Image Quality of Flat Detector Systems

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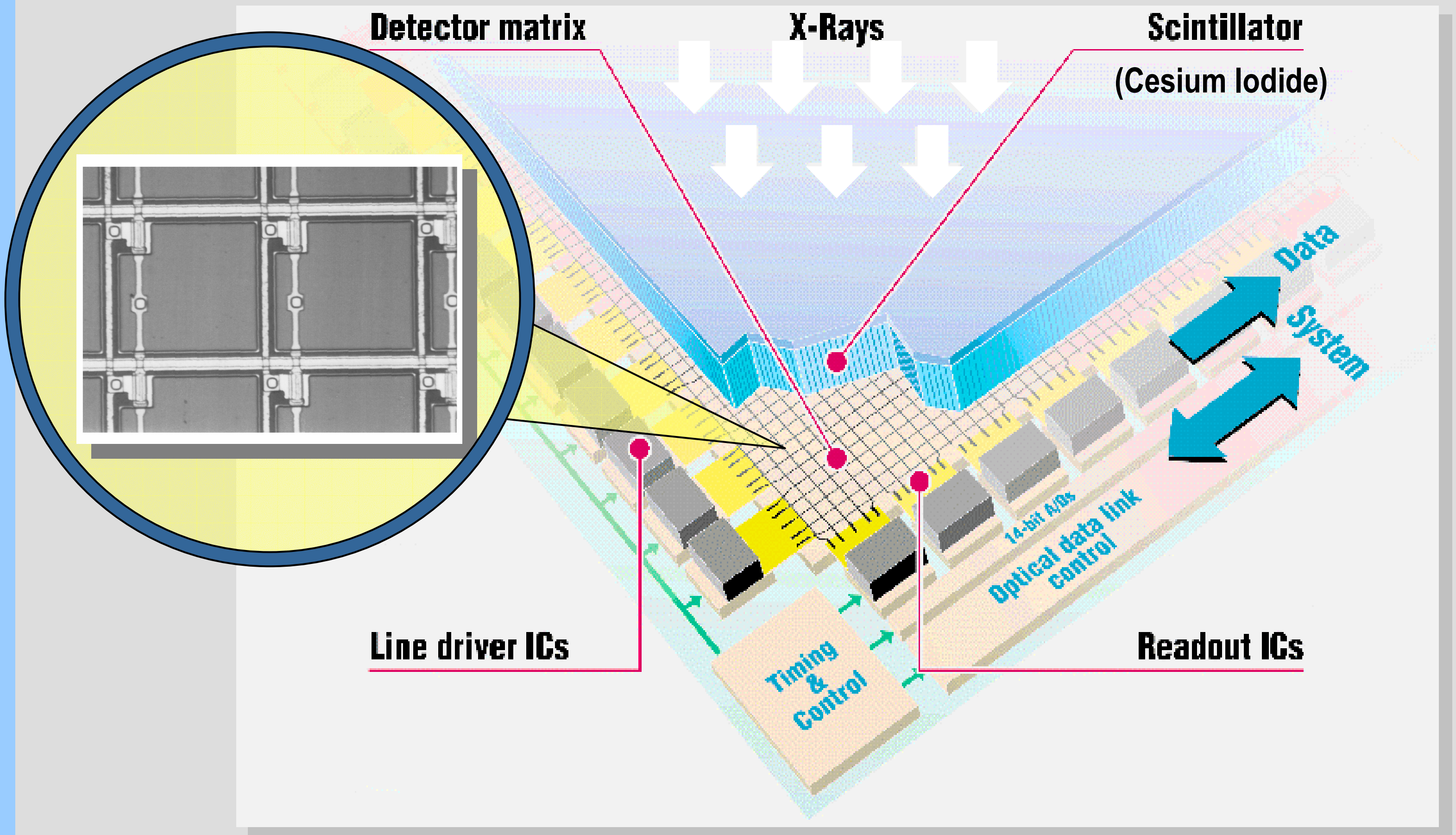
Agenda

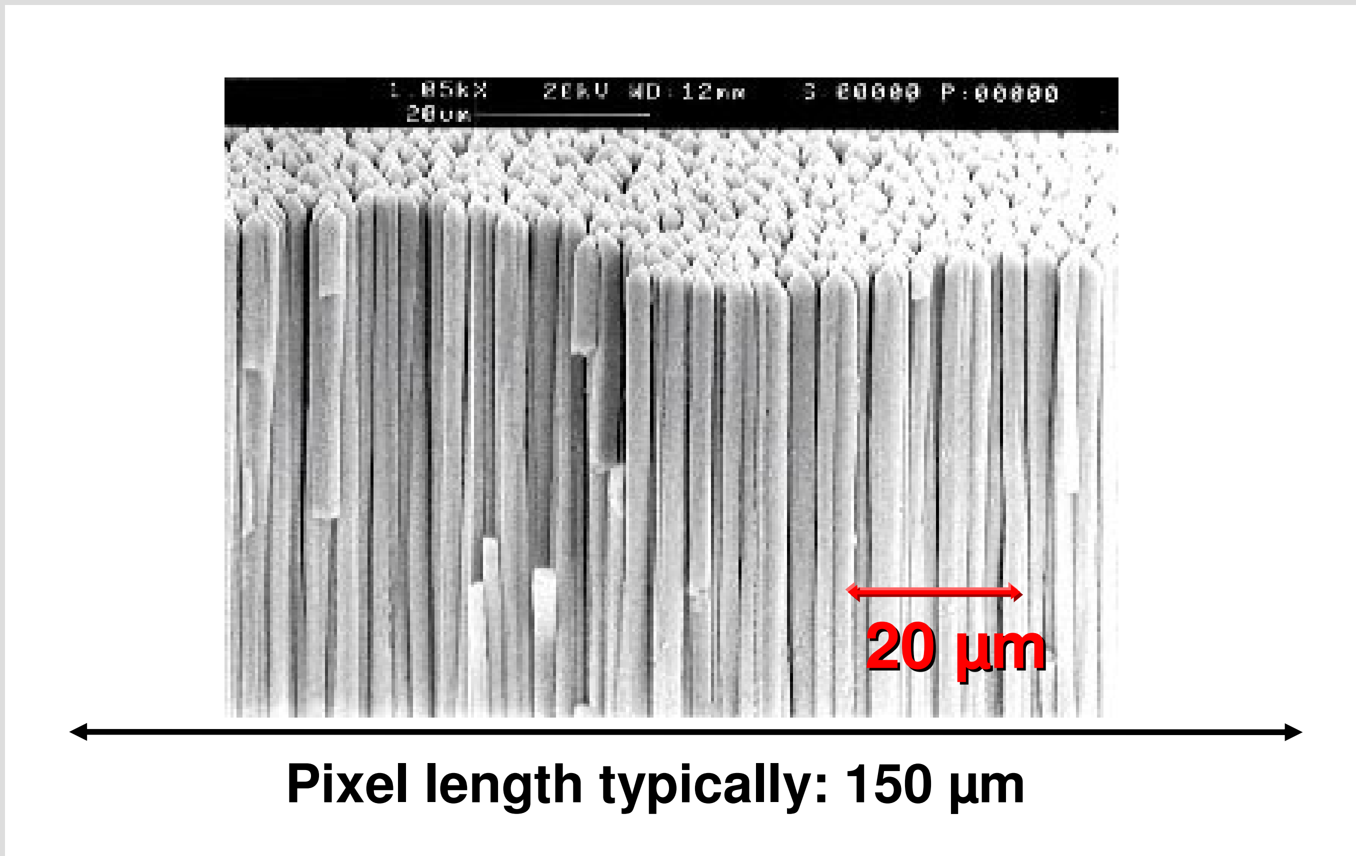
- Technical principles (FD)
- Performance characteristics (FD)
- Image processing
- Image quality control
- Applications in real-time imaging

Flat detector technology is based on CsI and an active pixel matrix of amorphous silicon



