High performance X-Ray spectroscopy

With Programmable Systems on Chip

Electromagnetic Radiation Spectrum

Speed of light in vacuum
$C \approx 3x10^8$ m/s

$C = \lambda f$

Quantization of energy,

wave- particle duality,

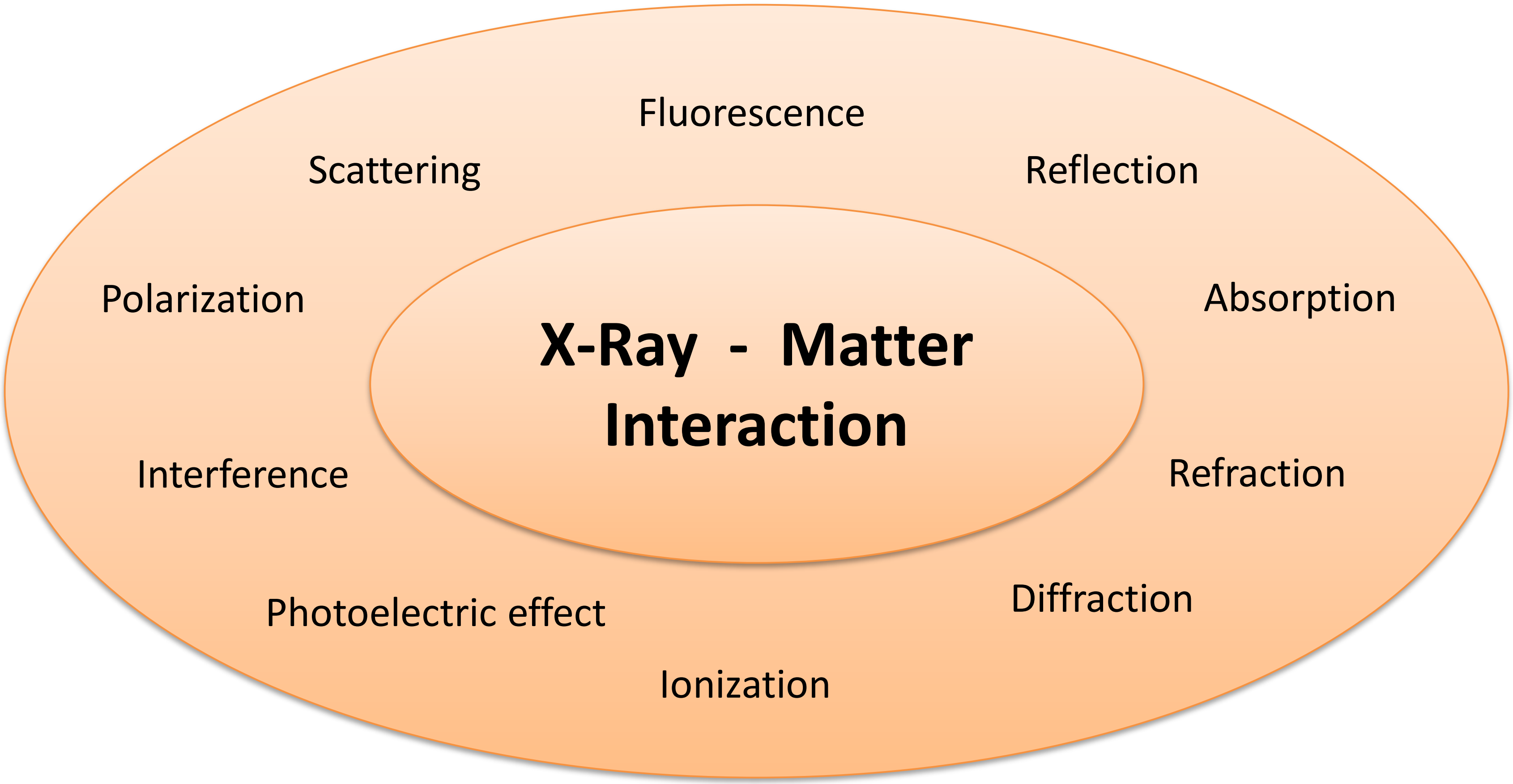
Planck's Law:

$E = h f$

where h = 4.135 x 10^{-15} eV seconds

Frequency (Hz)	**Wavelength** (m)	**Energy** (eV)	
3.00E+22	**1.00E-14**	1.24E+09	Cosmic Rays
3.00E+21	**1.00E-13**	1.24E+08	Gamma
3.00E+20	**1.00E-12**	1.24E+07	
3.00E+19	**1.00E-11**	1.24E+06	
3.00E+18	**1.00E-10**	1.24E+05	**X-Rays**
3.00E+17	**1.00E-09**	1.24E+04	
3.00E+16	**1.00E-08**	1.24E+03	
3.00E+15	**1.00E-07**	1.24E+02	
3.00E+14	**1.00E-06**	1.24E+01	Ultraviolet
3.00E+13	**1.00E-05**	1.24E+00	Visible
3.00E+12	**1.00E-04**	1.24E-01	Infrared
3.00E+11	**1.00E-03**	1.24E-02	
3.00E+10	**1.00E-02**	1.24E-03	Radar
3.00E+09	**1.00E-01**	1.24E-04	GPS
3.00E+08	**1.00E+00**	1.24E-05	Microwaves
3.00E+07	**1.00E+01**	1.24E-06	TV
3.00E+06	**1.00E+02**	1.24E-07	FM
3.00E+05	**1.00E+03**	1.24E-08	Radio Waves
3.00E+04	**1.00E+04**	1.24E-09	
3.00E+03	**1.00E+05**	1.24E-10	

