2011年1月28日

X線分析研究懇談会第238回例会：X線検出器

X線検出器の最近の信号処理技術

株式会社テクノエックス
谷口一雄

X線分析機器の小型化

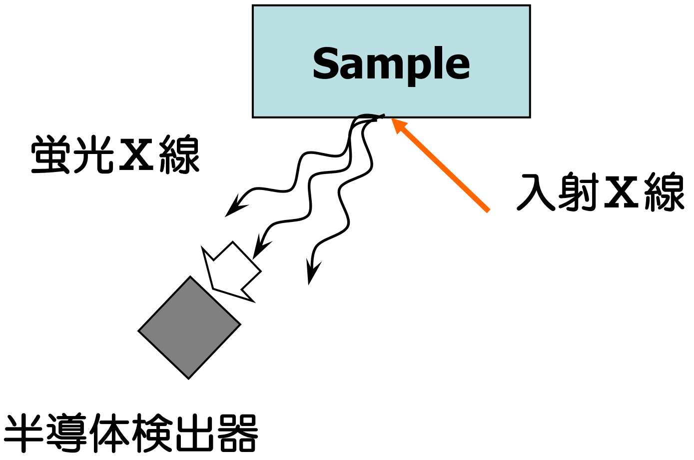
波長分散型

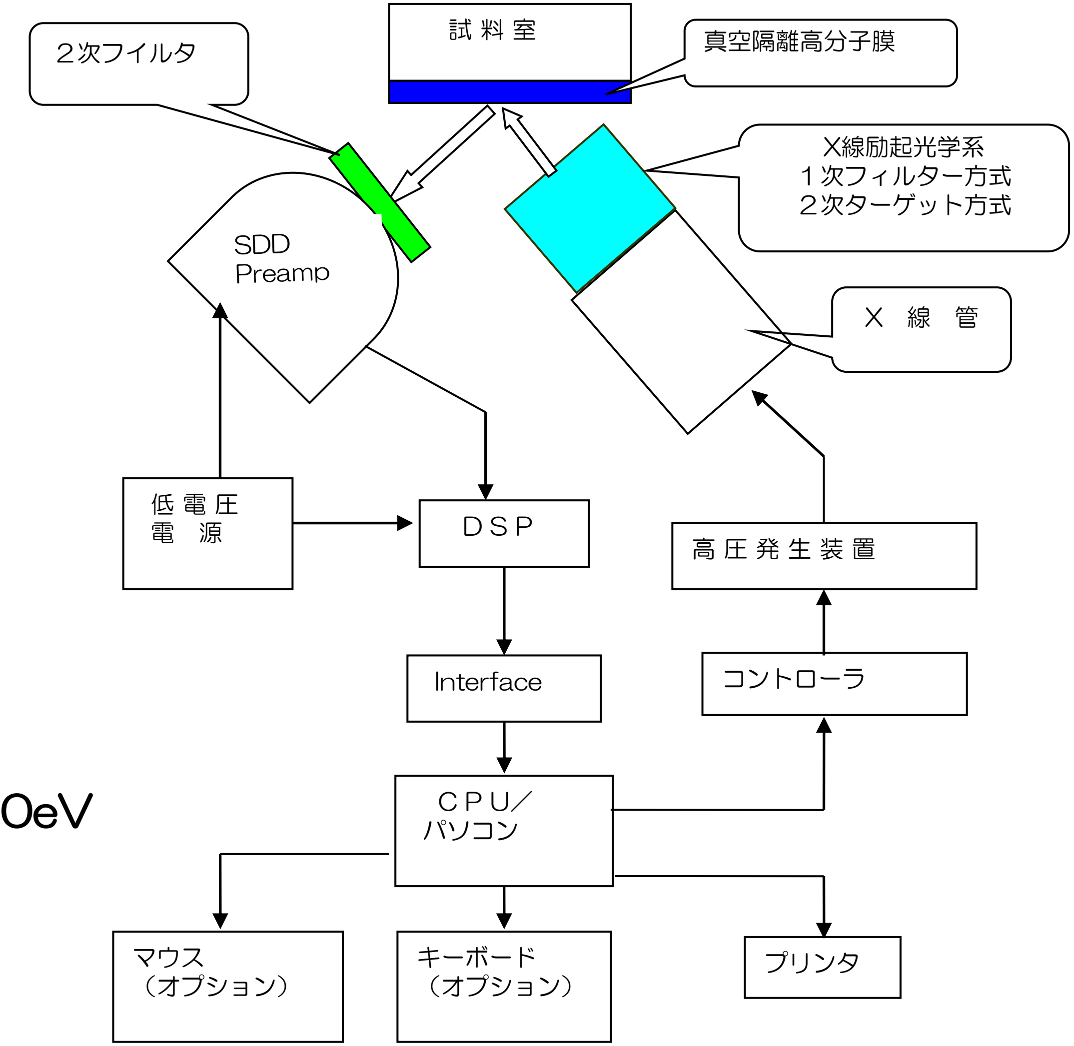
要素技術開発

励起X線源
分光・集光素子
検出器・計測回路

エネルギー分散型

エネルギー分散型蛍光X線分析装置





- 電気的処理による分光
- エネルギー分解能：ΔE ～160eV
- 散乱X線の影響大
- 検出下限：　～1 ppm
- 装置は小型（卓上式）

テクノエックスが誇る要素技術

励起X線

X線管

小型X線源

検出器

検出素子（SDD）

小型X線検出器

計測回路

（名刺大）

可搬型蛍光X線分析装置

日刊工業新聞　1996年(平成8年)2月8日　木曜日

現場で即座に成分分析

可搬型のX線装置開発

大阪電通大
兵庫県警

大阪電気通信大学工学部電子物性工学科の谷口一雄教授は、兵庫県警科学捜査研究所と共同で「可搬型蛍光X線分析装置＝写真」を開発した。犯罪や事故現場に持ち込んで採取したデータを即座に分析、初動段階での捜査、原因究明を迅速に行える。小型で高い分解能を持つX線検出器を半導体で作るなどの技術開発により実現した。固体と液体を分析でき、指紋やドル紙幣などの真がんチェックにも使えるという。持ち運びできるタイプは日本では初めて。

この装置では検出器の半導体素子化に加え、X線発生部も小型化するとともに、〇・二―〇・五秒のパルス発振しかできなかったX線発振管を連続発生できるようにして測定プローブ部を構成した。またデータを演算し、解析するコントローラー部はノートパソコンに処理プログラムを搭載、持ち運びを可能にした。

現在、現場で使われている蛍光X線分析装置は、線源がラジオアイソトープのため、移動の際の法的手続きが煩雑で、海外への持ち出しがとくに難しいという欠点があった。

すでに、谷口教授は事件現場に残されていた繊維、塗料片などから元素レベルの成分をリアルタイムに分析できる装置を兵庫県警科捜研と共同で開発している。X線が物質に当たると元素特有の蛍光を発する特性を生かしたもので、そのスペクトルから繊維片などの材料も突き止めることができる装置だが、本体寸法が畳一枚分ぐらいの大きさで、機動性がなかった。

今回の開発により工場排水の取り締まりなども現場でできる道が開けるほか、考古学の発掘調査などの効率化も図れるようになる。

同装置については新技術事業団が企業化開発支援を行うことも決定した。これを受けて谷口教授らは、チタンより軽い金属元素と気体の分析精度や処理速度の向上などを含めた改良を通じて、実用化に取り組む。

超小型携帯型成分分析計

NITON社製

多岐に亘る活用分野

鉱石分野
貴金属・宝飾品

食品分野
米・穀物・その他食品中の
重金属成分

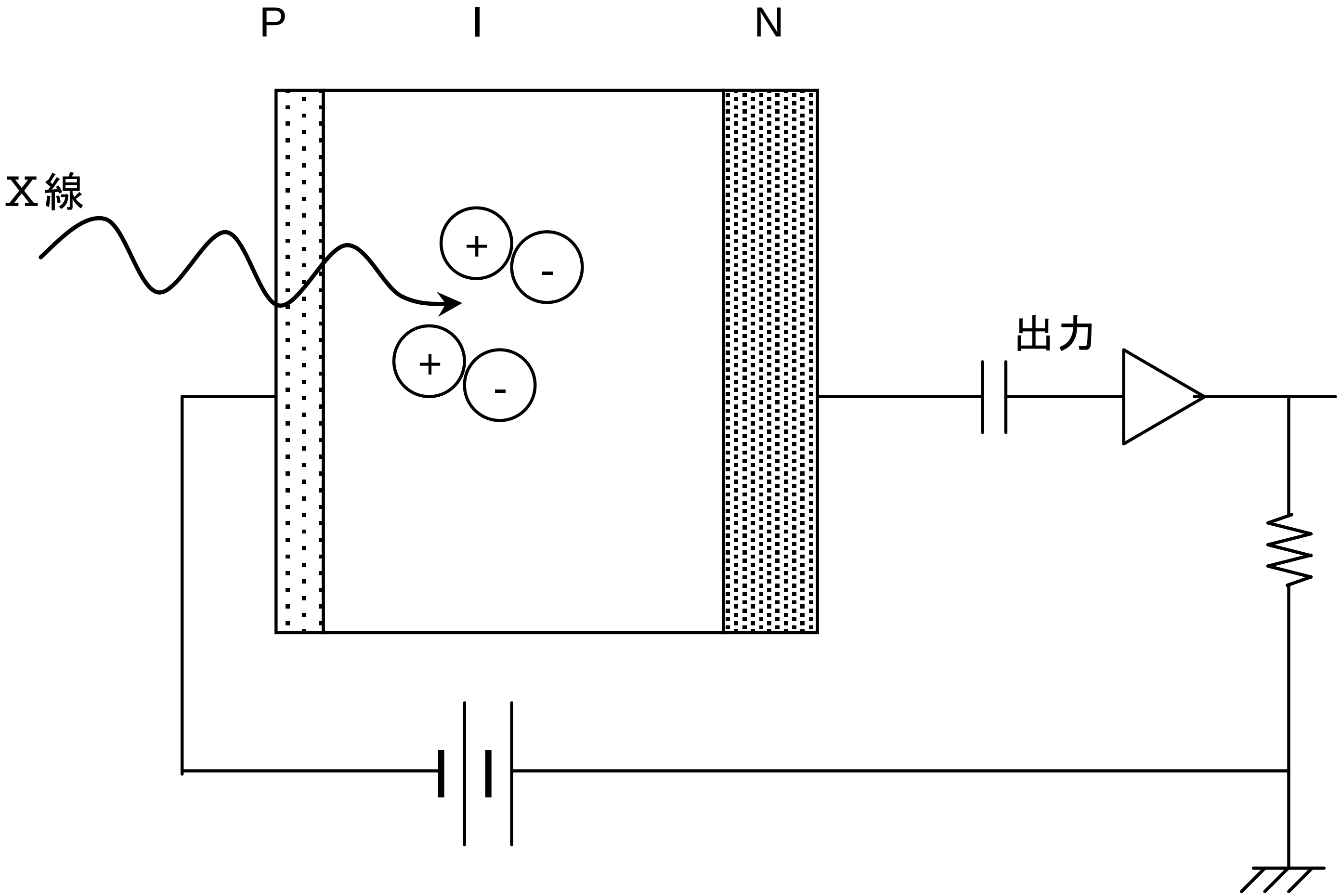
工程管理
ハンダ槽管理
メッキ厚測定
材料判別
スラグ分析

各種環境規制
電気電子部品に関する規制
WEEE／RoHS, ELV, J-MOSS
玩具に関する規制
EN71, ASTM, ST基準
土壌に関する規制
土壌汚染対策法の施行令
JIS「K0470」準拠

