ASIC front-end for Position Sensitive SiPM and Vacuum PMT with gain adjustment and depth of interaction measurement

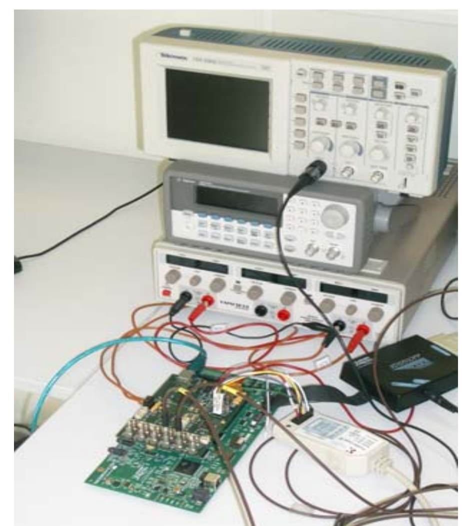
V. Herrero *, R. Colom*, R. Gadea*, J. Cerdà*,
A. Sebastià *, C.W. Lerche**, J. Benlloch**

* **DSD** – Departamento Ingeniería Electrónica – Universidad Politécnica de Valencia
** **IFIC** – Instituto de Fisica Corpuscular – Consejo Superior de Investigaciones Científicas / Universidad de Valencia

2-6 July - Facoltà di Scienze - Pisa, Italy

Research Project Collaboration

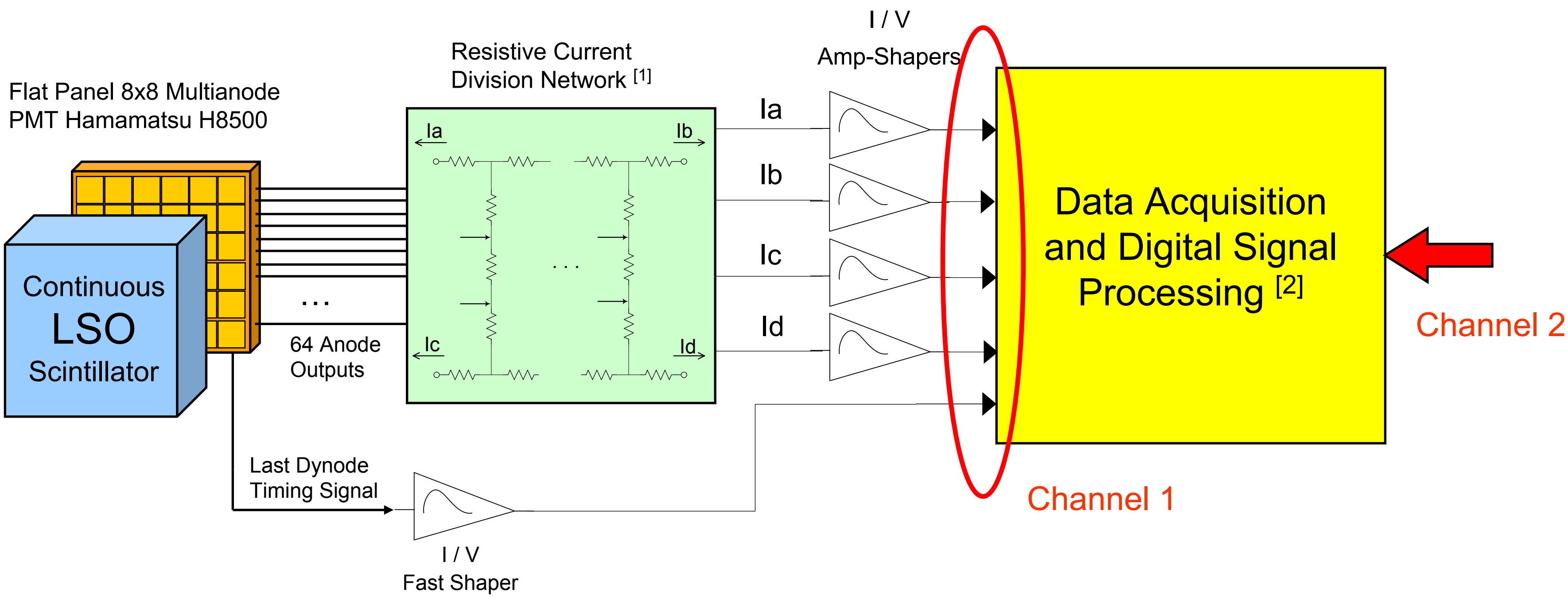
- **IFIC** (Corpuscular Physics Research Institute)
  - High Energy Physics research.
  - Nuclear Medical Instrumentation
    - Portable Gamma Camera for medical applications
    - Development of PET systems.
      - PET mammography.
      - Small Animal PET.



- **DSD** (Digital Systems Design)
  - Mixed Signal, front-end and read-out electronics for high energy phisics.
  - High-Speed Data Acquisition and Digital Signal Processing Systems for PET Mammography.
  - Mixed Signal ASIC development.

