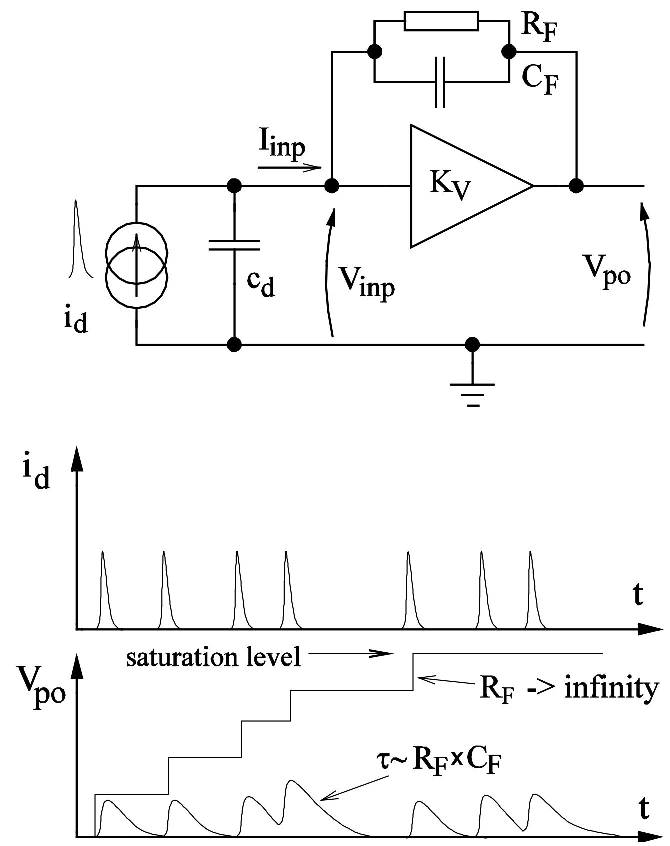
Cross talk signals in Charge Sensitive Amplifiers

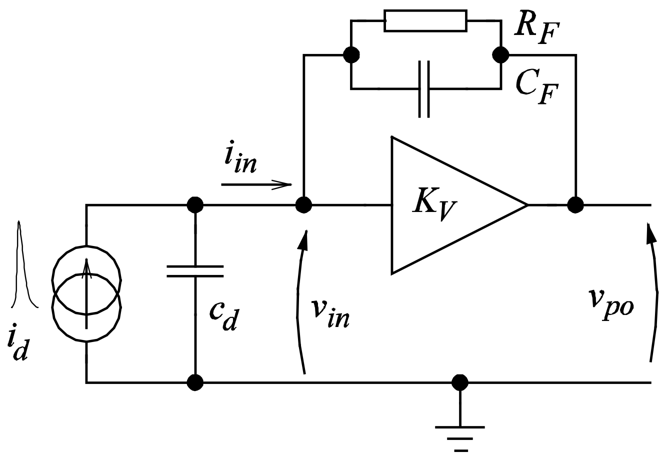
Comparison of charge and transimpedance preamplifiers

Reception of signals from silicon detector – basic configuration of the preamplifier

- ❑ Charge sensitive preamplifier
  - ❑ Delta-Dirac current pulses integrated on feedback capacitance
  - ❑ Discharge provided by the feedback resistor (prevents saturation)
- ❑ Mode of the preamplifier is defined by feedback time constant $\tau_F = R_F C_F$
  - ❑ τ_F comparable with the time constant of the shaper → transimpedance preamplifier
  - ❑ τ_F >> time constant of the shaper → charge preamplifier



Input impedance model (operator and frequency domain)



The input impedance in operator domain:

$$Z_{in}(s) = \frac{Z_F(s)}{1+K_V(s)} \approx \frac{Z_F(s)}{K_V(s)}$$

Considering dominant pole only the open loop gain is:

$$K_V(s) = \frac{K_V}{1+s\cdot\tau_{P0}}$$

Transimpedance mode:

$$Z_{in}(s) = \frac{R_F\cdot(1+s\cdot\tau_{P0})}{K_V\cdot(1+s\cdot\tau_f)}$$

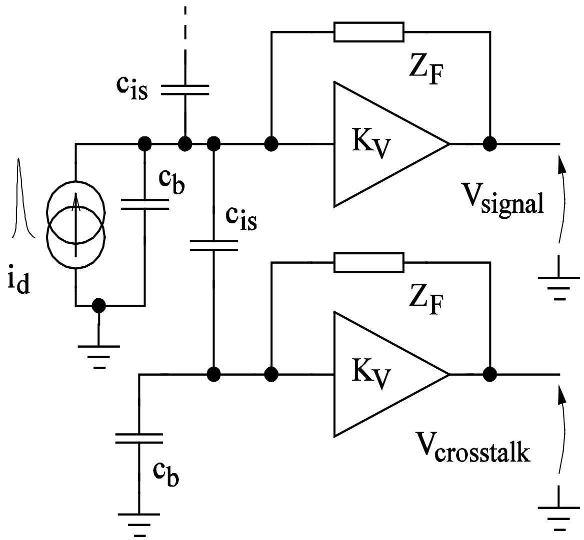
$$|Z_{in}| = \frac{R_F}{K_V}\cdot\frac{\sqrt{1+\omega^2\cdot\tau_{P0}^2}}{\sqrt{1+\omega^2\cdot\tau_f^2}}$$

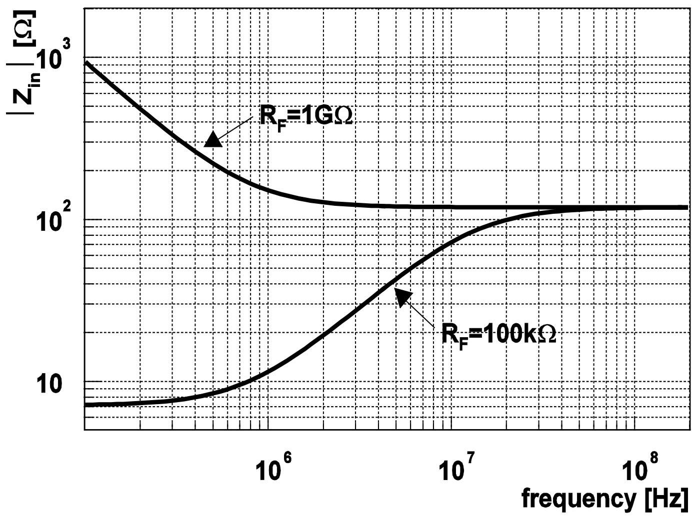
Charge preamplifier ($R_F \rightarrow \infty$):

$$Z_{in}(s) = \frac{1+s\cdot\tau_{P0}}{K_V\cdot s\cdot C_F}$$

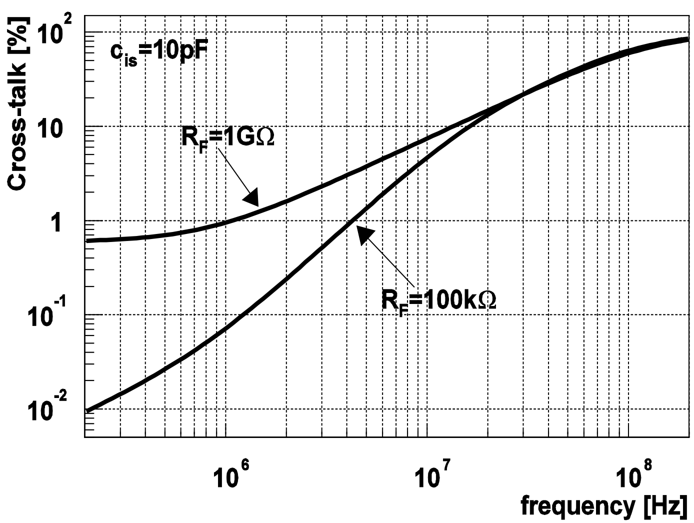
$$|Z_{in}| = \frac{\sqrt{1+\omega^2\cdot\tau_{P0}^2}}{\omega\cdot K_V\cdot C_F}$$