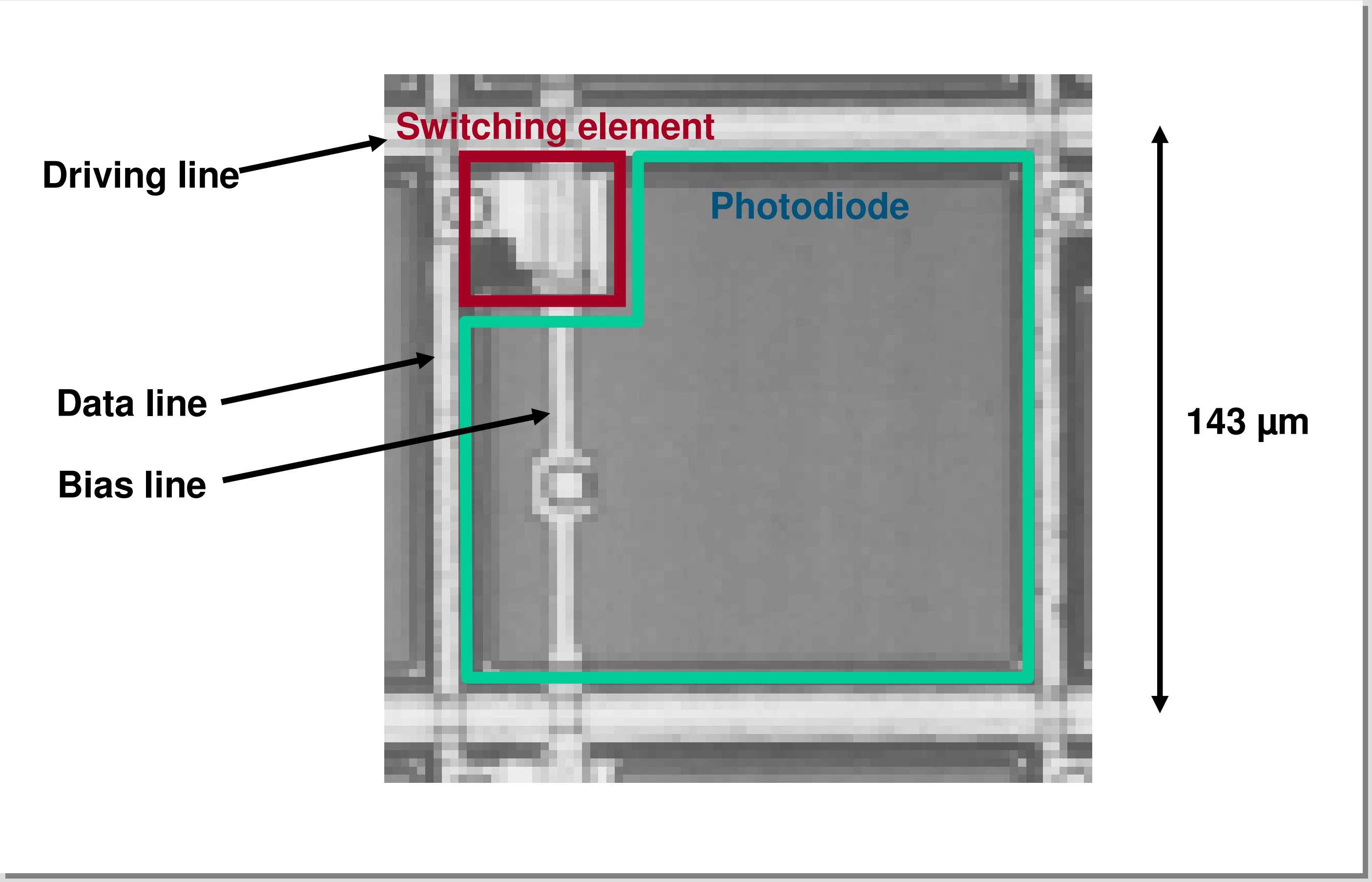
Source: Trixell

The high absorption of CsI and the needle structure are necessary for a high quantum efficiency (DQE)



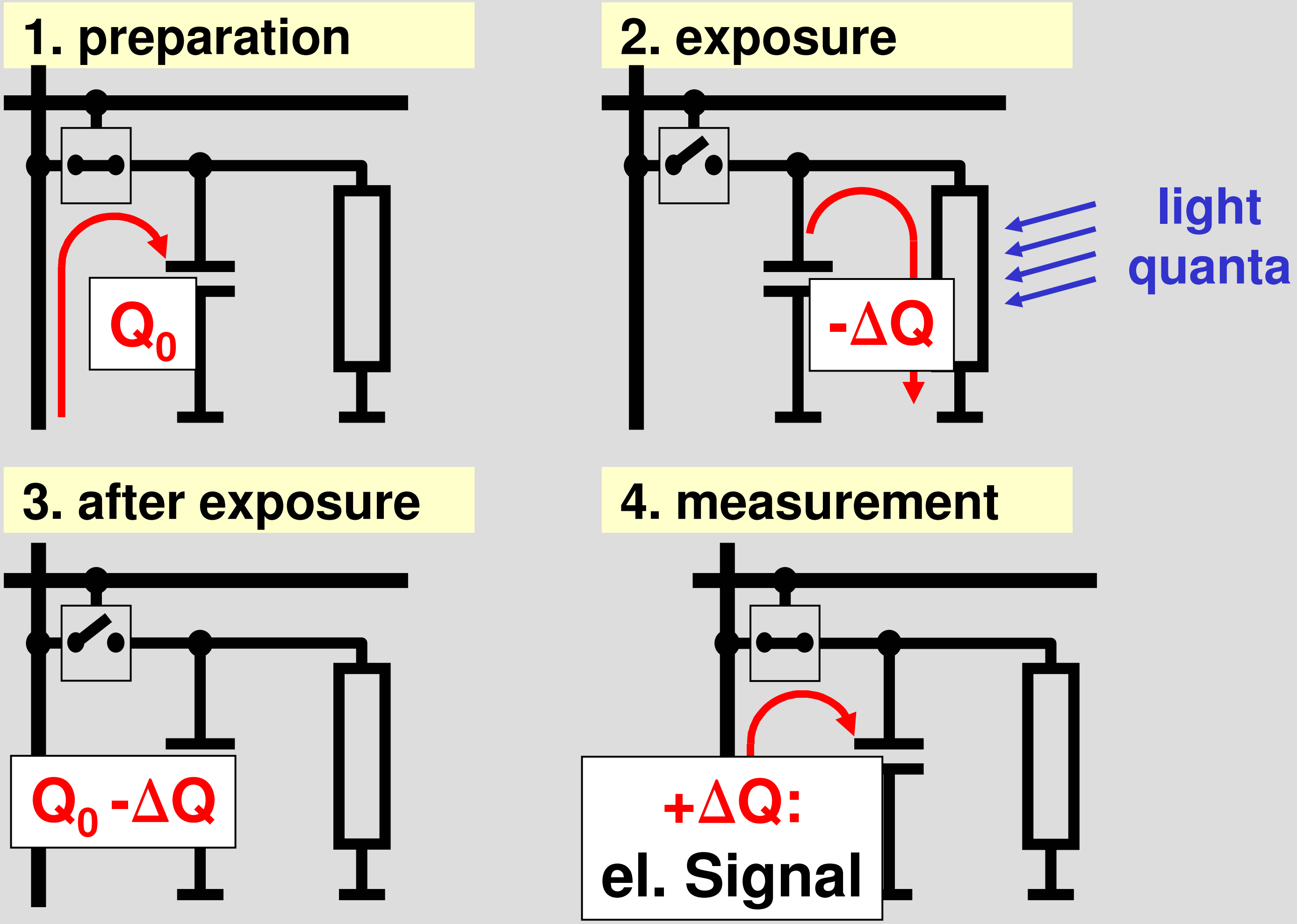
Source: Trixell

The individual pixel element is optimized for high photon detection efficiency



Source: dpiX, Trixell

The photodiode of the active pixel matrix translates light into electrical charge