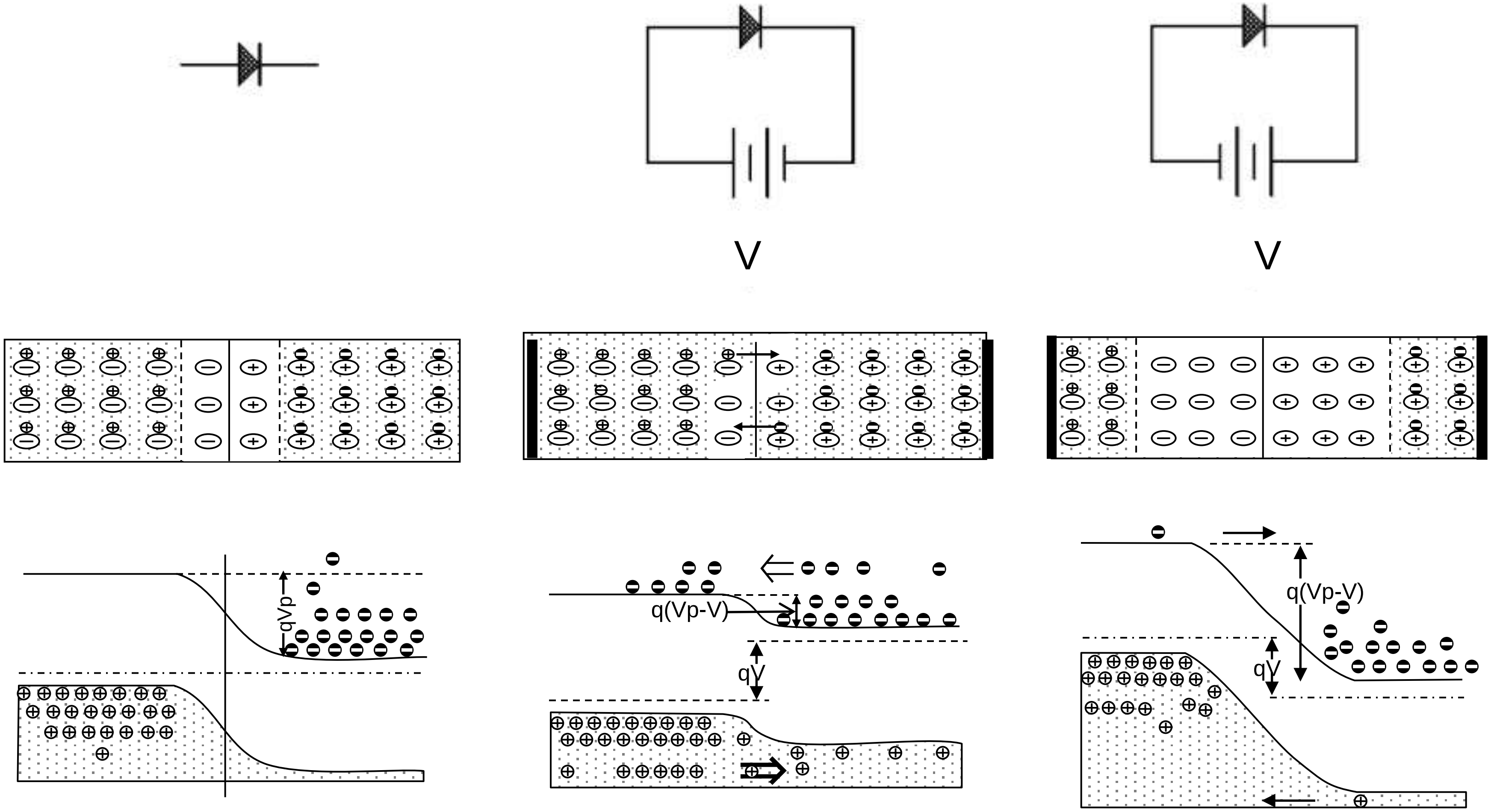
環境分析
土壌、焼却灰、汚泥、
廃棄物・リサイクル製品の
検査・分析など

考古学
考古学・遺跡・文化財

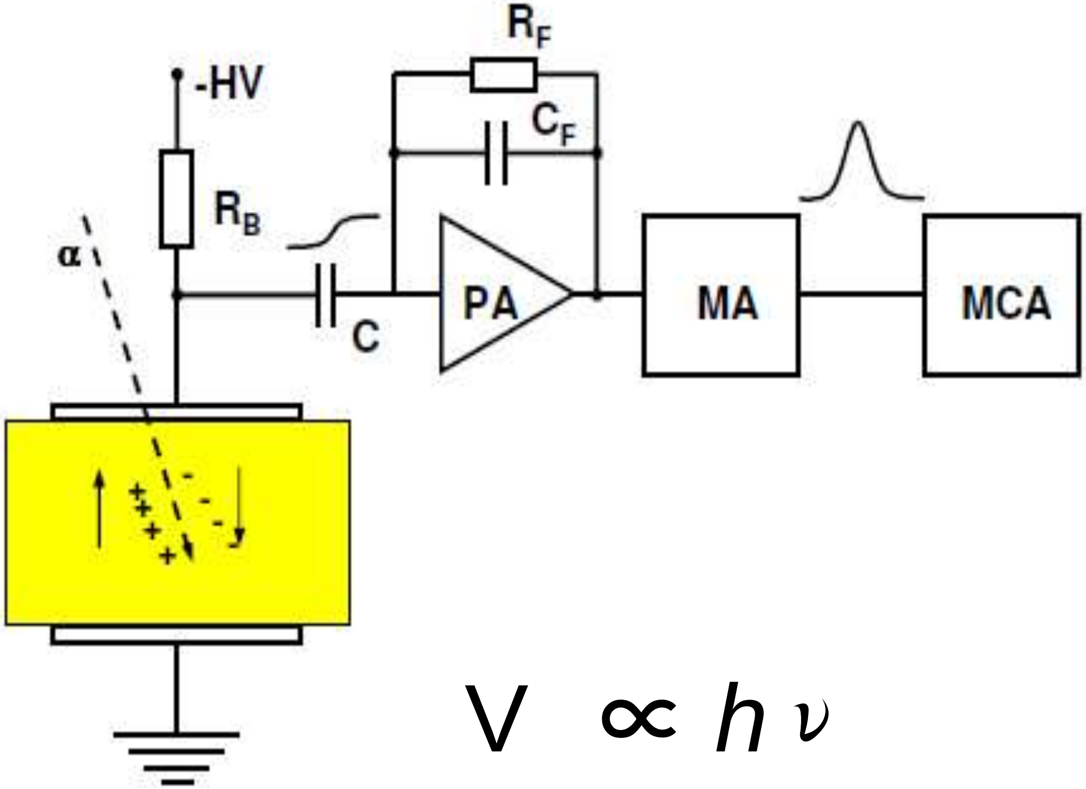
Si–PIN検出器の原理



pn-junction as a semiconductor-detector



Principle of solid state detectors



$$V \propto h\nu$$

$$N = \frac{h\nu}{\varepsilon}$$

E : Energy for e-h pair
N : number of e-h pair

$$Q = eN$$

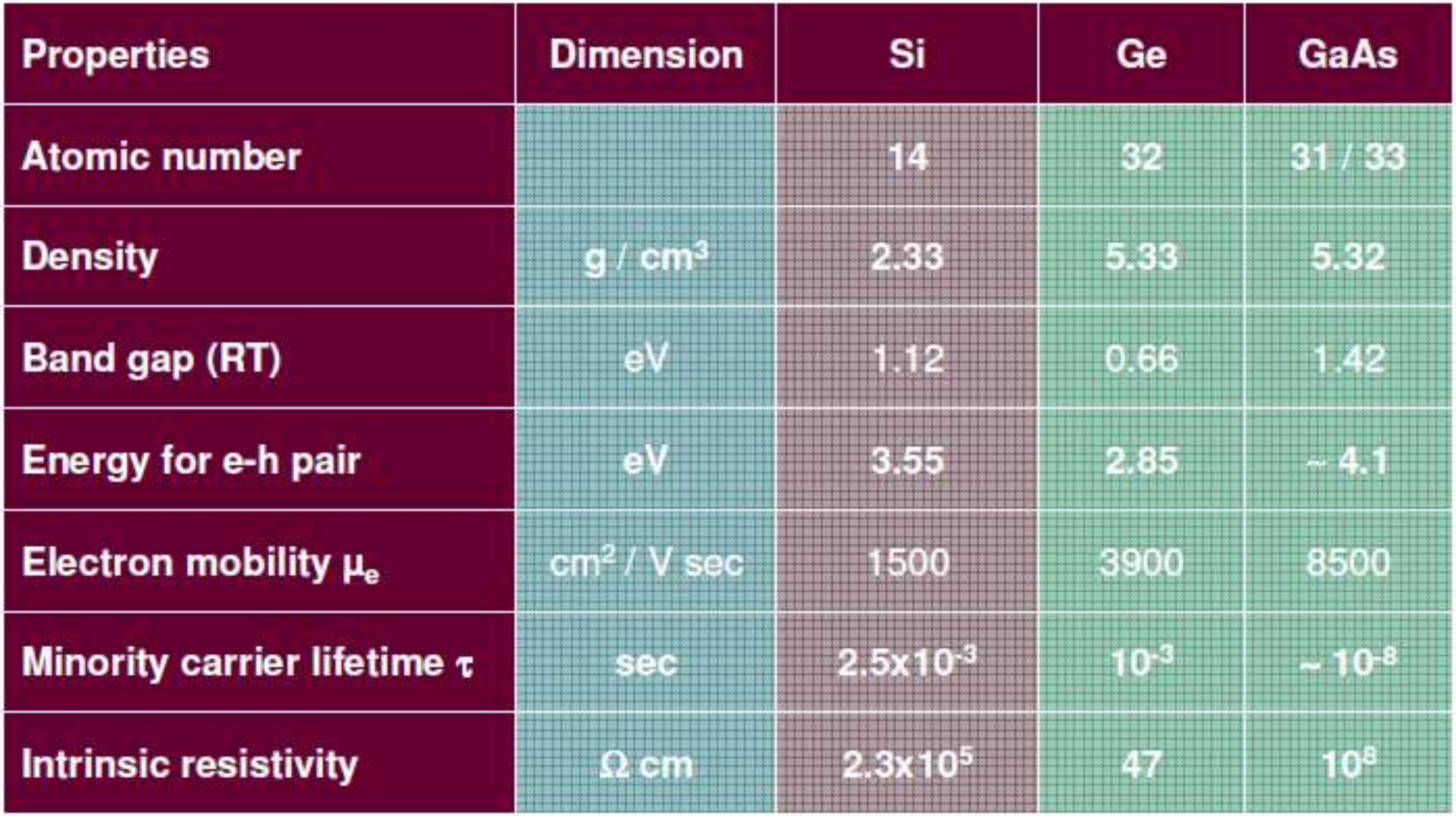
Q : Charge at input of PA

$$V = \frac{Q}{c} = \frac{eN}{c}$$

V : Voltage at input of P.A
C : capacitance at input of P.A

$$V = \frac{eN}{c} = \frac{eN}{c \cdot \varepsilon} \cdot h\nu$$

Physical properties of Si, Ge, GaAs, SiC



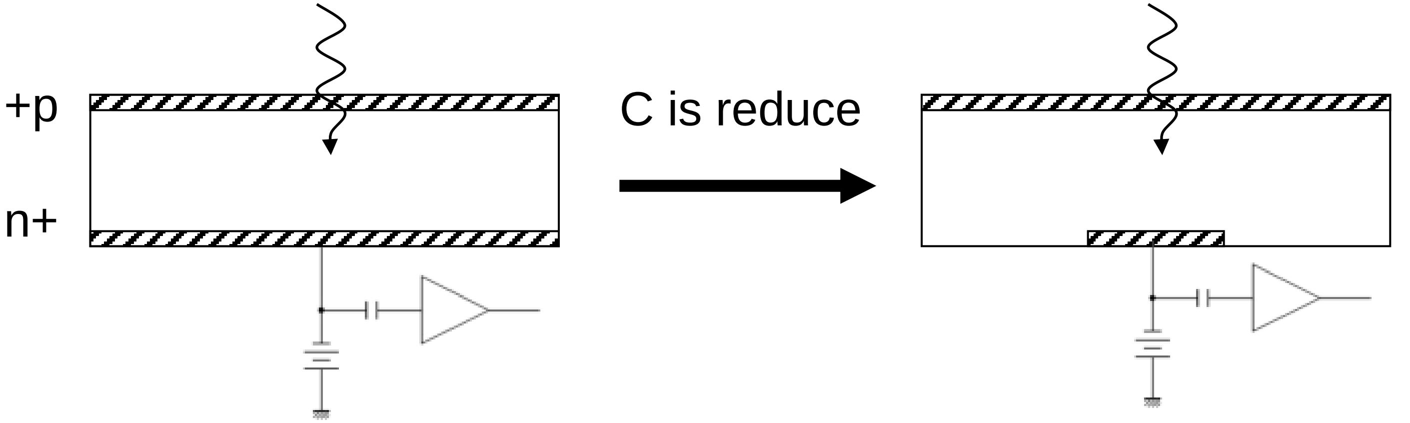
Properties	Dimension	Si	Ge	GaAs
Atomic number		14	32	31 / 33
Density	g / cm^3	2.33	5.33	5.32
Band gap (RT)	eV	1.12	0.66	1.42
Energy for e-h pair	eV	3.55	2.85	~ 4.1
Electron mobility μ_e	cm^2 / V sec	1500	3900	8500
Minority carrier lifetime τ	sec	2.5×10^{-3}	10^{-3}	~ 10^{-8}
Intrinsic resistivity	Ω cm	2.3×10^{5}	47	10^{8}

Capacitance of Detector

$$\text{Output } V = \frac{eN}{c}$$

v ← to large

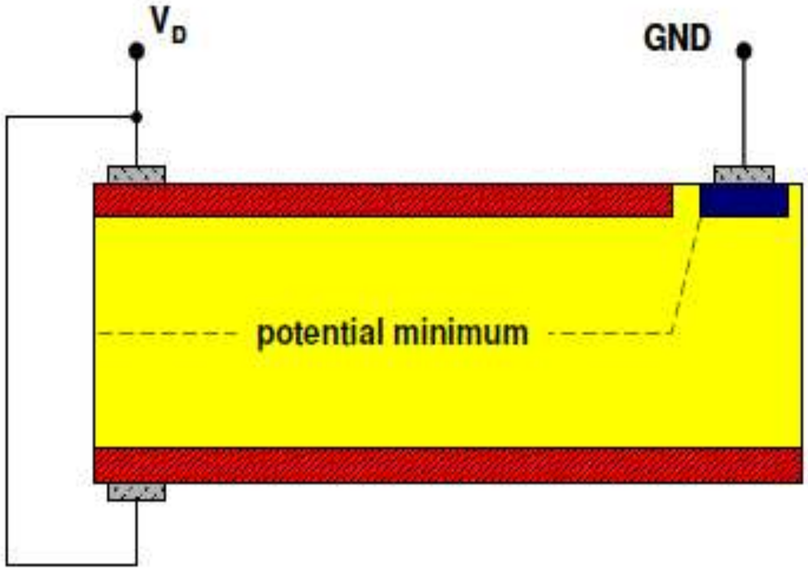
c ← to small



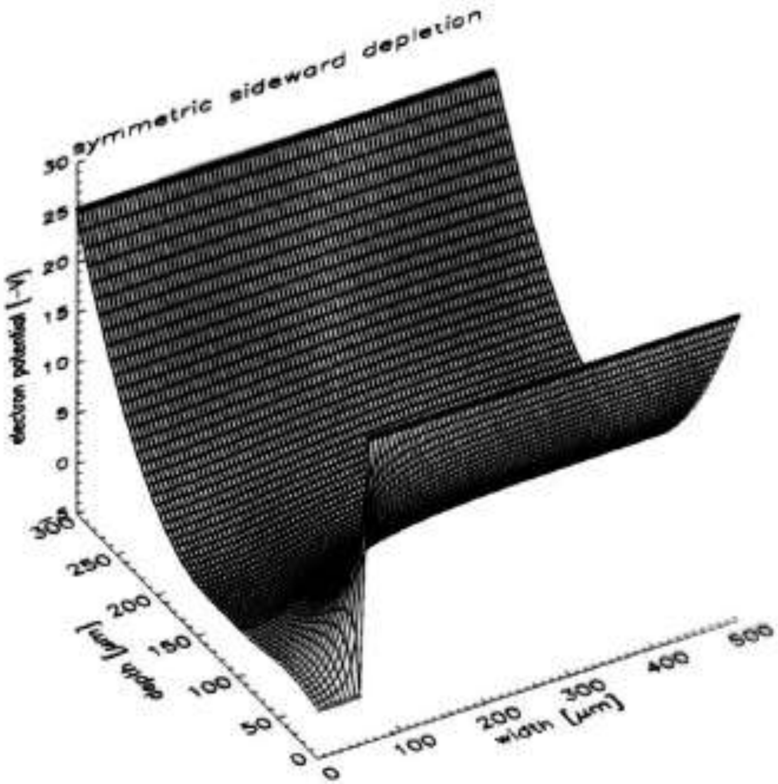
pn- Junction Detector

Silicon Drift Detector

Electron Potential fot pn-Junction Detector



Electron potential shows a minimum parallel to the surface

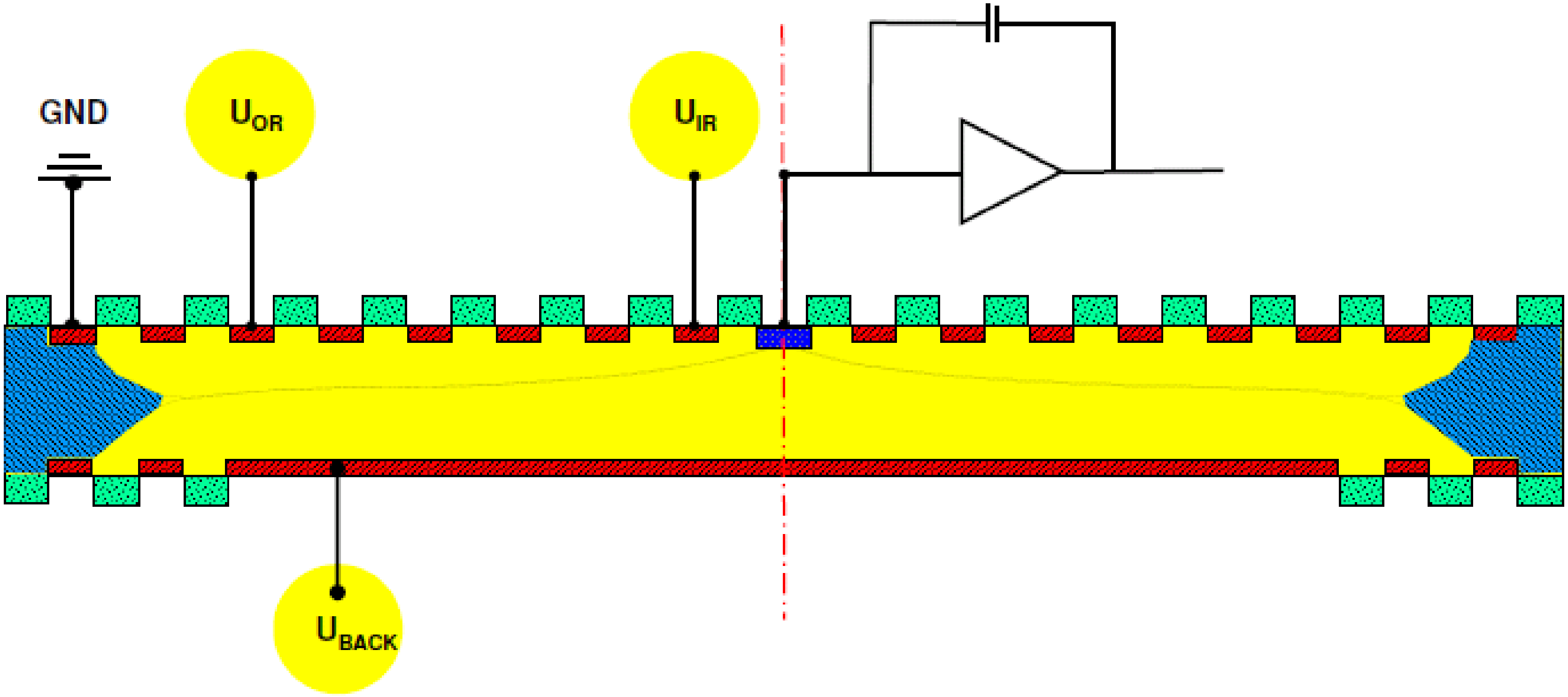


Charge collection

- holes move to the p+ electrodes
- electrons assemble in the center of the wafer
- uncontrolled charge diffusion to the anode

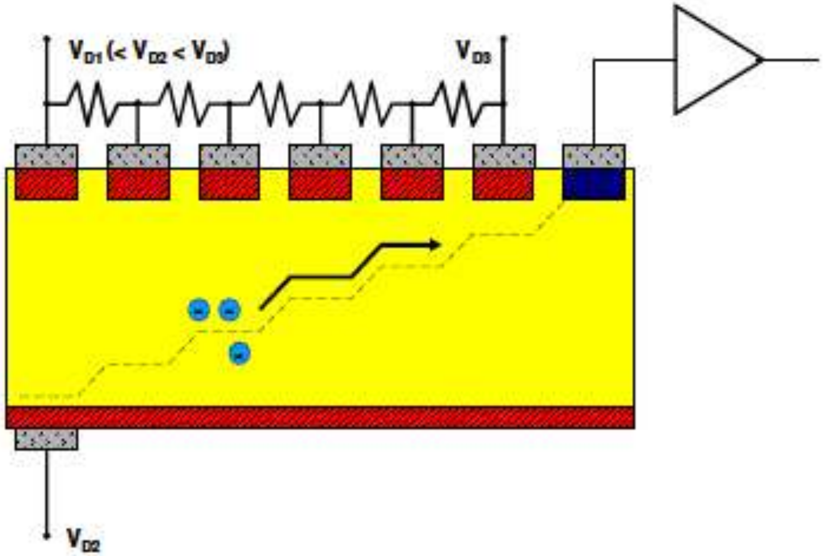
Apply horizontal electric field, to drift electrons to the anode