X-Ray Photons

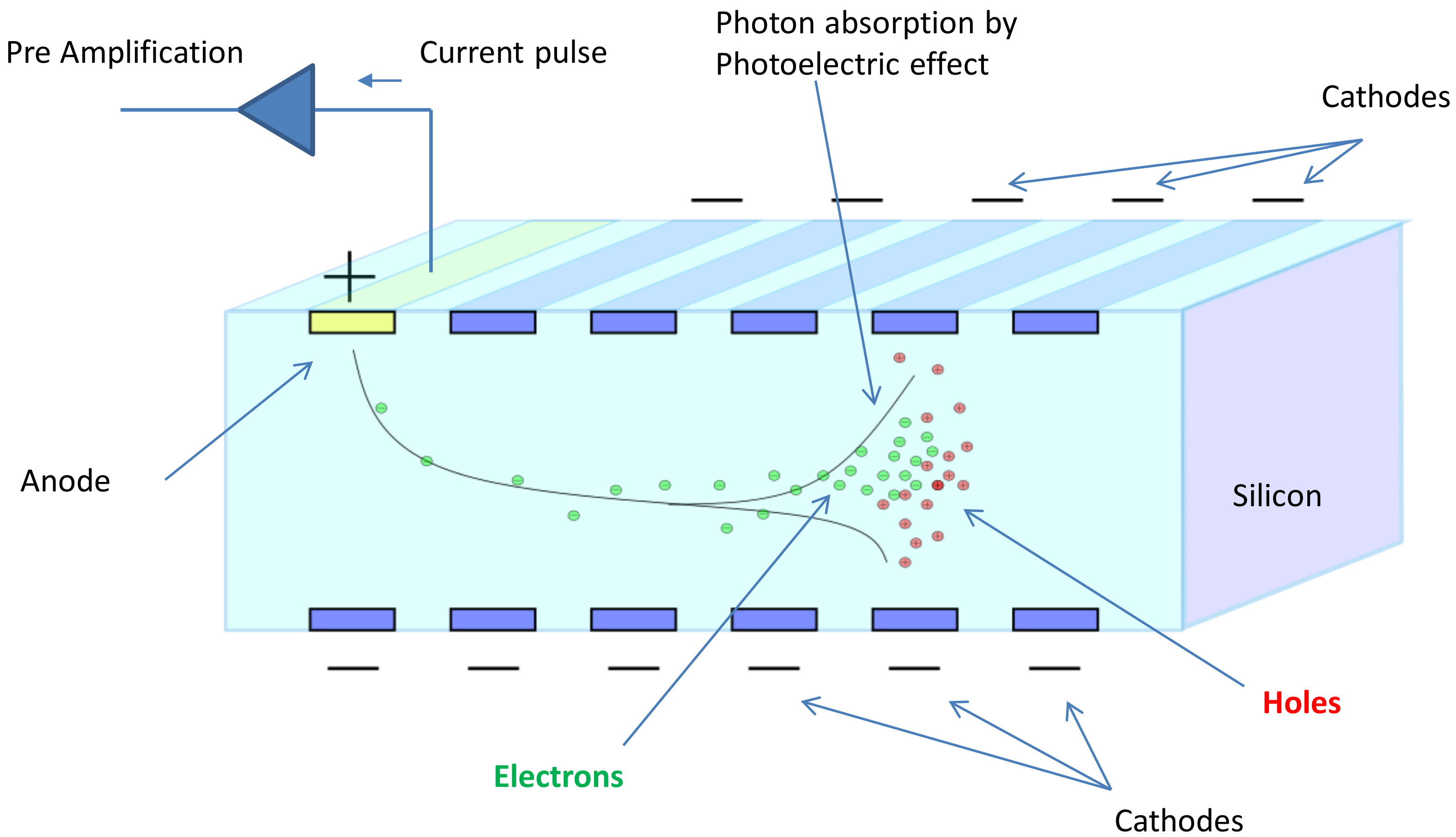


Digital Pulse Processing

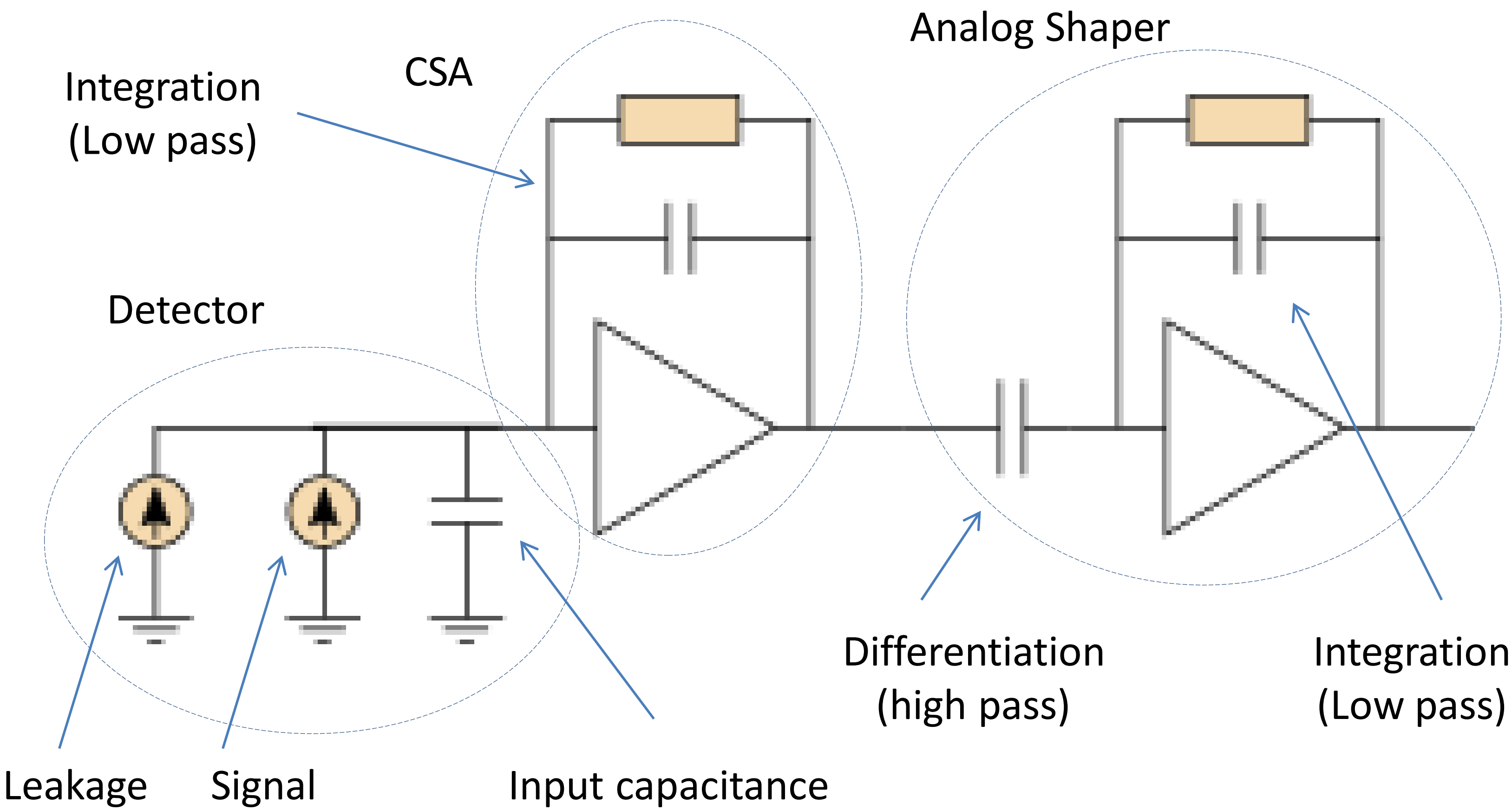
Desirable features of for modern X-Ray spectroscopy

- Single photon detection capability
- High energy resolution
- Extended energy range
- High photon counting rates
- Effective and efficient pile-up rejection capability
- High time resolution and time-stamping capability
- Adaptability to different requirements and experimental conditions such as
  - Flexible tradeoffs between energy resolution and detection efficiency
  - Possible optimization to different noise conditions and signal shapes

