Users Meeting Workshop
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Amorphous Silicon based matrix detectors for X-ray Imaging

OUTLINE

- X-ray imaging (medical): Challenges, needs, requirements ...
- **F**lat **P**anel **D**etector [FPD] basis.
  - Interaction layers ("direct/indirect" conversion)
  - Signal Storage
  - Readout schematics
  - Examples of structures
- Products characteristics
- Limitations for a-Si based FPDs.

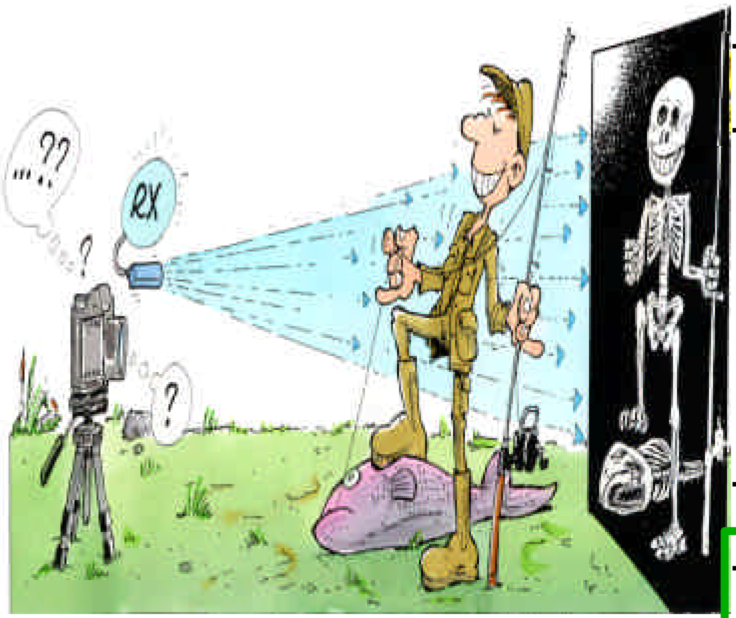
I- The Challenges In X-ray Imaging

- 1- **Replace gradually the film-screen** systems with a wholly electronic, digital detector for static medical imaging. Reduce **costs** and **dose.**

- 2- **Replace the XRII-camera** with a digital detector also offering radiographic quality on isolated images.

- 3- Address other specific applications (NDT, scientific ...)

Need of large area detectors



- X-ray images are formed as shadows (Projections) of the interior of the body/object.
- Not practical/possible to focus X-rays,
- A practical difficulty in making an x-ray detector is the **need to image a large area** (solutions: 1D detector + scanning; optical coupling "phosphor +lens+CCD ..."; photostimulable phosphor; ...)
- A full size detector is needed.
- Amorphous silicon flat-panel active matrix array, originally developed for **computer displays** is the only technology able to meet this demand.

Compared requirements for radiography and fluoroscopy

	General radiography	Mammography	Fluoroscopy
Size	> 40 x 40 cm	>18 x 24 cm	>30 x 30 cm
Pixel size	~ 150 µm	60-100 µm	200-400 µm
Typical nb of incid.X/pel	~1000	~5000	~10
Corresponding dose	2.5 µGy	100µGy	25 nGy
Energy range	30-120 keV	~20 keV	30-120 keV
Input equiv. noise	< 5 X quanta	< 5 X quanta	< 1 X quantum
Dynamic range	12 bit	12 bit	12 bit
Readout time	1-5 s	1-5 s	~30 ms (30fps)

Table I. Summary of the main requirements for medical X-ray imaging.

At 50 to 70 keV: 1µGy ~ 400 to 500 X photons per pixel of ~150x150µm²

II- FPD Basis

- The basis of **Flat Panel Detector** (FPD) = coupling traditional x-ray detection material (scintillators or photoconductors) with a large area active-matrix readout structure.
- **Creation of a x-ray image can be divided into 3 major steps**:
  - x-rays **Interaction** with a detection medium ➔ detectable signal.
  - Signal **Storage**
  - Stored signal **Measurement**
- In digital imaging systems the incident image must be **sampled:** in the **spatial** (pixels) and **intensity** (gray levels or bits) **dimensions**.

There exists two approaches
opto-direct ("indirect") and electro direct

Scintillator (optical photons)	**Interaction**	Semiconductor (electron-hole-pairs)
photodiode	**Storage**	electrode & capacitor

