for publication on NIM A)

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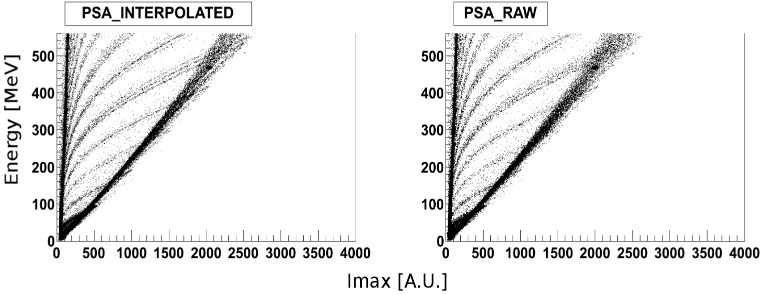
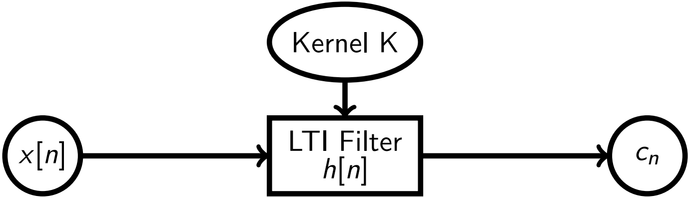
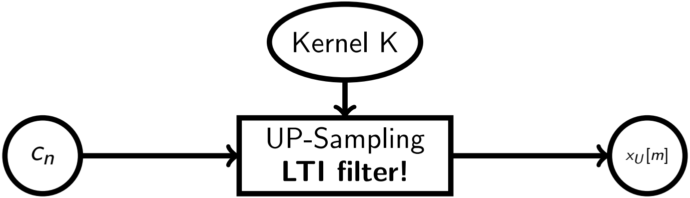


Interpolation through LTI filter



- coefficient of interpolating function obtained with LTI filter;
- discrete representation of a **continuous-time function**;
- LTI filter allows real-time on-board calculations!
- filter depends on interpolation kernel K.
- different interpolation kernel $\rightarrow$ different filter.
- **Configurable filter allows choice of interpolation type!**

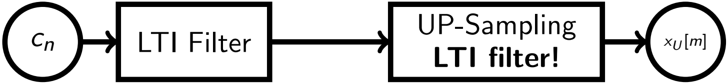
Treating the interpolated signal



- c_n represents a continuous-time signal;
- digital device can't handle continuous time domain;
- fine sampling of the signal: Up-Sampling;
- new samples $\rightarrow$ linear combinations of coefficients.
- **Up-sampled signal can be handled on digital device!**
- upsampling algorithm uses interpolation kernel K.
- **upsampling filter must be configurable.**

A further improvement...

Processing of the interpolated signal
Applying an LTI filter



- signals are often filtered (e.g. PZC algorithm);

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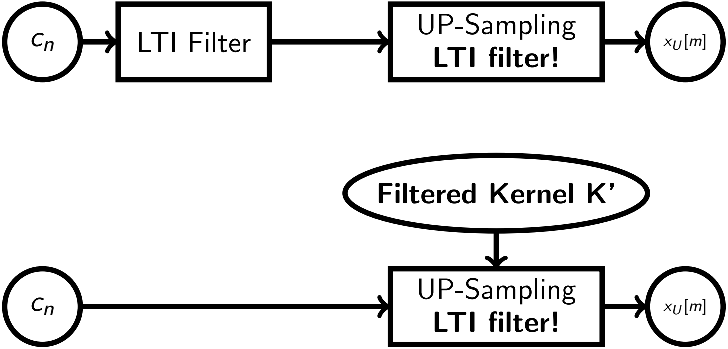

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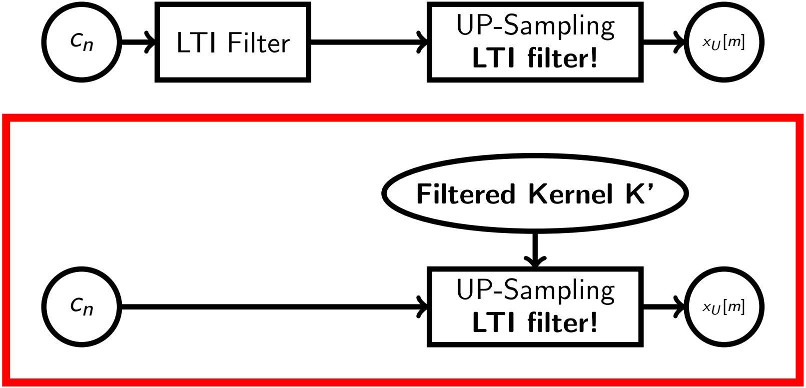