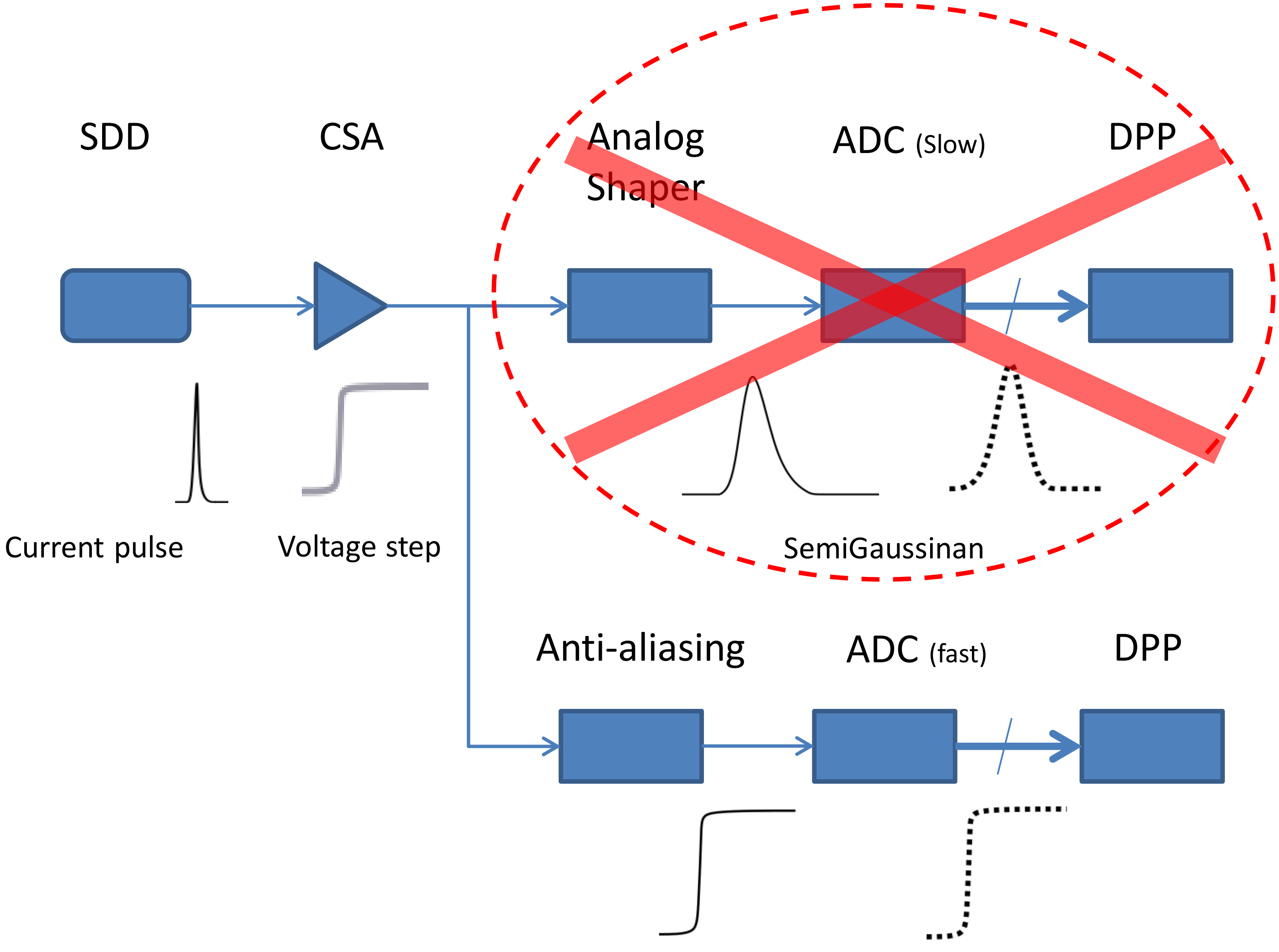
X-Ray Photons Detection



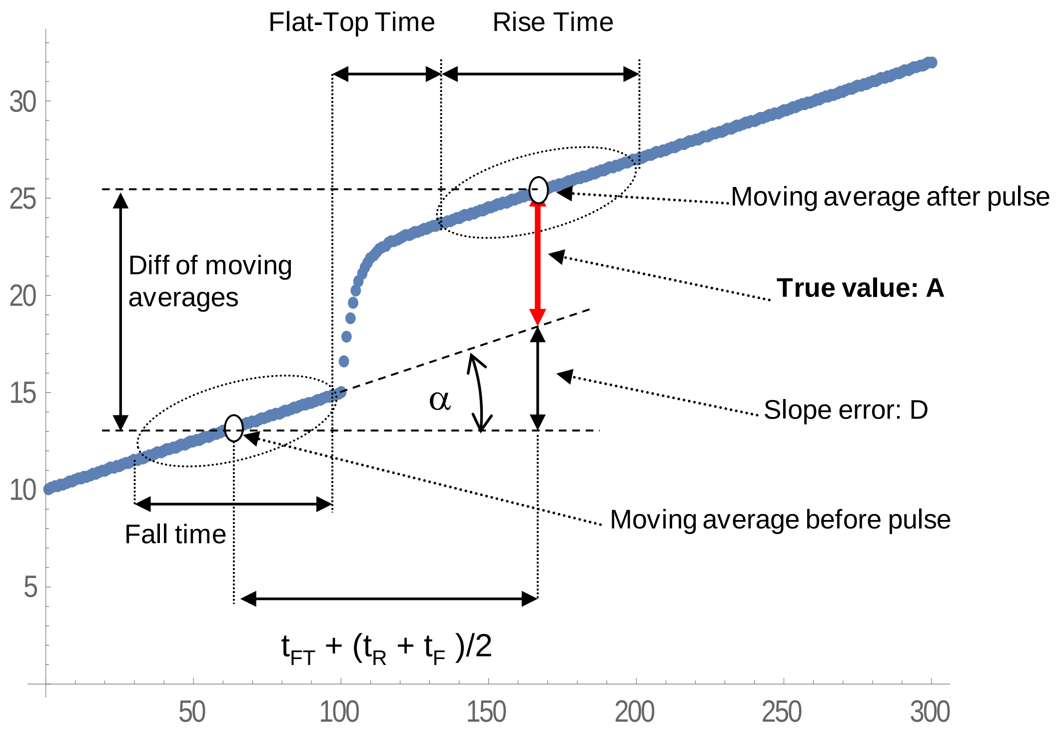
Detector, CSA, Pulse Shaper



Pulse Processing Chain

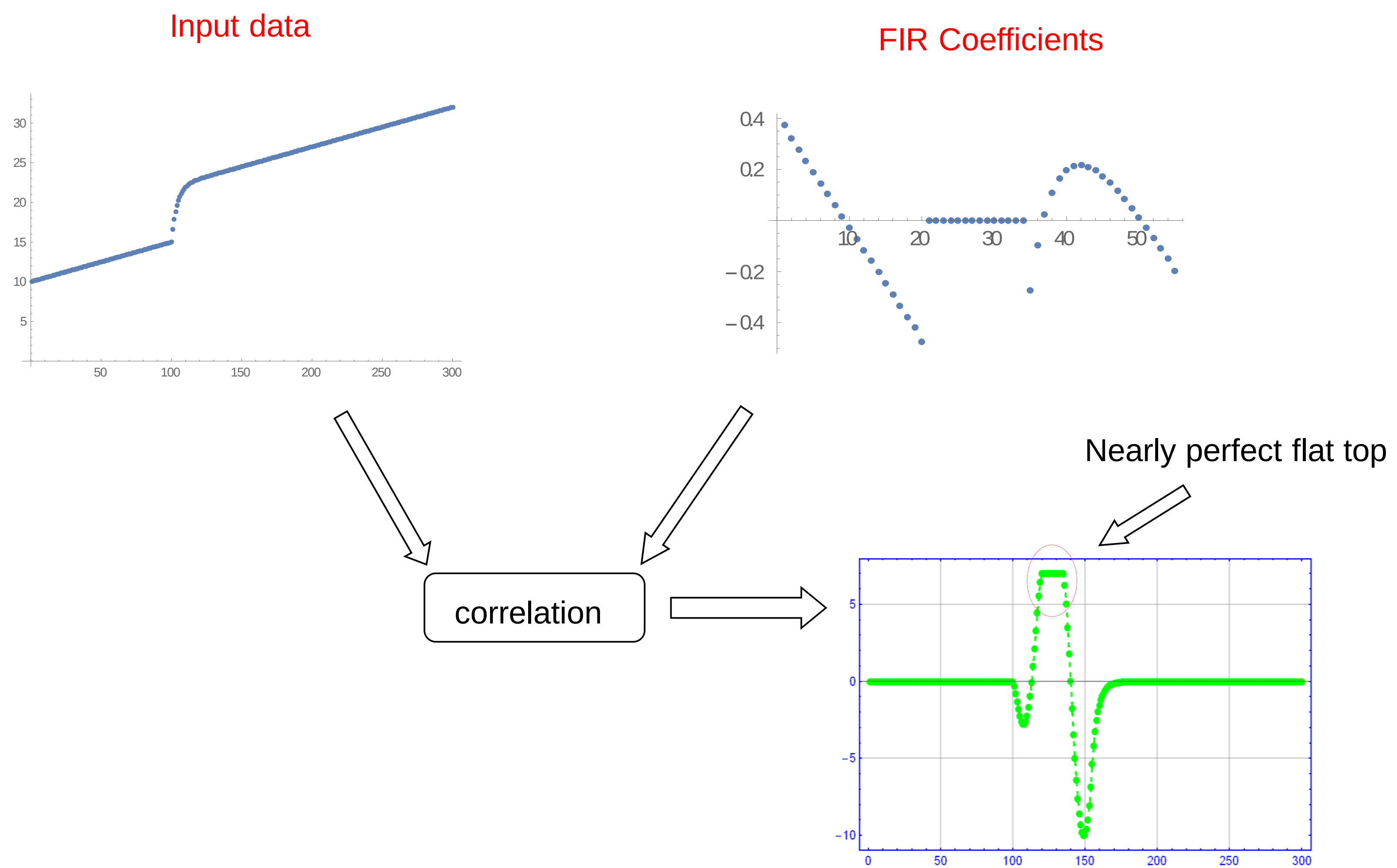