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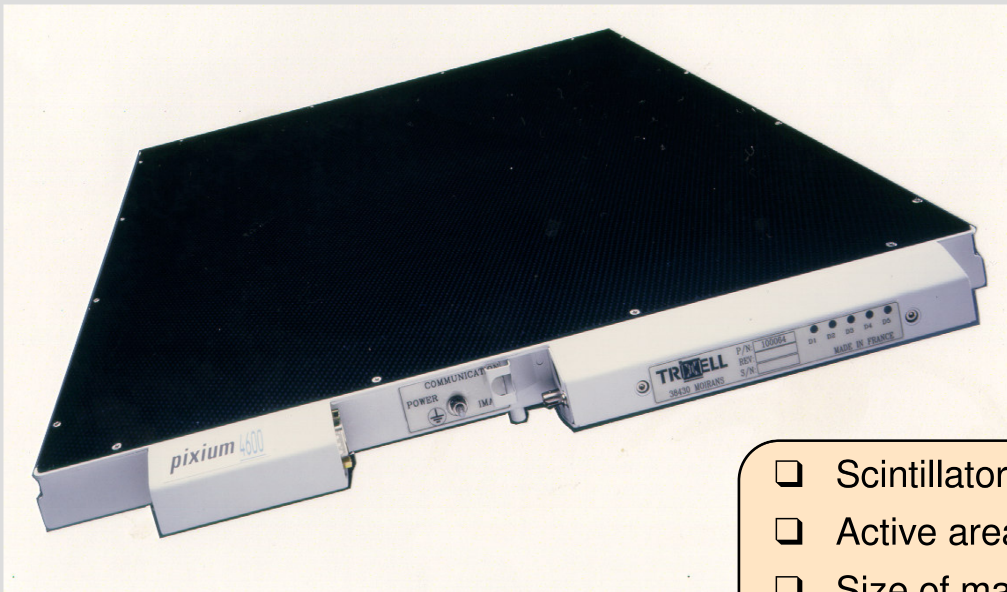
The Pixium 4600 is a flat detector optimized for radiographic applications

Image of the Pixium 4600 and key parameters

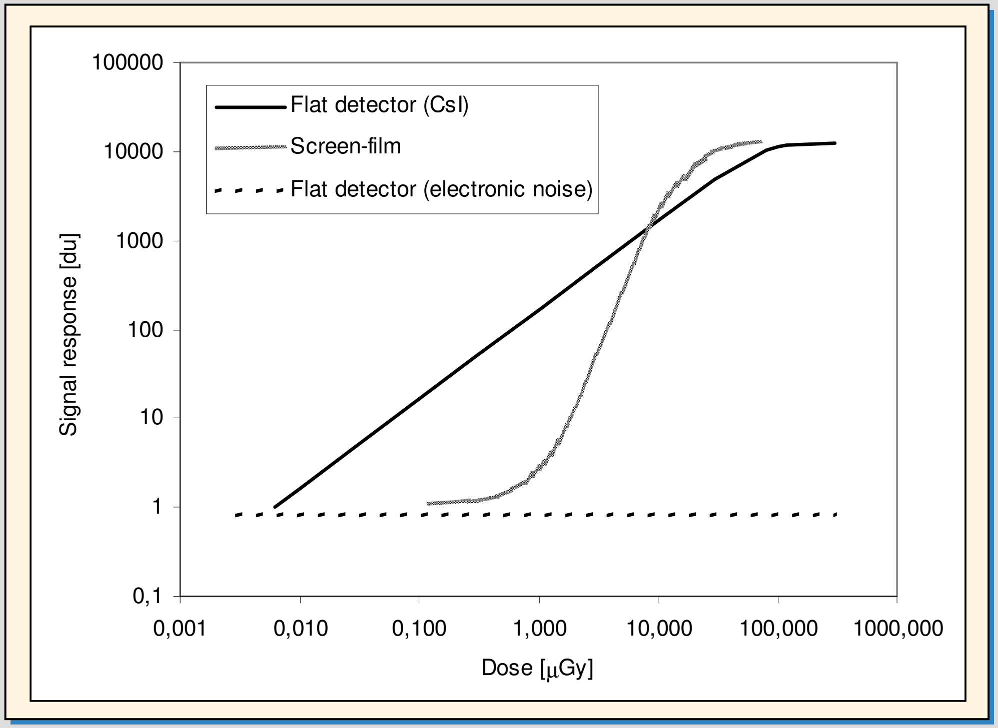


- Scintillator: CsI (600 µm)
- Active area: 43 x 43 cm^2
- Size of matrix: 3k x 3k
- Pixel size: 143 µm
  (Nyquist frequency: 3.5 lp/mm)
- Analog to digital converter: 14 bit
- Readout time: 1.2 s
- No cooling

Source: AX, Trixell

Flat detectors have a large dynamic range

Dynamic range: Comparison of dynamic range of Pixium 4600 and screen film system

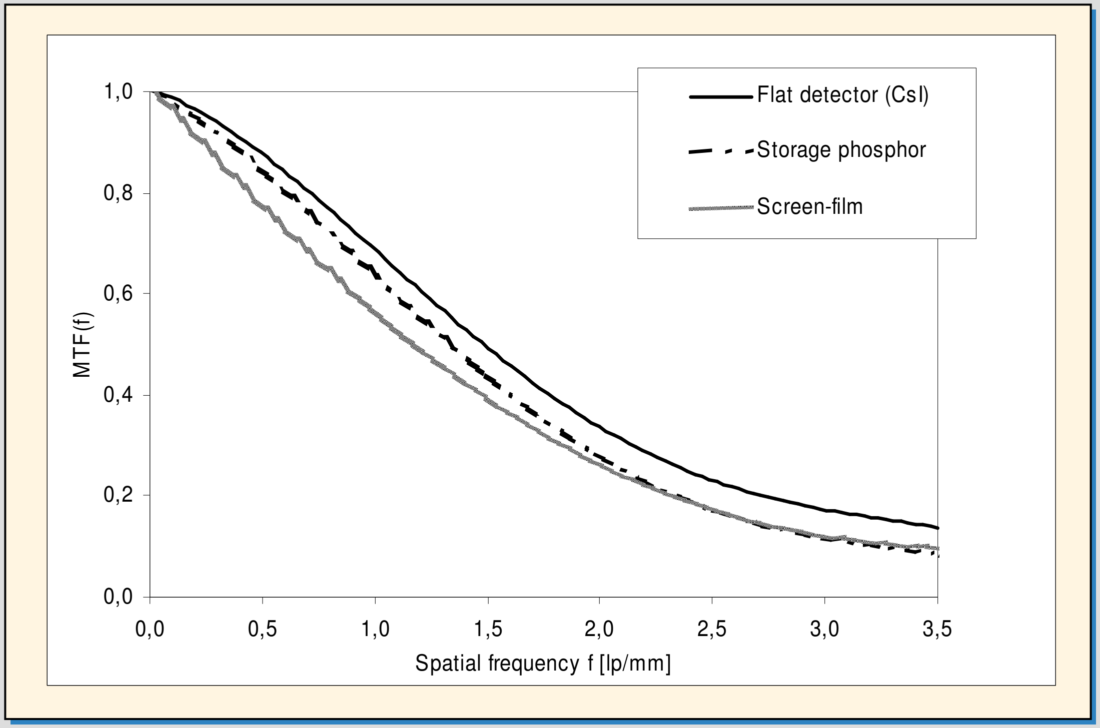


Spahn et al. “Digital radiography with a large-area, amorphous-silicon, flat-panel X-ray detector. Invest Radiol 35 (2002) 260

The large dynamic range allows a wide range of doses (speeds 200 - 800) and reduces the need for retakes

