Charge collection and crosstalk signals in ABCD3T
(by Jan Kaplon)
for SCT crosstalk study

24 August, 2010

SCT Digitization TF meeting

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on behalf of Jan Kaplon (CERN)

Present SCT digitization model

(1) 7% of the hole charge is absorbed by the HV plane.

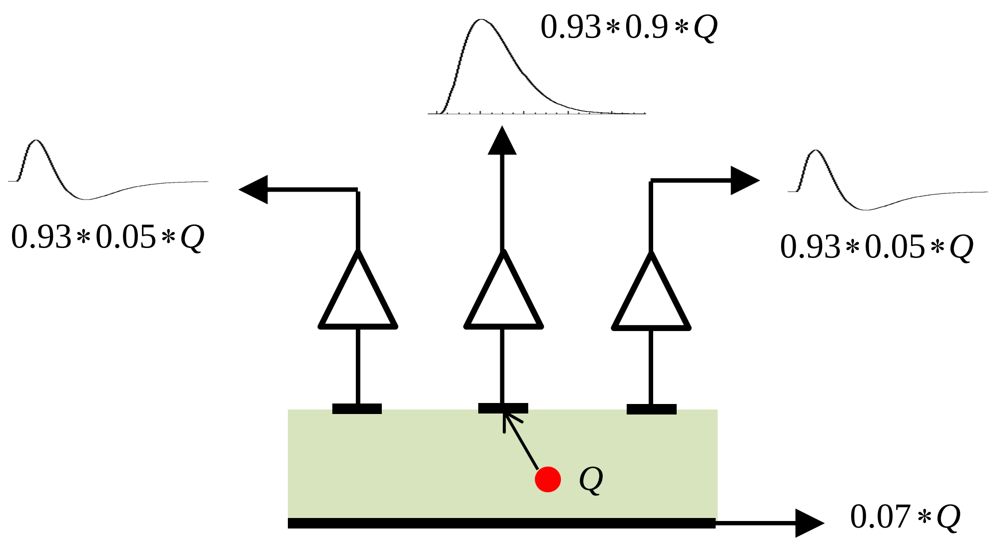
(2) 5% (10% total) of the hole charge is absorbed by the adjacent strip.

(3) The main signal has a shape:

$$a(t) = C_1 (t/\tau)^3 e^{-t/\tau}$$

(4) The crosstalk pulse is a differential form of the main signal

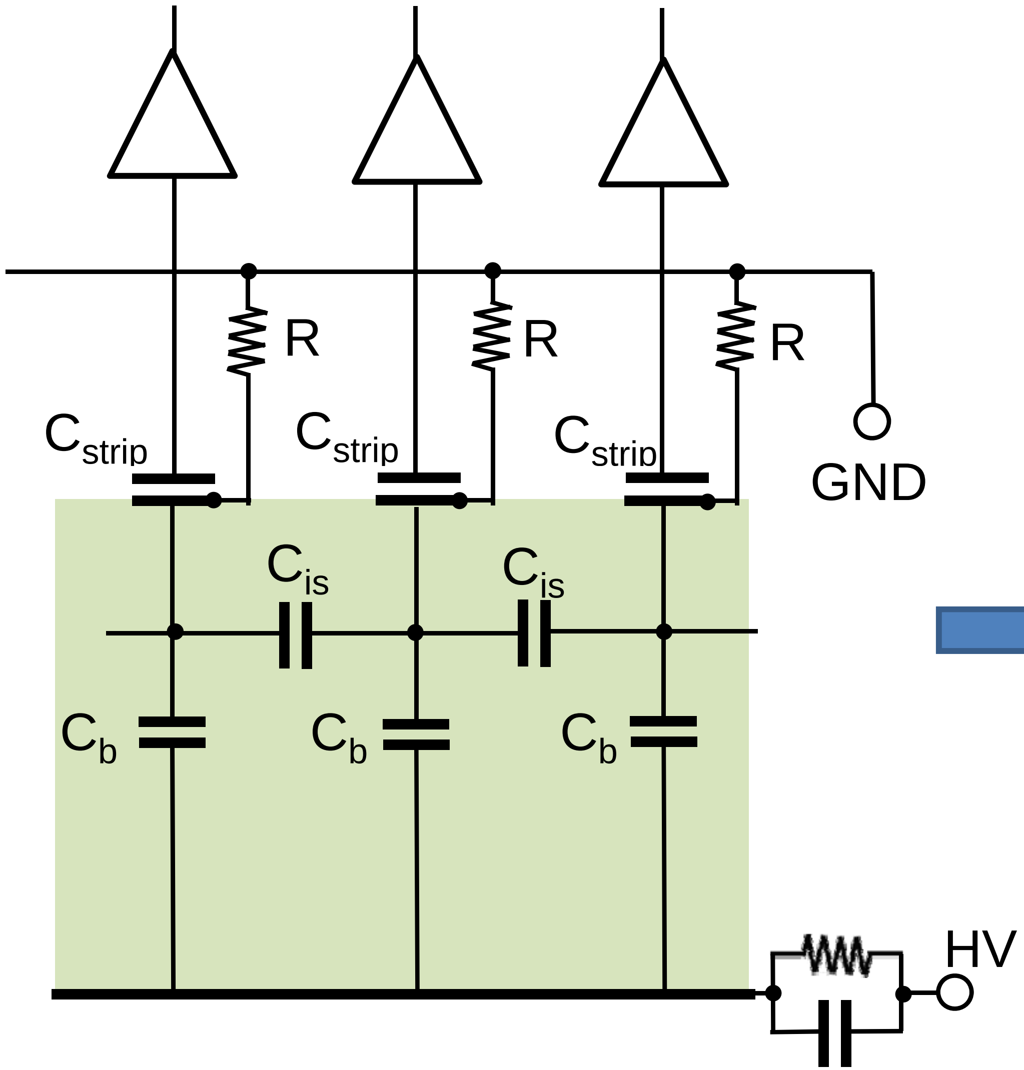
$$b(t) = C_2 (t/\tau)^2 e^{-t/\tau} (3 - t/\tau)$$