Switching matrix

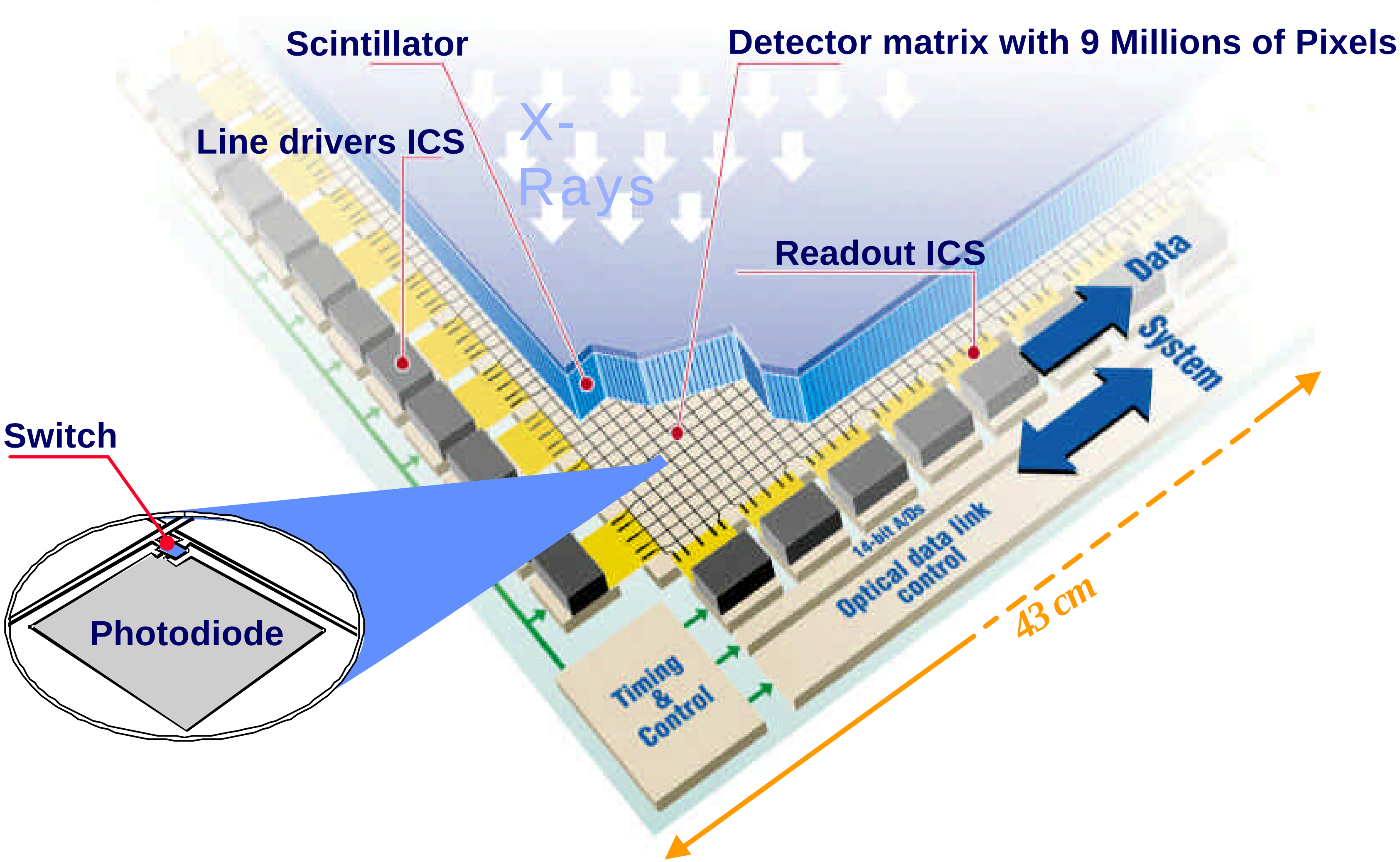
a-Si plate

Low noise amplifier, -electronics,
analog to digital converter,
system integration