Flat detectors exhibit high MTF values

MTF: Comparision of MTF measurements of different X-ray detectors

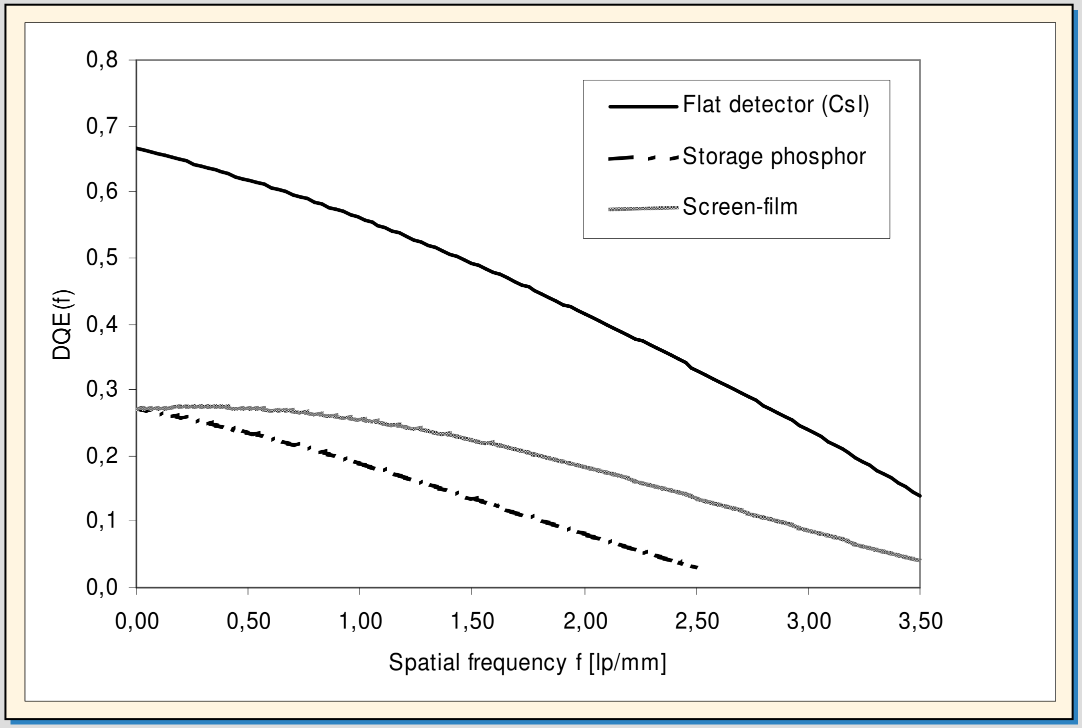


Spahn et al. "Digital radiography with a large-area, amorphous-silicon, flat-panel X-ray detector. Invest Radiol 35 (2002) 260
Dobbins et al. "DQE(f) of four generations of computed radiography acquisition devices. Med Phys 22 (1995) 1581
Van Metter et al. "Objective performance characteristics of a new asymmetric screen-film system. Med Phys 21 (1994) 1483

The built-in low pass filter of CsI-based flat detectors help to reduce aliasing effects and the back-folding of noise from beyond the Nyquist frequency limit

Flat detectors reach DQE values well above screen film or storage phosphor systems

DQE: Comparision of DQE measurements of different X-ray detectors



M. Spahn et. Al, “Flachbilddetektoren in der Röntgendagnostik”, Radiologe 43 (2003) 340-350

Superior DQE of flat detectors based on CsI/a-Si provides dose reduction potential w.r.t. conventional techniques

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Image processing is automatically pre-selected with the choice of the organ program

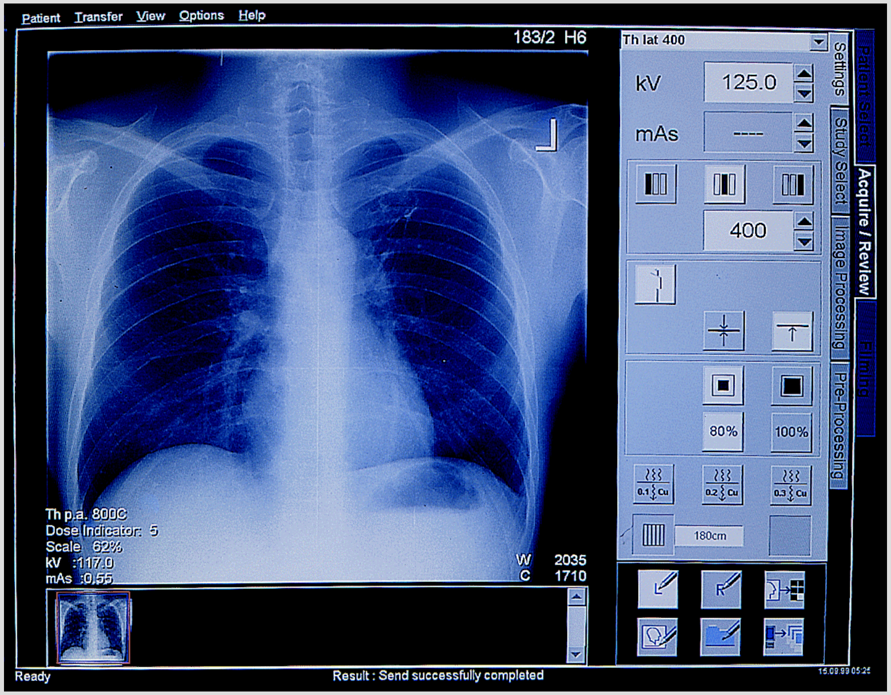
Image processing for general radiography

Image pre-processing

- Offset and gain corrections (flat fielding)

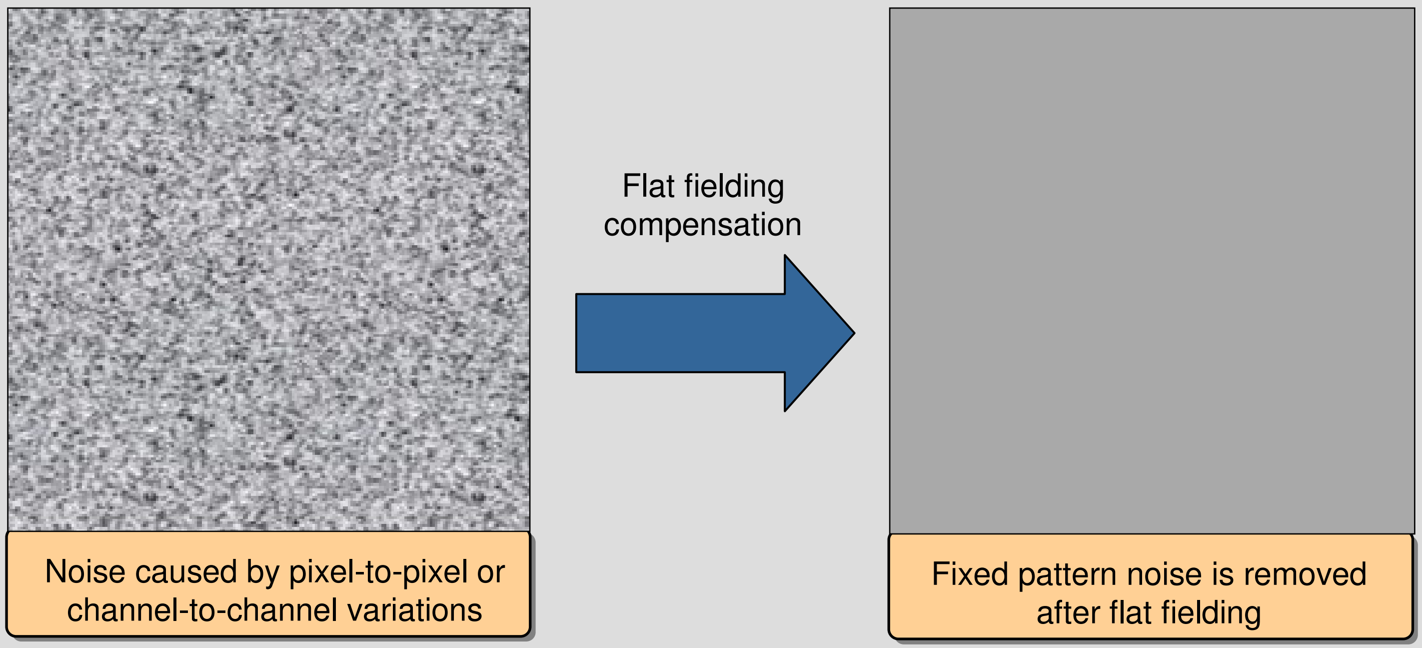
Image post-processing

- Look-up-tables
- Frequency filter methods (edge enhancement, harmonization, advanced methods)
- Automatic shutter recognition
- Automatic window and level
- Rotation and flip
- Automatic calculation of exposure index (EXI)



The processed image is displayed on the monitor within a few seconds

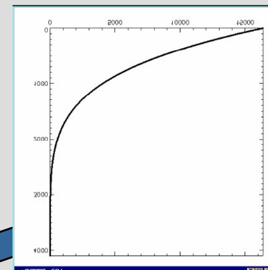
Example 1: Flat fielding reduces fixed pattern noise



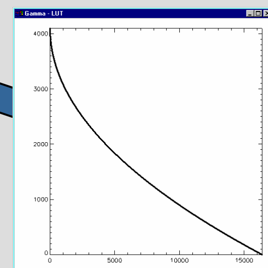
In addition, variations from the x-ray field due to geometry are compensated