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- **configurable upsampling filter → choice of filtering!**

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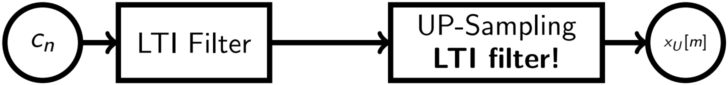

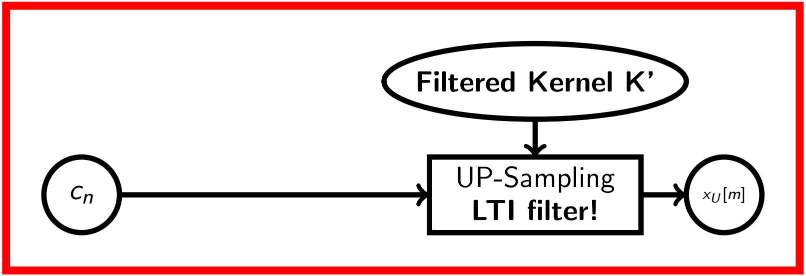

- signals are often filtered (e.g. PZC algorithm);
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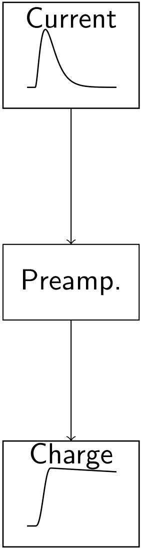
- **filtering in Continuous time domain!**

On-board PSD: I_{MAX} evaluation

From current and charge signal!



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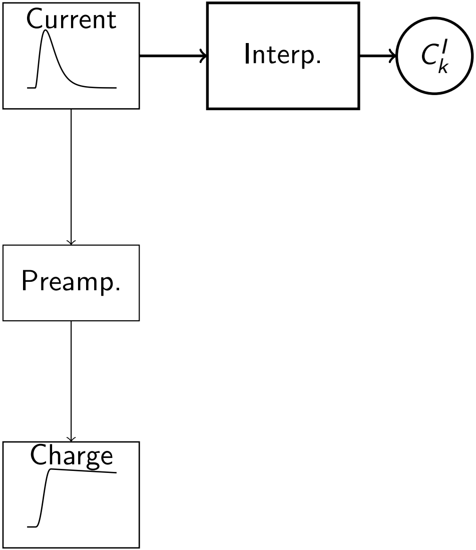

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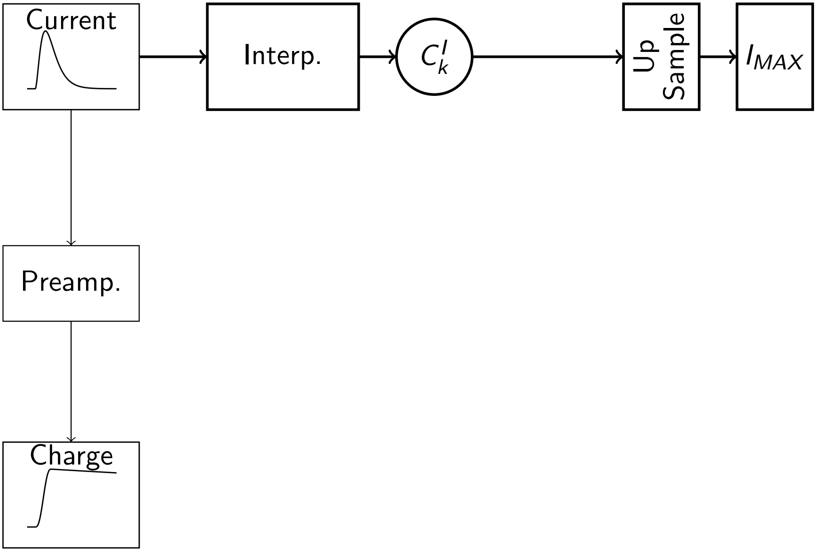