Input impedance and cross-talk signals for charge and transimpedance amplifiers





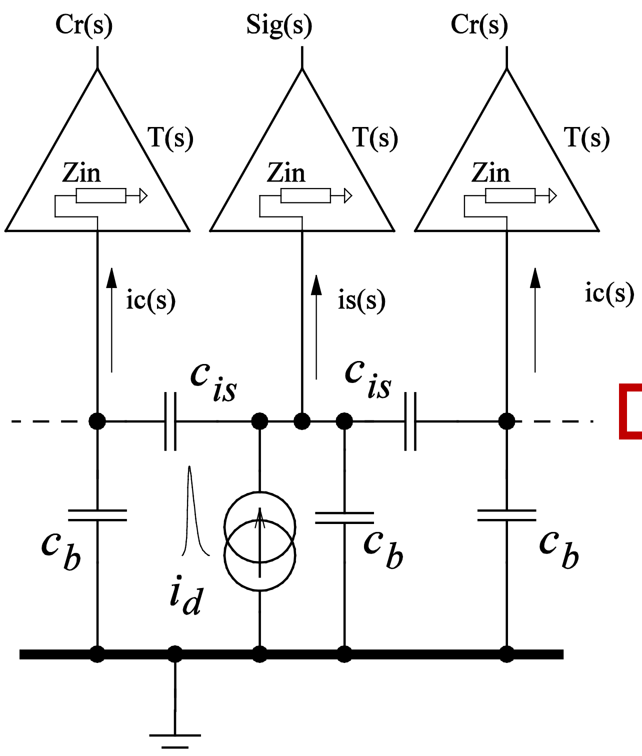
$$Cross\,Talk(s)=\frac{Z_{IN}(s)}{Z_{IN}(s)+Z_{IS}(s)}$$

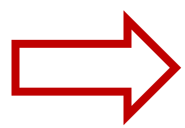


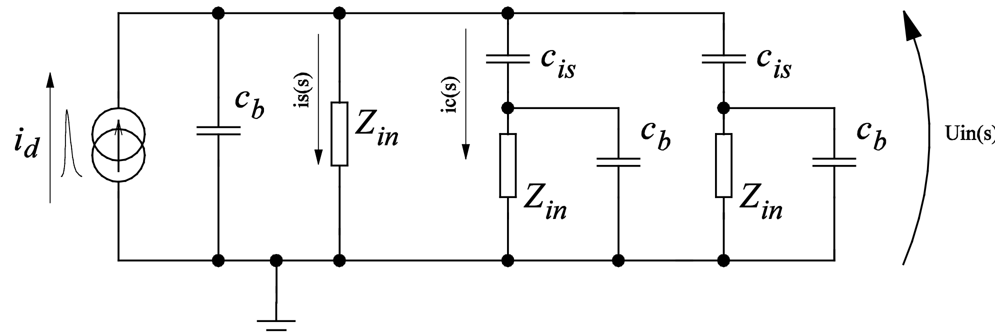
Input impedance and cross-talk for amplifier with 83dB gain and 1GHz Gain Bandwidth Product (GBP) working in charge and transimpedance configuration

Cross talk in time domain

Currents at front end inputs







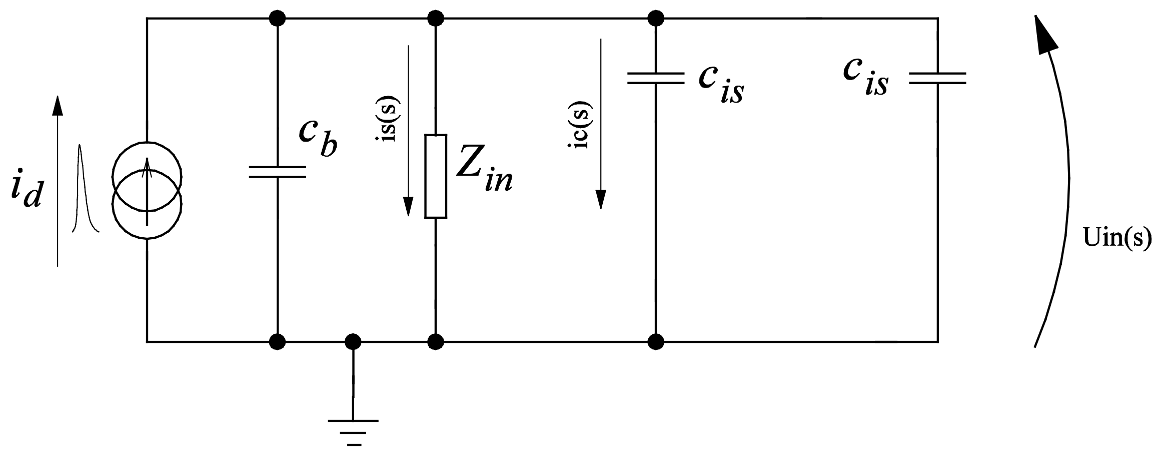
Using Kirchhoff law one can write:

$$i_d = u_{in} \cdot \left(s \cdot c_b + \frac{1}{Z_{in}} + \frac{2}{\dfrac{1}{s \cdot c_{is}} + \dfrac{Z_{in}}{s \cdot c_b \cdot Z_{in} + 1}} \right)$$

Unfortunately the use of this expression gives problems later during calculation of inverse Laplace functions. We have to simplify the model.