Detector Front-End

- First Development of Detector Front-End and Read-Out



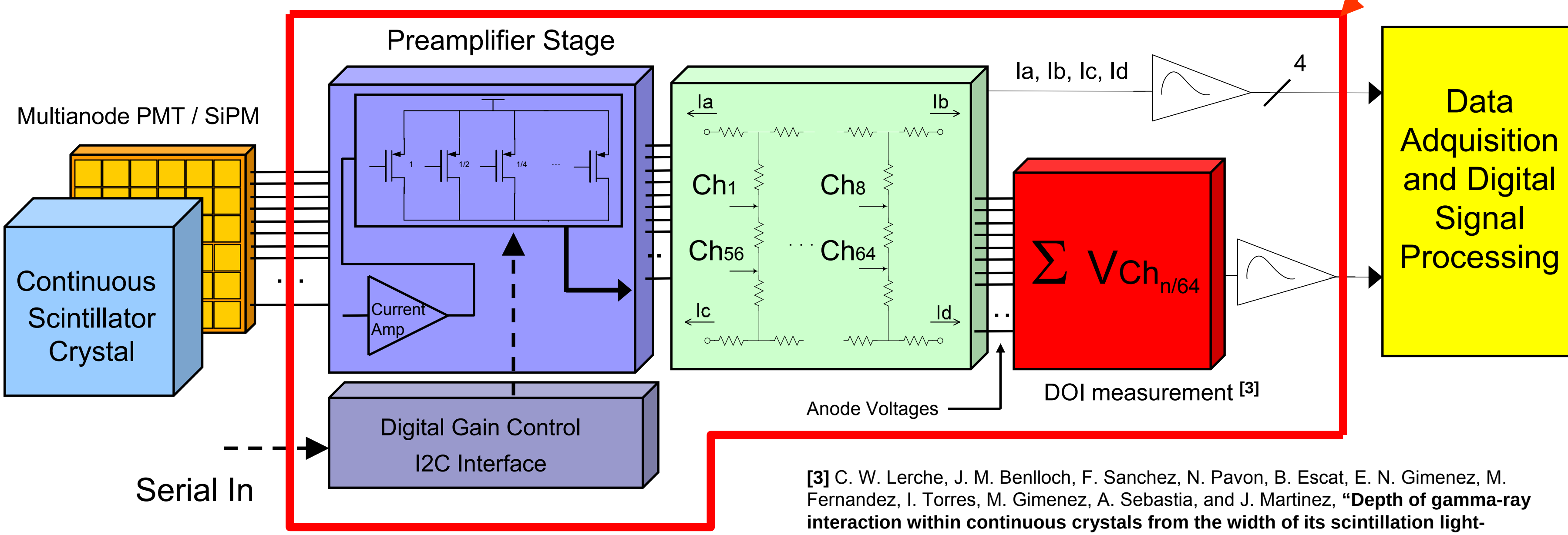
[1] S. Siegel, R. W. Silverman, Y. Shao, and S. R. Cherry, "Simple charge division readouts for imaging scintillator arrays using a multi-channel pmt," *IEEE Trans. Nucl. Sci.*, vol. 3, no. 43, pp. 1634–1641.

[2] J. D. Martinez, J. M. Benlloch, J. Cerdà, Ch. W. Lerche, N. Pavon, A. Sebastia. "High-speed data acquisition and digital signal Processing system for PET imaging techniques applied to mammography" *IEEE Trans. Nucl. Sci.*, Volume 51, Issue 3, Part 1, June 2004 Page(s):407 - 412