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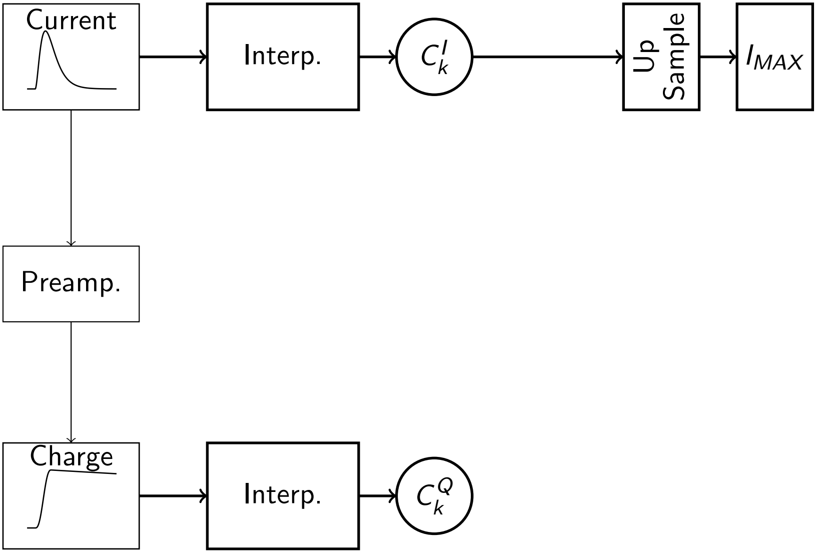

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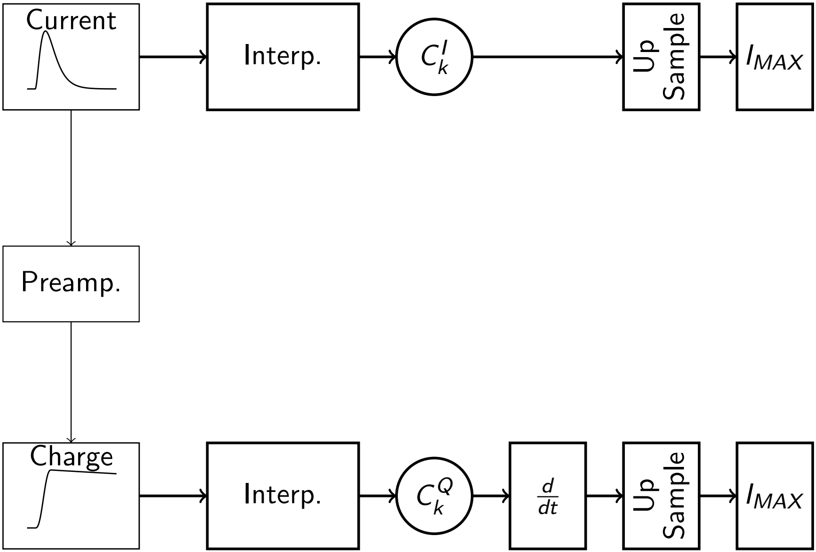

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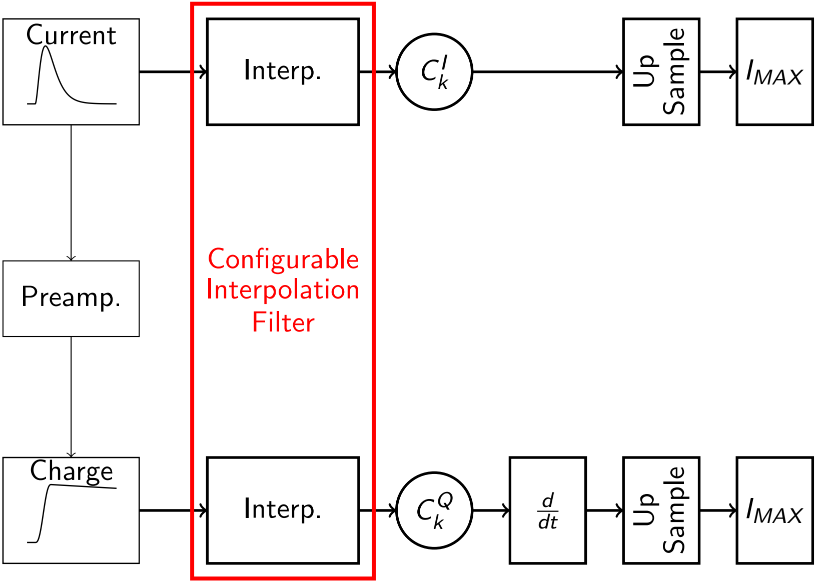