Time Domain Analysis of a Typical Voltage Step

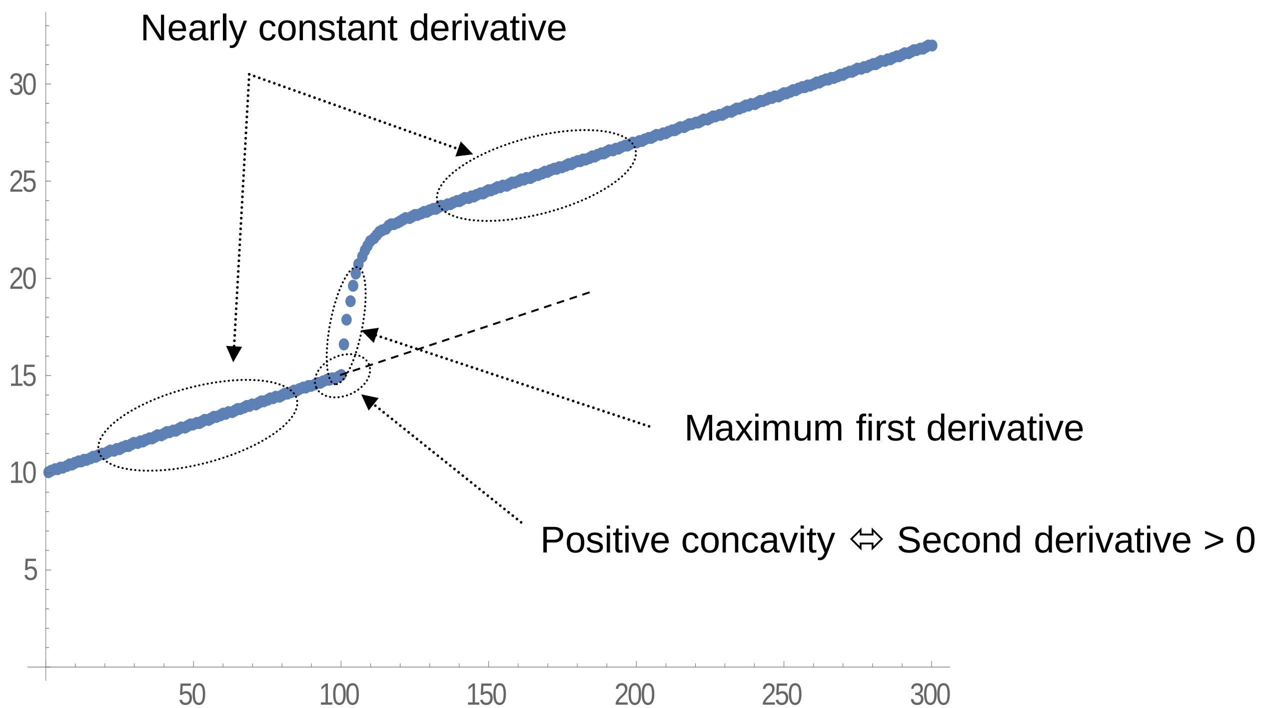


The true value can be calculated by mean of additions and multiplications