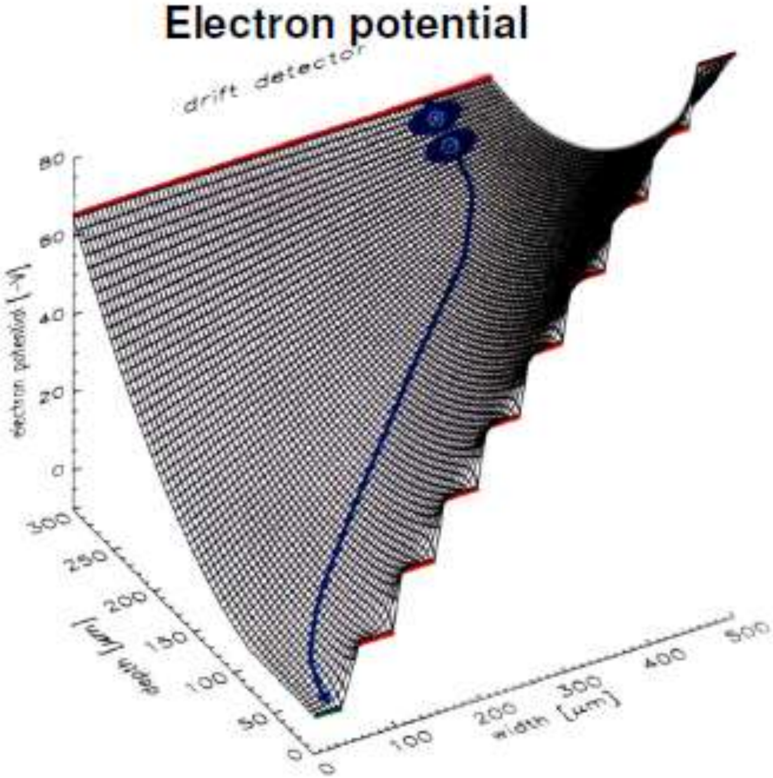
Function of Silicon Drift Detector



Full depletion of the bulk under reverse bias

Principle SDD

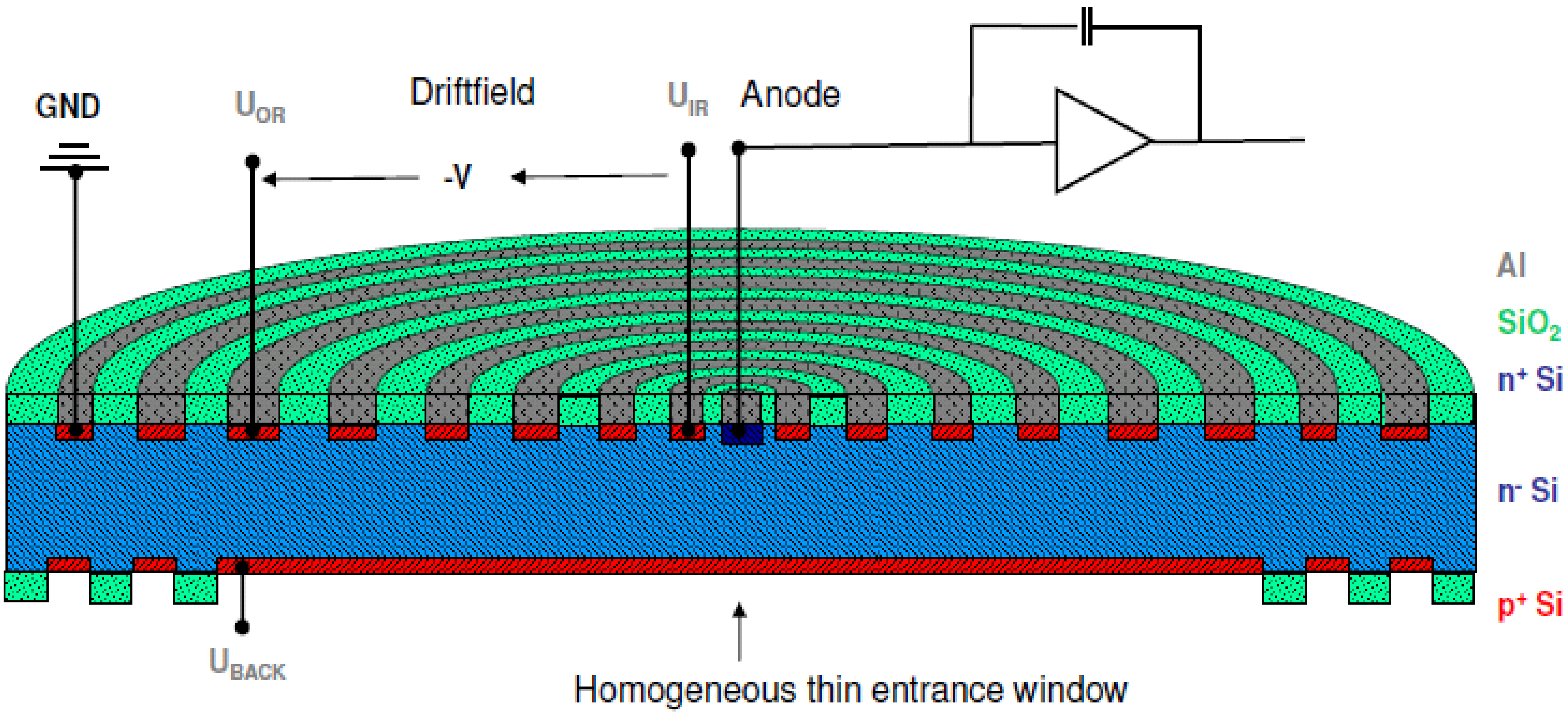




- **Homogeneous entrance window**
  uniform sensitivity for x-rays
- **Drift electrodes only at one side**
  simpler technology
- **Sloped potential valley**

Position measurement possible by hole signals from structured rear side

Silicon Drift Detector with Circular Geometry



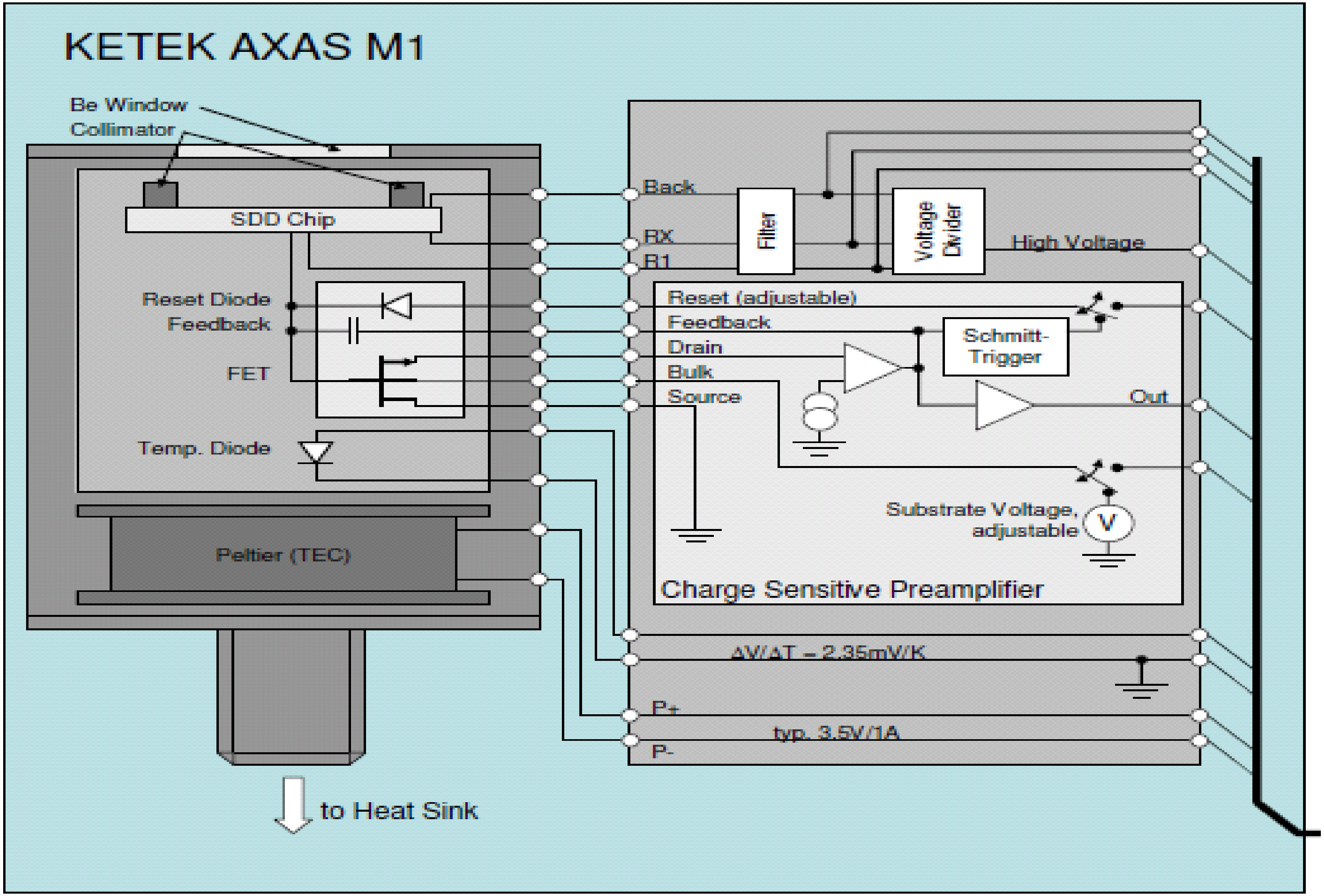
Small size of output capacitance

- high energy resolution
- high count rate capability

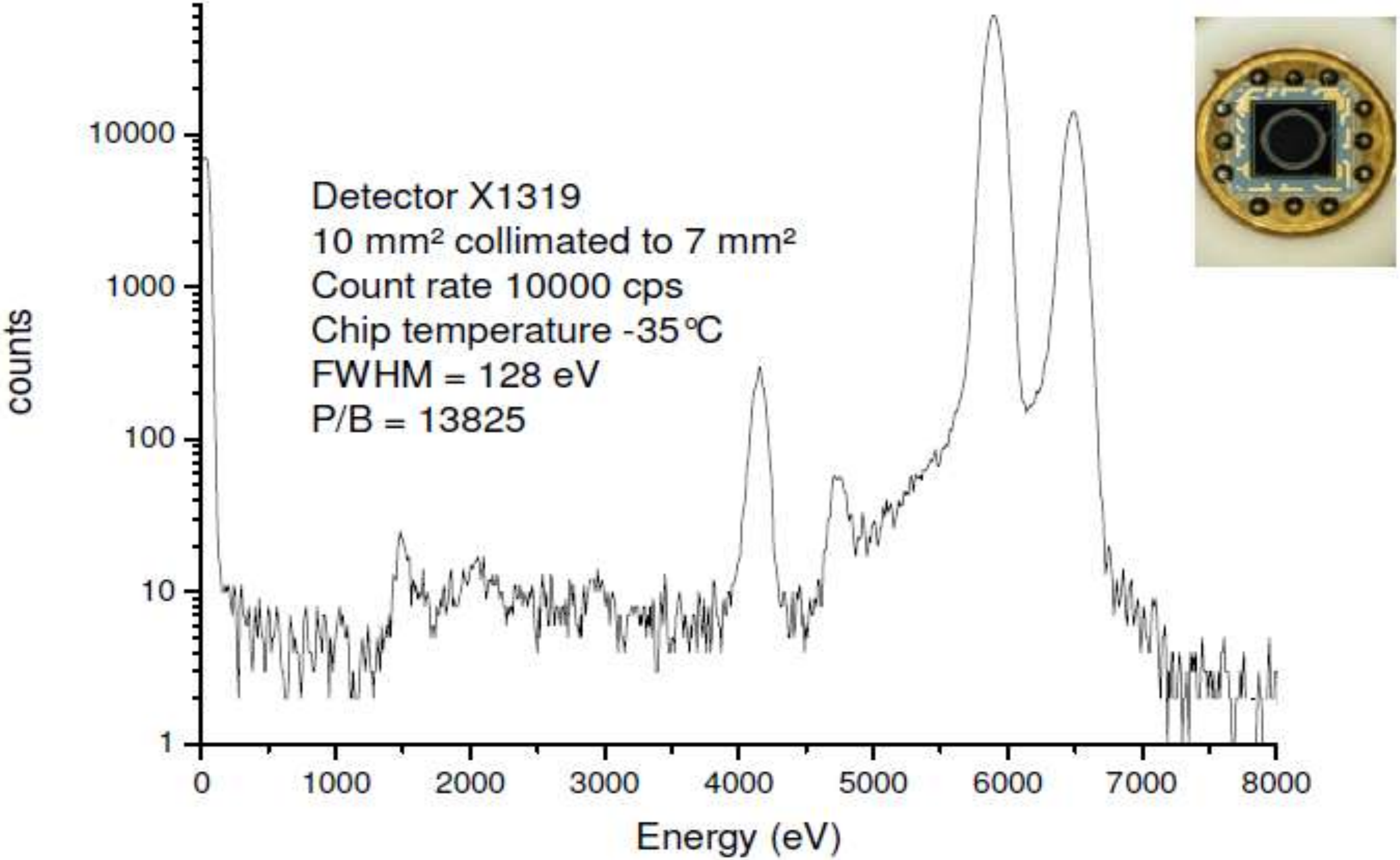
Low leakage current level

- operation at moderate cooling
- no liquid nitrogen necessary

General Requirements of SDD Electronics

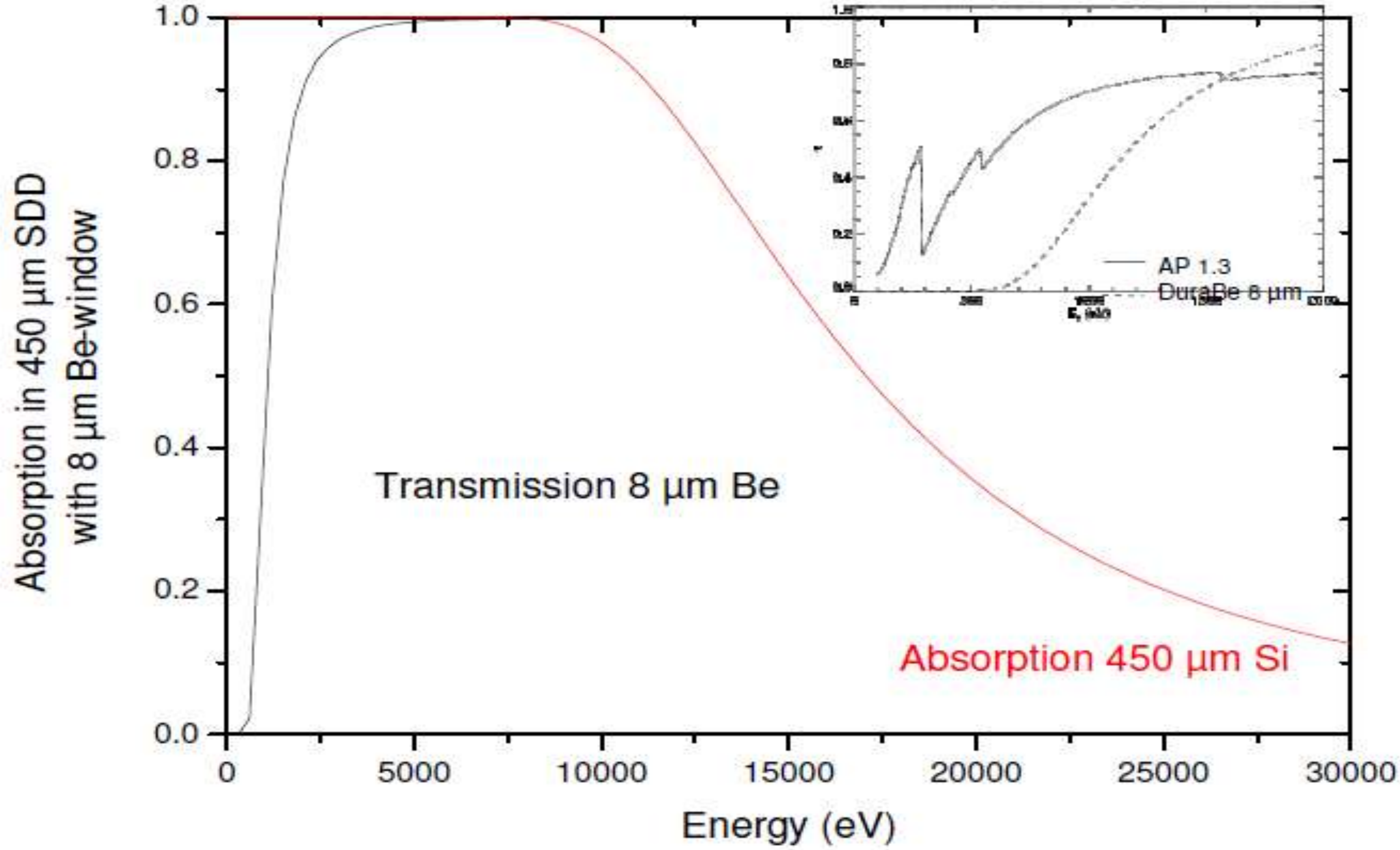


Spectrum of 10 mm2 KETEK Vitus SDD

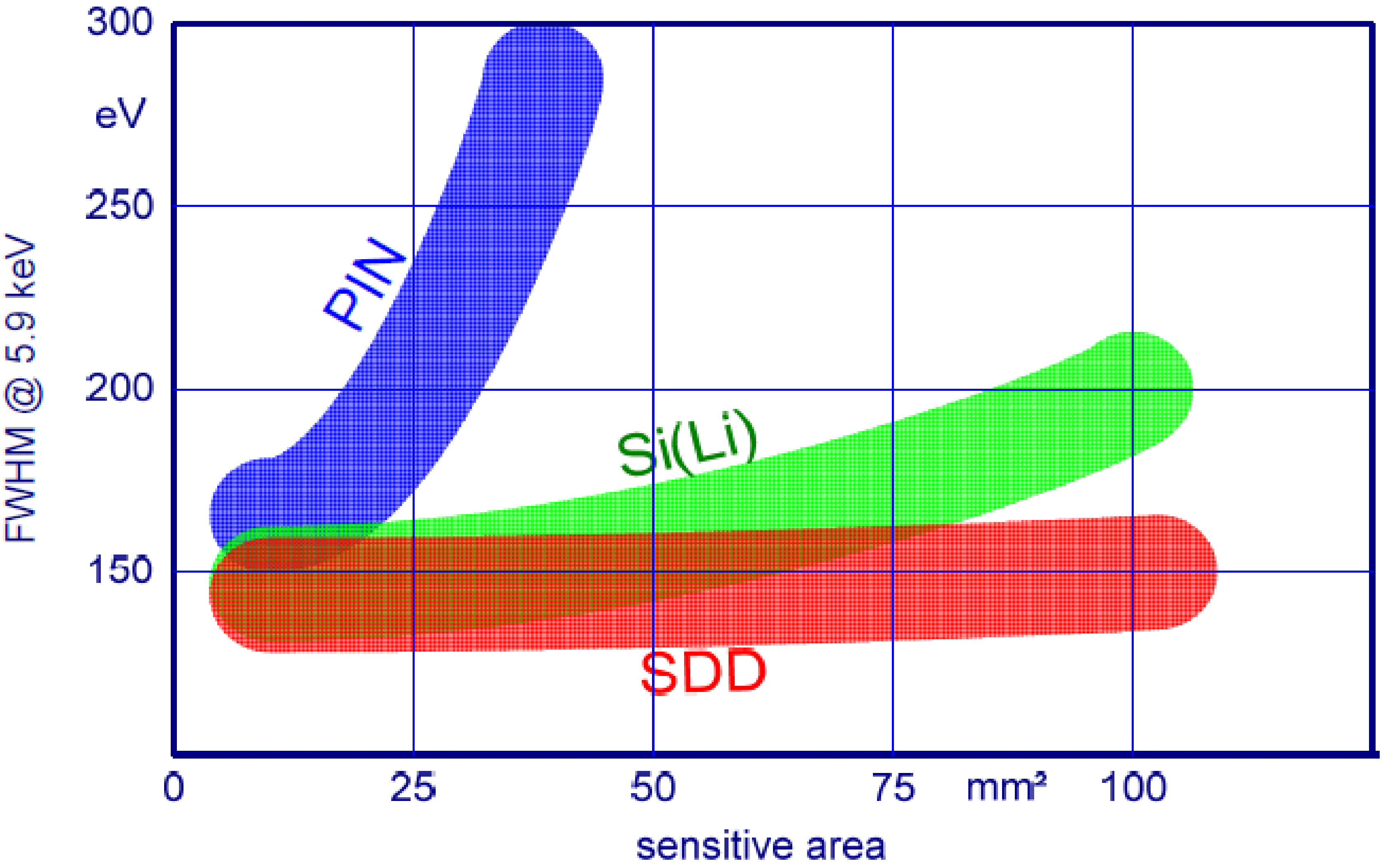


Detector X1319
10 mm² collimated to 7 mm²
Count rate 10000 cps
Chip temperature -35 °C
FWHM = 128 eV
P/B = 13825