electronics

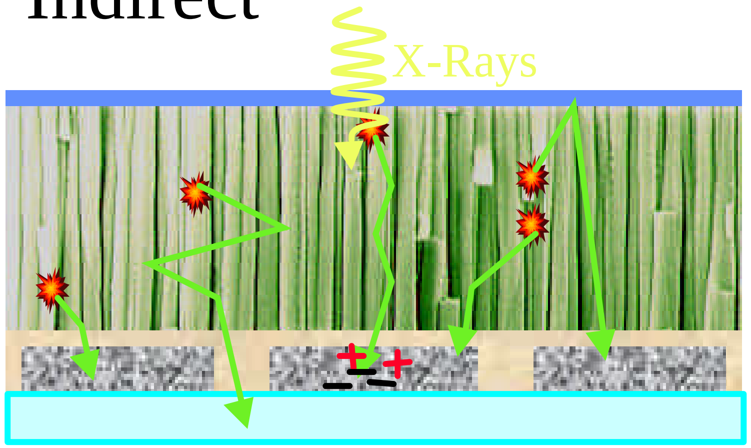
Measurement

Technical stack

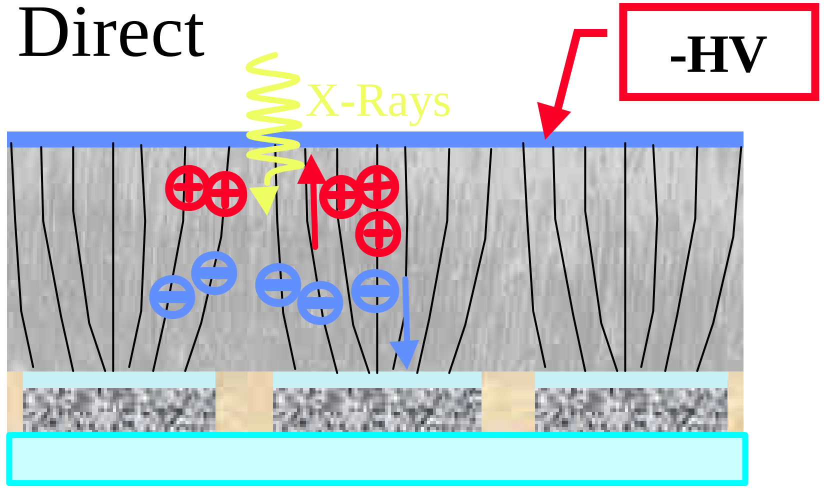


II-1 - Interaction: Direct vs. Indirect approaches

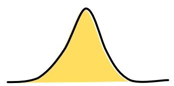
Indirect



Direct

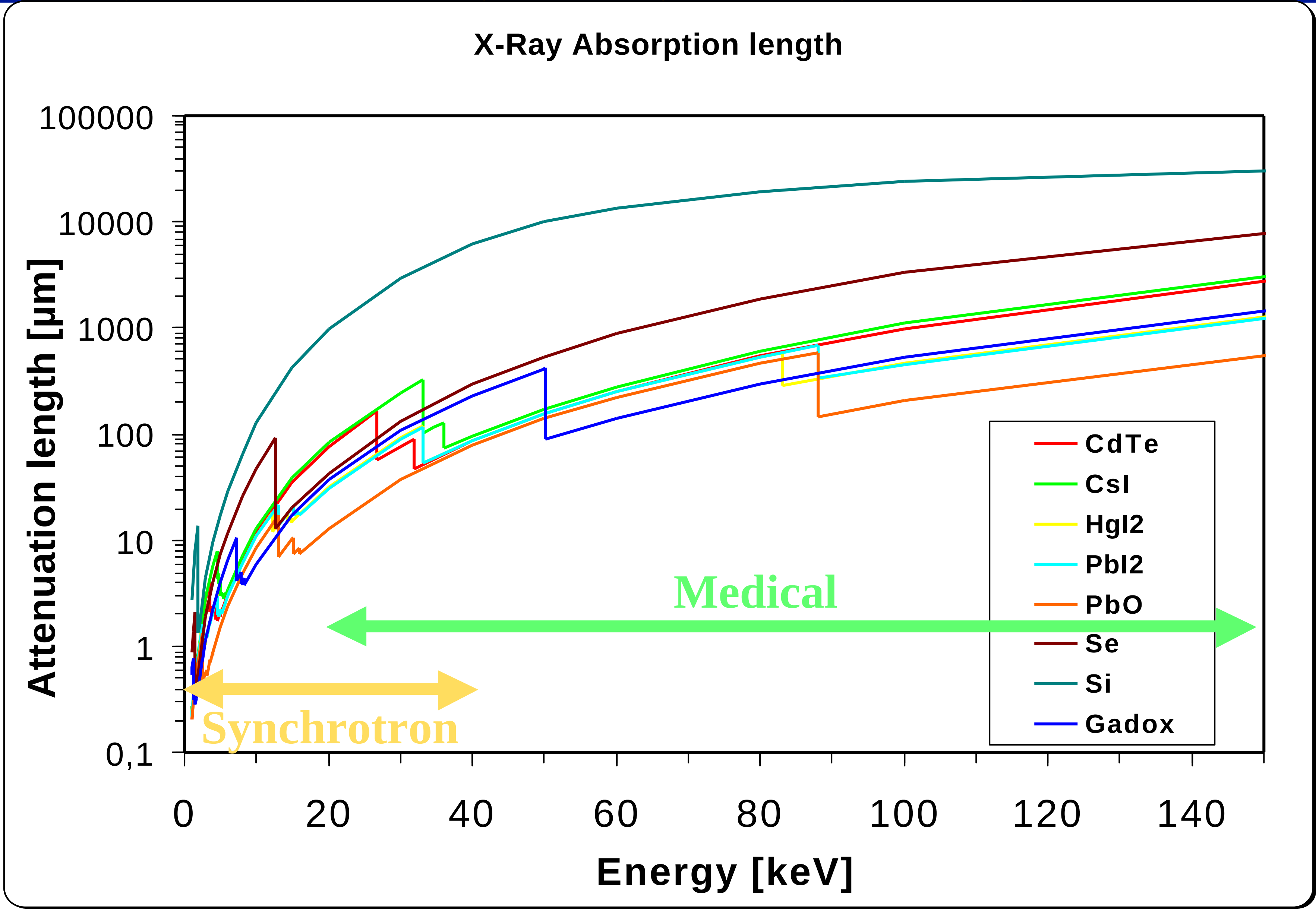


For CsI
~ 1000é /X at
60 keV



For a-Se
~ 800é /X at
60 keV

• a-Se based FPD is the only commercial available photoconductor solution
•For Direct conversion, charges carriers are driven by electrical field => good spatial resolution


X-Ray Absorption length
Attenuation length [µm]
100000
10000
1000
100
10
1
0,1
0
20
40
60
80
100
120
140
Energy [keV]
CdTe
CsI
HgI2
PbI2
PbO
Se
Si
Gadox
Medical
Synchrotron

Photoconductors vs. Scintillators (1)

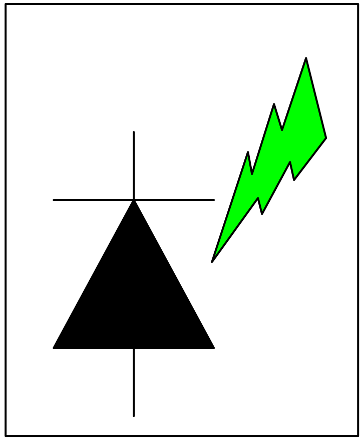
- **Resolution losses (blurring effects) common to all media:**
  - Geometrical (oblique x-rays) ➔ absorption at different depths.
  - K-fluorescent x-rays
  - Others: Lubberts, statistical fluctuations ...
- **Photoconductors:**
  - Theoretically nearly perfect MTF ... at first order
  - a-Se (only available solution) is an exception to Klein's rule (e-h pair creation energy W_{eff} ~ 3Eg); W_{eff} high > ~ 50 eV (Klein ==> ~ 7eV)
  - Recrystallization problems with a-Se
  - High voltage needed (E > 10V/µm), risk for active matrix.
  - basic condition : µτE > absorption length
  - Low Z for a-Se (34) require large thickness layers for high quantum efficiency at energies ~ 100 keV (diagnostic energies).
  - Other materials are under investigation (CdTe, HgI_2, PbI_2, PbO, TlBr, ...)
  - **No (?) Dynamic (30 Hz) product available !!**

Photoconductors vs. Scintillators (2)

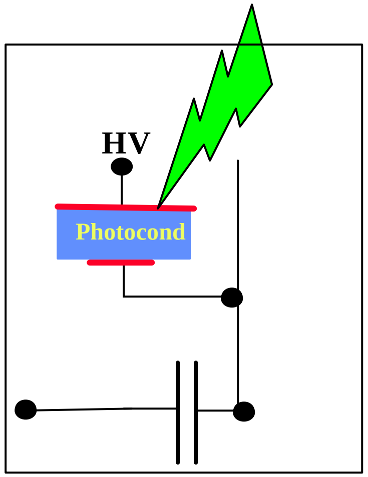
- **Scintillators:**
  - Many materials exists ($CaWO_4$, Gd_2O_2S:Tb; CsI:Na; CsI:Tl; ...),
  - Physical structure can be very different.
  - Main issue is the **balance between spatial resolution and X-ray detection efficiency**.
  - Solution = use of a structured scintillator eg. CsI (needle).
  - The type of activator impurity introduced into the layer controls the emission spectrum (CsI:Na→blue; CsI:Tl→green).
  - Problems with CsI: hydroscopic
  - **Dynamic products (^{3} 30 Hz) exists !!**