Digital Pulse Processing I: Measuring Amplitudes



Digital Pulse Processing II: Detecting Arrival Times



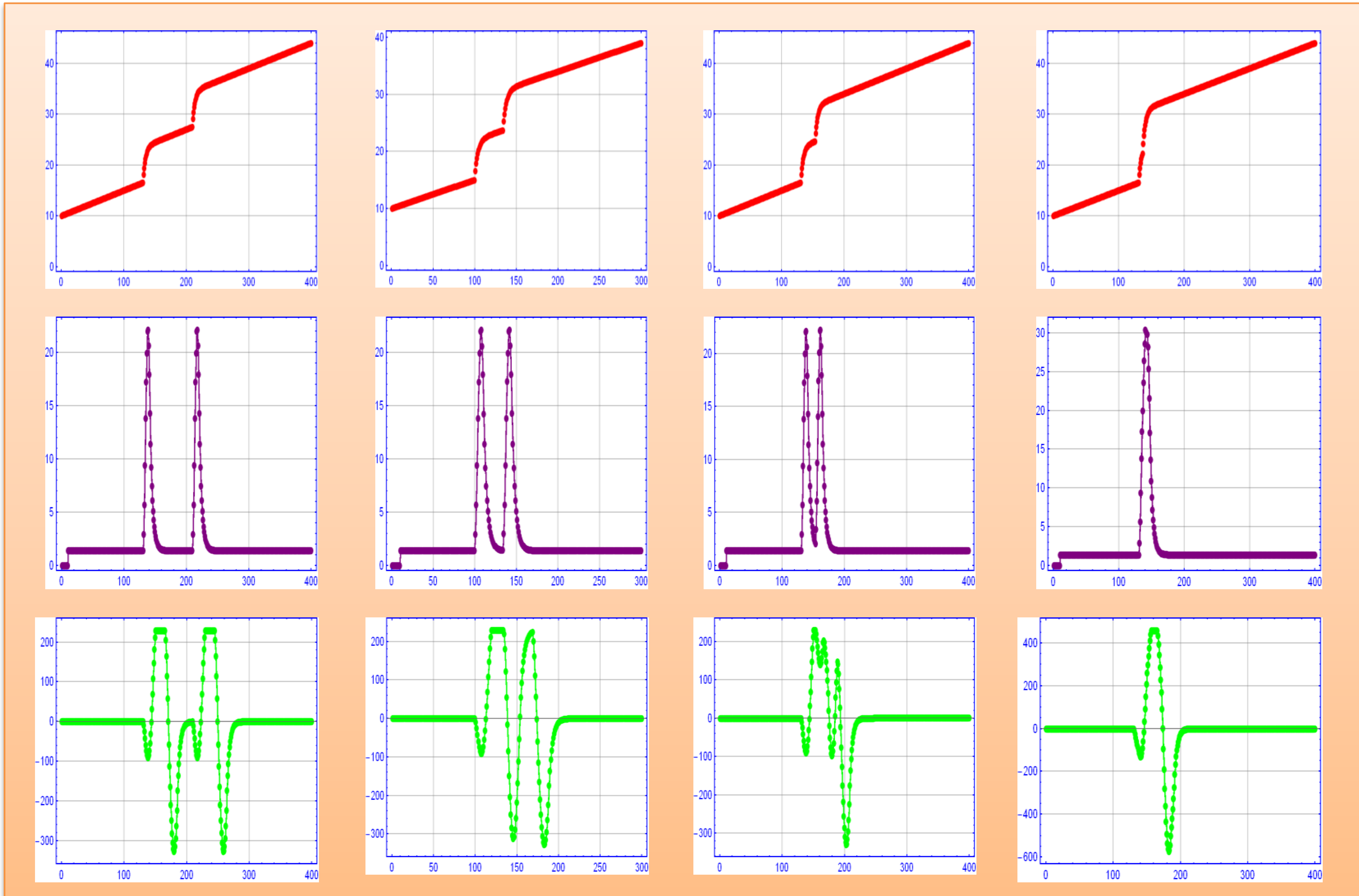
A short FIR can compute different discrete derivatives