Absorption curve for 450 μ m SDDs



Large Area Silicon Detectors



Properties of Silicon pn-Junction Detectors

Depletion layer thickness w:

$w\ (\mathrm{cm}) = 0.5 \times 10^{-4}\ (\rho\ U)^{1/2}$

$\rho\ (\Omega\mathrm{cm})$	resistivity
U (V)	bias voltage

Capacitance C:

$C\ (\mathrm{pF}) = 2 \times 10^{+4}\ A(\rho\ U)^{-1/2}$

$A\ (\mathrm{cm}^2)$	junction area

Reverse current i_R:

$i_R\ (\mathrm{A}) = i_D + i_S + i_G$

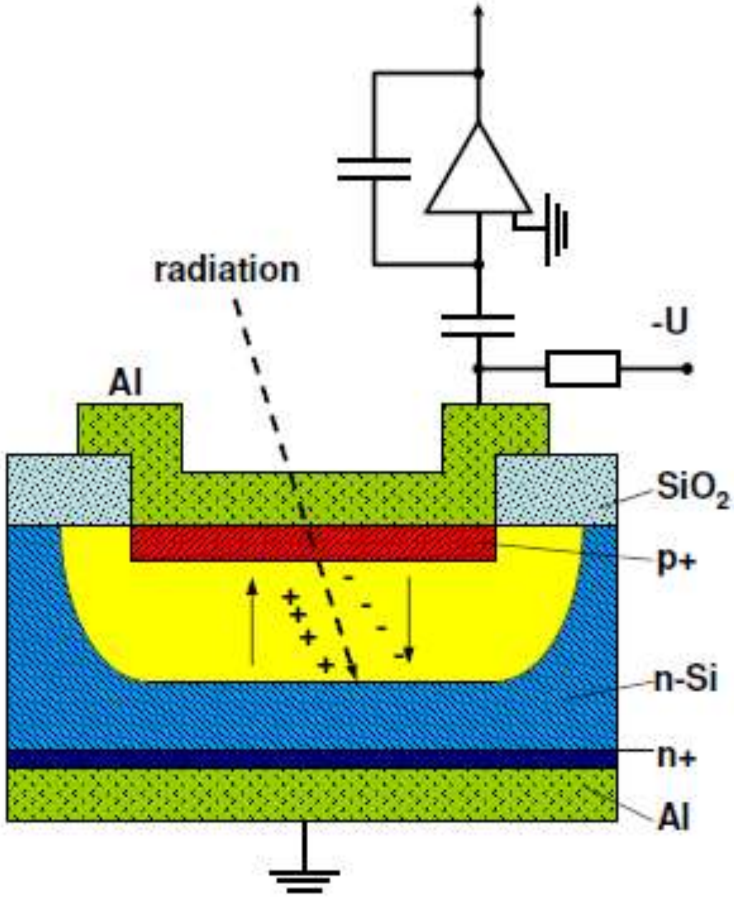
i_D	diffusion current
i_S	surface leakage c.
i_G	generation current

For deep depletion layer :

$i_R = i_G = q\ g\ V = q\ (n_i/\tau)\ A\ 0.5 \times 10^{-4}\ (\rho\ U)^{1/2}$

$i_R \sim U^{1/2}/\tau$

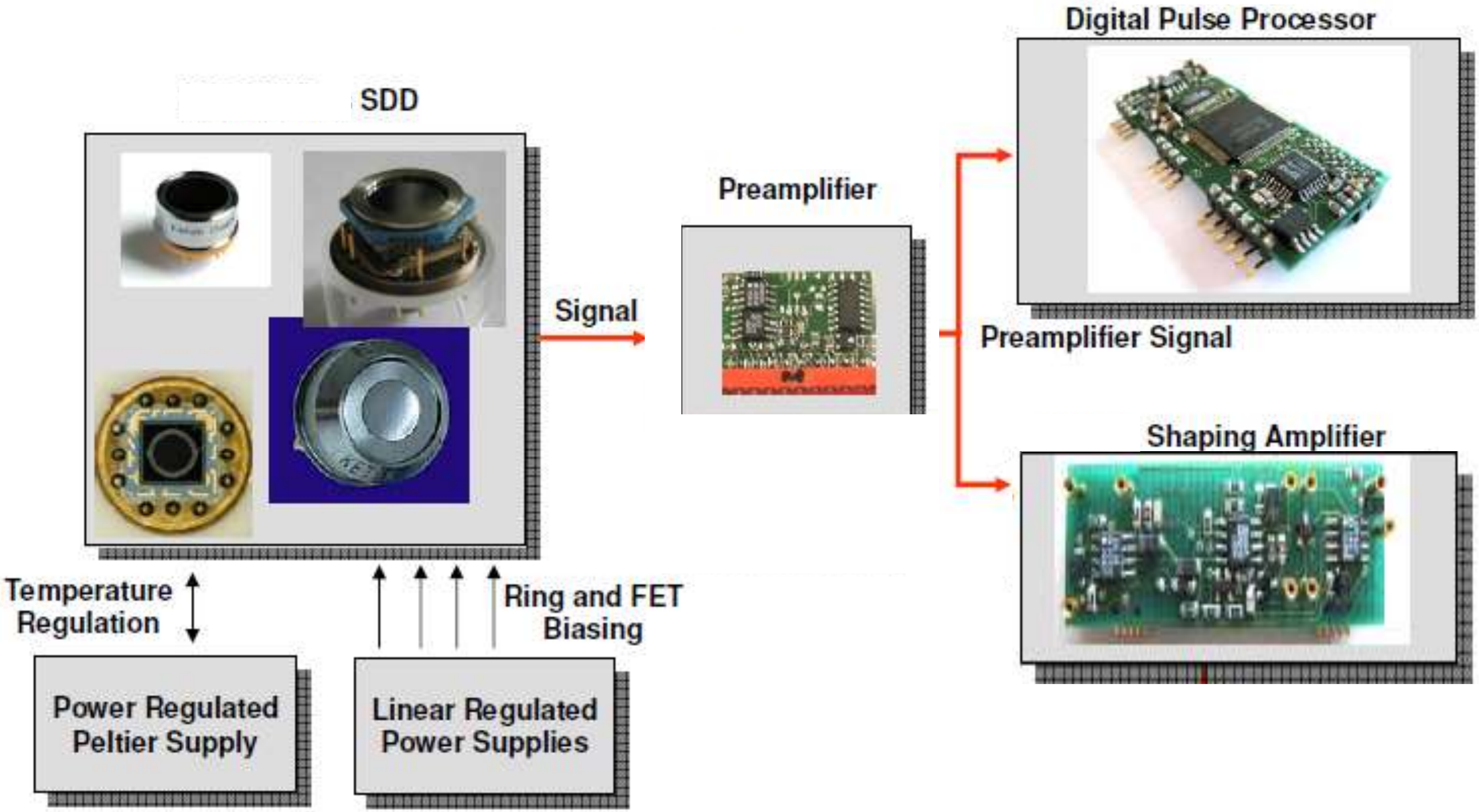
n_i	$1.45 \times 10^{10}\ \mathrm{cm}^{-3}$ intrinsic carrier cor
τ	lifetime
q	1.6×10^{-19} A s



Noise sources:

- **capacitance**
- **reverse current**

Schematic Overview of Electronics for Detector



SDD

Signal

Preamplifier

Preamplifier Signal

Digital Pulse Processor

Shaping Amplifier

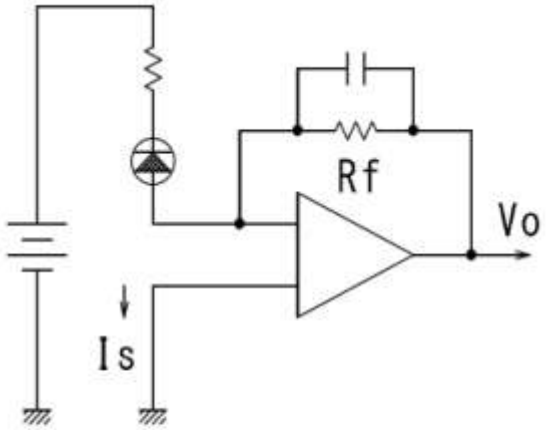
Temperature
Regulation

Ring and FET
Biasing

Power Regulated
Peltier Supply

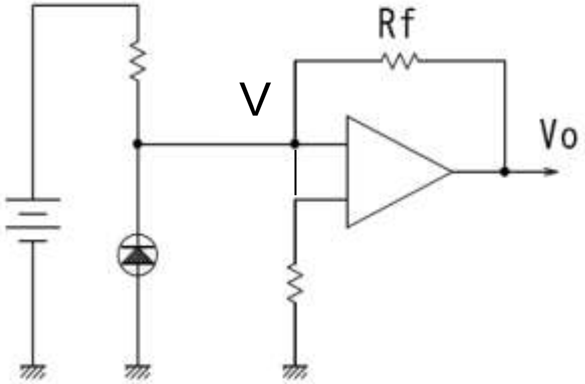
Linear Regulated
Power Supplies

Types of Preampfilter



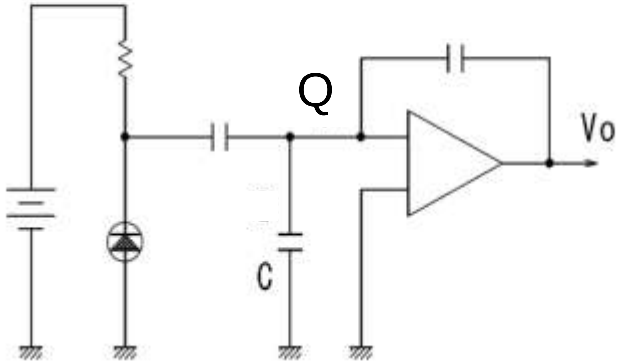
$V_0 = Rf \cdot I_s$

a) current sensitive



$V_0 = \left(\frac{R+Rf}{R}\right)V$

b) V0 leage sensitive

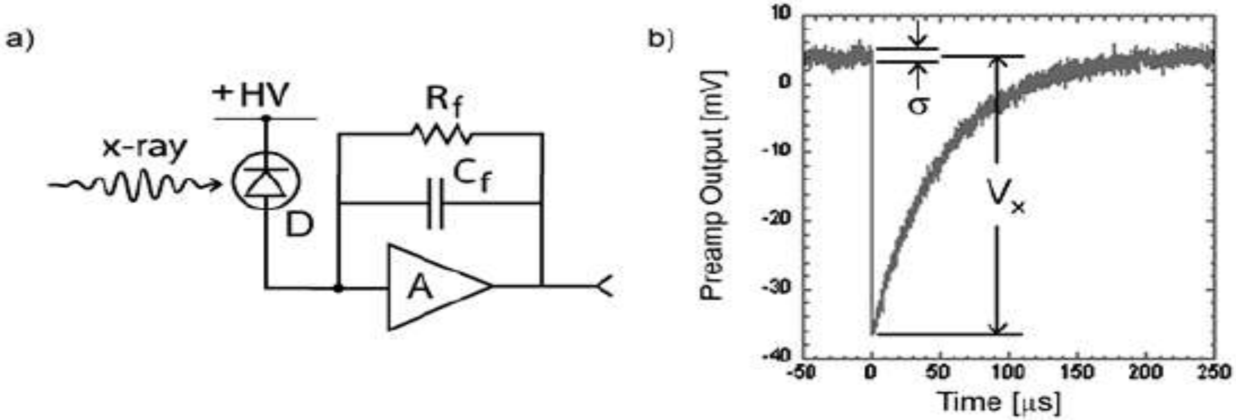


$V_0 = \frac{Q}{C}$

c) Charge sensitive

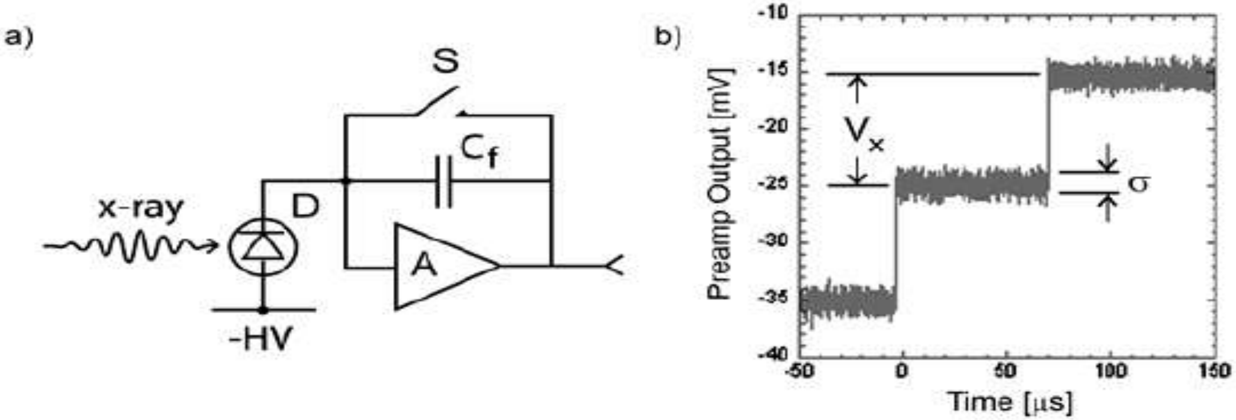
RC type & Reset type

RC type



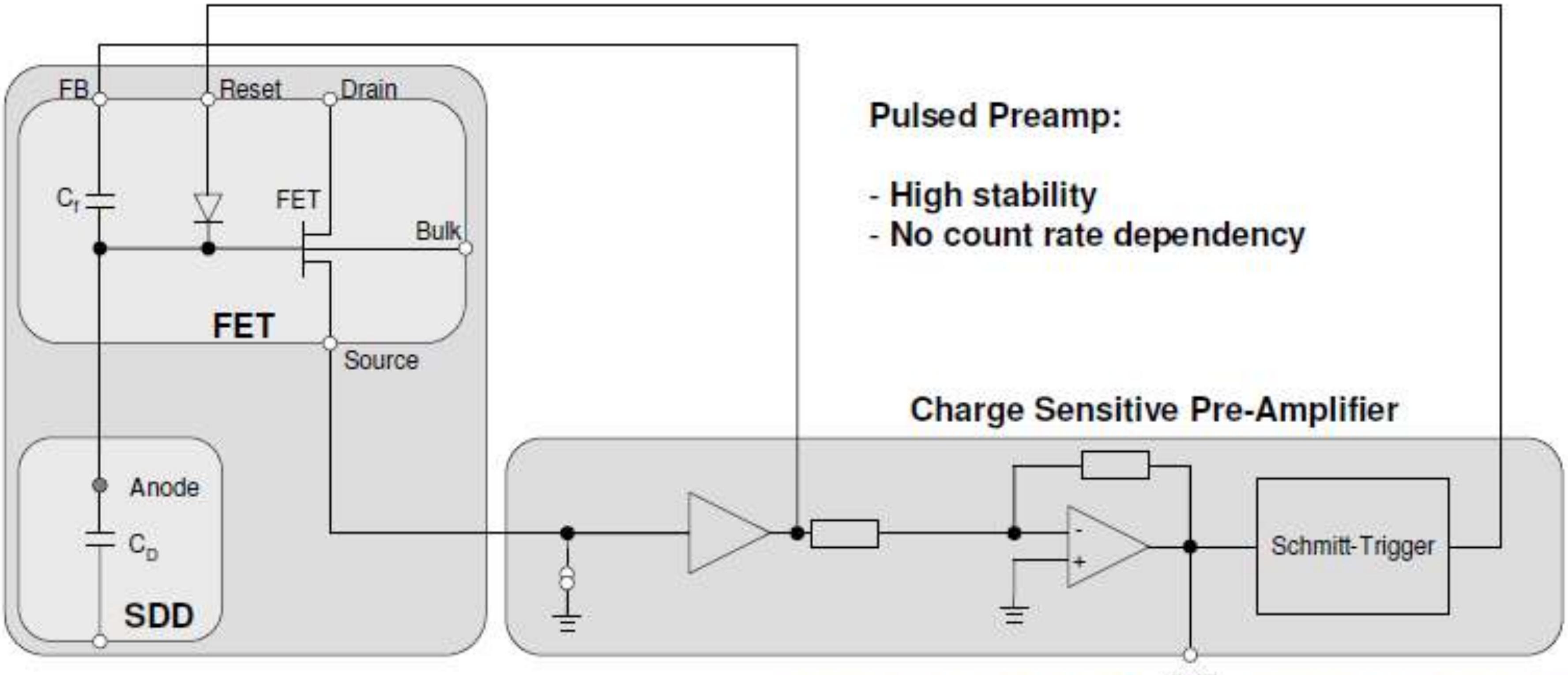
a)RC-type charge sensitive preamplifier with a positively biased detector;
b) Output on absorption of an x-ray. Note that the step has a falling edge, thus the signal polarity is negative.