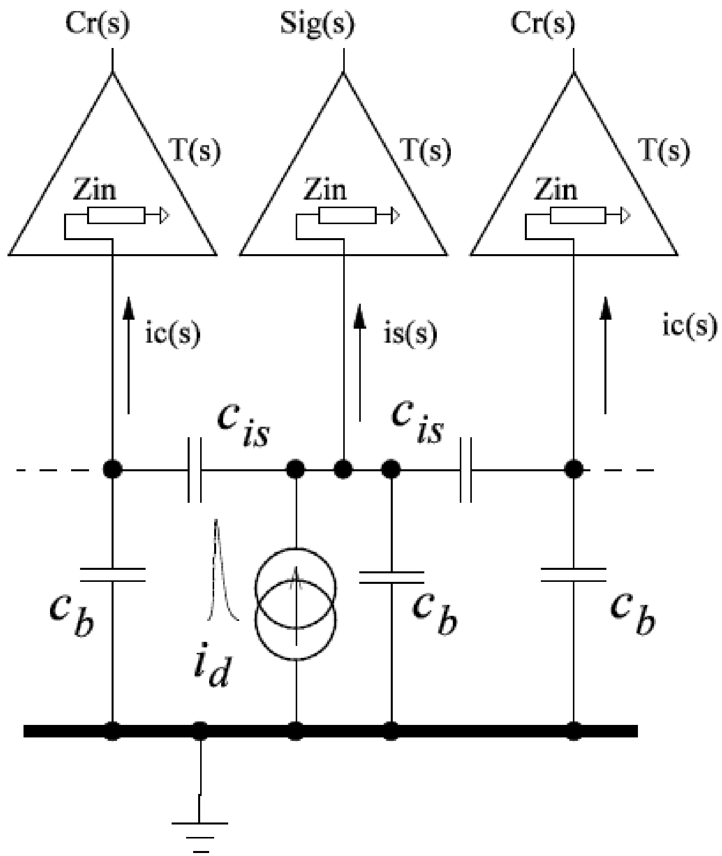


Studies so far indicated that the <cluster size>$_{average}$ is sensitive to the level and shape of the crosstalk.

Jan Kaplon (CERN) kindly worked on the input impedance of the ABCD chips, the key electrical parameter for crosstalk.

ABCD chips: Electrical parameters [1]





Kaplon's circuit model: neglecting C_{strip} and R

[1] F. Campabadal et al., NIMA 552 (2005) 292

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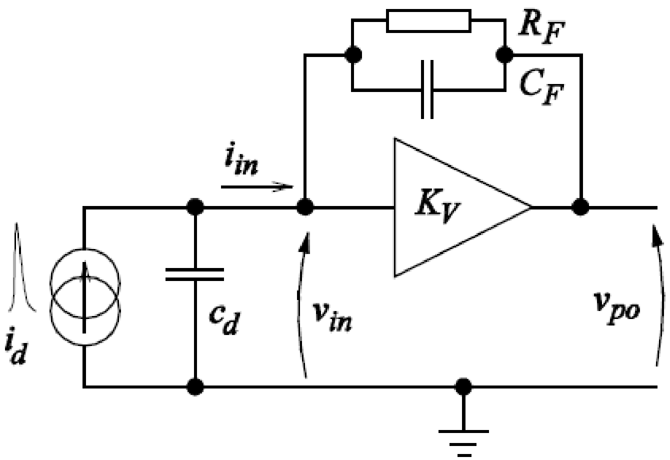
ABCD input impedance model



In operator domain:

Considering dominant pole only the open loop gain is:

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

And the input impedance in operator domain:

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

For ABCD3T preamplifier:

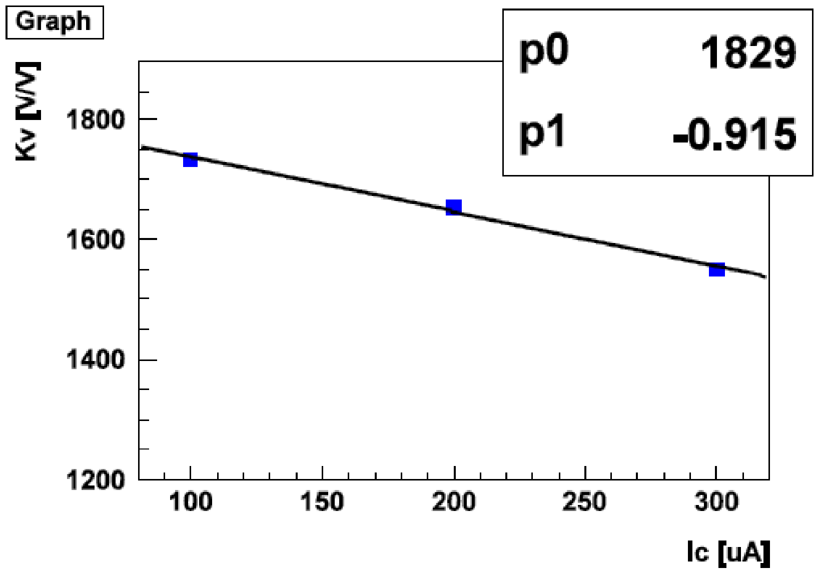
Rf=80k, Cf=120fF → τ_f = 10ns

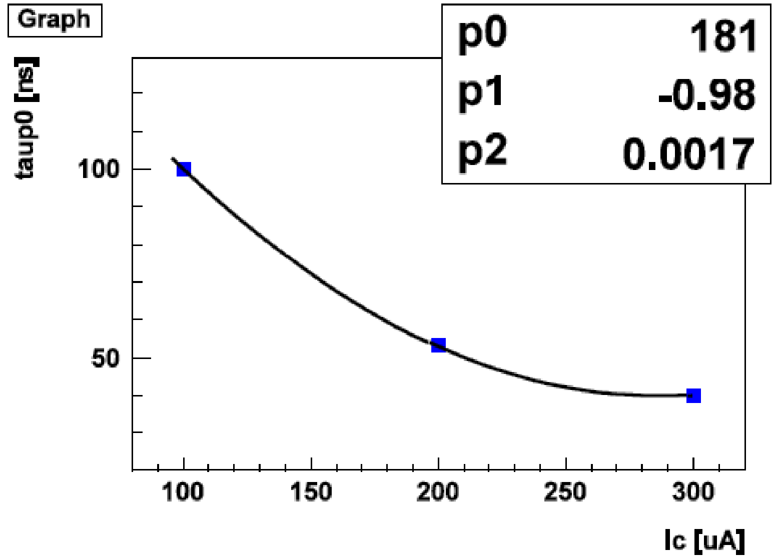
The Kv and τ_{p0} we obtain from AC Spice simulation for a given input transistor bias Ic

Ic	100uA	200uA	300uA
τ_{p0} [ns]	100	53	40
Kv [V/V]	1733	1654	1550

For intermediate values of bias current one should use interpolation function

ABCD input impedance model





For Ic values from 100 to 300uA range one can approximate the τ_{p0} and Kv as following:

$$\tau_{P0} = 181 - 0.98 \cdot I_C + 0.0017 \cdot I_C^2$$

$$Kv = 1829 - 0.915 \cdot I_C$$

where Ic in uA, τ_{p0} in ns, and Kv in [V/V]

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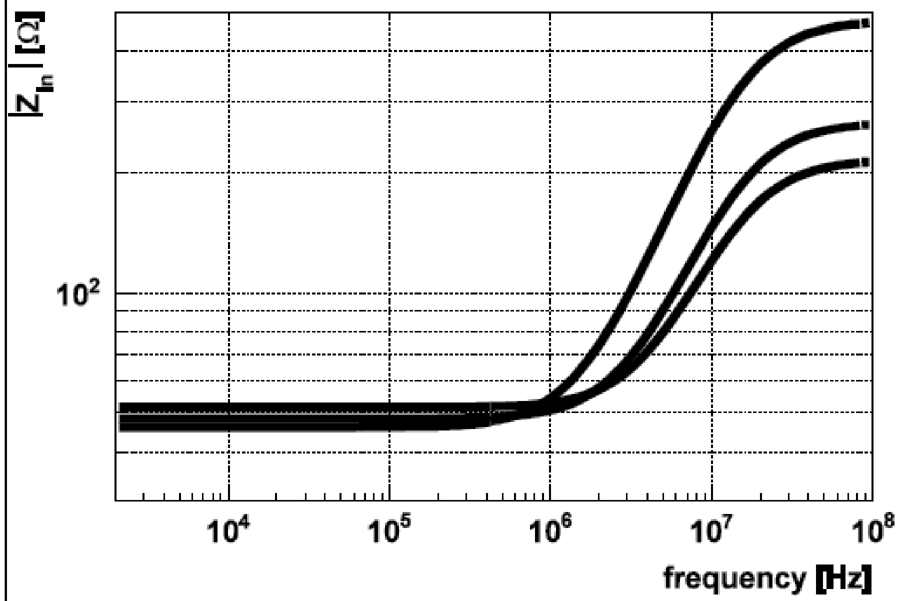
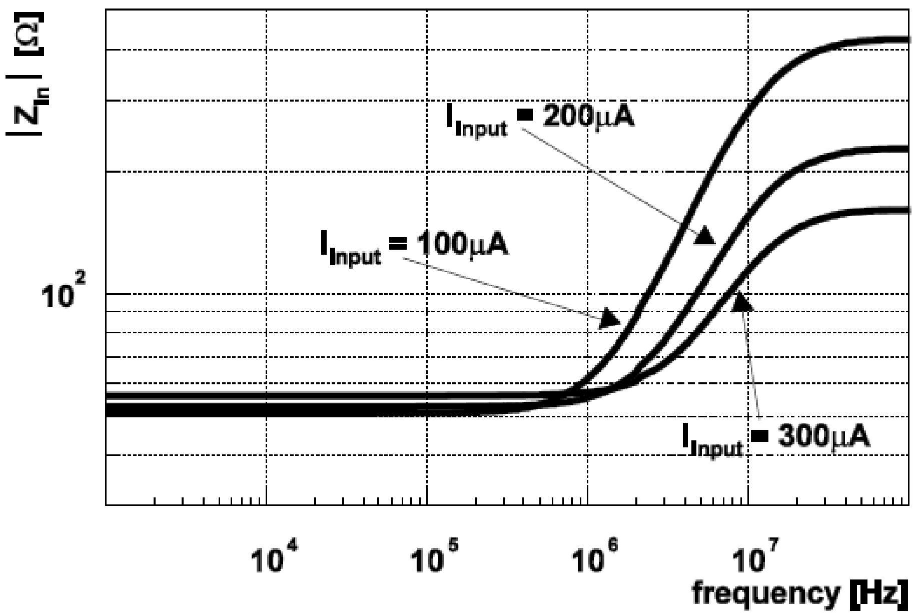
ABCD input impedance model