Digital Pulse Processing III: Pile-up Rejection

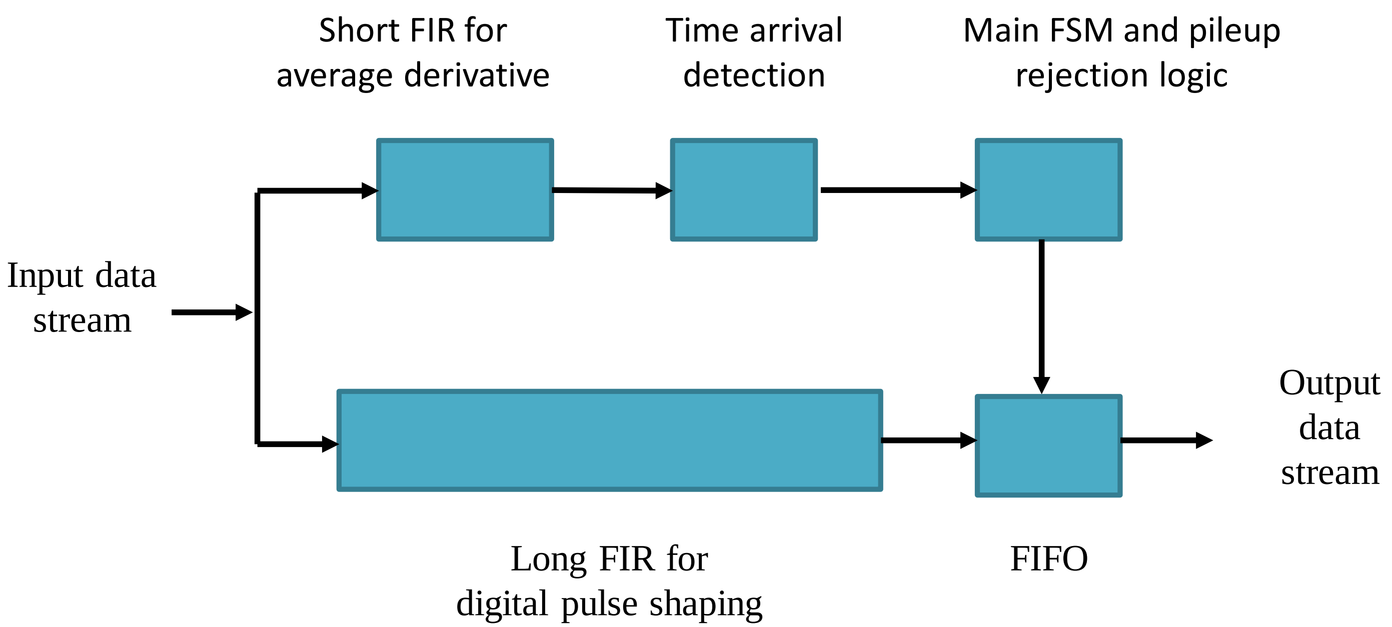
Input Pulses

First Derivs

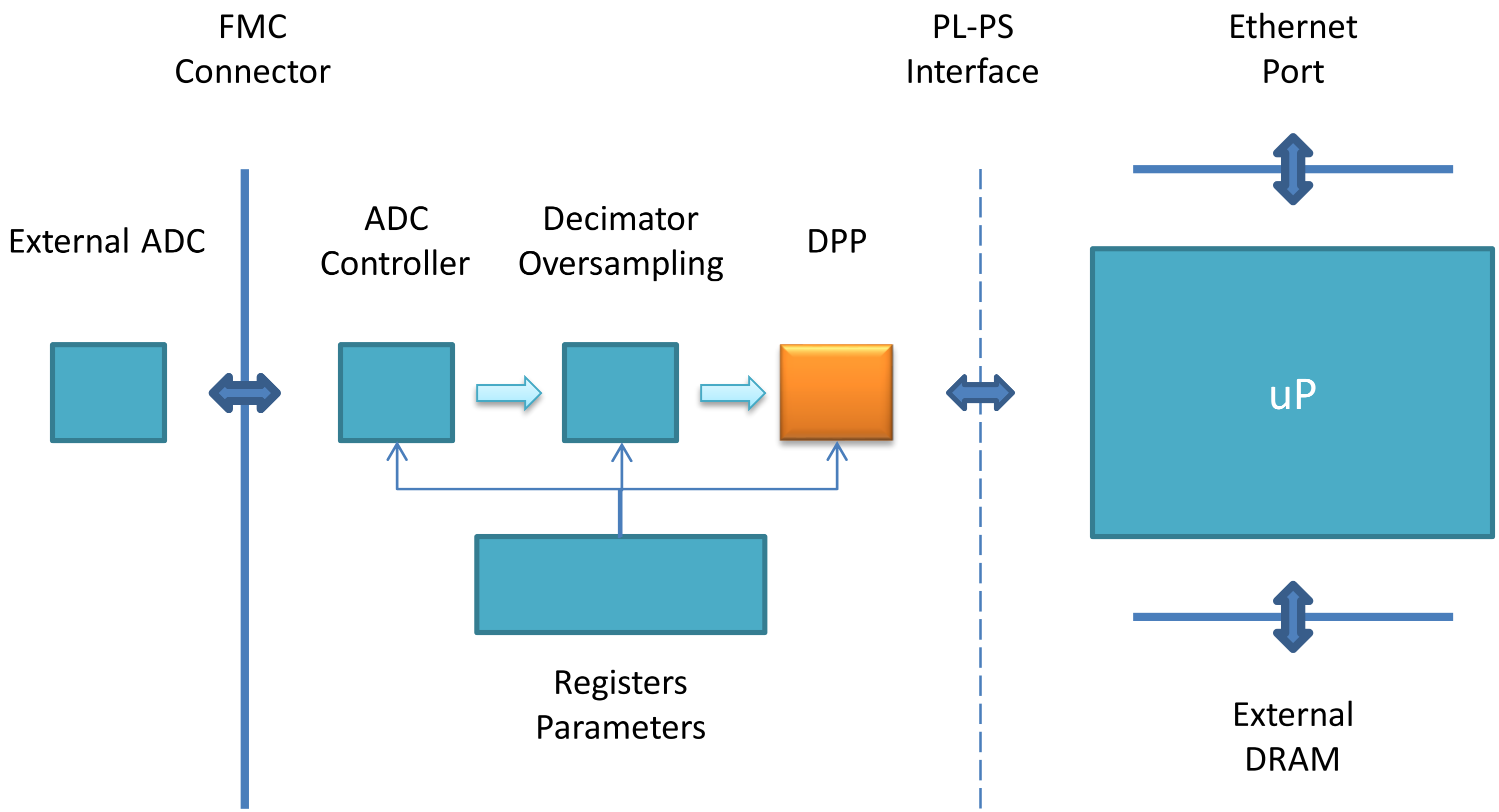
Shaped Pulses



Digital Pulse Processor

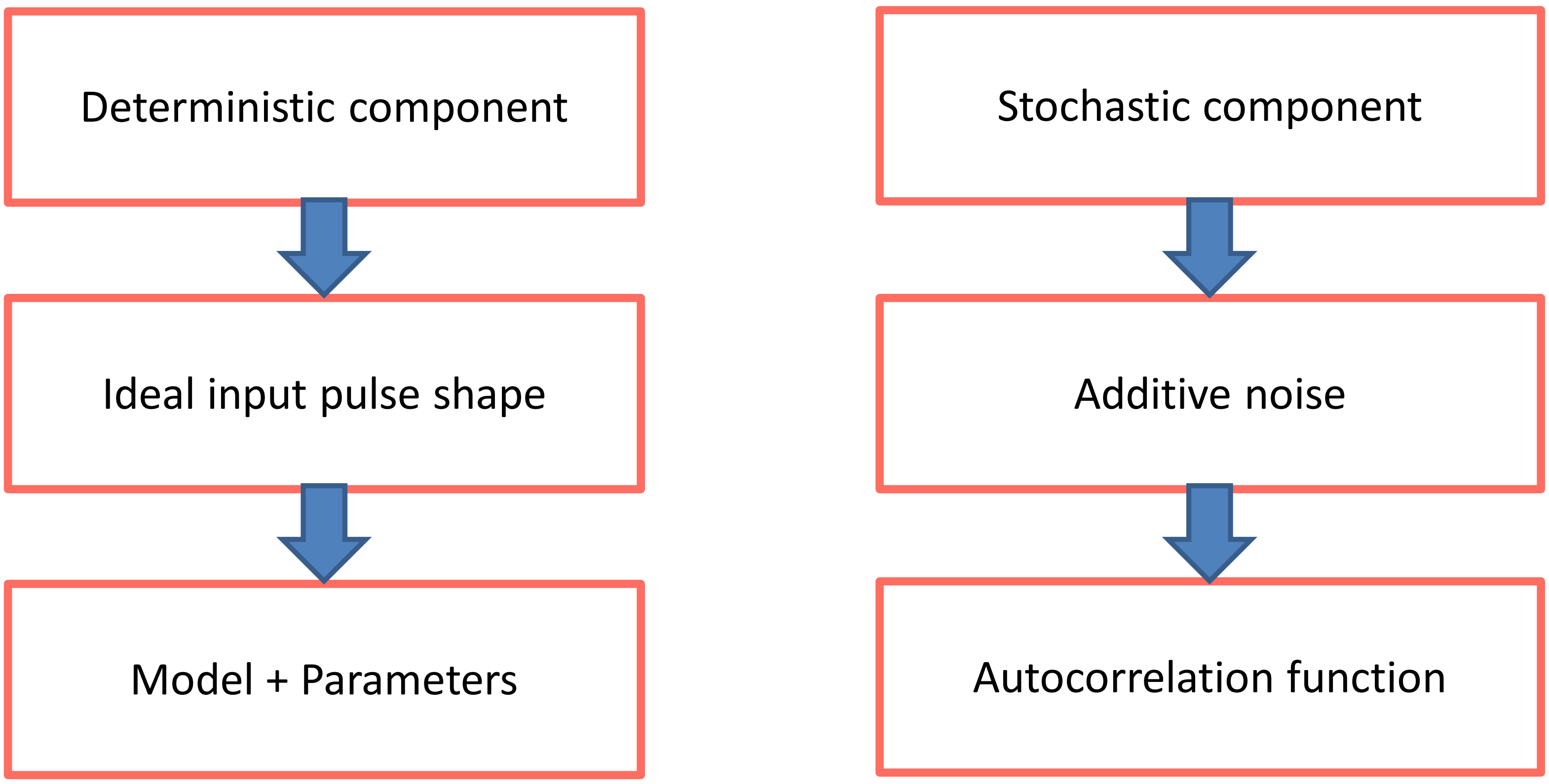


DPP Context in SOC: Global Architecture



FIR Design and Optimization

Input signal analysis



FIR Design and Optimization

Input pulse modeling I

The ideal case corresponding to a single photon detection is represented by the step function S_i

$$S_i = \begin{cases} 0, & i \leq t_0 \\ A, & i > t_0 \end{cases}$$

The finite frequency response of the CSA determines a limited rise time that could be modeled (1st aprox) as an exponential growth

$$S_i = \begin{cases} 0, & i \leq t_0 \\ A(1 - e^{-(i-t_0)/\tau}), & i > t_0 \end{cases}$$

A constant detector leakage current determines a baseline with a steady slope and a variable offset on top of which the signal segment must be processed

$$S_i = \begin{cases} B_0 + iB_1, & i \leq t_0 \\ A\left(1 - e^{-(i-t_0)/\tau}\right) + B_0 + iB_1, & i > t_0 \end{cases}$$

Several sources of noise will contribute with an additive spurious signal n_i that degrades the voltage step measurement