II-2 - Signal Storage

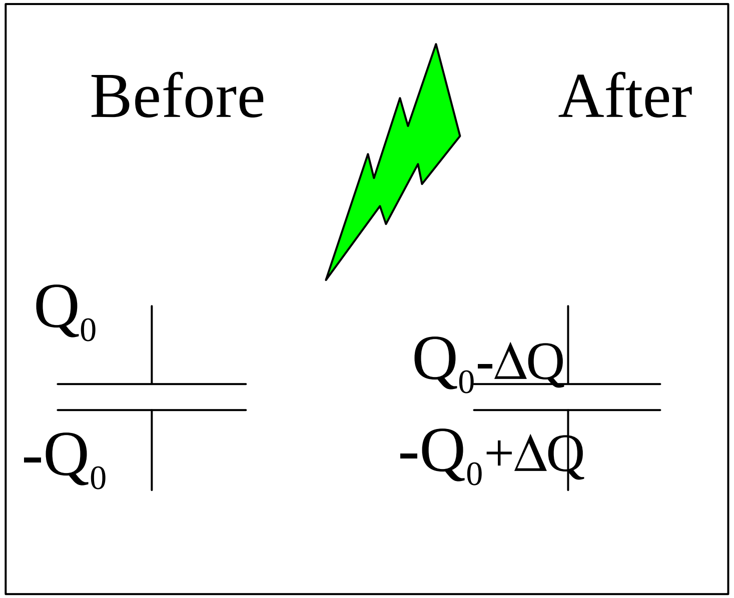
Signal (direct on indirect) generates electron-hole pairs in either photodiode or photoconductor