In frequency domain the Zin is following :

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

This simple model using extracted parameters Kv and τ_{p0} (left figure) can be verified with the Spice simulation of the ABCD3T input impedance (right) for the same input transistor bias currents





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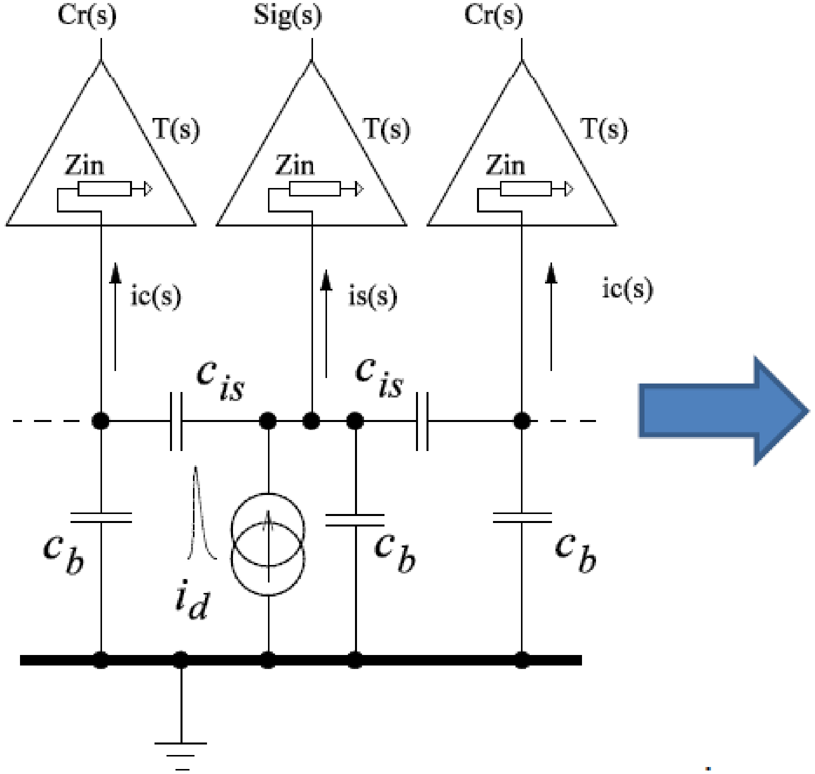
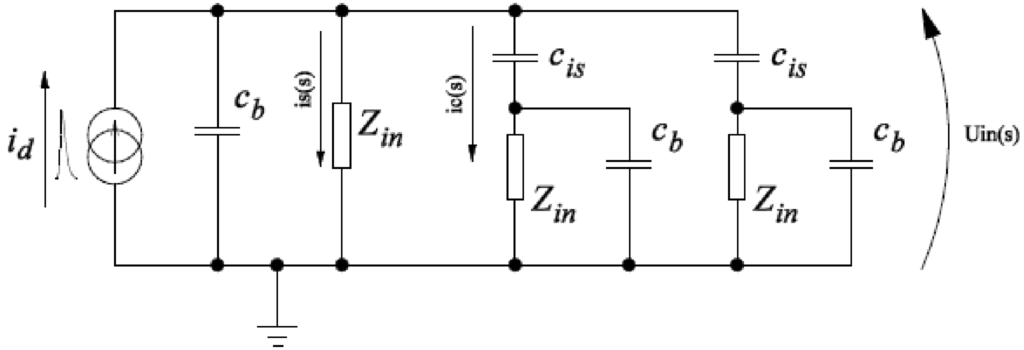
Currents at front end inputs





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.

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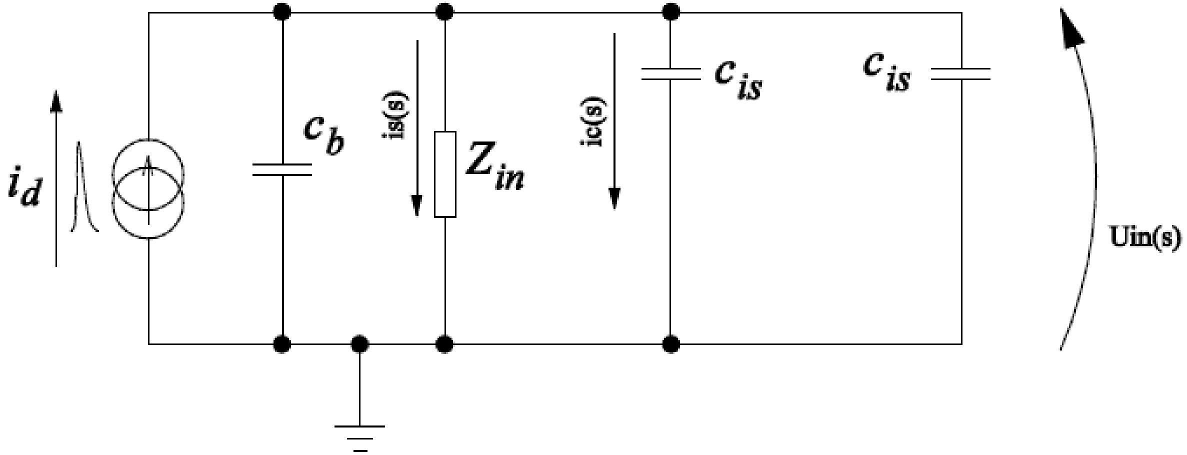
Currents at front end inputs