Detector Front-End

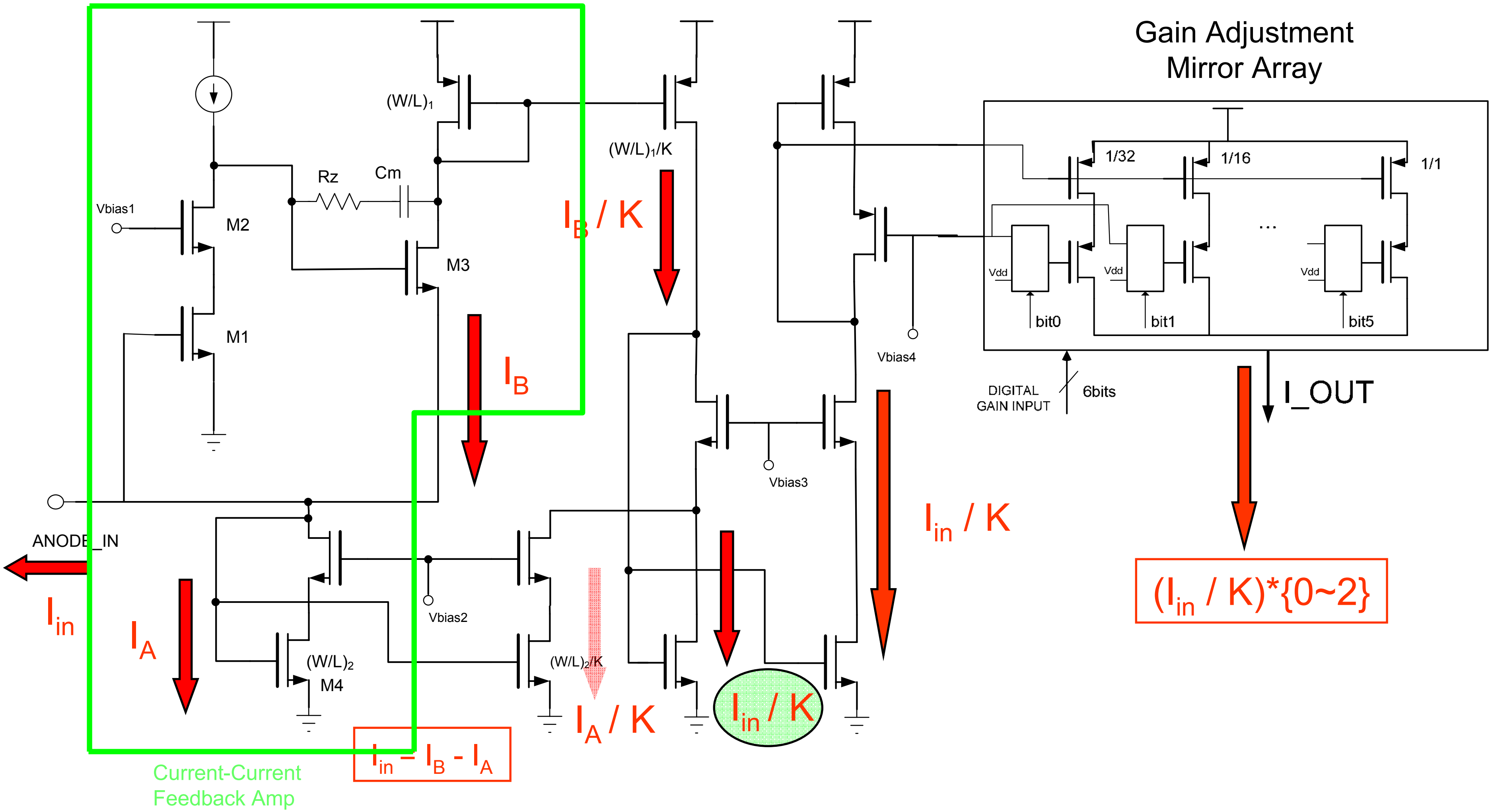
- New system requirements and extended features.
  - Depth of Interaction Measurement.
  - Individual Anode Gain Adjustment.
  - Possible use of different types of Photomultipliers (SiPMs).
  - Reduce Front-End delay and Increase timing and spatial resolution.

Mixed Signal ASIC



[3] C. W. Lerche, J. M. Benlloch, F. Sanchez, N. Pavon, B. Escat, E. N. Gimenez, M. Fernandez, I. Torres, M. Gimenez, A. Sebastia, and J. Martinez, **"Depth of gamma-ray interaction within continuous crystals from the width of its scintillation light-distribution"** *IEEE Trans. Nucl. Sci.*, vol. 52, no. 3, pp. 560–572, 2005.

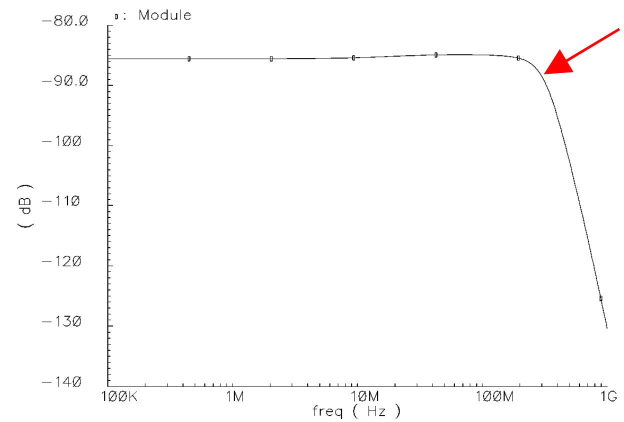
Anode Preamplifier (I)



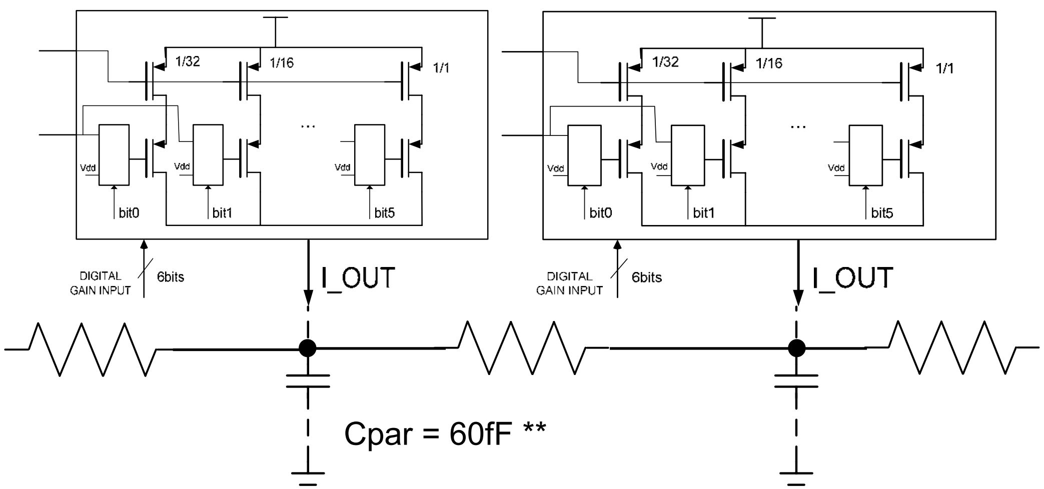
Anode Preamplifier (II)