Example 2: Various Look-up-tables are available for optimized image processing

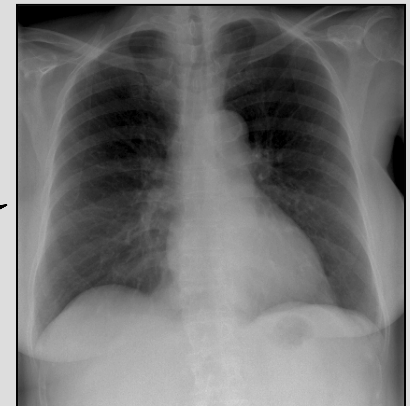
Original 14-bit image



LUT 1



LUT 2



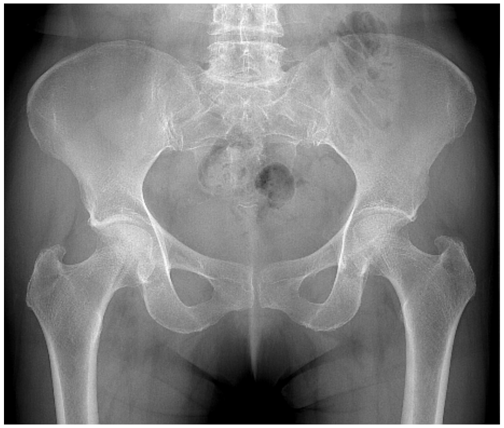
12-bit image: LUT 1

12-bit image: LUT 2

The FD systems allow to reprocess images with different parameter settings

Example 3: Filter techniques allow to enhance the sharpness or reduce the noise within images

Enhancement of sharpness



Reduction of noise

Example 4: Advanced image processing methods apply a variety of intelligent filter operations (1/3)

Signal adaptive spatial filtering

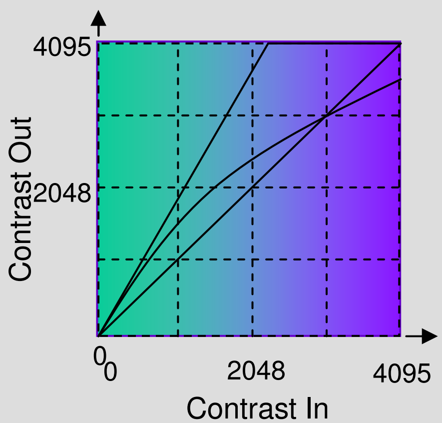
- Amplify signals in regions of low contrast
- Reduce signals in regions of high contrast

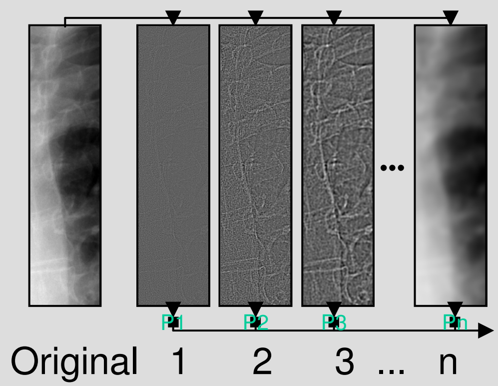
Image decomposition w.r.t. structure size

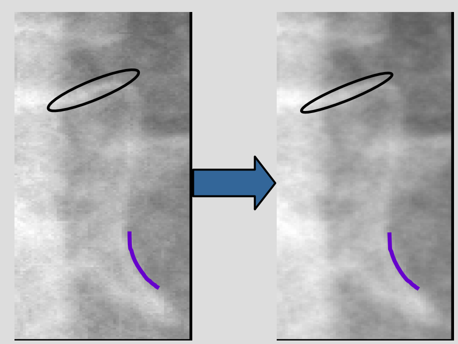
- Decompose the image into n layers of different structures size
- Perform a weighted reconstruction

Direction sensitive noise reduction

- The direction of images structures is detected and noise reduction done accordingly