Reset type



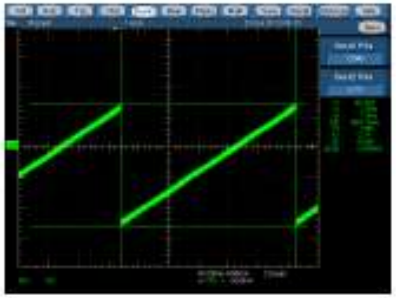
a) Reset-type charge sensitive preamplifier with a negatively biased detector;
b) Output on absorption of x-ray rays. Note that the steps have a rising edge, so that the signal polarity is positive.

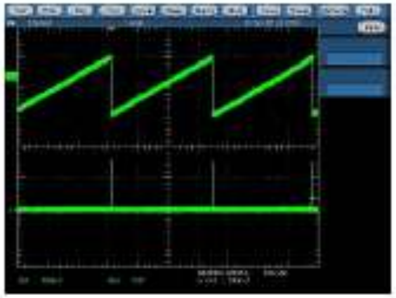
Reset type Preampfilter



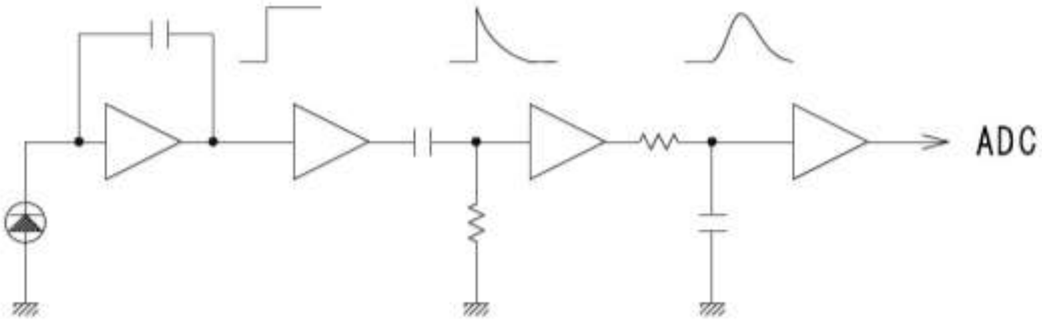
Pulsed Preamp:

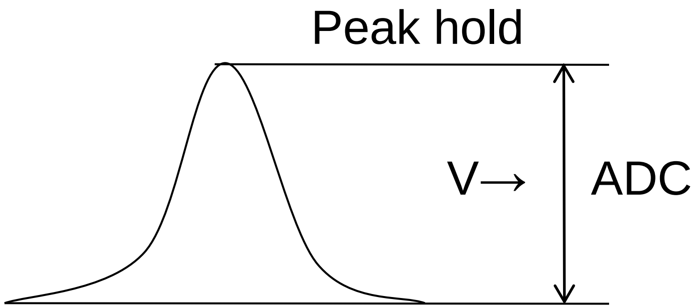
- **High stability**
- **No count rate dependency**