- Low Input Impedance increases Bandwidth
- Gain Adjustment compensates Anode Gain dispersion.
- Isolates PM from Resistor Network.
  - Resistor values can be designed to optimize V_{Ch} (increases DOI precision)
  - **Reduction of capacitances in Resistor Network input nodes**

~200MHz *



* Including Cout PMT ≈ 10pF

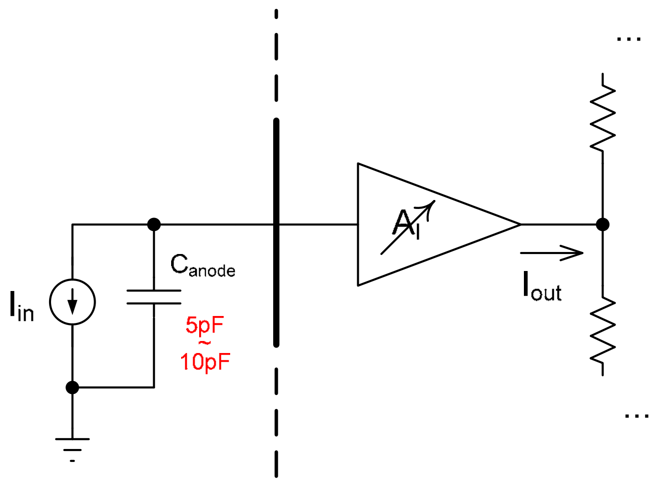


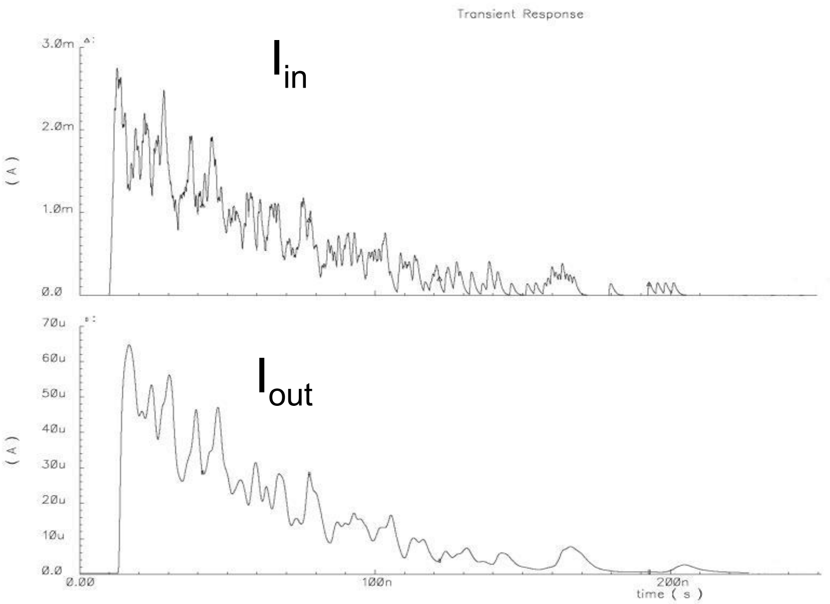
Cpar = 60fF **

** AMS 0.35um - Extracted layout

Anode Preamplifier (III)

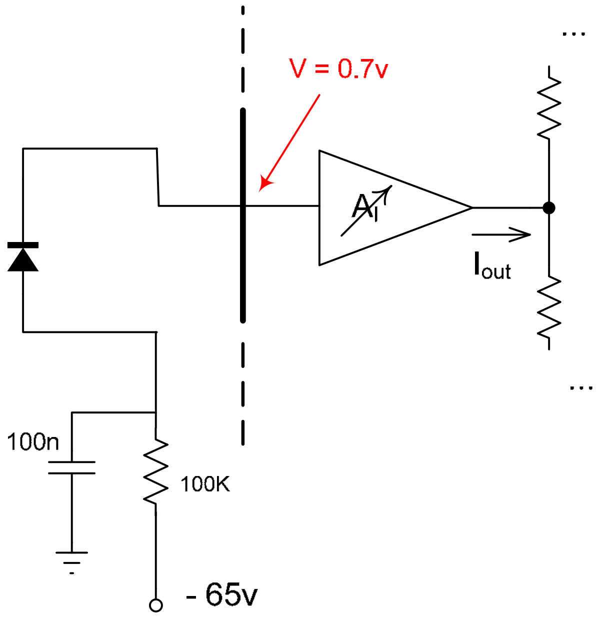
- Conection to PMT and SiPM
  - PMT Scheme