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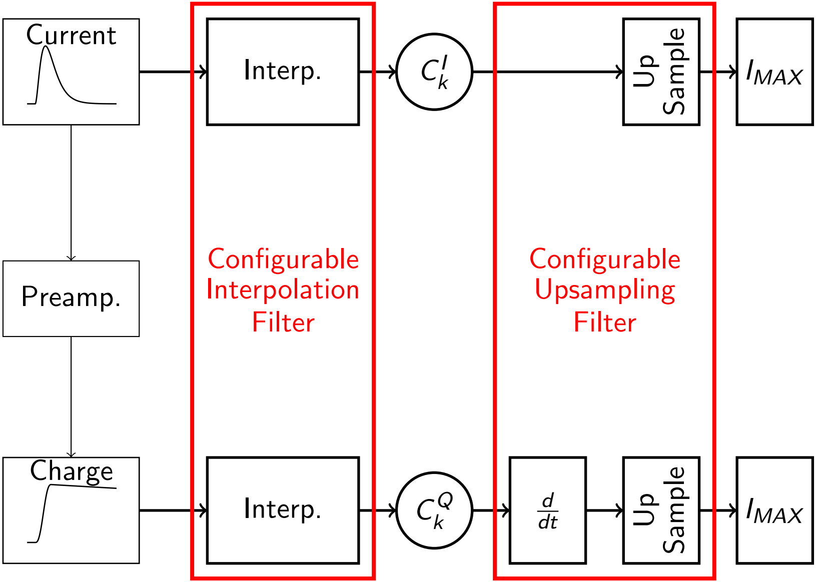

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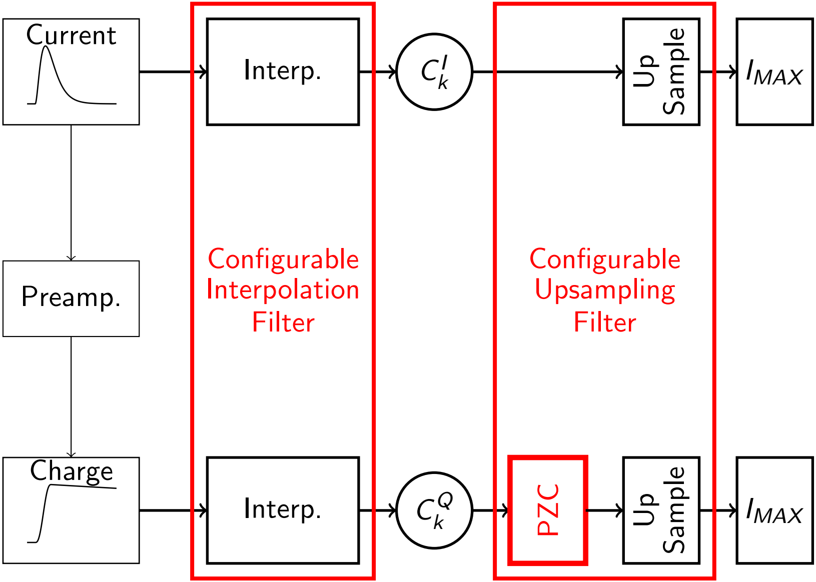
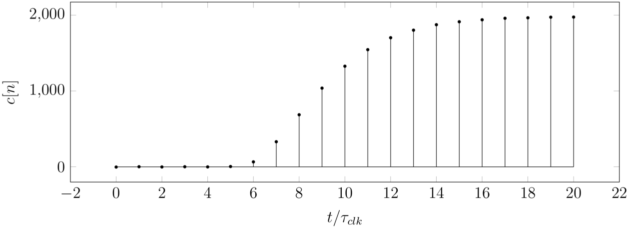