Indirect approach:
Storage in photodiode



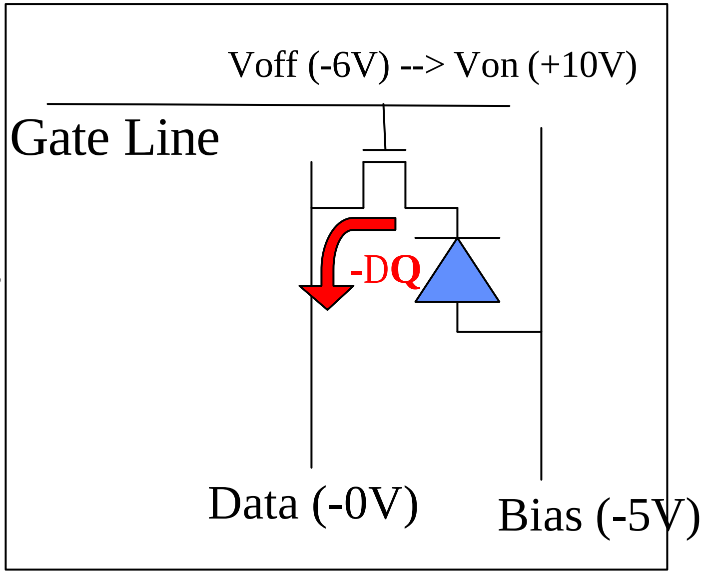
Direct approach:
Storage in capacitor



ΔQ proportionnal to incident signal

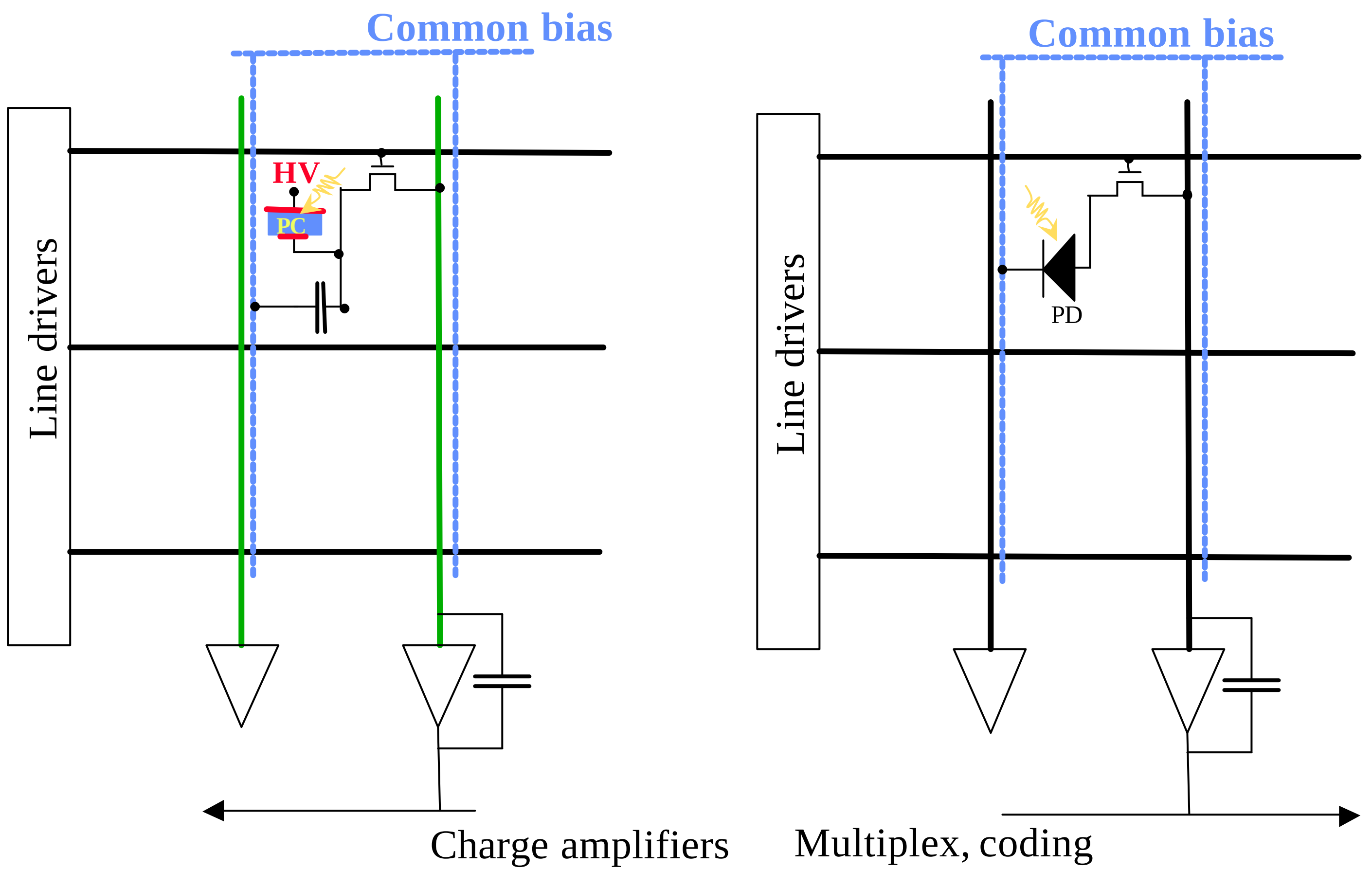
Switching element

- The charge resulting from X-ray exposure is temporarily stored until it is transferred to the readout amplifier via the data column.
- Transfer is performed by a switch
- This switch is activated by an appropriate control pulse.
- Two concepts have been implemented:
  - **a. Switching Diodes.**
  - **b. TFT.**



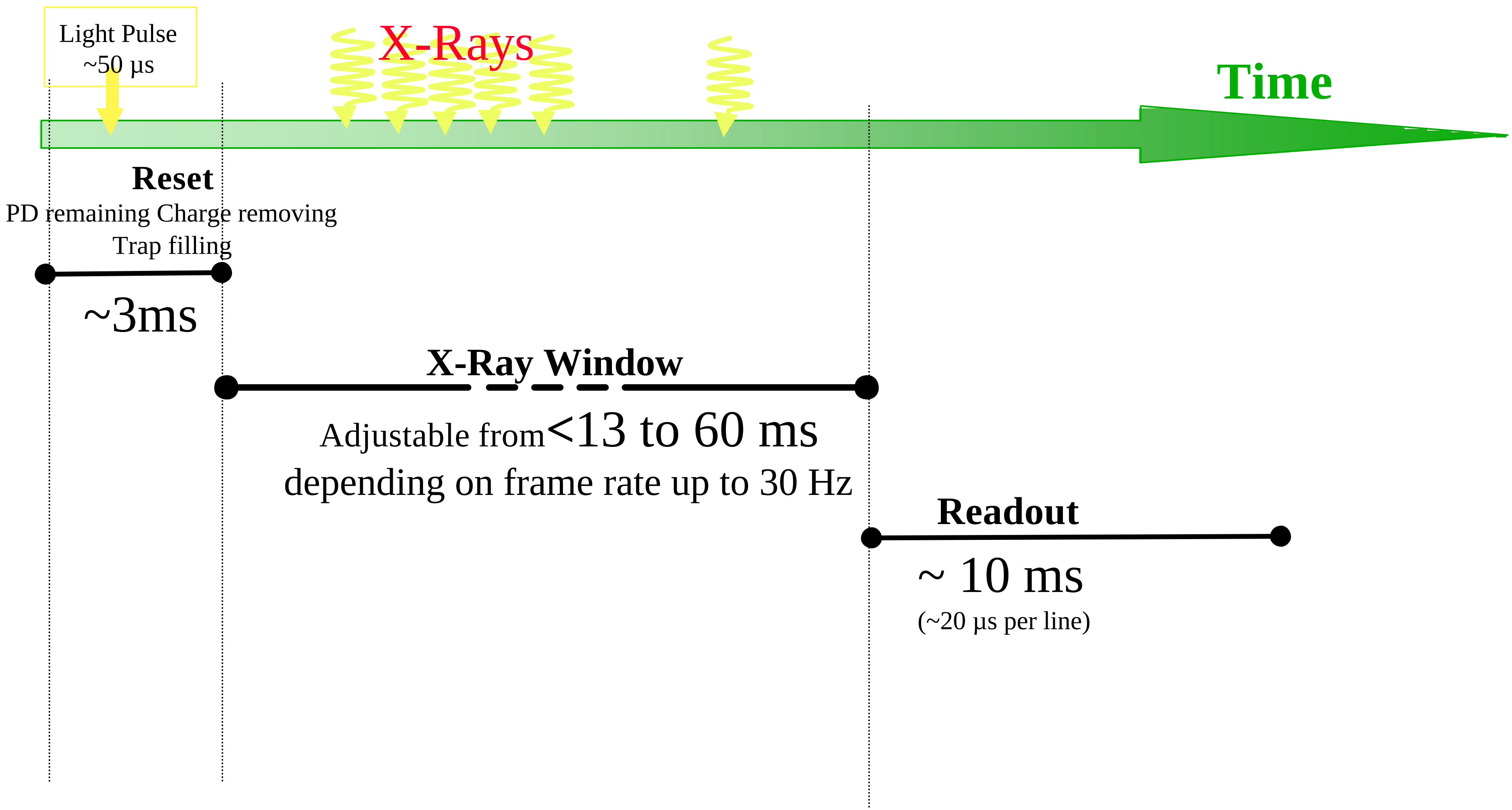
- Properties of the switch:
  - more than 1000 switches in parallel on a data column,
  - Large dynamic range => $R_{off} / R_{on} > 10^6$.
  - $R_{on}.C_{pixel}$ < readout time
  - negligible noise