$$S_i = \begin{cases} B_0 + iB_1 + n_i, & i \leq t_0 \\ A\left(1 - e^{-(i-t_0)/\tau}\right) + B_0 + iB_1 + n_i, & i > t_0 \end{cases}$$

FIR Design and Optimization

Input pulse modeling II

Pile up: Being a Poissonian process, two or more photons could be absorbed in the SDD within any arbitrary small time window. The superposition of two photons absorbed at times t_0 and t_1 and respectively with amplitudes A_0 and A_1 is then given by

$$S_i = \begin{cases} B_0 + iB_1 + n_i, & i \le t_0 \\ A_0\left(1 - e^{-(i-t_0)/\tau}\right) + B_0 + iB_1 + n_i, & t_0 < i \le t_1 \\ A_0\left(1 - e^{-(i-t_0)/\tau}\right) + A_1\left(1 - e^{-(i-t_1)/\tau}\right) + B_0 + iB_1 + n_i, & i > t_1 \end{cases}$$

FIR Design and Optimization

Input pulse modeling III

. . . and in general for *m+1* photons

$$S_i = \begin{cases} B_0 + iB_1 + n_i, & i \le t_0 \\ A_0\left(1 - e^{-(i-t_0)/\tau}\right) + B_0 + iB_1 + n_i, & t_0 < i \le t_1 \\ A_0\left(1 - e^{-(i-t_0)/\tau}\right) + A_1\left(1 - e^{-(i-t_1)/\tau}\right) + B_0 + iB_1 + n_i, & t_1 < i \le t_2 \\ \vdots & \\ \sum_{j=0}^{m} A_j\left(1 - e^{-(i-t_j)/\tau}\right) + B_0 + iB_1 + n_i, & i > t_m \end{cases}$$

FIR Design and Optimization

Input noise characterization