On-board PSD: I_{MAX} evaluation.
An example



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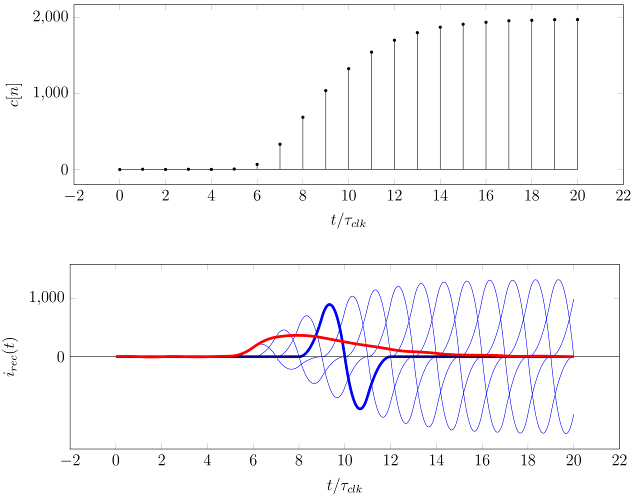

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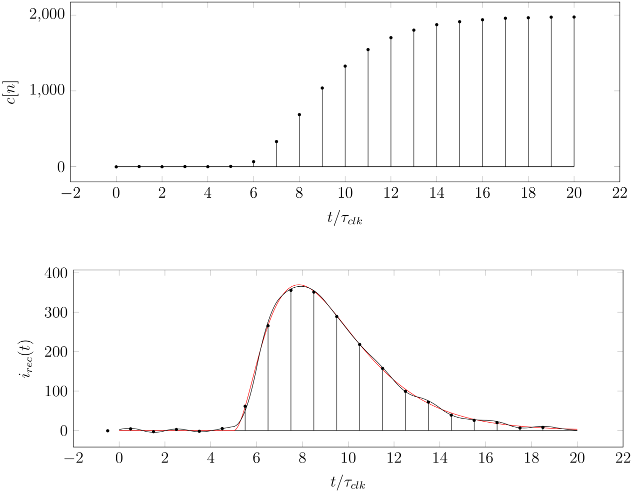

Results: ^{48}Ca+^{48}Ca
On-board elaboration with GARFIELD FEE

- Study of the reaction $^{48}Ca + ^{48}Ca$@35 MeV/A;

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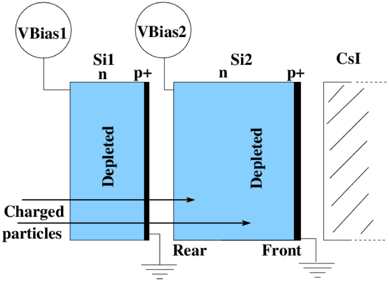

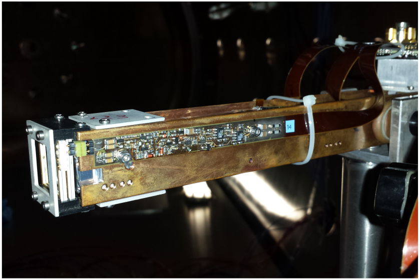

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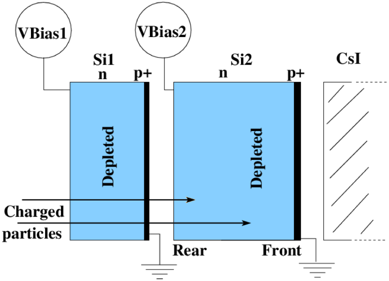
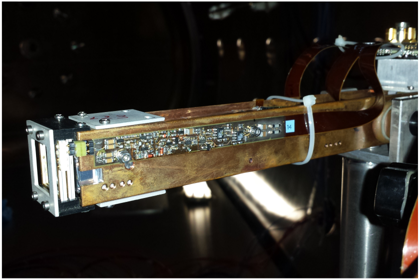
- first test with non optimized setup;
- all data extracted on-board in real-time;