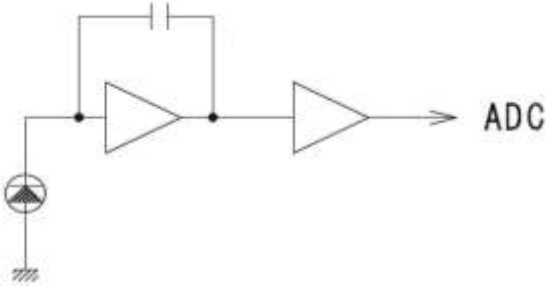


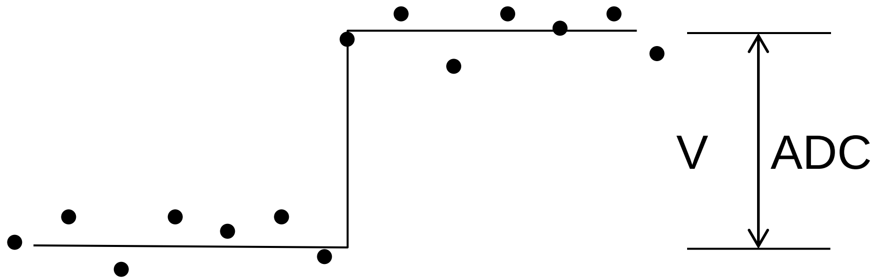


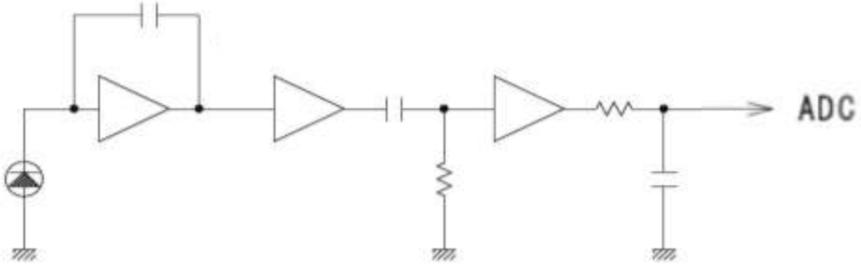
Principle of Signal Processing

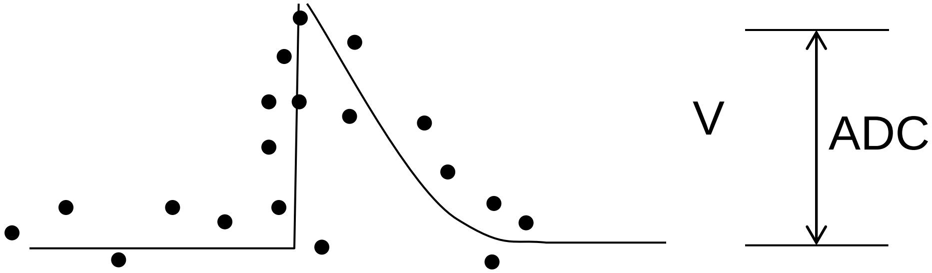




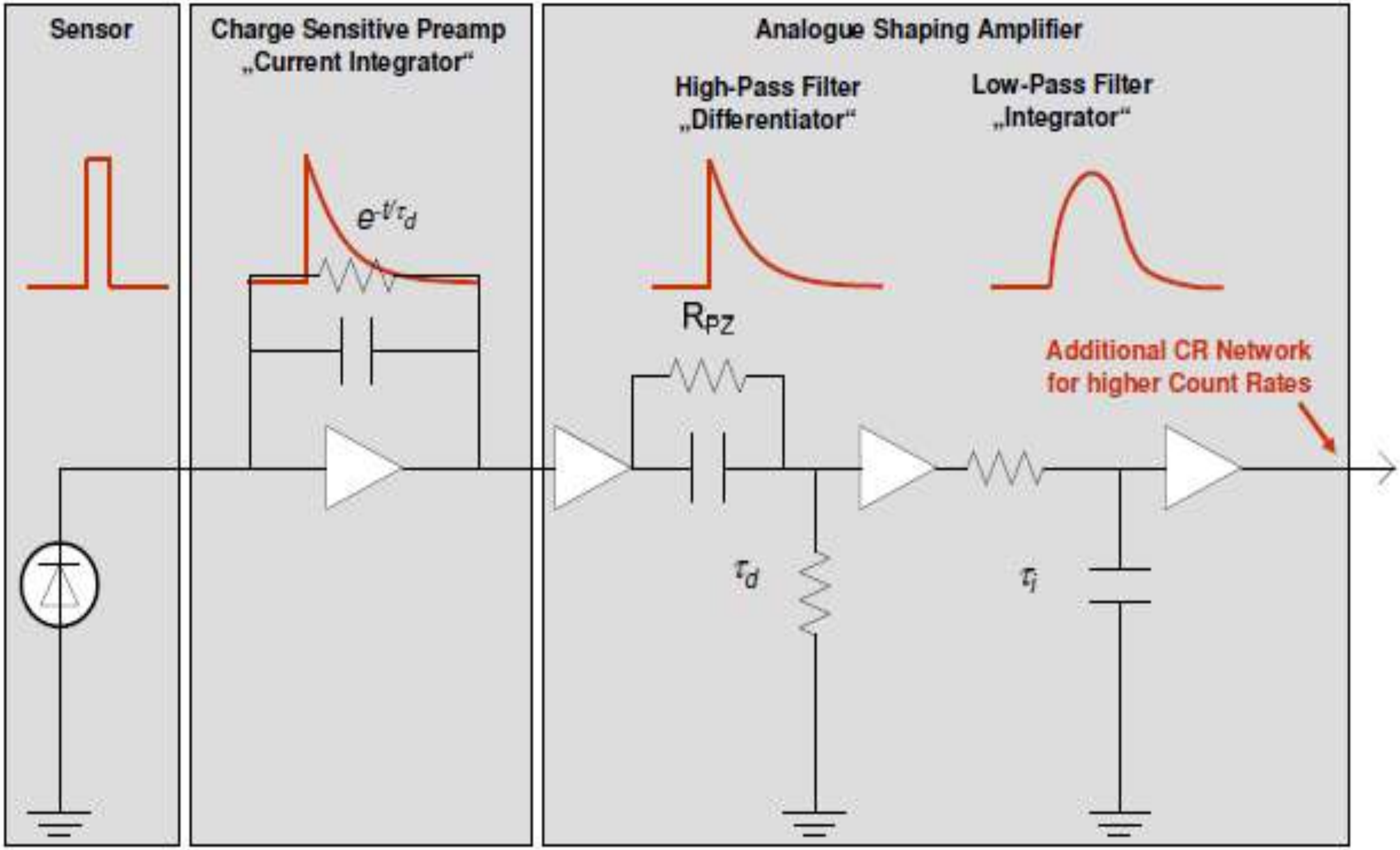




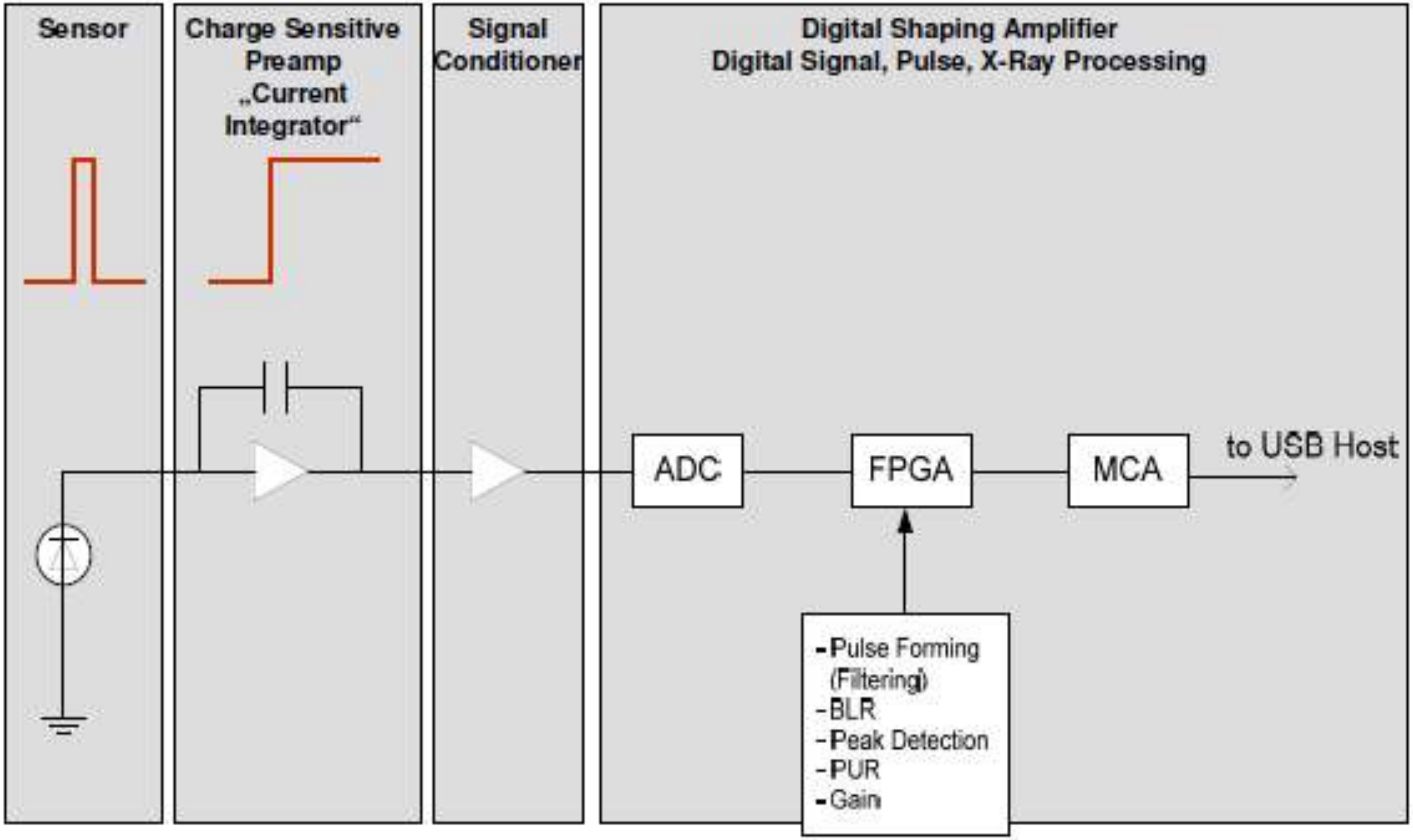




Principle of Analogue Signal Shaping

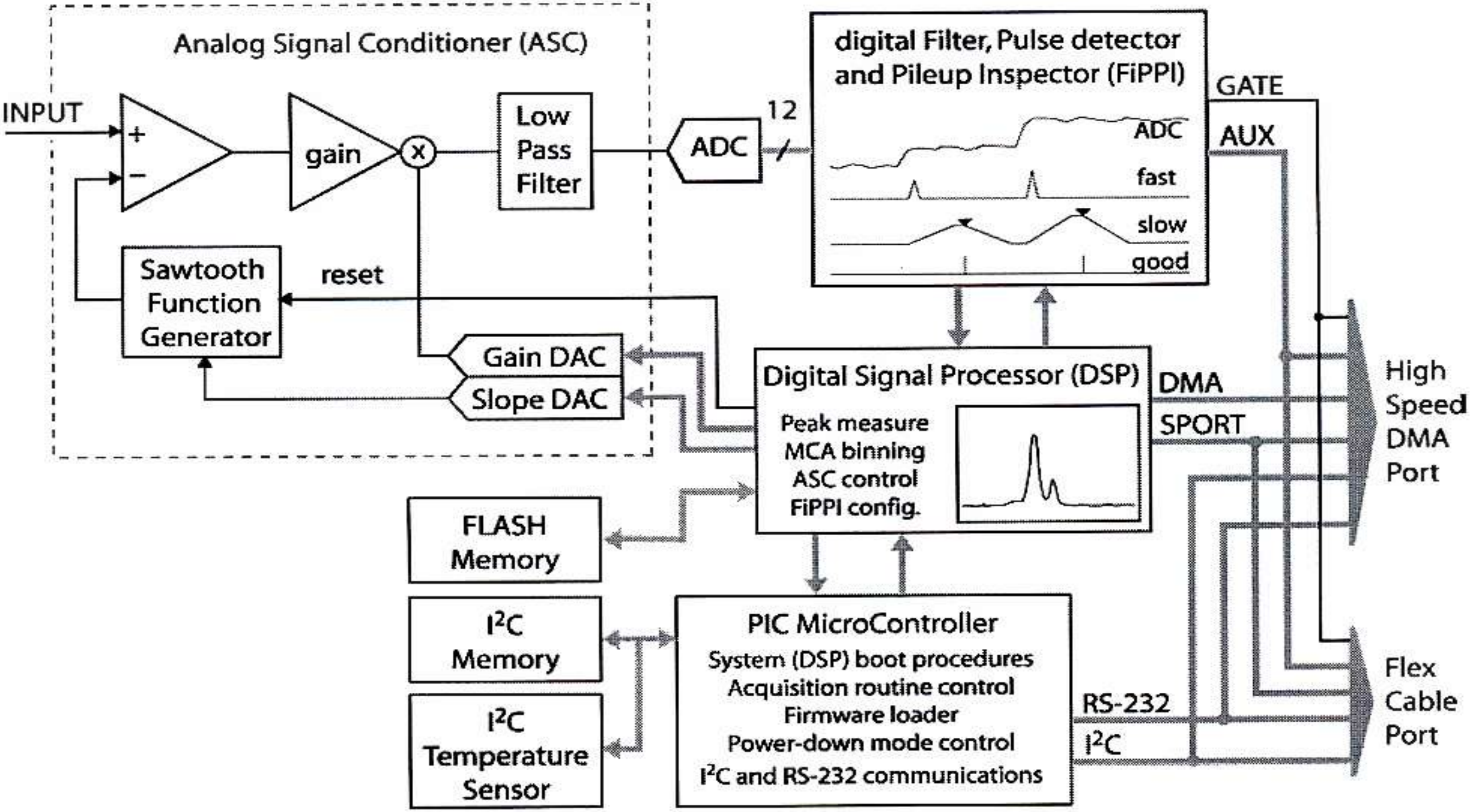


Digital Signal Processing – Principle of Operation

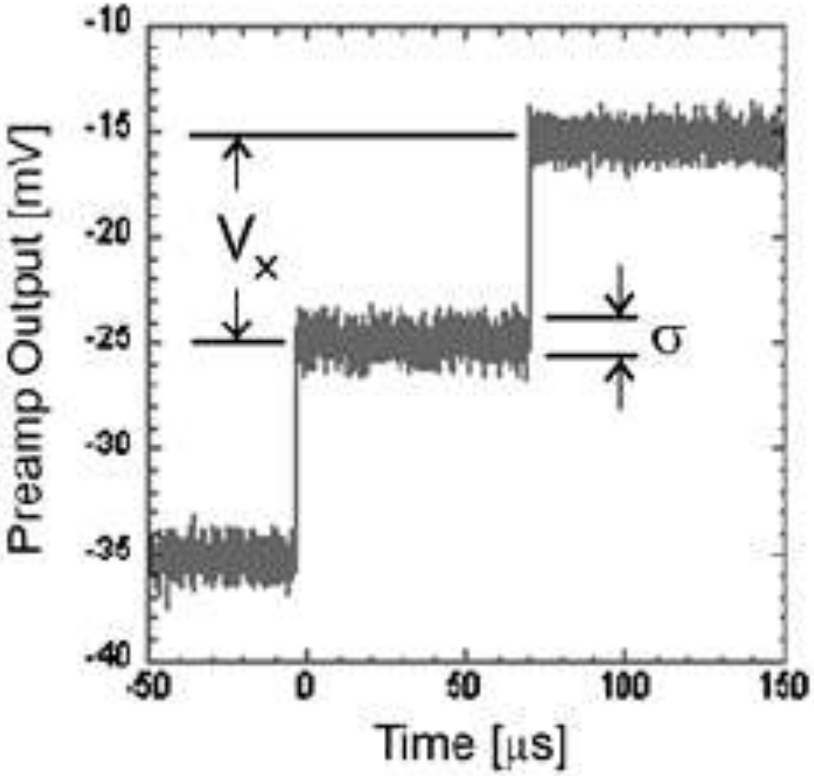


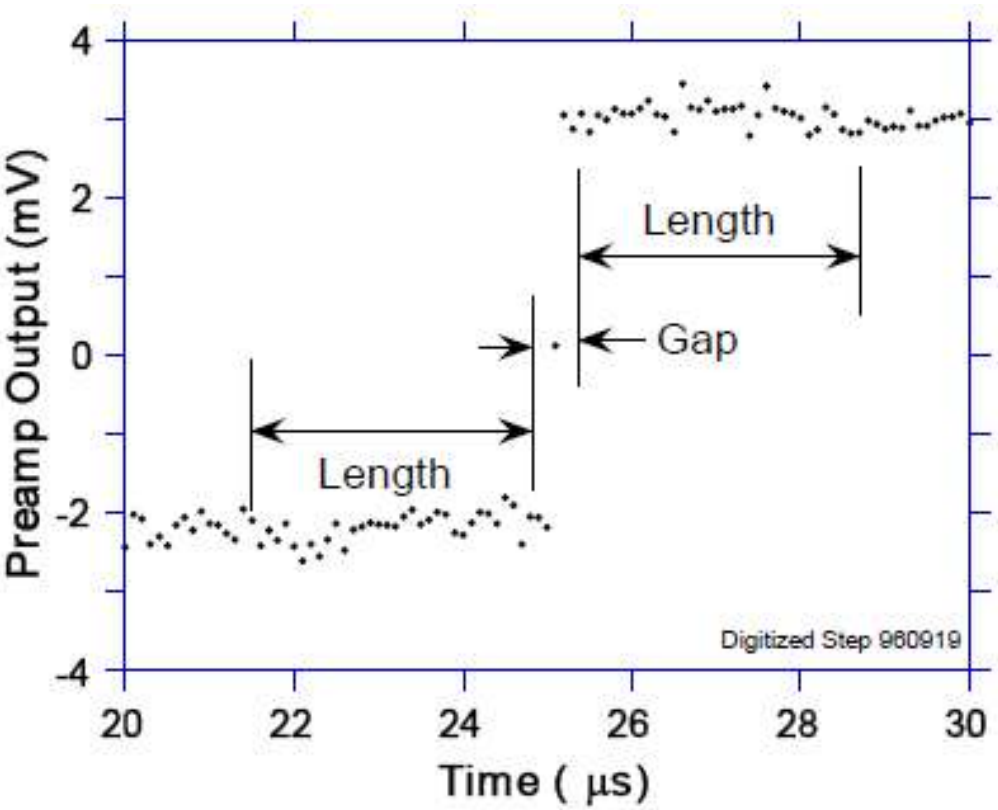
Techno

DSPのブロック構成図

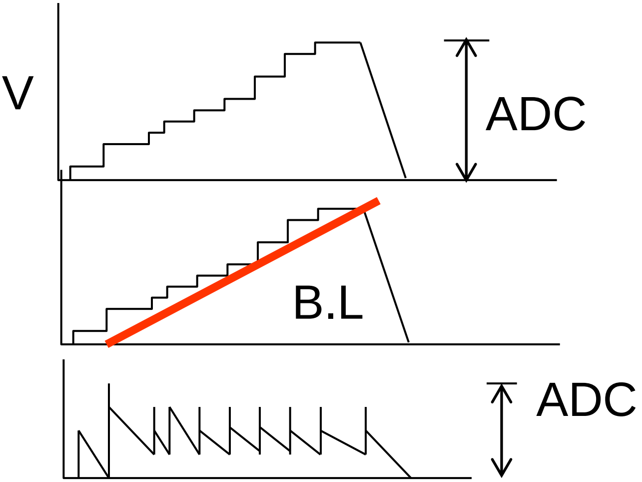


Digital signal data processing

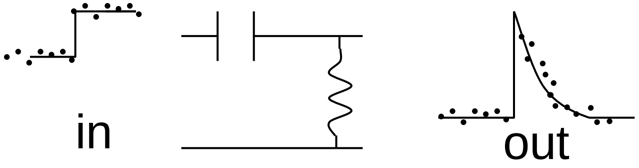




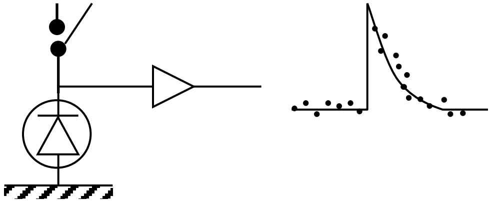
Signal Conditioning for Digital Processing



XIA
Analog Signal Conditioner (ASC):
– Subtraction of a Saw Tooth Function from the ramped Preamplifier Output Signal
– Amplification and Offset of the Difference Signal to fit the ADC input range

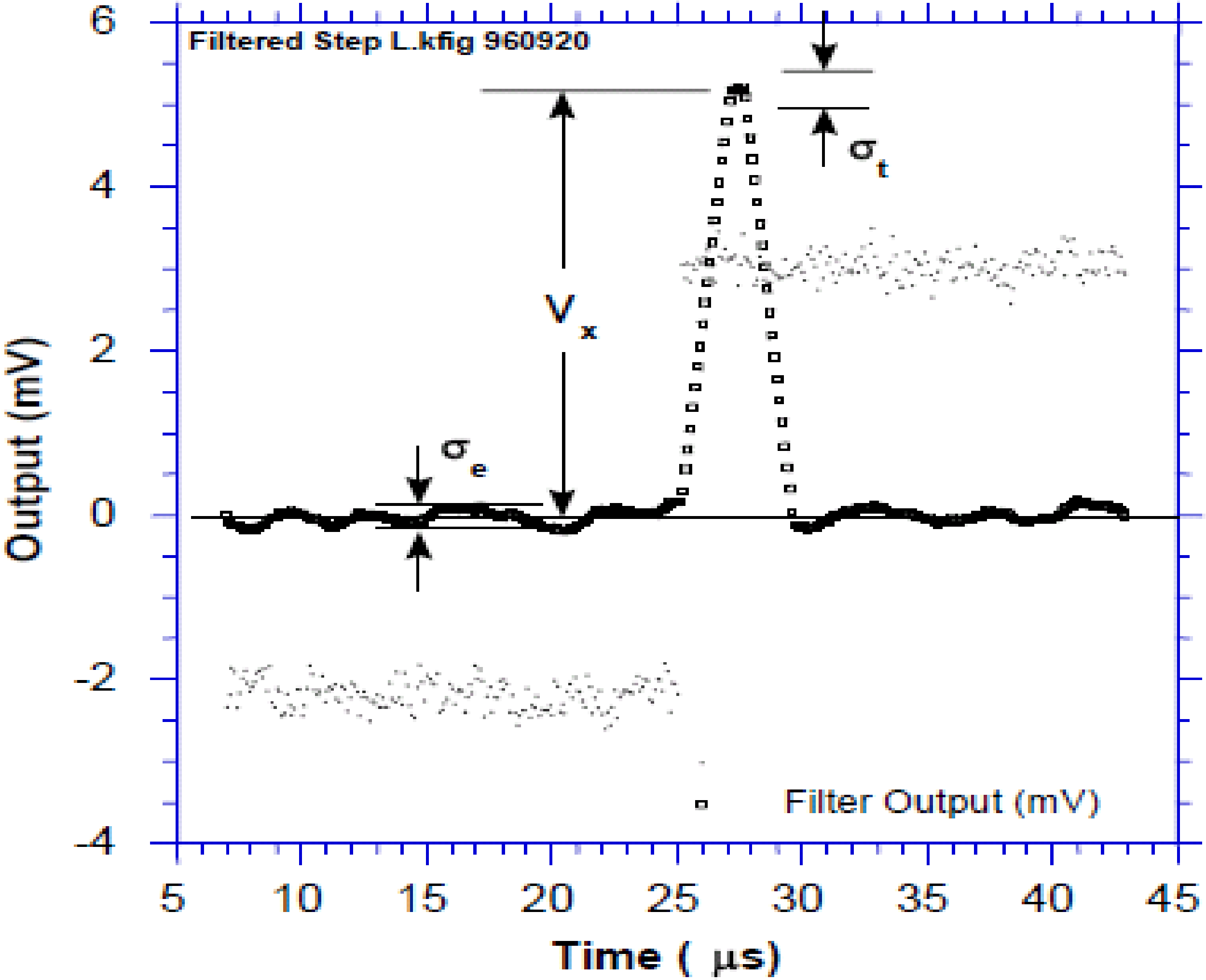


KETEK
Analog Signal Conversion
– Conversion of the ramped Preamplifier Output Signal to an exponential Output
Signal by differentiating with a High Pass Filter of maximum 6μs Decay Time
– Amplification and Offset of the differentiated Signal to fit the ADC input range



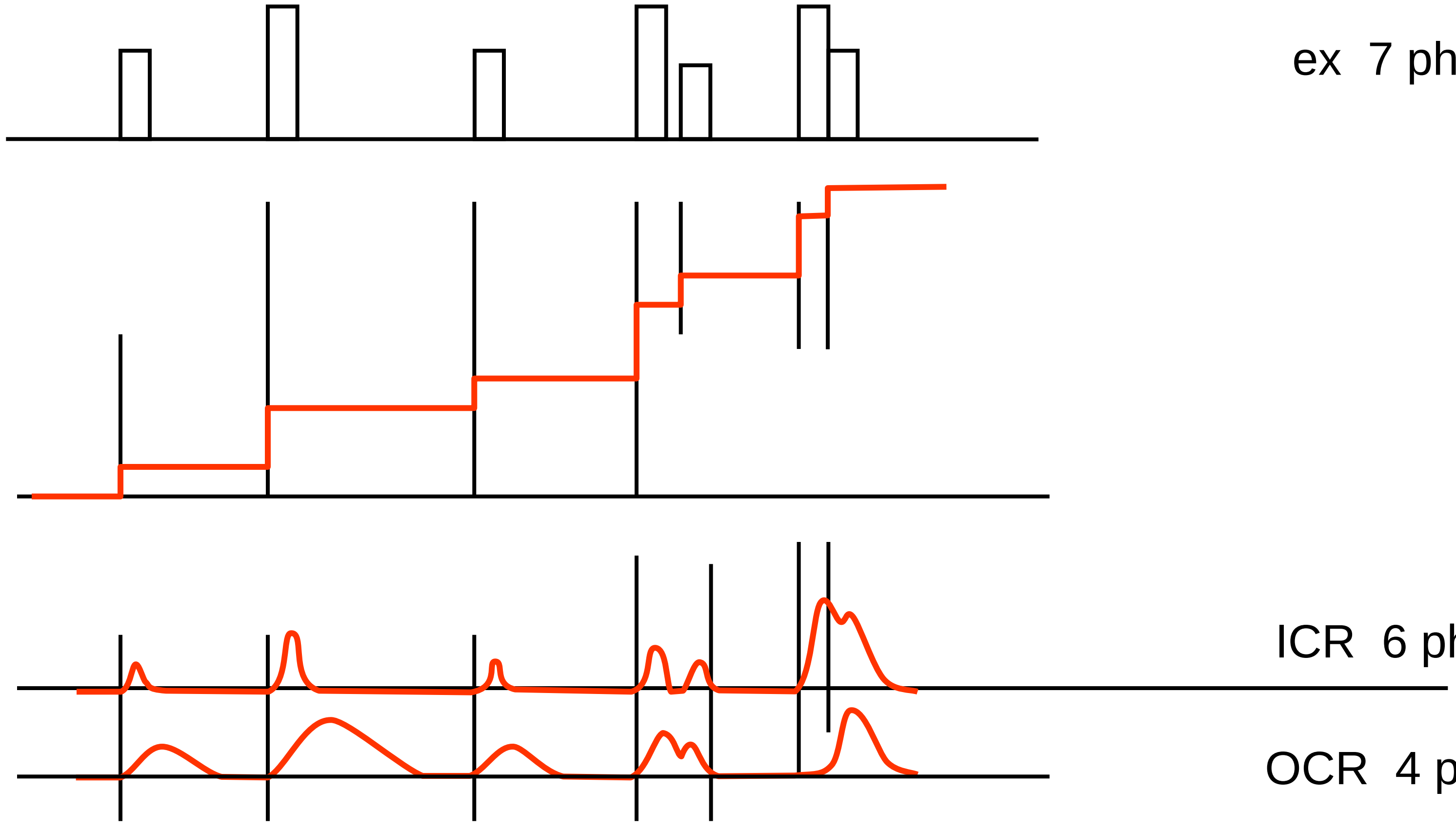
Oxford Instruments
High Frequency Reset triggered by the DSP to keep the ramped Preamplifier
Output Signal in the ADC input range

Digital Filtering



Displayed over a longer time period to show baseline noise.