II-3 - a-Si Matrix &Readout architecture

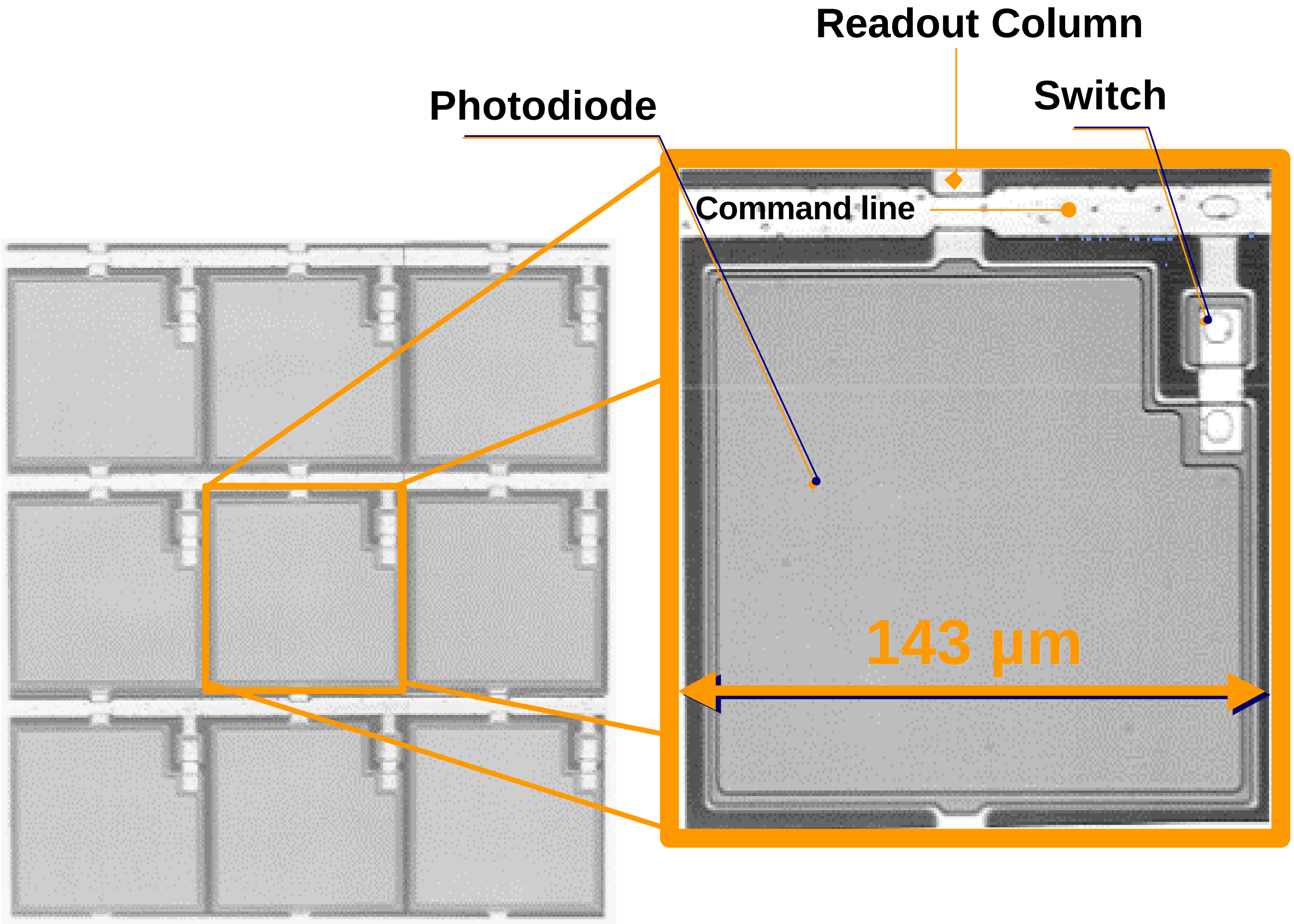


photoconductor scintillator / Photodiode

Dynamic Imager operation

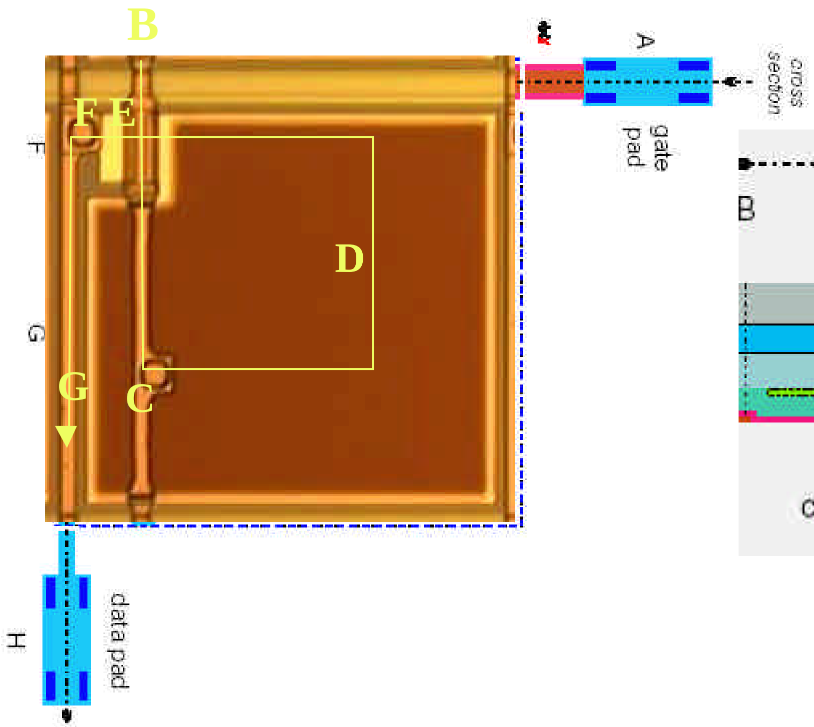


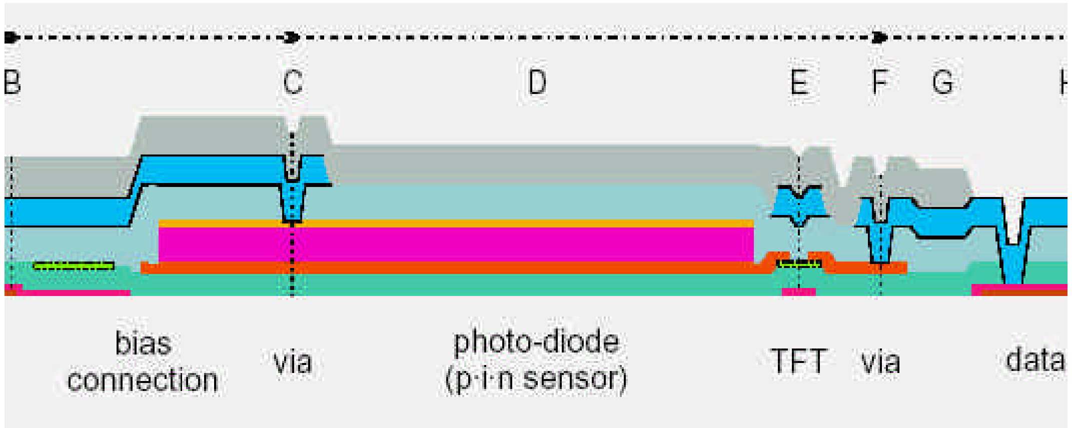
II-4 - a-Si matrix (Double diode)



Example of TFT a-Si Matrix Structure

- TFT switch + Photodiode



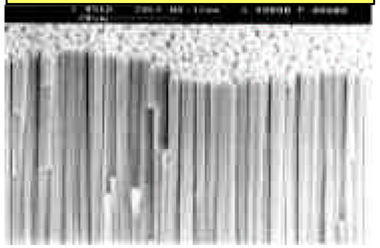


Top view

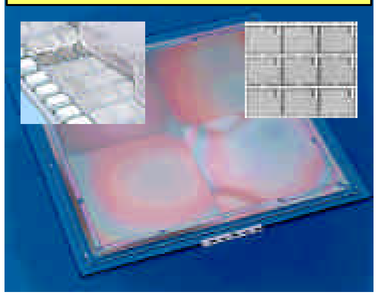
Cross section (not to scale)

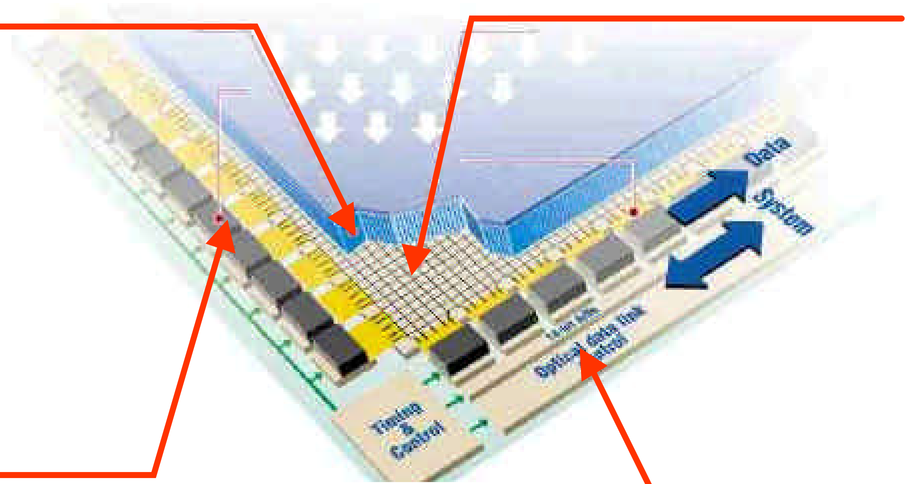
Technology

Scintillator

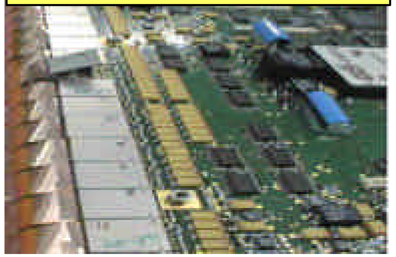


Pixel Matrix

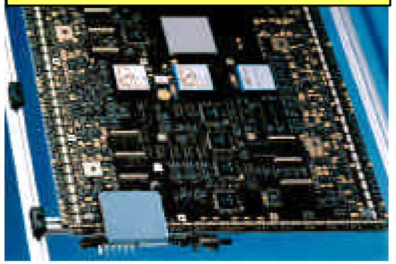




Electronic modules

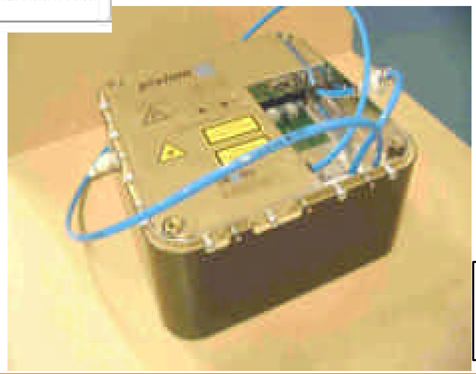


Electronic board



pixium

4600



4800

TRIXELL Products		Pixium 4600	Pixium 4800	Pixium 4700
Application		Graphy	Cardiology	Scopy/graphy
Image Geometry				**in Development**
Pixel Pitch [µm]		143	184	155
X-ray sensitive array [mm x mm]		H426,3 x V432,0	176,6x176,6	~ 420 x340