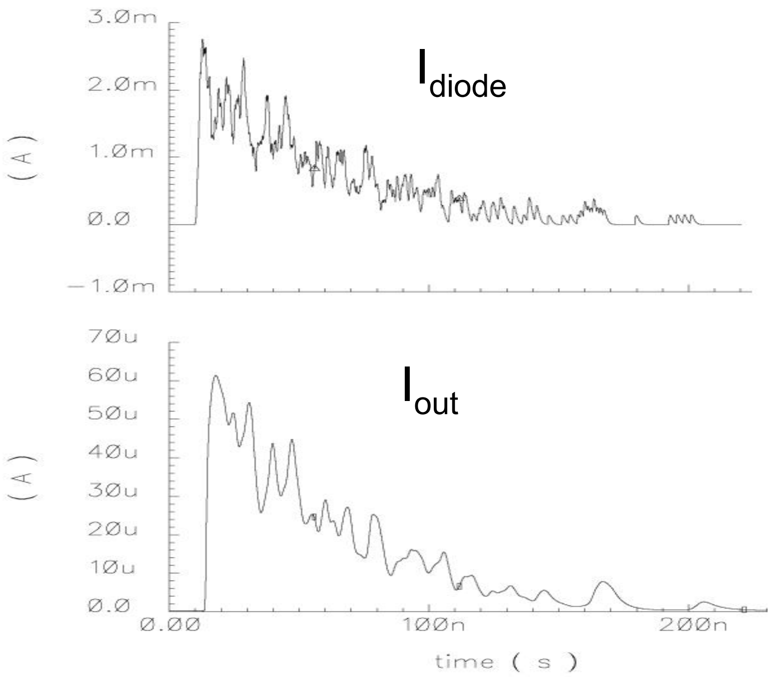




Anode Preamplifier (IV)

- SiPM Scheme. Biasing.





Impact Position Calculation

- Centre of Gravity of total energy of gamma event:

$$X = \frac{(I_a + I_c) - (I_b + I_d)}{I_a + I_c + I_b + I_d} \qquad Y = \frac{(I_a + I_b) - (I_c + I_d)}{I_a + I_b + I_c + I_d}$$

- Sources of error in Impact Position Calculation

Thermal Noise from Resistor Network ΔX_1

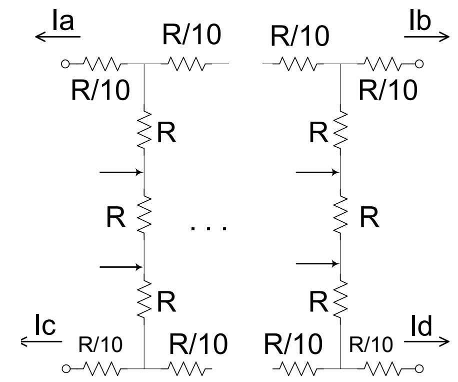
PreAmplifier Noise ΔX_2

Frequency Response of Resistor Network ΔX_3

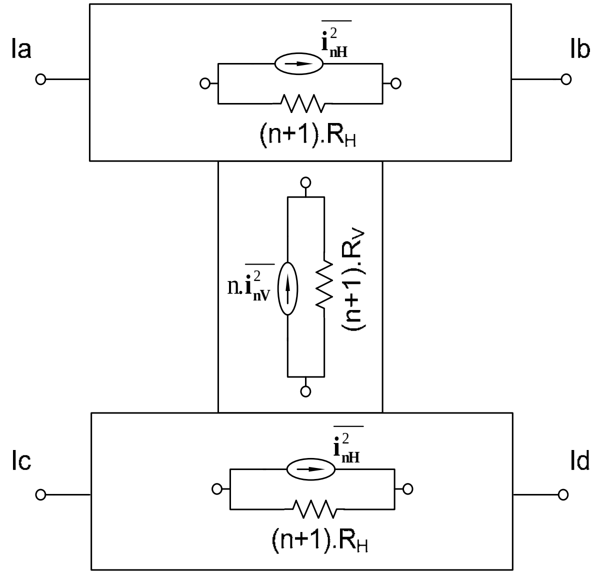
$$\frac{(I_a + I_c) - (I_b + I_d)}{I_a + I_c + I_b + I_d} = X + \Delta X$$

$$\Delta X = \sqrt{(\Delta X_1)^2 + (\Delta X_2)^2 + (\Delta X_3)^2}$$

Impact Position Calculation



Noise Model



- Error in Impact Position Calculation
  - PreAmplifier Noise: Very Low (~40nA) and affects uniformly all network inputs.
  - Thermal Noise from Resistor Network:

• Instantaneous noise generated by in^2_V in **Ia** and **Ic** is anticorrelated (same as in **Ib** and **Id**).