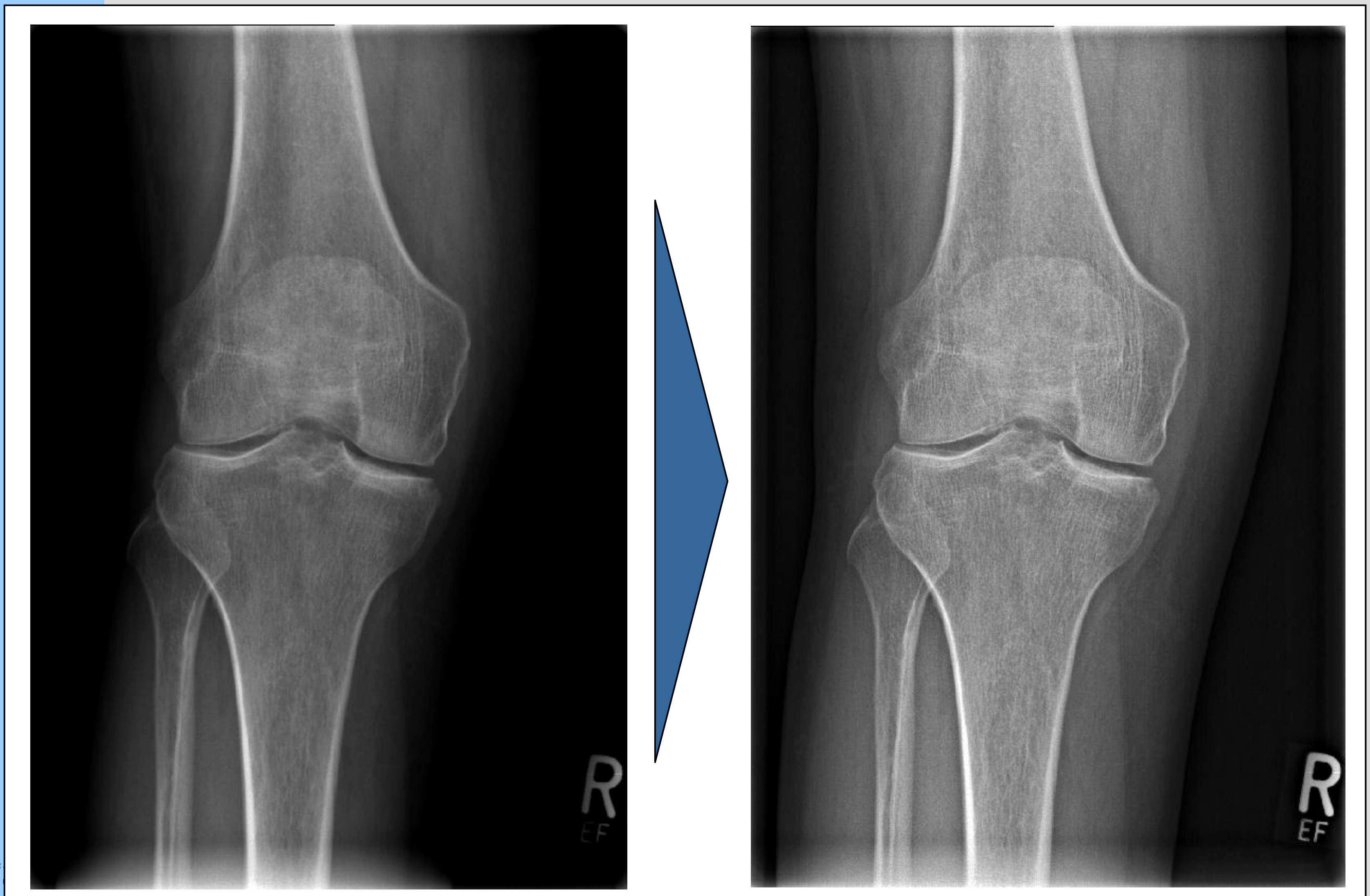




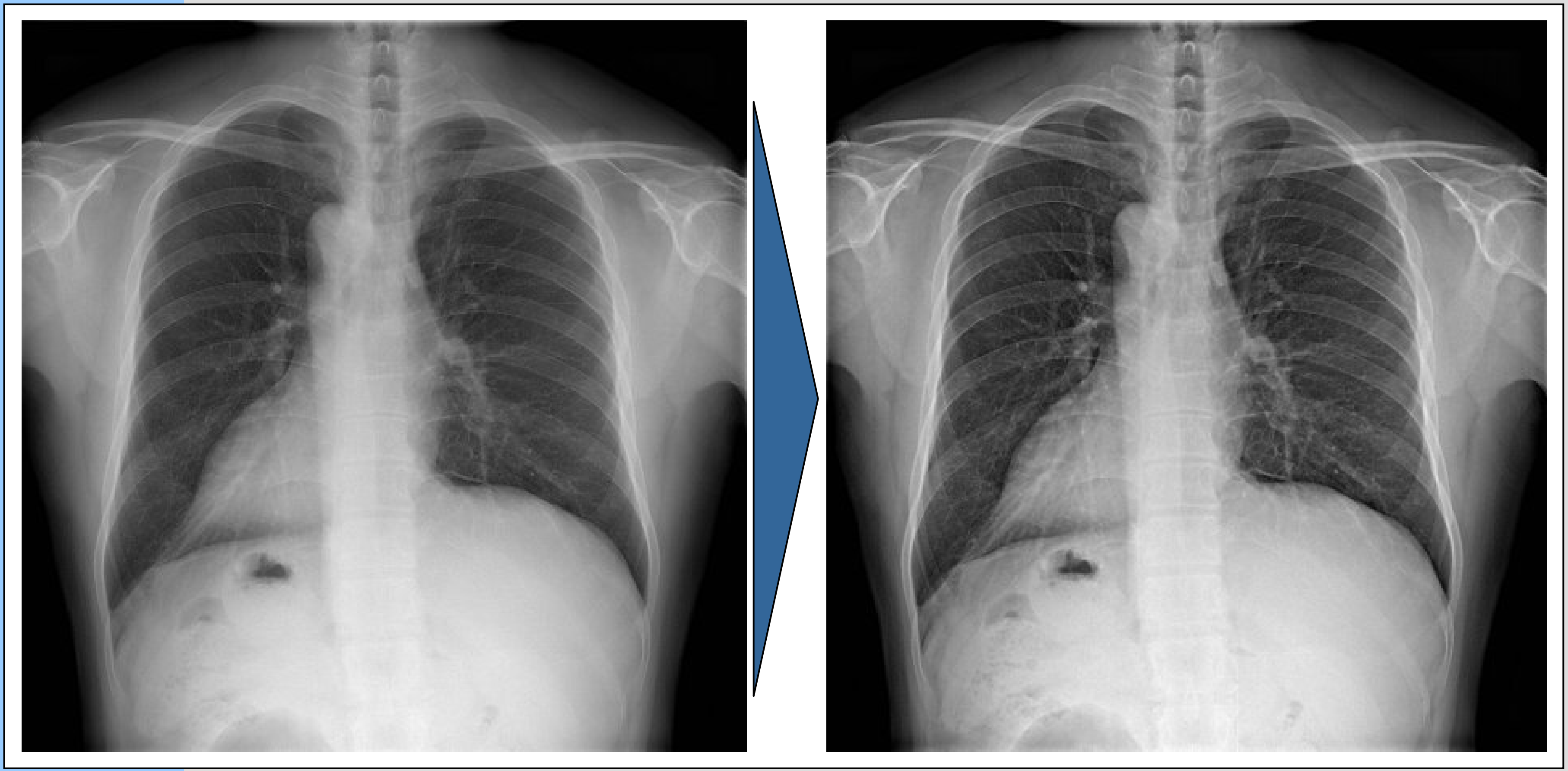


Advanced image processing

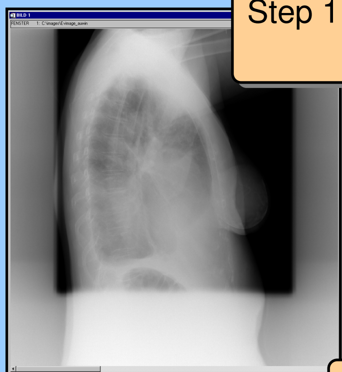
Example 4: Advanced image processing methods apply a variety of intelligent filter operations (2/3)



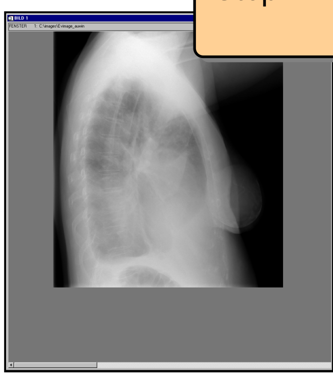
Example 4: Advanced image processing methods apply a variety of intelligent filter operations (3/3)



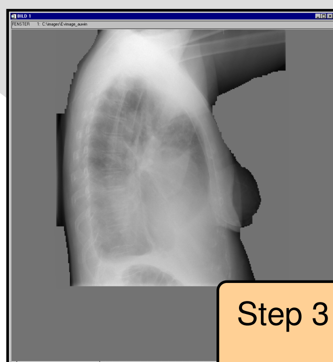
Example 5: Automatic windowing via detection of the collimators and the directly exposed areas



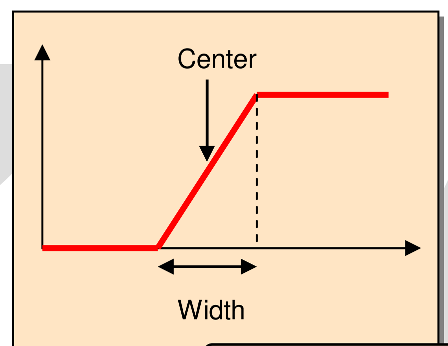
Step 1: image after applying the look-up-table



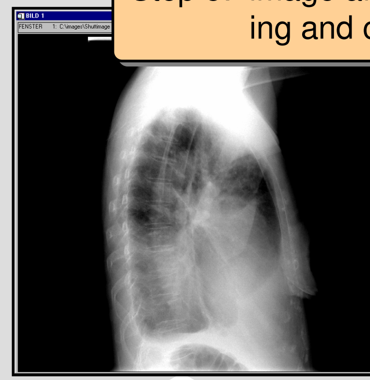
Step 2: detection of collimator area



Step 3: detection of directly exposed area



Step 4: calculation of center and width



Step 5: image after windowing and cropping

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- **Image quality control**
- Applications in real-time imaging

System setup includes sensitivity, image receptor dose adjustments and acceptance tests

Main steps to ensure system setup and quality control

Automatic exposure control (AEC)

- Adjusted at a well defined and reproducible beam quality (70 kVp, precision filter of 2.1 mm Cu)
- True dose adjustment, i.e. S400 corresponds to 2.5 µGy image receptor dose
- kV response set to constant detector output signal for full kVp range (kV-independent conditions for image processing)
- User interface provides a “sensitivity class” (e.g. S400) which compares easily to former screen-film systems