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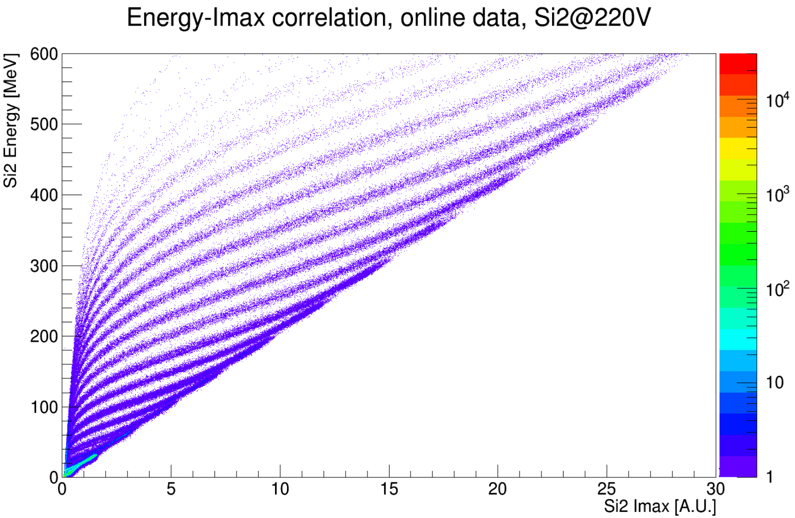

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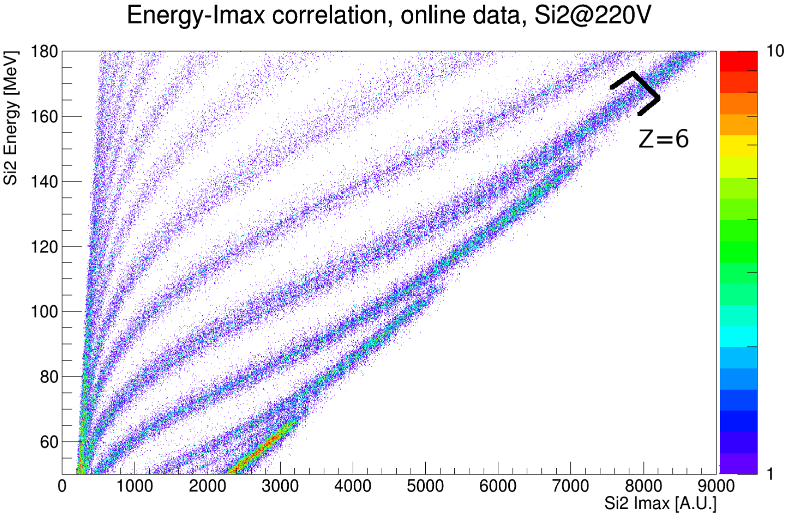

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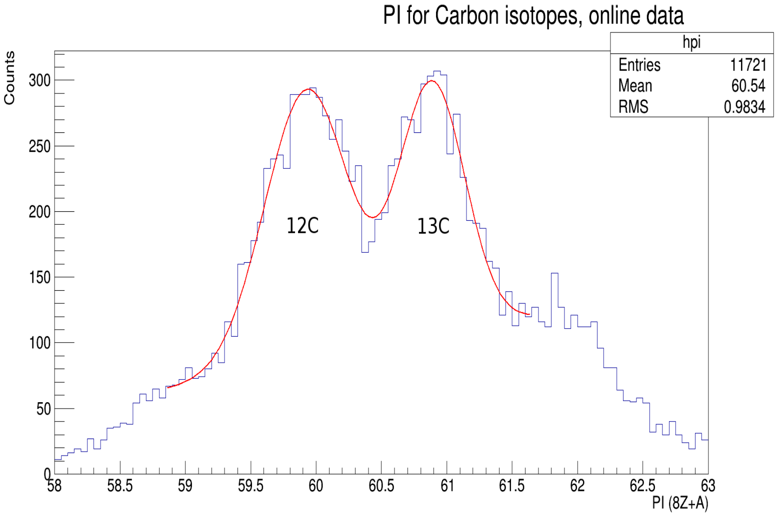

FoM: 0.71 ± 0.02

Results: FAZIASYM data, offline analysis

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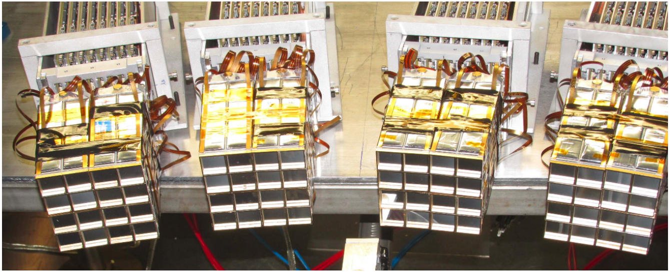