Currents at front end inputs

A reasonable trade off between accuracy and simplicity is shown below:



In this case we assume that input of the preamplifier is loaded with c_b and two c_{is} capacitances (neglecting input impedances of the neighbors). Using Kirchhoff law one can write:

$$i_d = u_{in} \cdot \left(s \cdot (c_b + 2 \cdot c_{is}) + \frac{1}{Z_{in}} \right)$$

Since we assume **delta Dirac input** we can write expression for voltage at the preamplifier input:

$$u_{in} = \frac{Z_{in}}{1 + s \cdot (c_b + 2 \cdot c_{is}) \cdot Z_{in}}$$

Currents at front end inputs

Expressions for current flowing into the input of readout channel:

$$i_s = u_{in} \cdot \frac{1}{Z_{in}}$$

For the expression of current flowing into neighboring channel we use simplified expression for u_{in} and expression for input impedance of neighboring channel connected in series with c_{is} capacitance (neglecting c_b):

$$i_c = u_{in} \cdot \frac{1}{Z_{in} + \frac{1}{s \cdot c_{is}}}$$

Front End transfer function and responses to signal and crosstalk

For calculation we will consider CR-RC^2 type of the shaper. The transfer function in operator domain is following;

$$T_{FE} = \frac{\tau_f}{(1 + s \cdot \tau_f)^3}$$

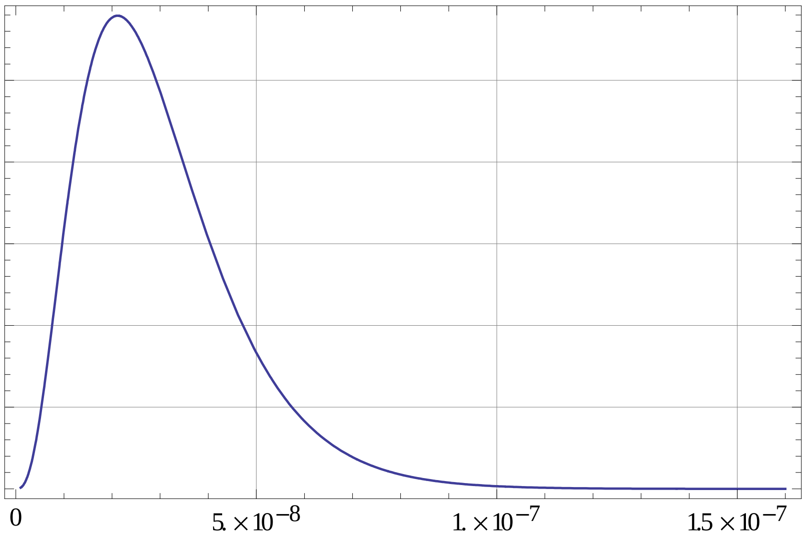
The response of Front End to delta Dirac function in time domain will be:

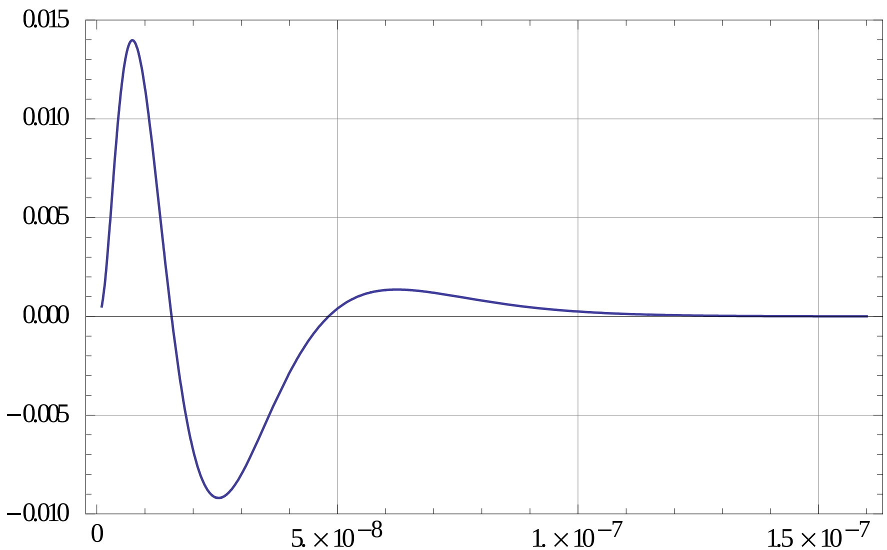
$$L^{-1}\left(T_{FE} \cdot i_s\right)$$

The crosstalk of first neighbor in time domain will be:

$$L^{-1}\left(T_{FE} \cdot i_c\right)$$

Example of calculation for transimpedance mode





Kv=83dB, τ_{p0} =200ns, GBP=1GHz *)

Detector; c_{is}=7pF, c_b=4pF (ATLAS SCT)

Response; Max=0.289 for t=21ns
(0.27 for 20ns without detector)

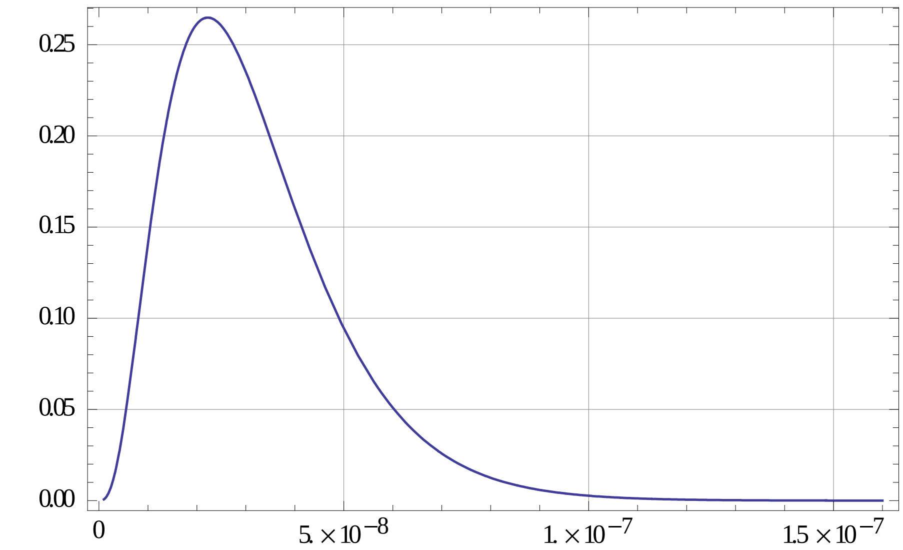
$$\int_0^\infty i_s(t)\,\partial t = 1$$

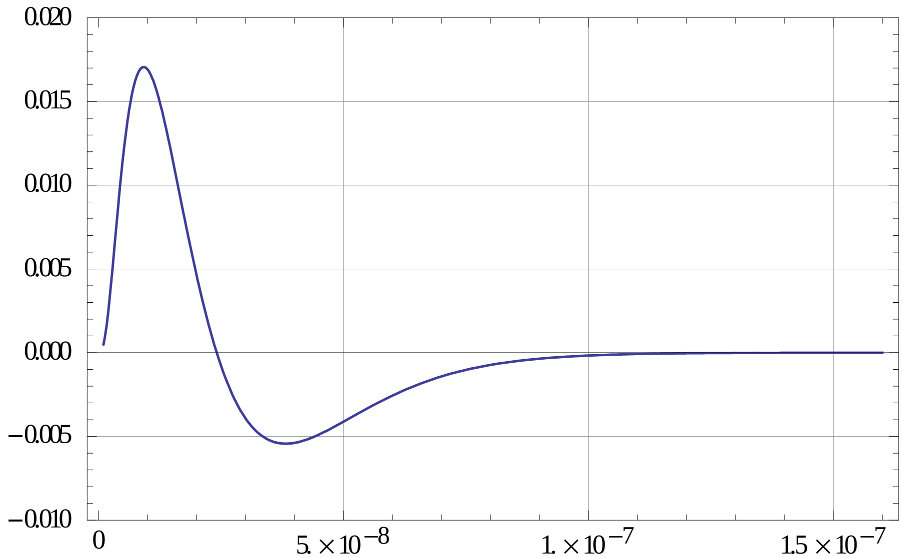
The overall charge readout by front end for transimpedance preamplifier is full!