• Noise from upper and lower horizontal resistor chain is uncorrelated.

$$\overline{(I_a+I_c)_n^2} = 2.\overline{i_{nH}^2}$$

$$\overline{(I_b+I_d)_n^2} = 2.\overline{i_{nH}^2}$$

$$X = \frac{(I_a+I_c)-(I_b+I_d)}{I_a+I_c+I_b+I_d}$$

$$\overline{\Delta X^2} = \left|\frac{\partial X}{\partial(I_a+I_c)}\right|^2 .\overline{|(I_a+I_c)_n|^2} + \left|\frac{\partial X}{\partial(I_b+I_d)}\right|^2 .\overline{|(I_b+I_d)_n|^2} + 2\left[\frac{\partial X}{\partial(I_a+I_c)}.\frac{\partial X}{\partial(I_b+I_d)}.\overline{(I_a+I_c)_n.(I_b+I_d)_n}\right]$$

$$\overline{\Delta X^2} = \frac{8.\overline{i_{nH}^2}}{(I_a+I_b+I_c+I_d)^2}$$

Impact Position Calculation

- Error in Impact Position Calculation
  - Thermal Noise from Resistor Network. **Conclusions**

$$\overline{\Delta Y^2} = \frac{n.4\overline{i_{nV}^2}}{(I_a+I_b+I_c+I_d)^2}$$

$$\overline{\Delta X^2} = \frac{8.\overline{i_{nH}^2}}{(I_a+I_b+I_c+I_d)^2}$$

$$\overline{i_{nV}^2} = \frac{4K.T.\Delta f}{(n+1).R}$$

$$\overline{i_{nH}^2} = \frac{4K.T.\Delta f}{(n+1).\frac{R}{10}}$$

← Siegel

n=8

1. $\Delta X \neq \Delta Y$ Do not depend on impact position

2. **Higher R values do not reduce error because:**

(V_{chMAX} < Vdd) → (Ia+Ib+Ic+Id) must decrease

$$(I_a+I_b+I_c+I_d) = \frac{V_{chMAX}}{K.R}$$

K factor depends on impact depth [3]

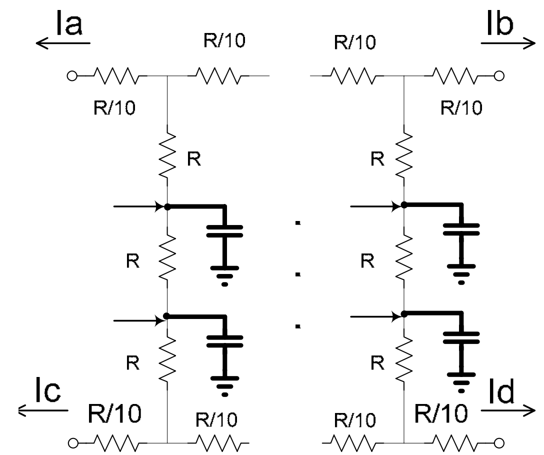
Examples:

Vchmax=2.6V	Vchmax=2.6V
R=6k6	R=1k
BW=150MHz	BW=150MHz
↓	↓
ΔX =2.5E-4	ΔX =1E-4
(0.12% of Pitch)	(0.04% of Pitch)

[3] C. W. Lerche, J. M. Benlloch, F. Sanchez, N. Pavon, B. Escat, E. N. Gimenez, M. Fernandez, I. Torres, M. Gimenez, A. Sebastia, and J. Martinez, **"Depth of gamma-ray interaction within continuous crystals from the width of its scintillation light-distribution"** *IEEE Trans. Nucl. Sci.*, vol. 52, no. 3, pp. 560–572, 2005.

Impact Position Calculation

- Error in Impact Position Calculation
  - Frequency Response of Resistor Network [4]
    - Current Signal Amplitudes are affected by Frequency Response of resistor network (Capacitances in input nodes).
    - Frequency response depends on input node position.
    - Horizontal chain resistors 10 times lower → Horizontal resistor chains effects not included.
    - Currents in different input points will not sum in phase // Higher amplitude signals are close to centre of impact.



[4] A. Pullia, W. F. J. Muller, C. Boiano, and R. Bassini, **“Resistive or capacitive charge-division readout for position-sensitive detectors”** *IEEETrans. Nucl. Sci.*, vol. 49, no. 6, pp. 3269–3277, 2002.

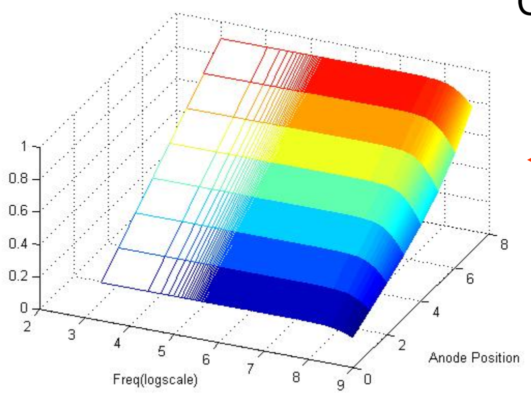
Impact Position Calculation

- Frequency Response of R. Network Read-Out.