Image size [pixels]		H2981 x V3021	960 x 960	~2300 x 1900
Operation Mode				
A/D conversion dynamic range [bits]		14	14	14
Frame Rate [Hz]		n.a.	30 (max.)	30
Time between images [ms]		> 5000	> 33	> 33
X-ray window duration [ms]		1 to 3200	13 to 60	4,5 to 5000
Image readout Time [ms]		1250	< 10	< 10 to 150
Characteristics				
X-ray generator voltage range [kV]		40-150	40-125	40-125
Noise equivalent dose		0,3 µGy	1,3 nGy/fr	
System dose		0,5 to 5 µGy	430 nGy/fr	7nGy/fr to 100nGy/fr
Maximum linear dose		60 µGy	4,3 µGy/fr	24 µGy/fr
Differential non linearity (0 to Dmax)		< +/- 3%	< +/- 2%	
MTF @ 1lp/mm [%]		60	65	
MTF @ 2lp/mm [%]	DN5	35	32	30
DQE @ 0,1lp/mm [%]	2,5 & 1 µGy	55	65	70
DQE @ 1lp/mm [%]	2,5 & 1 µGy	40	58	
DQE @ 2lp/mm [%]	2,5 & 1 µGy	25	40	
Residual Signal (lag & memory effect) after X-Ray off				
@1rst frame : @ 30fr/s [%]		n.a.	< 3%	
@ 1s		n.a.	< 1%	
@ 10s		< 0,2%	< 0,2%	
@ 60s		< 0,02%	n.a.	
PC Acquisition Card		PCI 32 bits 33 MHz	PCI 64 bits 66 MHz	