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- Study of the reaction ${}^{48}Ca + {}^{48}Ca$@35 MeV/A;
- Si(300μm)-Si(500μm)-CsI (FAZIA block telescope→Barlini);
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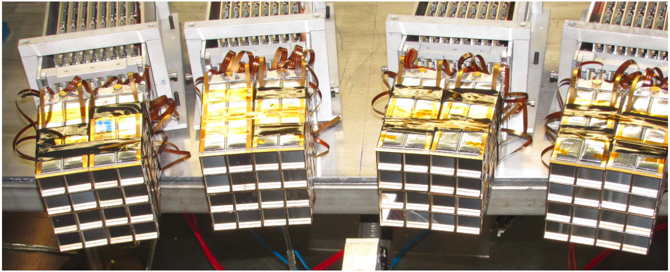
- three digitizing channels (2 gains for charge, 1 current);
- offline reproduction of the described algorithms.



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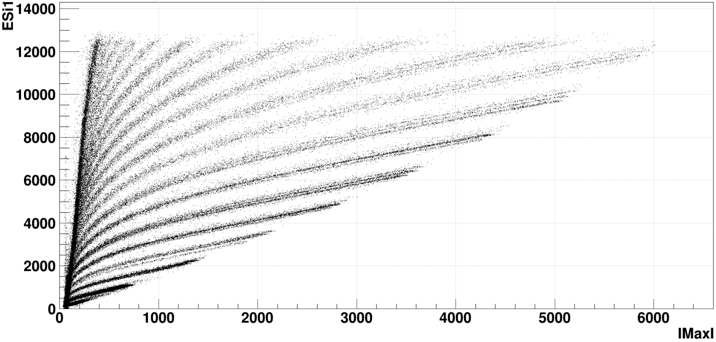
I_{MAX} from current signal sampled at 250MHz, 14 bits.



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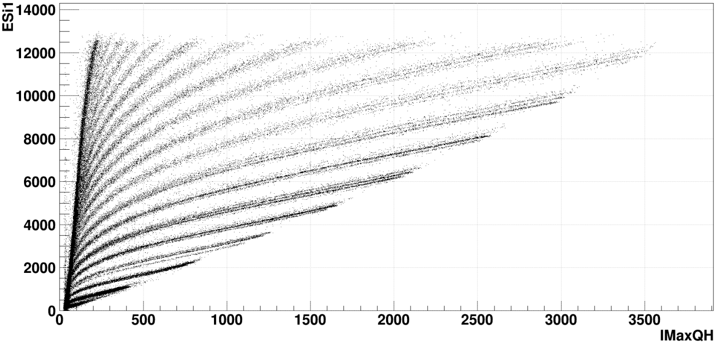

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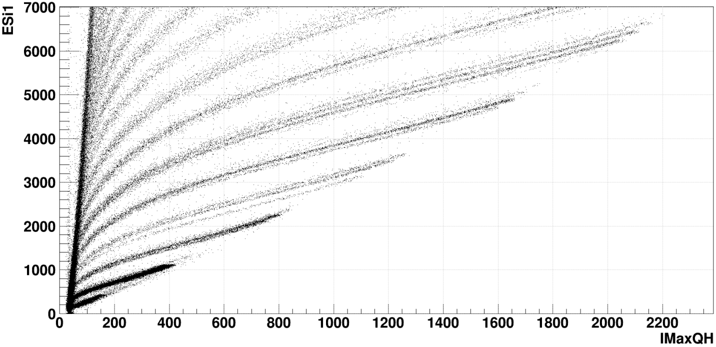

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Garfield FEE Firmware

- Trapezoidal shaper with PZC (Energy measure);
- Bipolar shaper for trigger generation (CFD);
- Configurable interpolation and upsampling filters;
- Internal trigger logic;
- External interface.

Conclusions

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- further tests on the algorithms will be done.

Thanks for your attention!