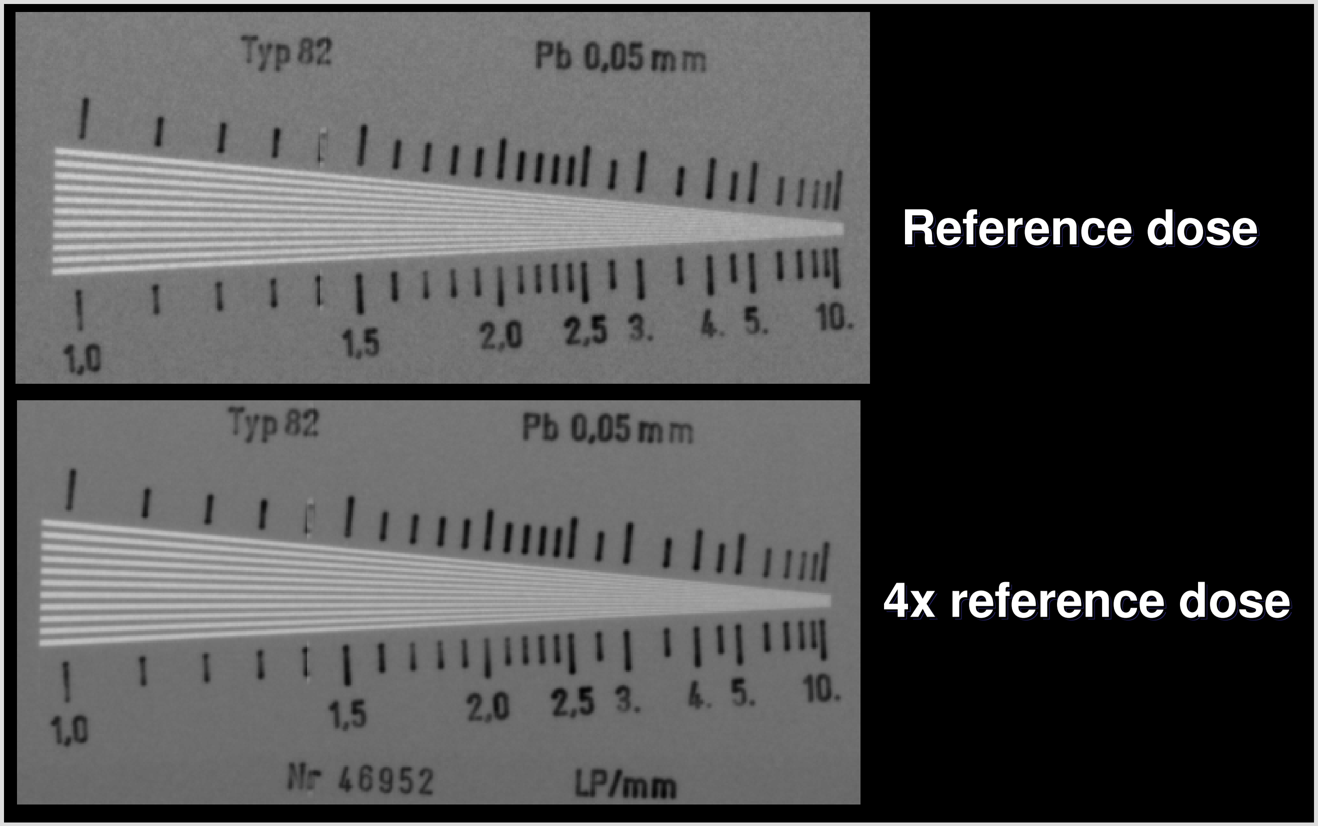
Acceptance and quality control (QC) tests

- Flat fielding calibration on regular basis
- Flat field test
- Dynamic range test (Cu step wedge)
- Spatial resolution test
- Low contrast resolution test
- Exposure index (EXI)

Reviewed on following slides

The visual resolution limit is tested at different dose levels

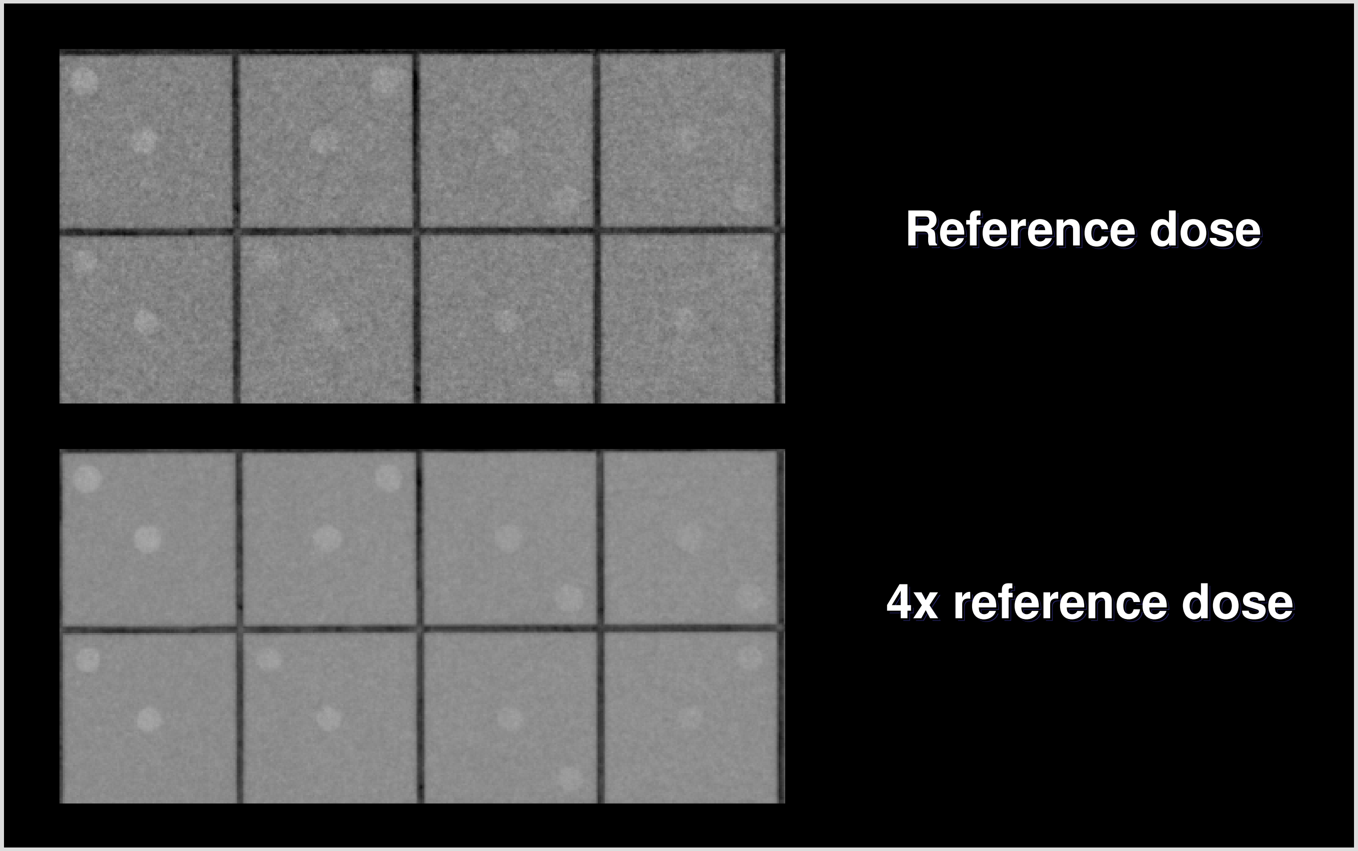
Limiting resolution test using a lead bar pattern



The limiting resolution does not depend on dose – as expected

The low contrast resolution is tested using a detail contrast phantom at different dose levels

Low contrast resolution test using the CDRAD test phantom



Significant visibility difference – as expected

The calculation of the exposure index (EXI) helps to track the consistency of system settings

Concept of exposure index

What does the EXI provide?

- A linear relationship to the image receptor dose
- A dose indicator depending on the specific organ

How does EXI work?

- The mean value within one or more ROIs within the image area is caluculated

Which conditions influence EXI?

- The center mean value depends on the organ
- Geometry, collimation, beam quality (kVp, filtration) influence the EXI

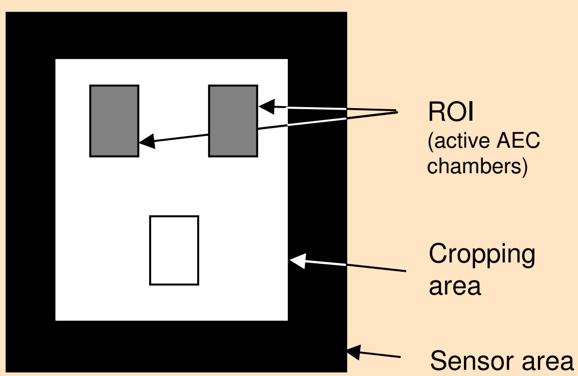
Application of the EXI

- A twofold EXI value means a twofold receptor dose (comparable conditions)
- The EXI is a valuable parameter checked in quality assurance e.g. periodic constancy testing

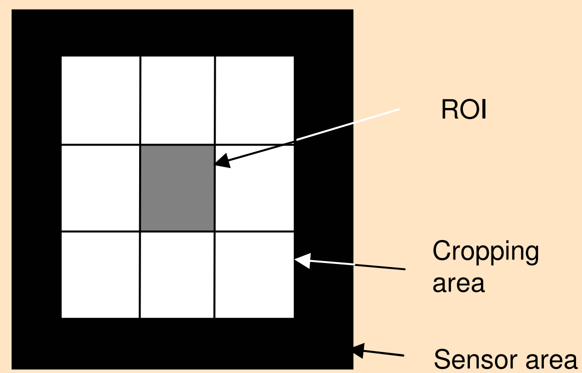
There are 2 alternatives to determine the EXI