ASIC with PreAmplifier

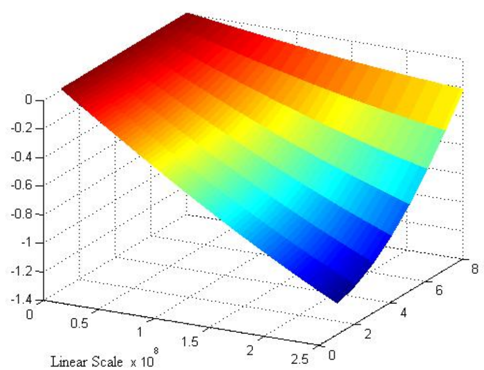
R=6k6

Cap=60fF



Higher Bandwidth

Reduced Position Dependency of Response



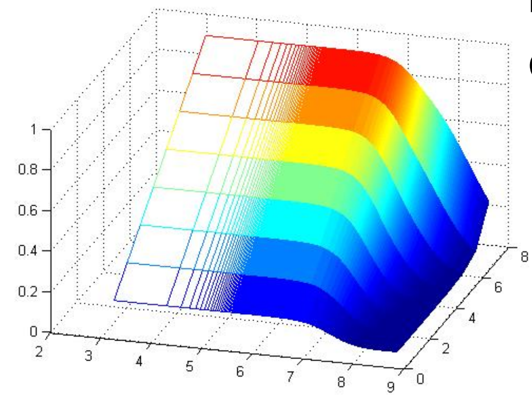
Linear Phase!!

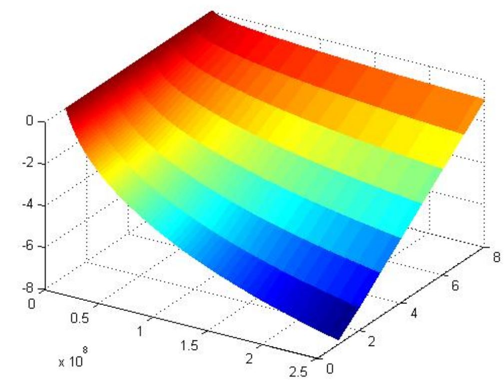
Position Dependent Time Delay

Discrete Imp. Without PreAmplifier

R=1k

Cap=10pF

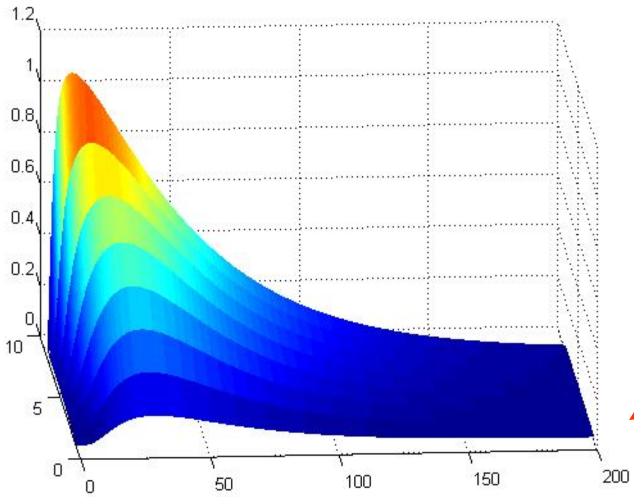




Impact Position Calculation

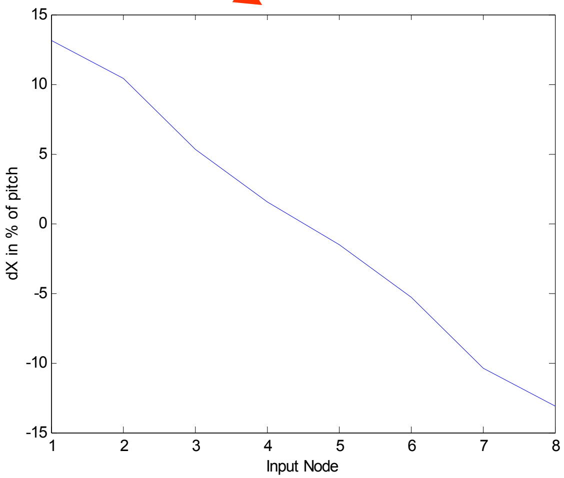
- Error in Impact Position Calculation
  - Evaluation of error due to Frequency response of R. Network Read-Out.
    - Gaussian Pulse (10n rise / 50n decay, LSO-PMT systems).
    - Measure the position error in every input point of a vertical resistor chain.