Fast & Slow



ex 7 photon

ICR 6 photon

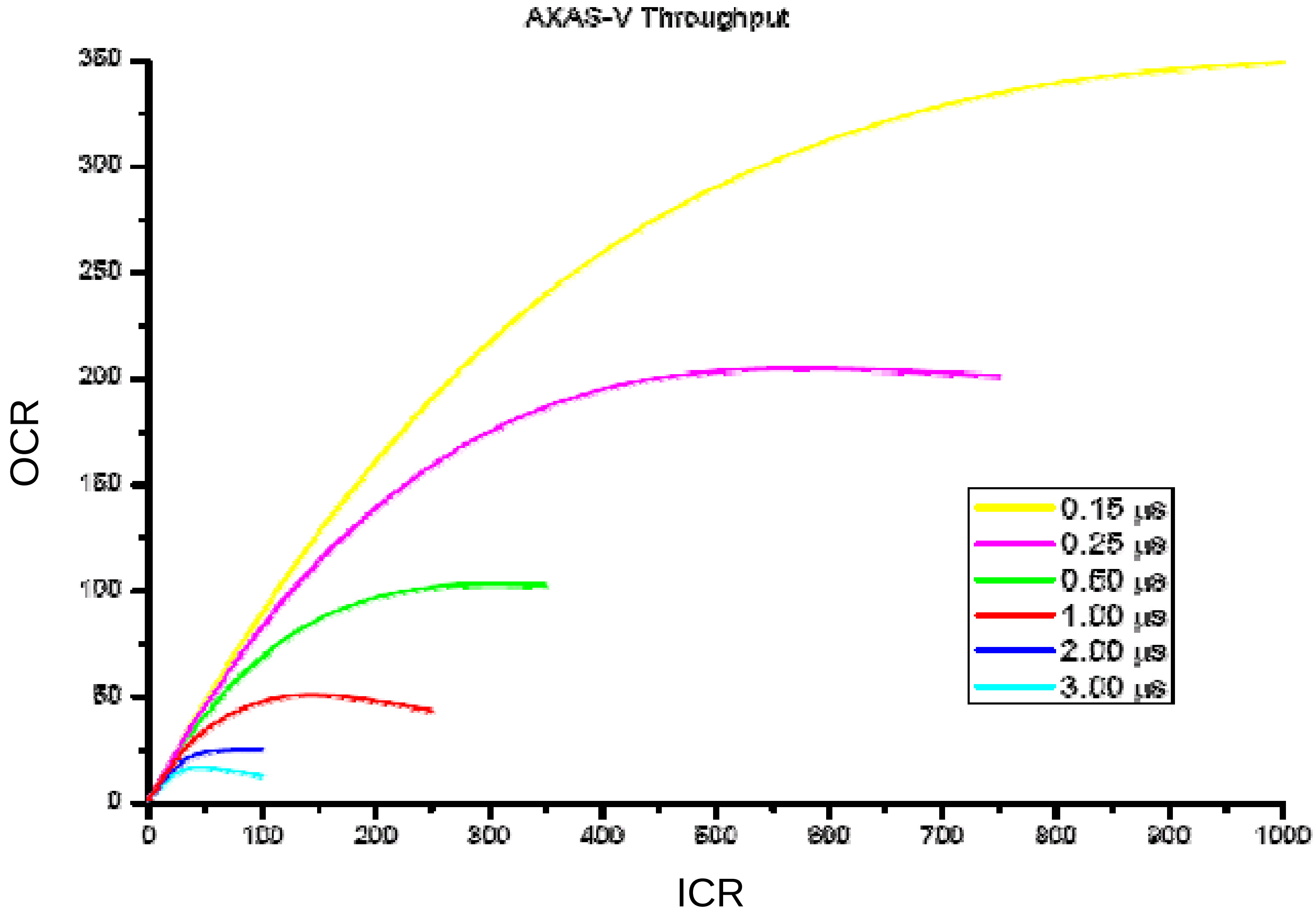
OCR 4 photon

pile up sumpeak

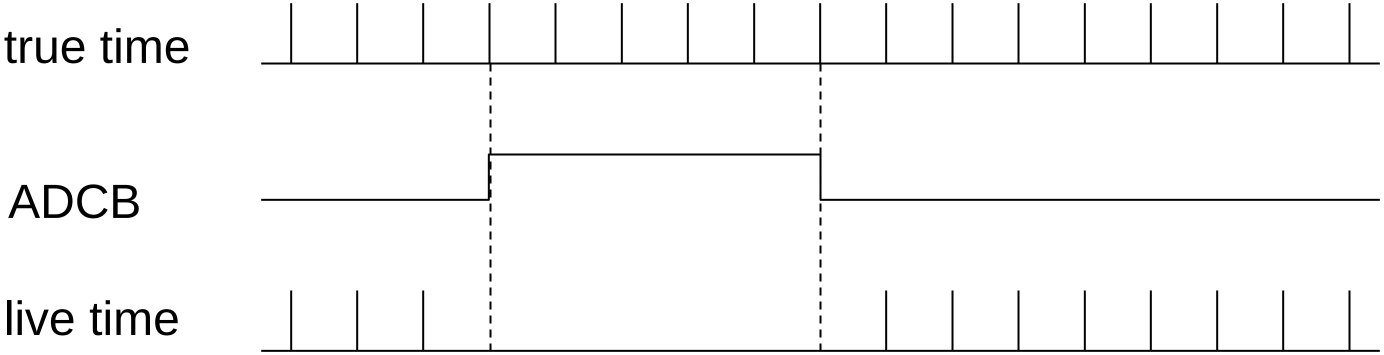
⟷

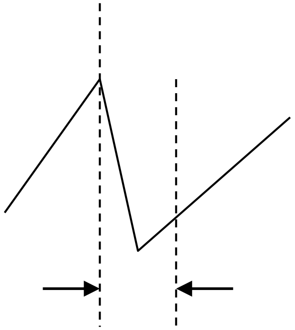
Dead time

Throughput Curves

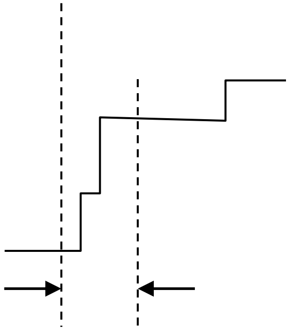


True time &Live time

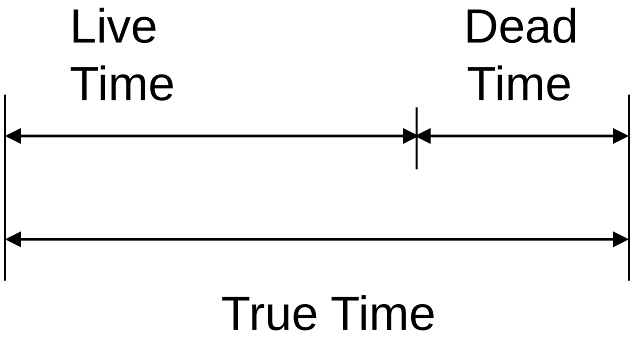




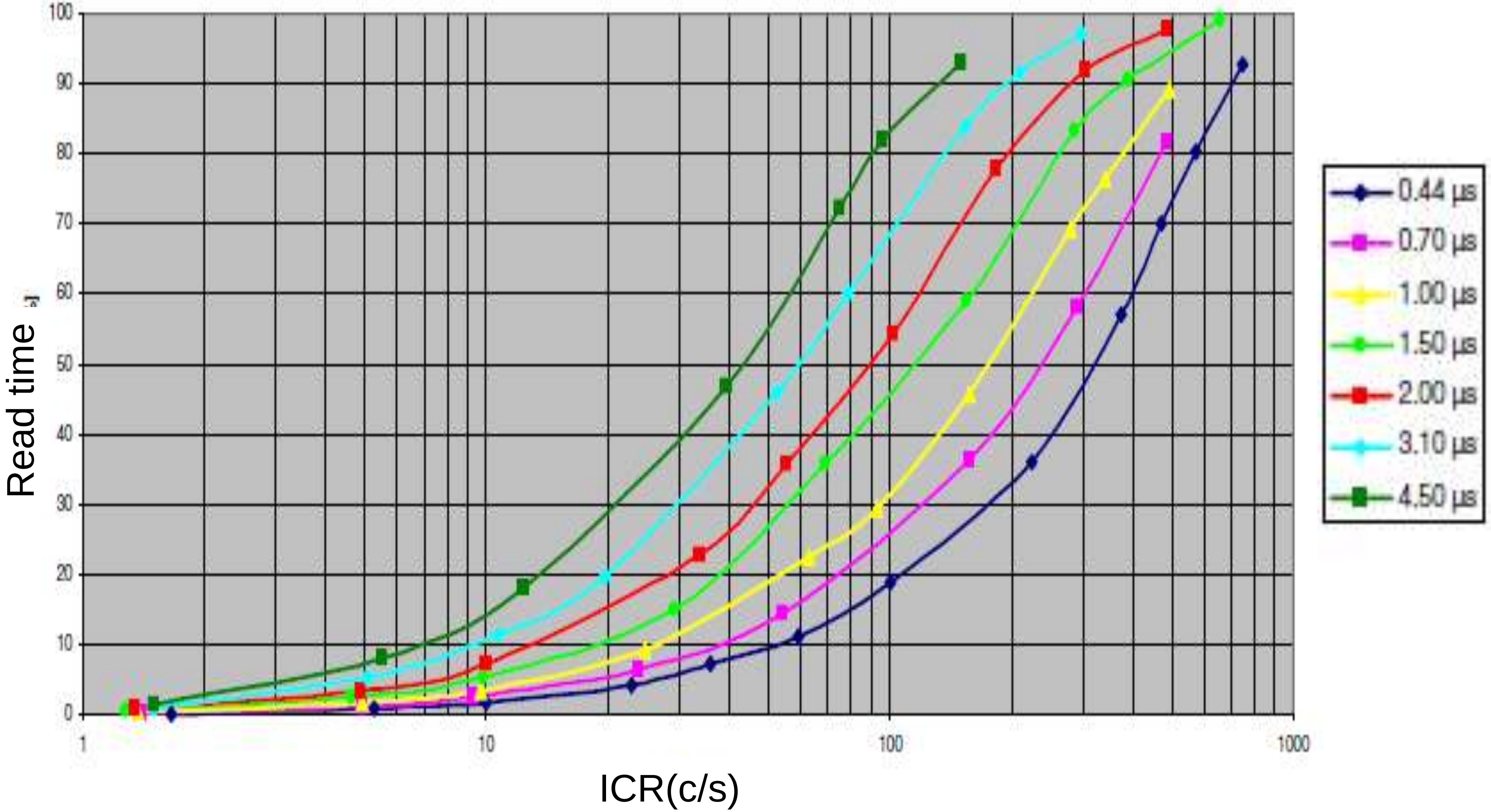
inhibit



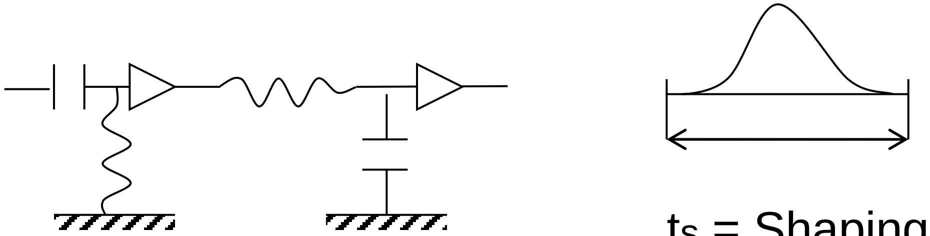
pile up



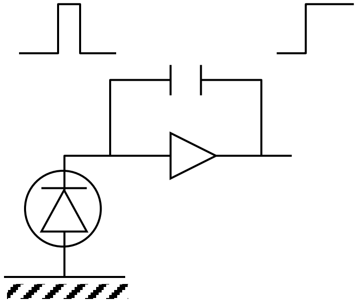
Dead Time versus Input Count Rate

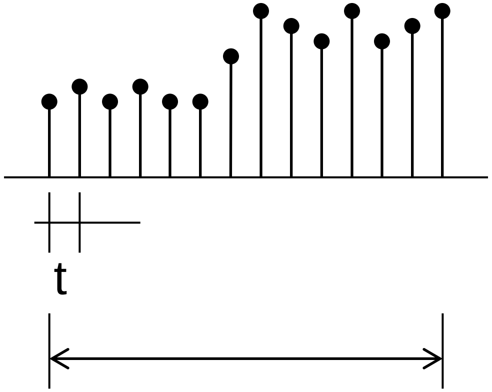


Shaping time & Peaking time



t_s = Shaping time
= Tome constant
for Filter



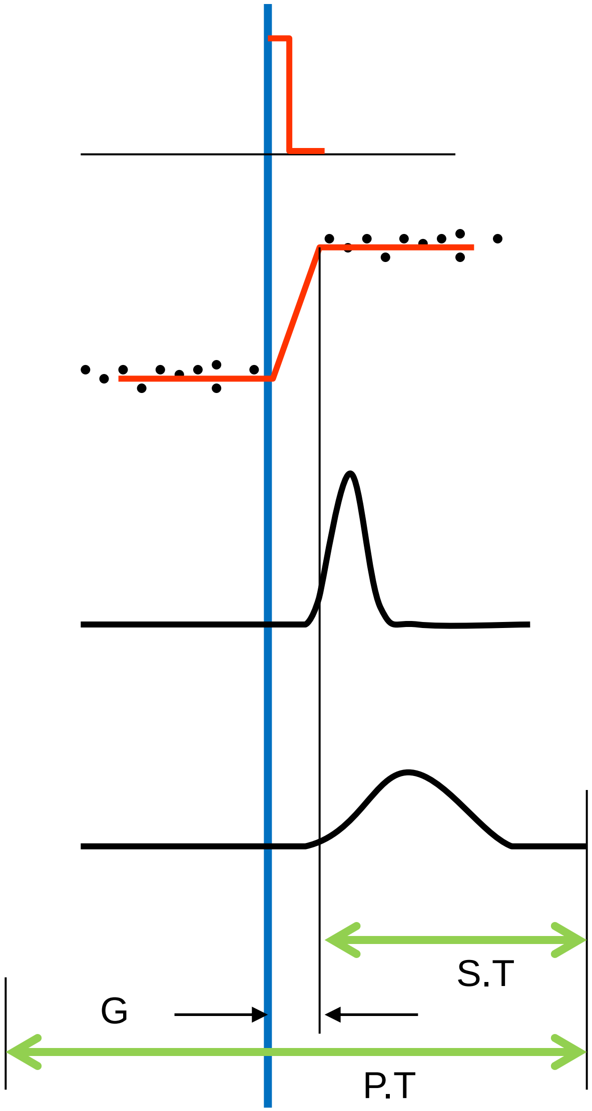


t_p = Peaking time

$t_p = t \times n$
t = time of sampling
n = number of sampling

for ex. 16MHz t = 62.5nsec
n = 24
t × n = 62.5 nsec × 24 =1.5μsec

Relation between Shaping time & Peaking time



photon coming to detector

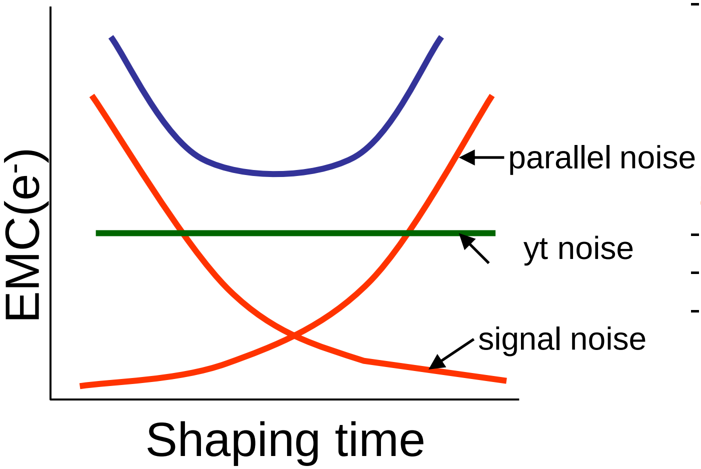
charge increase at preamplifier

short shaping time

long shaping time

$P.T > 2 \times S.T$

Noise Sources of a SDD



Serial Noise

- Determined by capacitance of complete setup:
anode capacitance + input capacitance of FET + stray capacitance
(bond wire + mounting technique)
- Dependent on transconductance of the FET
-Slightly temperature dependent

Influences short shaping times (high count rates applications)
reducing serial noise → high count rates with very good FWHM

1/f Noise

- Dependent on mounting technique
- Noise of FET
-Dependent on capacitance

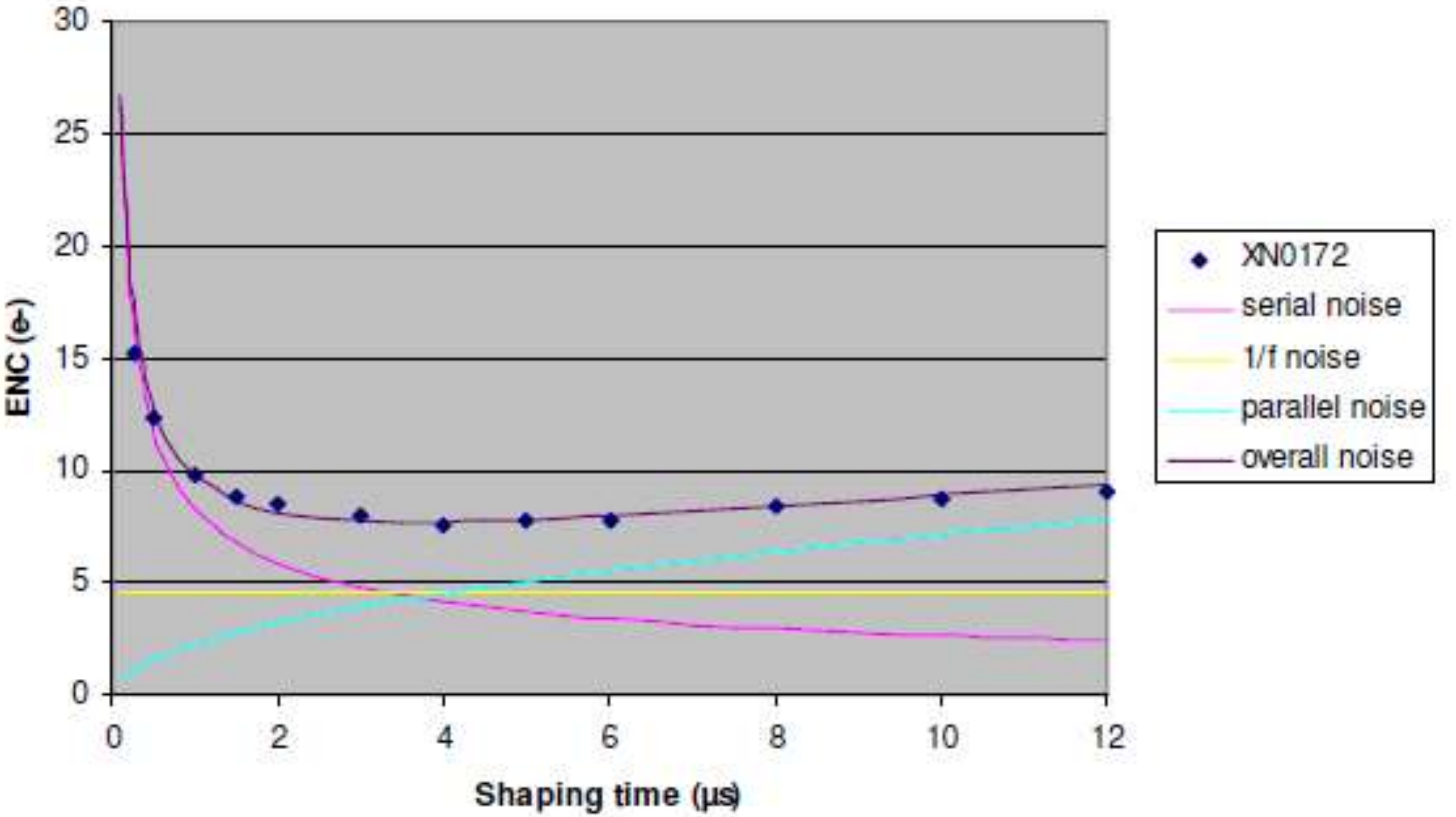
Independent of shaping time;
reducing the 1/f noise improves the energy resolution for all shaping times