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:

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

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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):

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

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Currents at front end inputs; what is happening to signal charge

Current flowing into the input of neighboring channels and backplane capacitance:

$$i_{lost} = u_{in} \cdot s \cdot (c_b + 2 \cdot c_{is})$$

One should note than the overall charge transfer to readout channel is full i.e.

$$\int_0^\infty i_s(t)\,\partial t = 1 \quad and \int_0^\infty i_{lost}(t)\,\partial t = 0$$

That means that after some delay caused by Zin all charge flows finally into the input of preamplifier connected to the hit strip i.e. we do not see the loss of charge however the response of the preamplifier stage is generally slower due to extra time constant created by Zin and detector capacitance (detector time constant) .

In general the detector time constant modifies the preamplifier transfer function changing the gain, peaking time and phase margin. All those changes and possible loss of signal at the end of the full signal processing chain will depends on detector time constant and time constants of all stages contributing to the signal formation.

N.B. This applies to transimpedance preamplifiers, where the input impedance has real part. In case of pure charge preamplifier with non-continuous reset (reset switch) there will be real charge sharing in between all capacitances at the preamplifier input during the readout phase.

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ABCD transfer function and responses to signal and crosstalk

Overall transfer function of ABCD3T channel can be approximated with CR-RC response of preamplifier with time constant of τ_f = 10ns and two stages of integrators with time constant τ_i = 4ns

$$T_{ABCD} = \frac{\tau_f}{(1 + s \cdot \tau_f)^2} \frac{1}{(1 + s \cdot \tau_i)^2}$$

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

$$L^{-1}(T_{ABCD} \cdot i_s)$$

The crosstalk of first neighbor in time domain will be:

$$L^{-1}(T_{ABCD} \cdot i_c)$$

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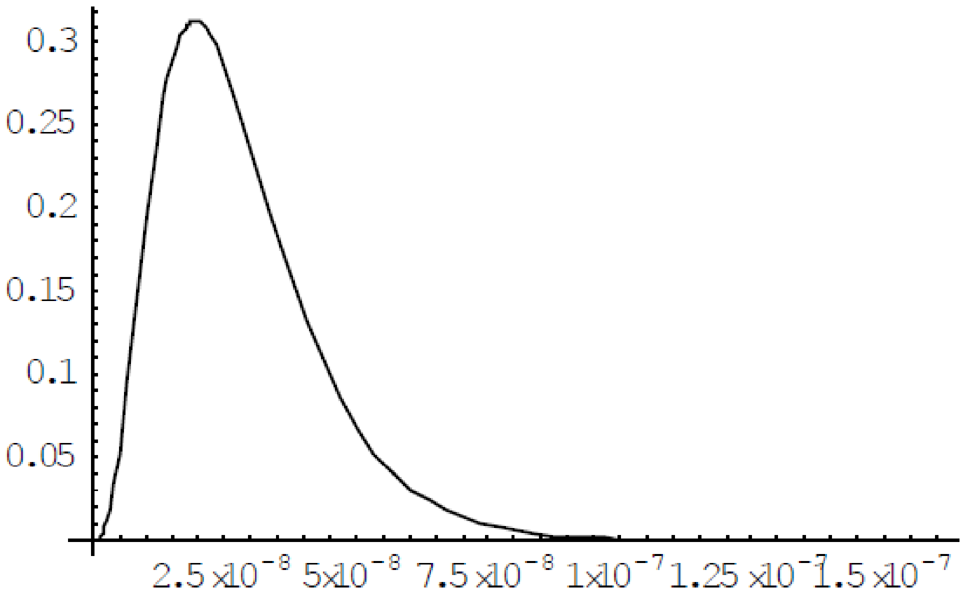
Example of calculation

Kv and τ_{p0} for Ic=200uA (table page 1)