Discrete Imp. Without PreAmplifier



Time Delay > 15ns

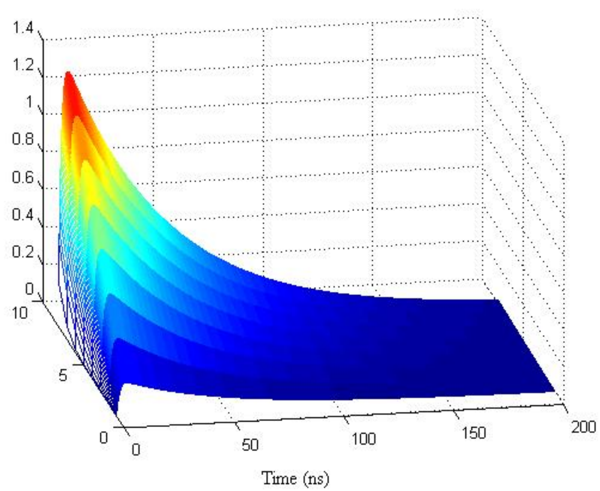
$\Delta X \approx \pm 13\%$ of pitch



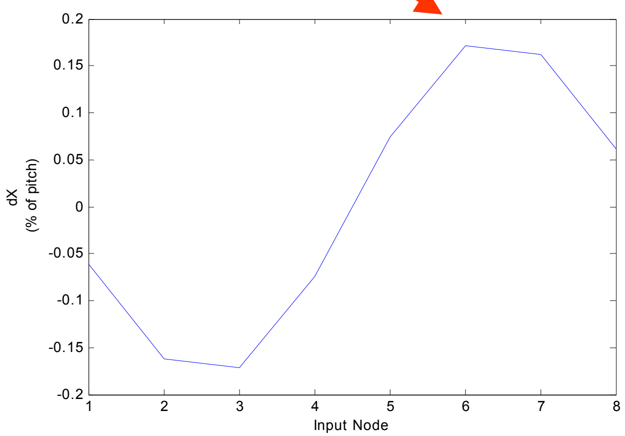
Impact Position Calculation

- Error in Impact Position Calculation
  - Evaluation of error due to Frequency response of R. Network Read-Out.
    - Gaussian Pulse (10n rise / 50n decay, LSO-PMT systems).
    - Measure the position error in every input point of a vertical resistor chain.

ASIC with PreAmplifier



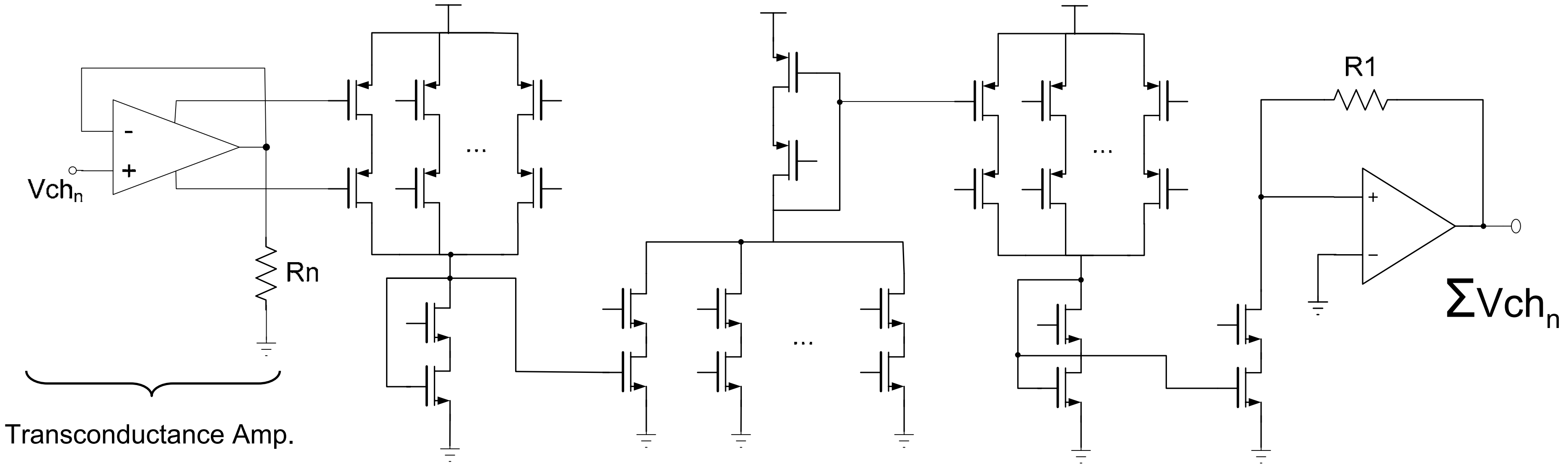
ΔX ≈ ±0.17% of pitch



0.8ns of max Time Delay

Depth of Interaction Measurement

- Depth of Gamma-Ray Interaction within a continuous scintillator crystal is related to the width of the generated light-distribution [3].
  - The light-distribution width can be calculated with the sum of all anode voltages.



[3] C. W. Lerche, J. M. Benlloch, F. Sanchez, N. Pavon, B. Escat, E. N. Gimenez, M. Fernandez, I. Torres, M. Gimenez, A. Sebastia, and J. Martinez, **"Depth of gamma-ray interaction within continuous crystals from the width of its scintillation light-distribution"** *IEEE Trans. Nucl. Sci.*, vol. 52, no. 3, pp. 560–572, 2005.

Conclusions

- PreAmplifier stage isolates read-out from PM.
- Gain Adjustment can equalize dispersion of PM characteristics.
- Frequency Response improvement in ASIC implementation reduces overall front-end delay.
- Implementation of ASIC front-end increases timing and spatial resolution.