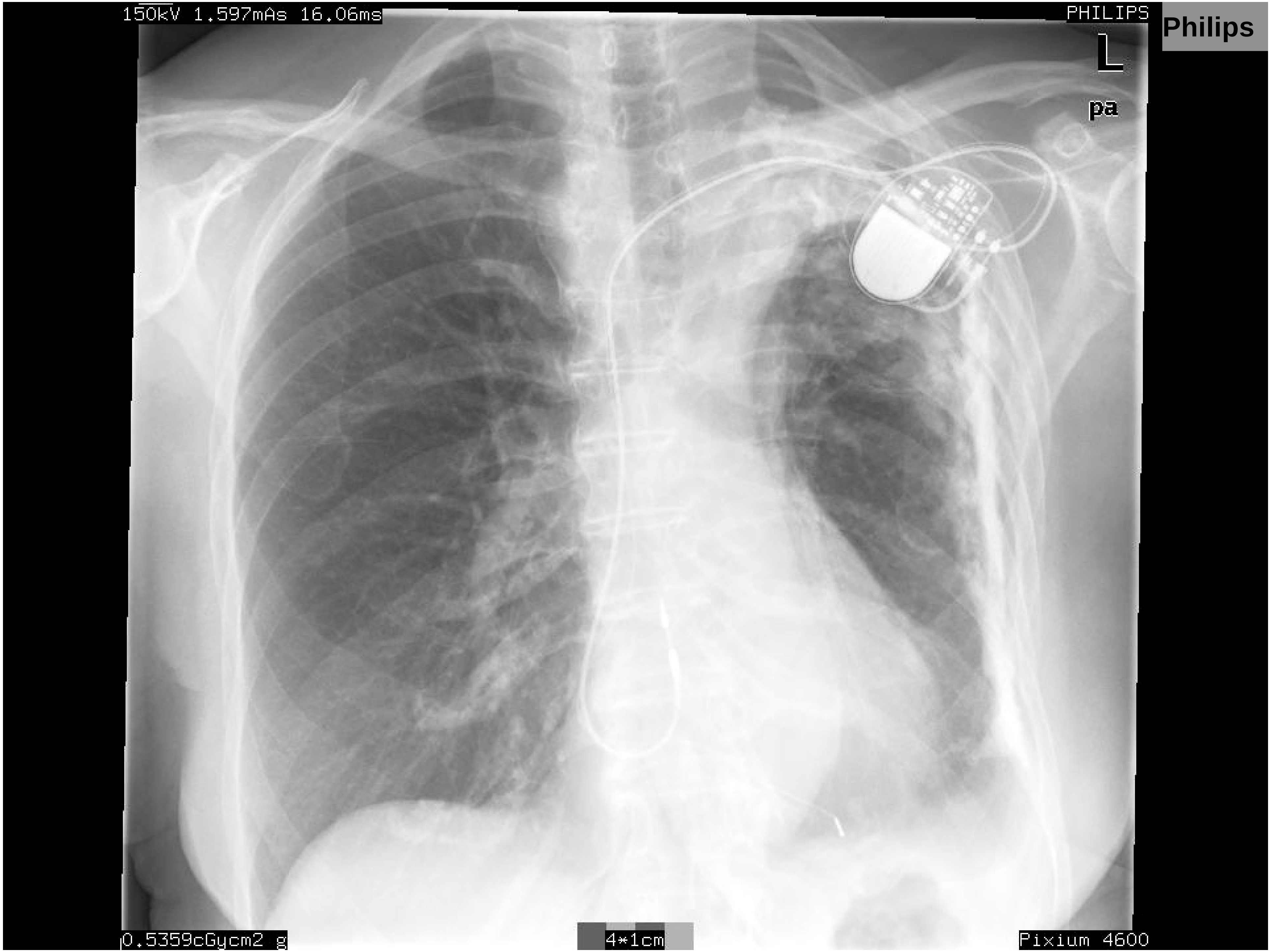
Limitations for a-Si based FPD

- Conversion layer Absorption (a-Se, Gd_2O_2S ...).
- Fill factor (indirect approach only ?), shrinking of pixel size difficult.
- Residual signal
  - Incomplete readout (RC constant of the switching TFT)
  - Release of trapped charge from photodiode (or photoconductor), "memory effect". (solution = light pulse to fill traps in PD (Nt # 5.10^{15} cm^{-3}) } **Dominant**
  - scintillator "after glow"
- Leakage current (photodiode (~fA) or photoconductor), ==> small reduction of dynamic range with time
- Defects (pixels, gain differences ...)
- Electronic noise associated to line capacitance and resistance
- Integration of "pixel electronics" limited.

CsI:Tl/a-Si is the good compromise now (medical)

- Technical reasons:
  - X-ray absorption, conversion efficiency, needle structure
  - a-Si sensitivity well matched to CsI emission,
  - a-Si double diode or photodiode/TFT with appropriate performance available.
- Industrial Reasons:
  - Long experience of CsI deposition
  - Mastering the technology has been achieved
  - Costs of the existing products will decrease in the future.
- Performance
  - Good in radiography, and in cardio-vascular (fluoroscopy).


46kV 3.948mAs 16.27ms
Philips
0.2128cGycm2 g
4*1cm
Pixium 4600


150kV 1.597mAs 16.06ms
PHILIPS
Philips
L
pa
0.5359cGycm2 g
4*1cm
Pixium 4600