Parallel Noise

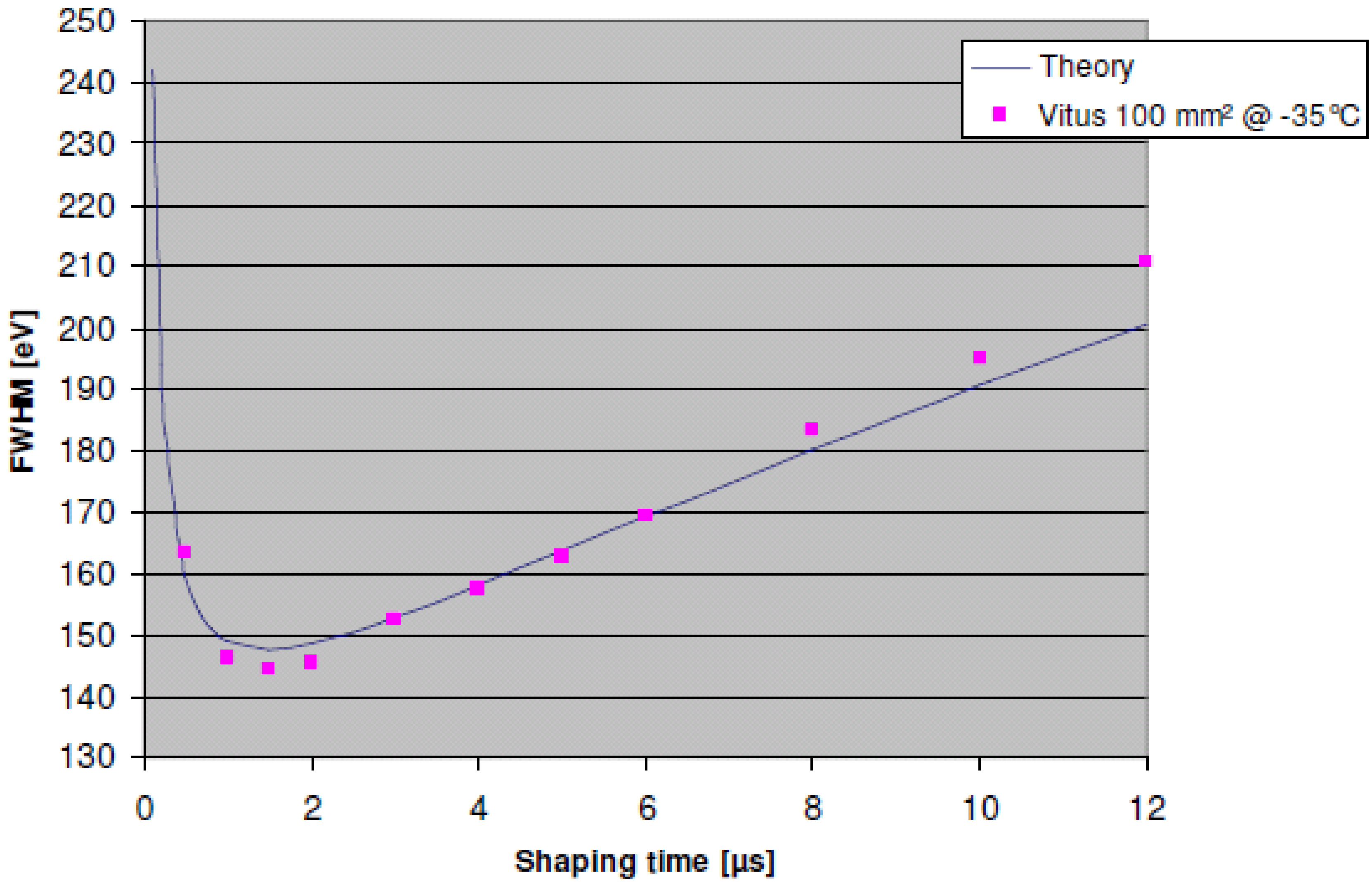
- Dependent on leakage current of SDD (therefore strong dependency on operating temperature – cooling by approx. 7° C halves leakage current)

Influences long shaping times; can be reduced by lower operating temperatures
Reducing parallel noise is important for large area detectors and for operating conditions under high ambient temperatures

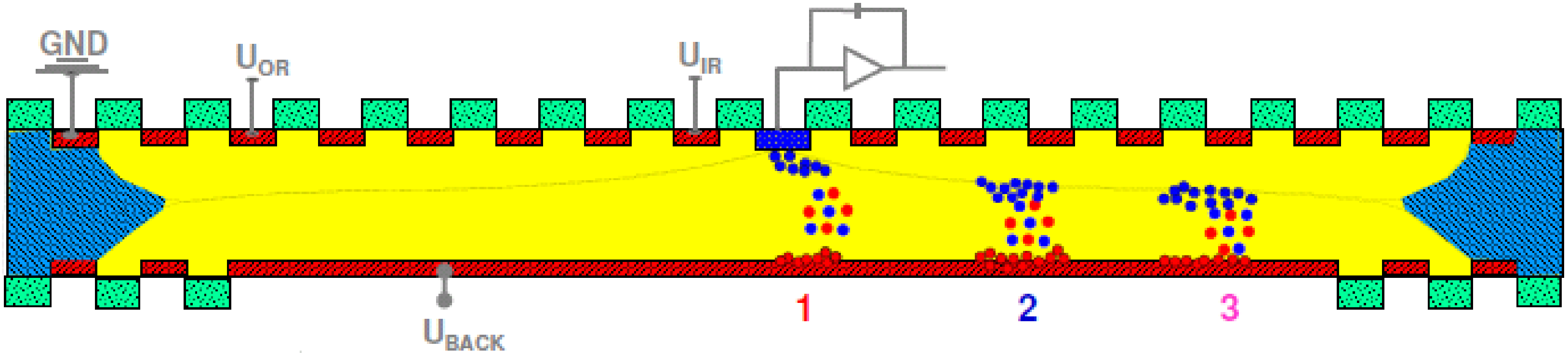
Noise plot of a 10 mm² Vitus SDD



Noise plot of a 100 mm² Vitus SDD

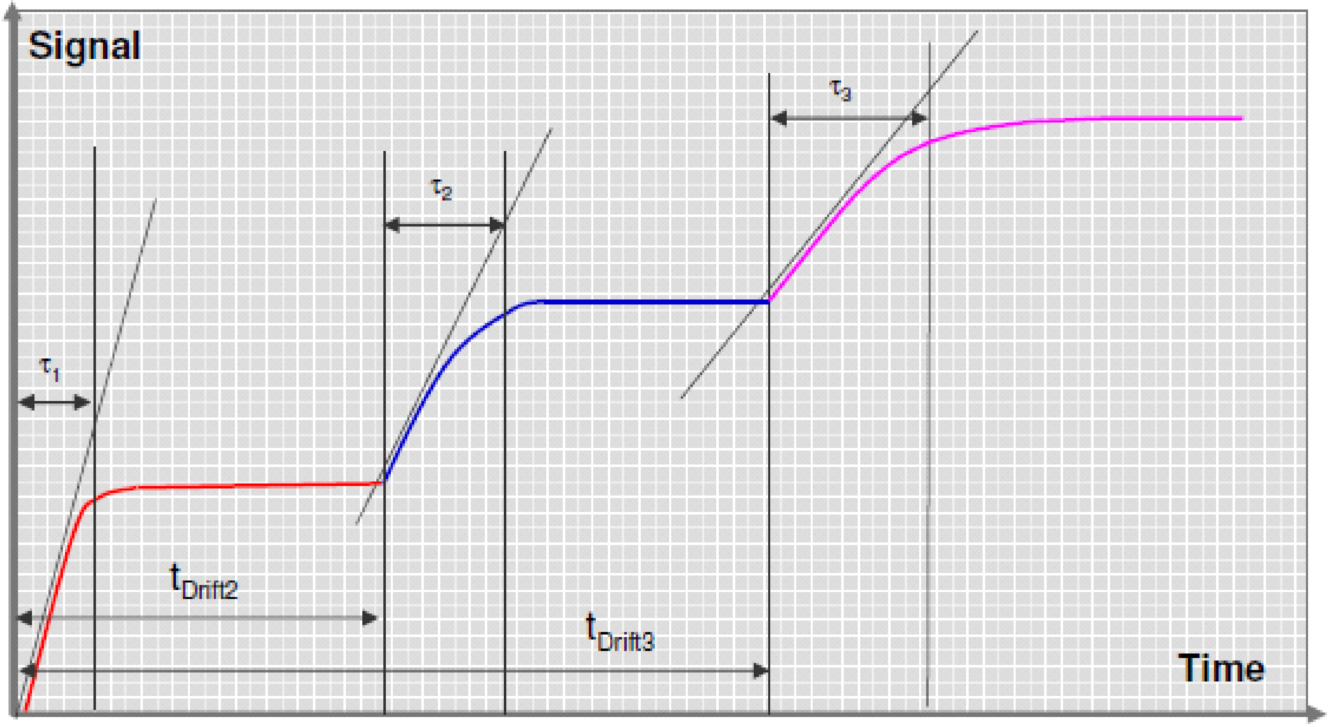


Function of Silicon Drift Detector

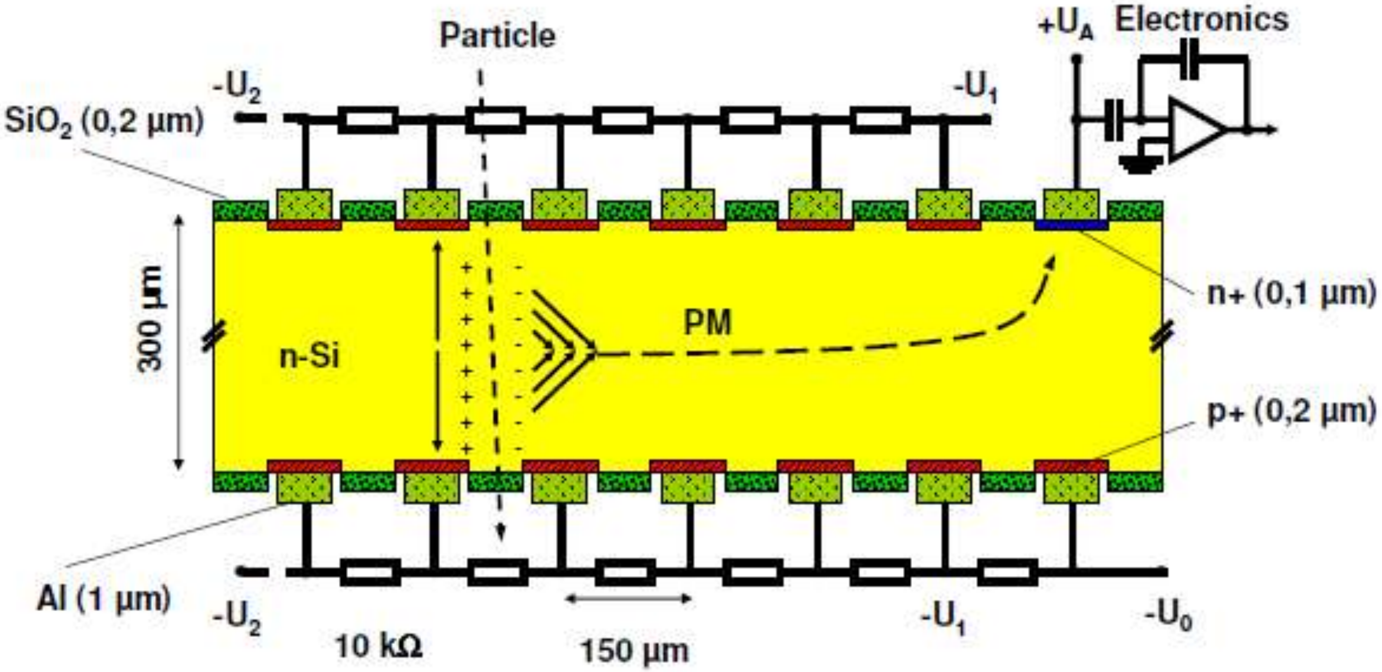


Charge Collection:

Event 1	signal 1
Event 2	signal 2
Event 3	signal 3



Information of Energy & Position



Horizontal electric field by

- division of electrodes into strips
- applying of increasing bias at strips

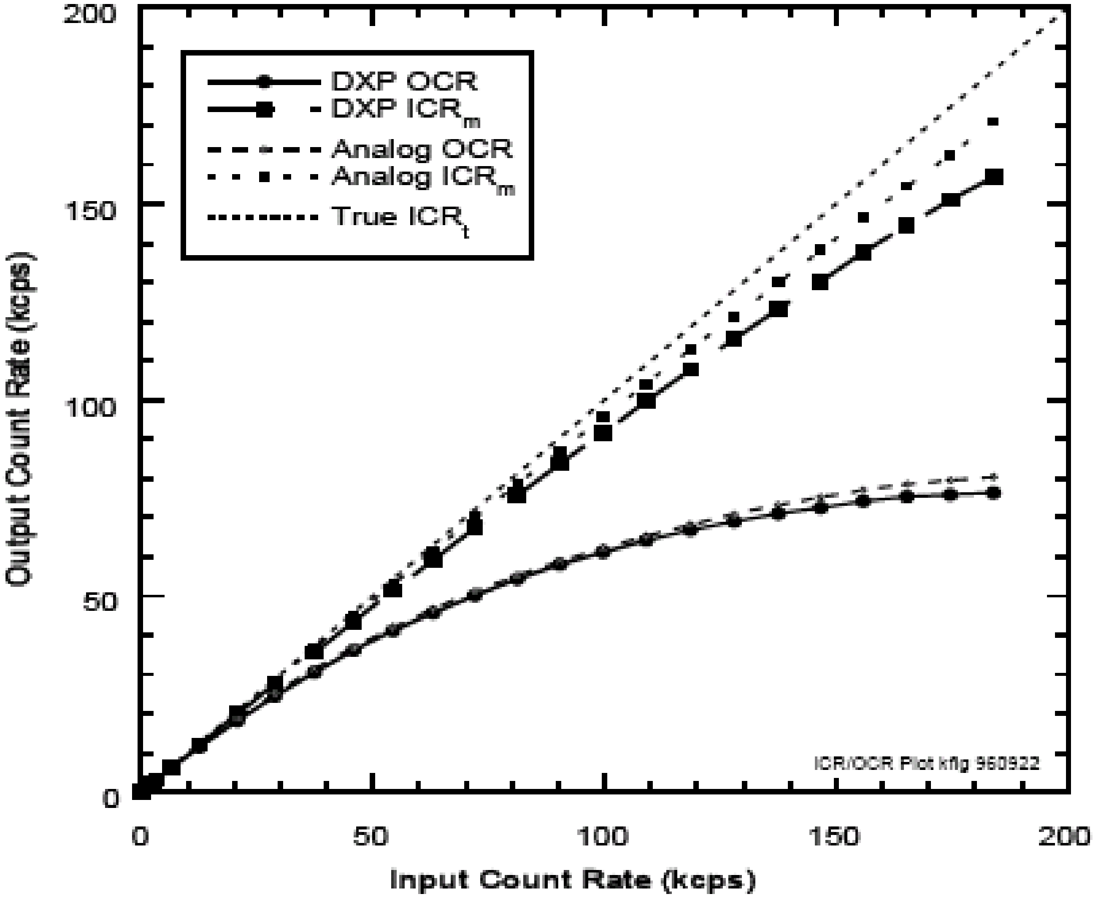
Charge collection

- electrons are drifting to readout anode
- low noise amplification of signal at anode

signal height ⇒ energy of radiation
drift time ⇒ position of radiation

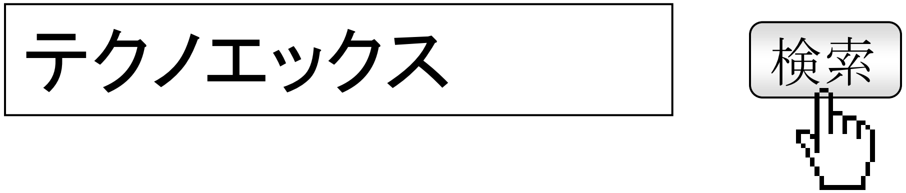
Comparison of Analog & Degital

NOTE: The DXP's peaking time is twice as long as the analog system peaking time in this comparison, and yet the throughput is nearly the same.



Curves of ICR$_m$ and OCR for the DXP using 2 µs peaking time, compared to a common analog SCA system using 1 µs peaking time.

Thank you for you attention



テクノエックス

http://techno-x.co.jp/