Response for channel not loaded with detector

Max=0.313349 for t=19.4366ns

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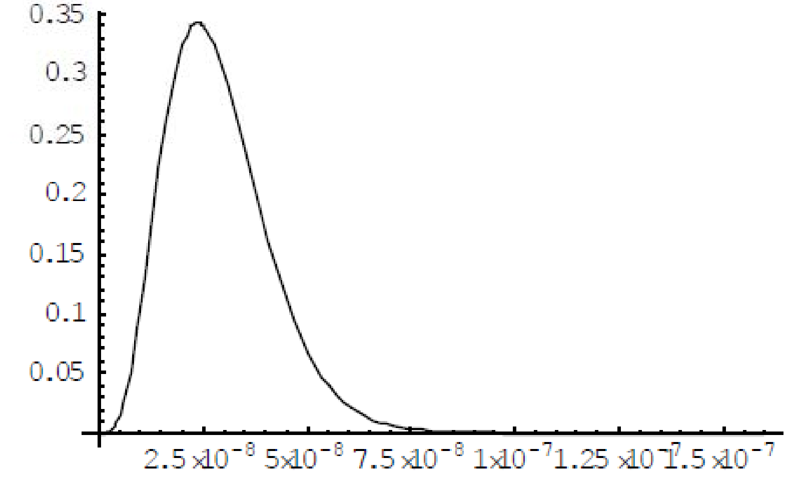
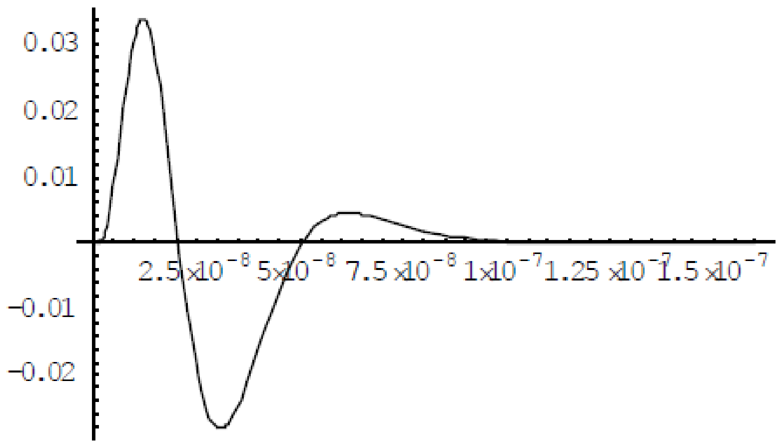
Example of calculation

Kv and τ_{p0} for Ic=200uA (table page 1), c_b=4pF, c_{is}=7pF





Response for channel loaded with detector

Max=0.34299 for t=23.7339ns

When compare to response of the open channel (previous page) we can see that the peaking time has been changed from 19.4ns to 23.7ns and the peak gain has been increased from 0.313 to 0.343. The change of gain and peaking time is caused by detector time constant which change the overall response of the preamplifier (modifying also the phase margin).

Crosstalk

Max=0.0339311 for t=12.012ns

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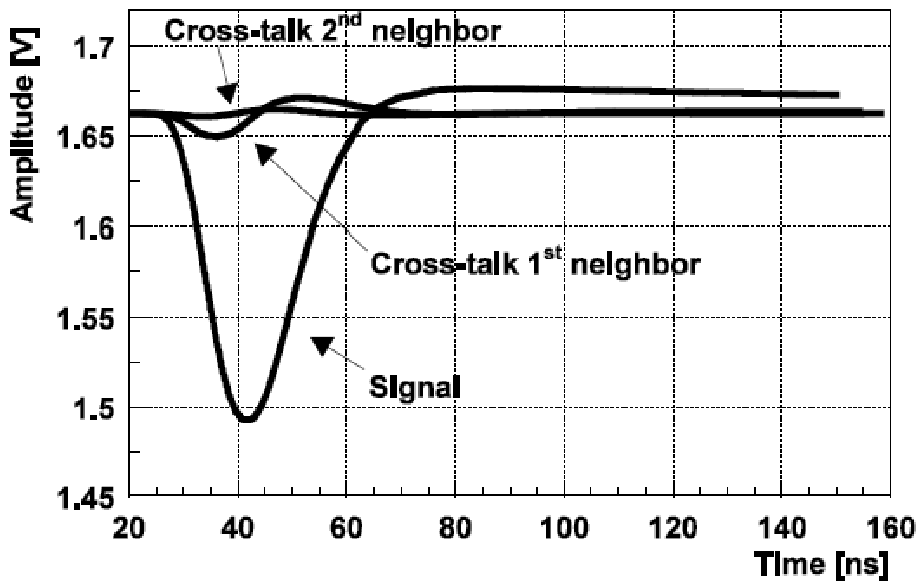
Comparison of analytical model to Spice simulations

Crosstalk for cis=7pF and cb=4pF and Ic=200uA calculated using presented formulas is in the range of 10%.
Crosstalk simulated in Spice for the same detector and front end parameters is in the range of 8% (see figure below). The overestimation of the crosstalk can be both to analytical model inaccuracy as well as to the fact that in the Spice we have used longer charge collection times (8ns) when in calculation we use as the detector signals delta Dirac function.



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Summary of Jan Kaplon's work

1. Using the Laplace transformation of the equivalent circuit (with some simplifications) and the inverse-Laplace transfer function of Mathematica, analytic expressions of the signal and crosstalk are obtained.