Crosstalk; Max=0.0139 for t=7.4ns (5%)

Design presented in; J. Kaplon and W. Dabrowski, “Fast CMOS binary front end for silicon strip detectors at LHC Experiments,” *IEEE Trans. Nucl. Sci.*, vol. 52, no. 6, pp. 2713–2720, Dec. 2005

Example of calculation for charge preamp





Kv=83dB, τ_{p0} =200ns, GBP=1GHz *)

Detector; c_{is}=7pF, c_b=4pF (ATLAS SCT)

Response; Max=0.265 for t=22.2ns
(0.27 for 20ns without detector)

$$\int_0^\infty i_s(t)\,\partial t = 0.99$$

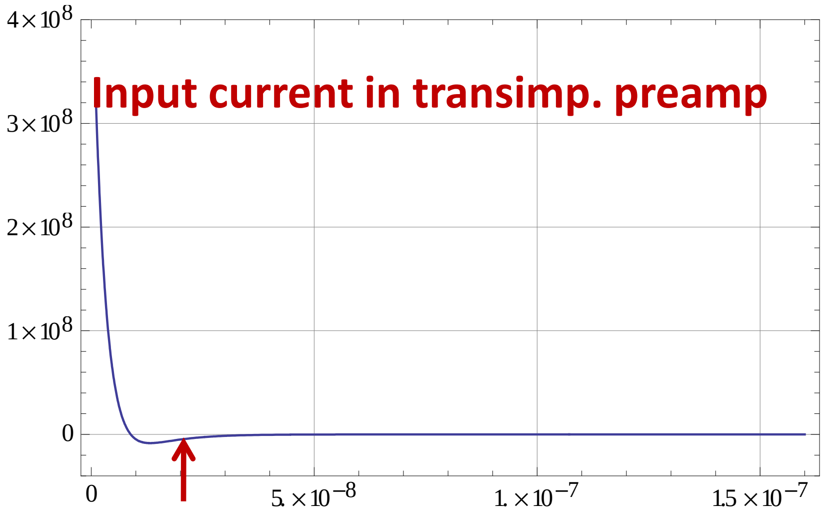
Lost of charge related to finite open loop gain of the preamplifier!

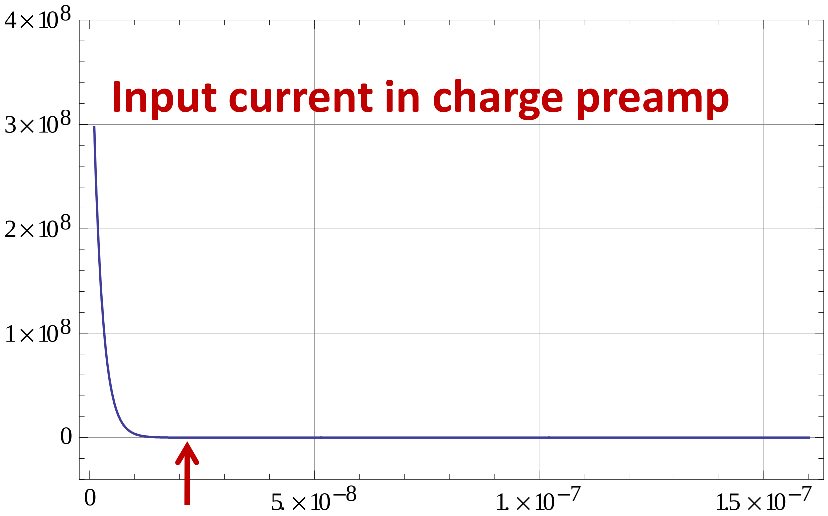
Crosstalk; Max=0.017 for t=9.2ns (~6.5%)

Preamplifier stage the same as in the last slide but working in charge mode (very high RF, CR-RC2 filter build with shaper only)

Ballistic deficit as a result of detector time constant

Previous calculactions of integrals of current flowing to the preamplifier input assumes collection of charge faster than peaking time...





Effective input impedance and detector capacitance create detector time constant integrating current pulses from the detector.
One must make sure that all current will be flown into the input faster than peaking time of the shaper → otherwise we will loose the slower part of the signal (effect similar to the ballistic deficit caused by slow charge collection from the detector) →
For a given detector size we have to lower the input impedance of the preamp