Interpolation through LTI filter

Given a signal $x[n]$ by definition an interpolating function is a function of the type

$$f(t) = \sum_m c_m K(t/t_s - m)$$

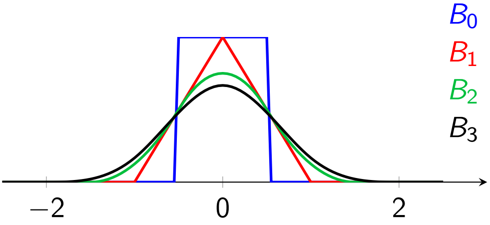
passing for the samples. Hence

$$x[n] = f(nt_s) = \sum_m c_m K(n - m) = F(c)$$

where F is an LTI filter with impulse response $h[n] = K(n)$.
By inverting the relation then

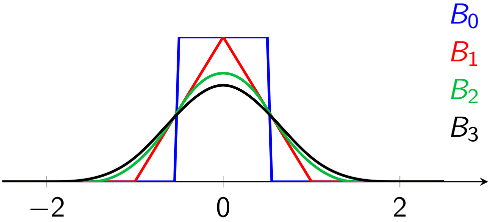
$$c_m = F^{-1}(x)$$

- functions widely used for interpolation (e.g. imaging);



Interpolation: Box Splines

- functions widely used for interpolation (e.g. imaging);
- B-Spline of n-th order $\rightarrow$ piecewise polynomial function with continuity up to $(n-1)$th derivative;



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- functions widely used for interpolation (e.g. imaging);
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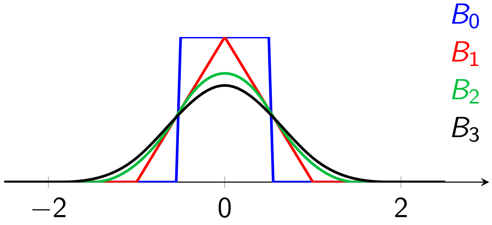
- Cubic B-Spline is ideal for treating physical signals

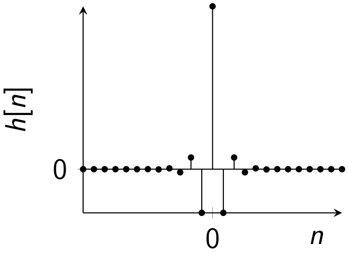


Cubic B-Spline interpolation

M.Unser, IEEE TSP 1993 41:

Cubic Spline interpolation realizable with IIR linear filter, impulse response

$$h[n] = \sqrt{3}\alpha^{|n|} \qquad \alpha = \sqrt{3} - 2$$



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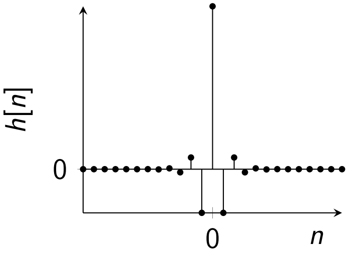

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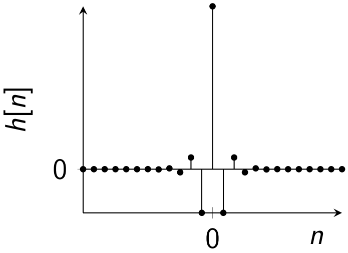
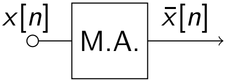


Problem:

- $h[n] \to$ infinite length;
- real-time signal$\to$ infinite length;
- **IMPOSSIBLE TO CALCULATE** $b[n] = \sum_{m=-\infty}^{\infty} h[m]x[n-m]$**!!!**
- approximative calculation by truncation of $h[n]$.

Interpolating filter implementation



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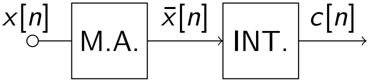

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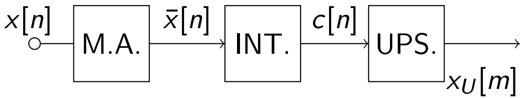

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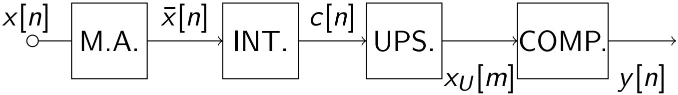

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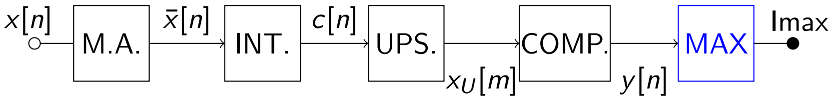

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- a pipelined algorithm (COMP.) compares 10 samples per clock cycles;
- only the maximum samples is kept (1 per clock), producing a signal with no upsampling;
- when triggered, the blue block (MAX) searches for the maximum of its input signal