2. With C_b=4pf, C_{is}=7pF and I_C=200 uA, the crosstalk level for delta-function input is

$$\frac{peak_{crosstalk}}{peak_{signal}} \approx \frac{0.03393}{0.34299} \approx 10\% \text{ (per each side)}$$

with peak timings of

$$t_{peak} \approx 23.7 \text{ ns} \quad \text{(signal)}$$
$$t_{peak} \approx 12.0 \text{ ns} \quad \text{(crosstalk)}$$

5% in current SCT digitization model

Relevant parameters for Barrel modules

	Un-irradiated	Irradiated	ref
C_{strip}	> 20 pF/cm	> 20 pF/cm	[2]
$2*C_{is}$	1.03 pF/cm	1.40 pF/cm	[1]
	< 1.1 pF/cm	< 1.5 pF/cm	[2]
C_b	0.30 pF/cm	0.30 pF/cm	[1]
I_C	220 μA	120 – 140 μA	[3]
R	1.25+–0.75 MΩ		[2]
Strip length	126.09 – 2.090(gap) = 124.0 mm		[2]
Rf	80 kΩ		[4]
Cf	120 fF		[4]
τ_i	4 ns		[4]

[1] F. Campabadal et al., NIMA 552 (2005) 292
[2] A. Abdesselam et al., NIMA 568 (2006) 642
[3] F. Campabadal et al., NIMA 538 (2006) 384
[4] J. Kaplon (this talk)

Parameters and solutions for SCT barrel case (t in [ns])

	R_f	τ_f	τ_i	C_{is}	C_b	τ_{p0}	K_V
un-irradiated	80	9.6	4	6.39	3.72	47.68	1628
Irradiated				8.68		82.33	1710
[unit]	[kΩ]	[ns]	[ns]	[pF]	[pF]	[ns]	[V/V]

$$v_{signal}^{unirrad} = \frac{0.622\cos(0.0879t) - 9.37\sin(0.0879t)}{e^{0.135t}} + \frac{8.77}{e^{0.104t}} - \frac{9.40 + 0.527t}{e^{0.25t}}$$

$$v_{crosstalk}^{unirrad} = \frac{0.1765}{e^{0.538t}} - \frac{0.393\cos(0.0879t) - 5.92\sin(0.0879t)}{e^{0.135t}} - \frac{20.15}{e^{0.124t}} + \frac{8.77}{e^{0.104t}} + \frac{11.59 + 0.872t}{e^{0.25t}}$$

$$v_{signal}^{irrad} = \frac{3.78}{e^{0.104t}} - \frac{1.82\cos(0.0898t) + 0.986\sin(0.0879t)}{e^{0.135t}} - \frac{1.952 + 0.125t}{e^{0.25t}}$$

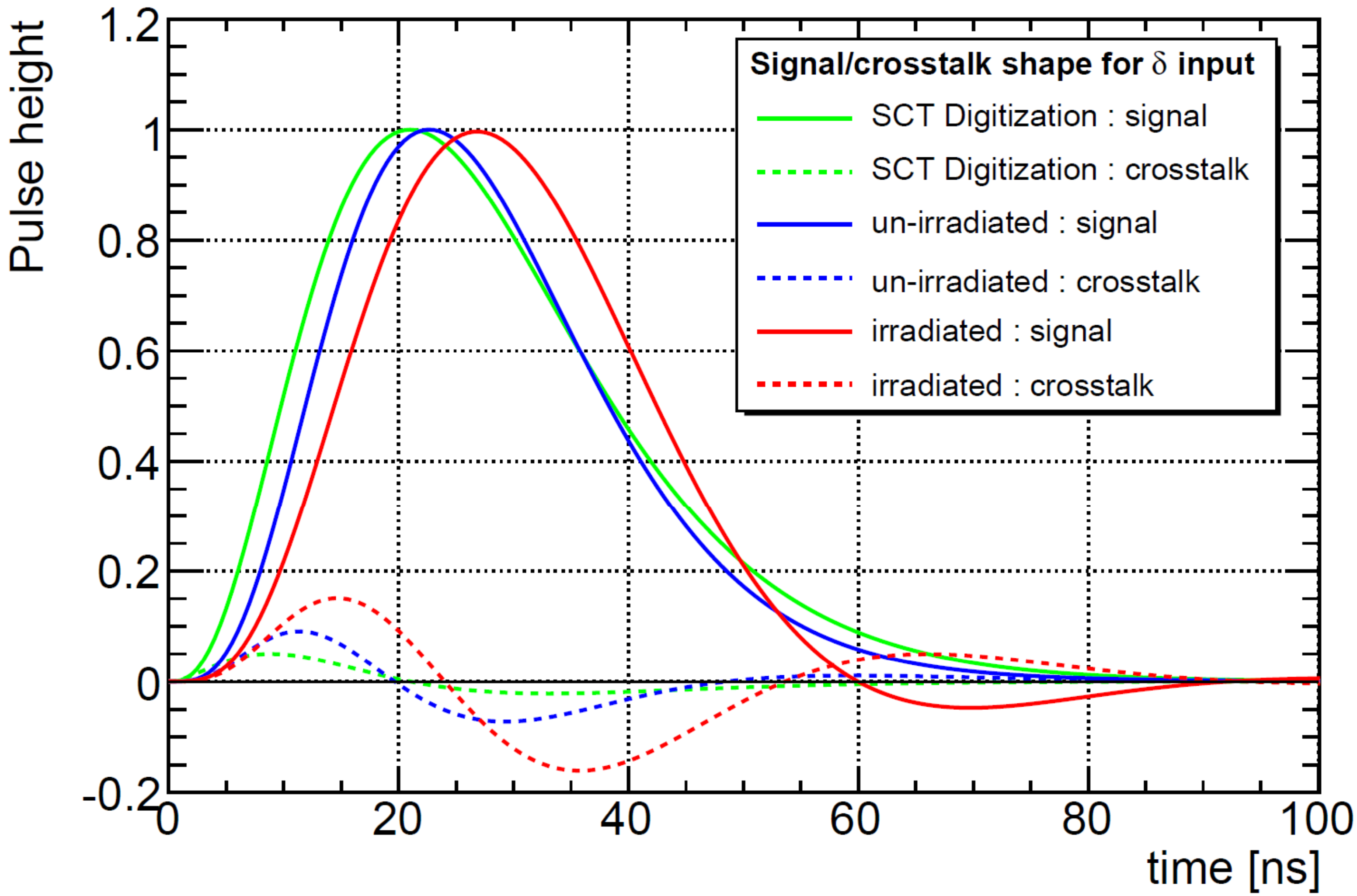
$$v_{crosstalk}^{irrad} = \frac{2.90\cos(0.0867t) - 8.27\sin(0.0867t)}{e^{0.135t}} + \frac{3.78}{e^{0.104t}}$$

$$+ \frac{1.277\cos(0.0898t) - 0.690\sin(0.0898t)}{e^{0.135t}} - \frac{7.96 + 0.423t}{e^{0.25t}} \qquad \text{where } t \text{ in [ns]}$$

Response to δ-function input

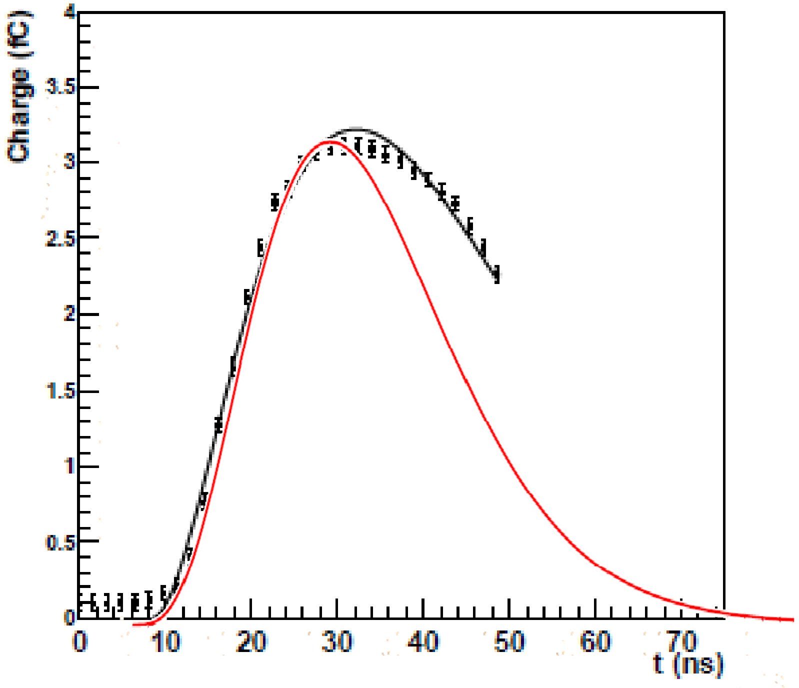
(signal peak is normalized to 1)

models	t_{peak}	crosstalk
SCT Digitization	21 ns	5 %
un-irradiated	22.5 ns	10 %
irradiated	27 ns	15 %

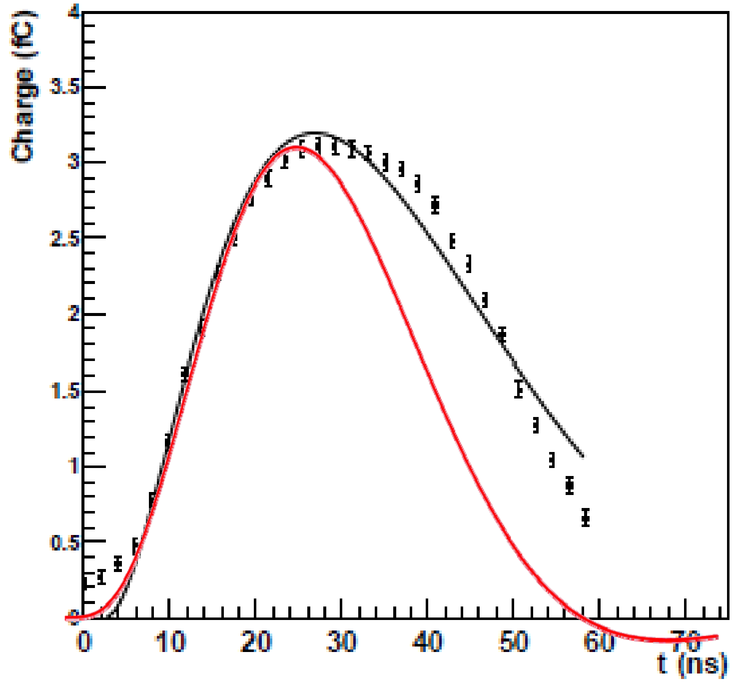


Comparison with test beam data [1]

un-irradiated module (150V)



irradiated module (350V)



Black points: response data for calibration pulses. [1]

Red curves : present model for δ-function input pulse.

Note that the heights were adjusted arbitrary and also the start times are shifted arbitrary for better comparison.

[1] A.J.Barr et al., ATL-INDET-2002-024 Fig. 24

Summary

J. Kaplon provided a model for signal and crosstalk shapes based on the electrical parameters of the ABCD3T chips.

Using electrical parameters available today, the signal and crosstalk levels and shapes are calculated.

The crosstalk level is ~x2 higher (10% each side) than the current SCT Digitization model.

Comparison with calibration-pulse data indicates the rising shapes are well reproduced but not in the trailing part.