Concept of exposure index calculation

Fully integrated system provides positions of active AEC elements:



Fully integrated system provides positions of active AEC elements:

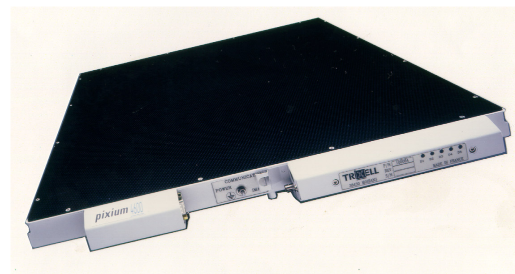


Determine mean value on pre-processed 14-bit data

AXIOM Aristos FX is a fully integrated radiography system using motorized positioning of the detector

Flat Detector for Radiography

Area:	43 x 43 cm^2
Pixel size:	143 x 143 μm^2
Matrix size:	3k x 3k
Analog to digital conversion:	14 bit



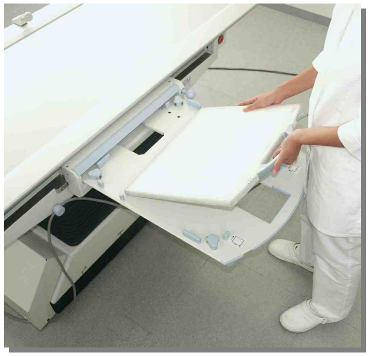
AXIOM Aristos FX

- Automatic positioning via organ program
- New applications:
  - Lateral and oblique exposures
  - Trauma applications
  - Imaging of immobile patients

Organ programs automatically provide sensitivity class and AEC positions for EXI calculation

To provide a flexible entry into the digital world a portable detector is used for the AXIOM Multix M

Portable Detector for Radiography	
Area:	35 x 43 cm^2
Pixel size:	160 x 160 μm^2
Nyquist frequency:	3.1 lp/mm
Analog to digital conversion:	14 bit



EXI is calculated automatically from cropped sub-image

The calculation of an exposure index (EXI) provides a simple way to check consistencies

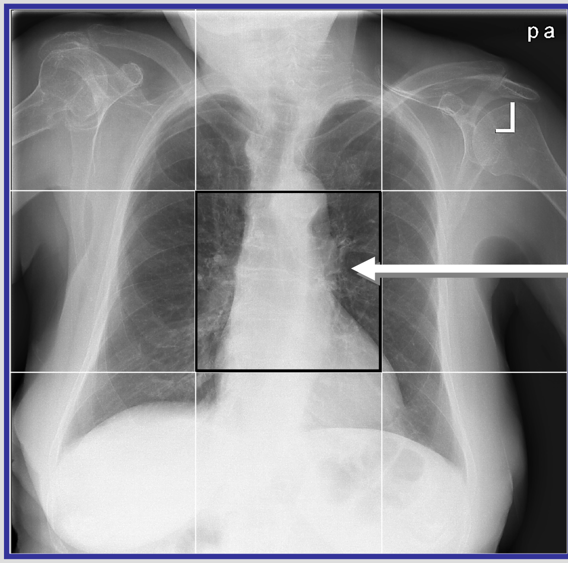
Examples of exposure index calculation

Example 1: Thorax p.a.

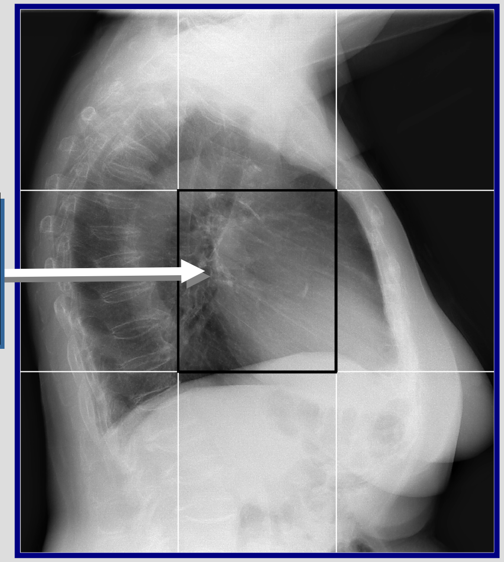
- S400 @ 125 kV, 0.8 mAs
- Dose area product: 3.8 µGym²
- EXI: 147

Example 2: Thorax lat.

- S400 @ 125 kV, 1.9 mAs
- Dose area product: 10.2 µGym²
- EXI: 314



ROI determined from acutal image size (cropped image)



The EXI is a dose indicator but not a substitute for the dose area product

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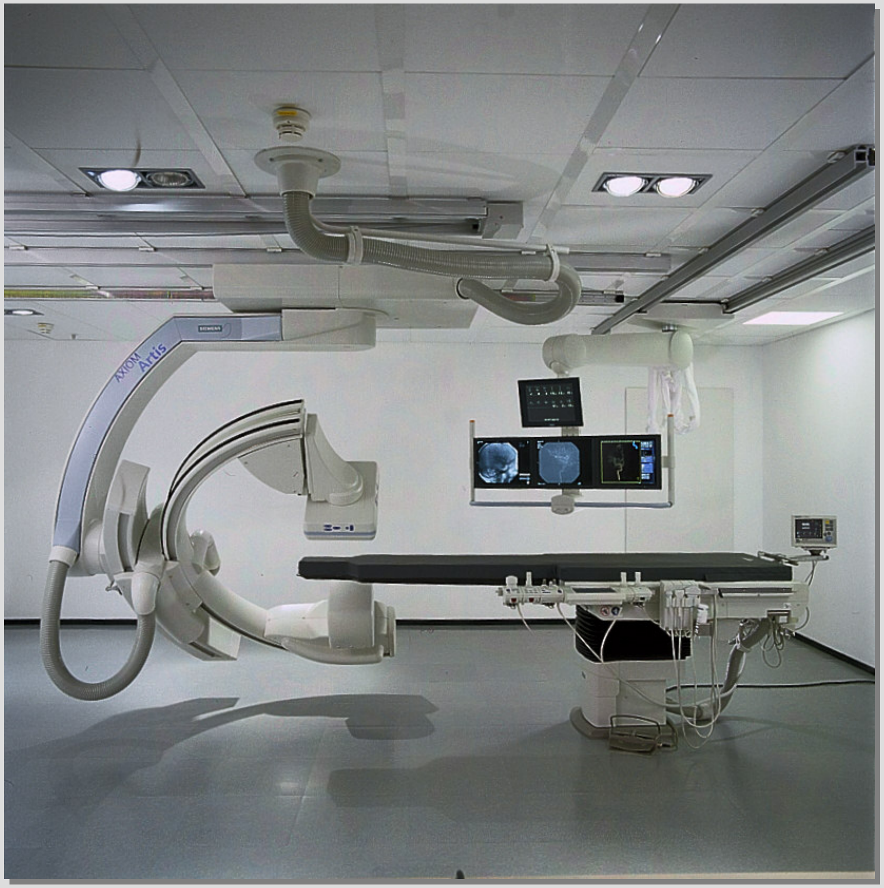
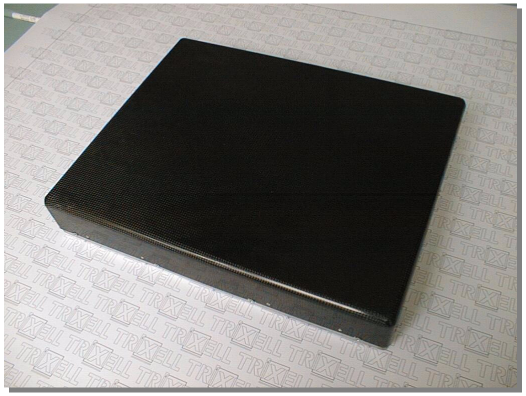
AXIOM Artis *d*TA systems with large flat detectors were introduced end of 2003

AXIOM Artis *d*TA: Overview and 30x40 Flat Detector



Flat Detector for Angiography

Area:	30 x 40 cm^2
Pixel size:	154 x 154 μm^2
Frame rates:	
▸ No binning	7,5 fps
▸ Binning 2x2 pixels	30 fps
Dose ranges:	10 nGy - 3,5 µGy
Analog to digital conversion:	14 bit



Source: AX PLM-CW

First results of 3D imaging with a large flat detector system

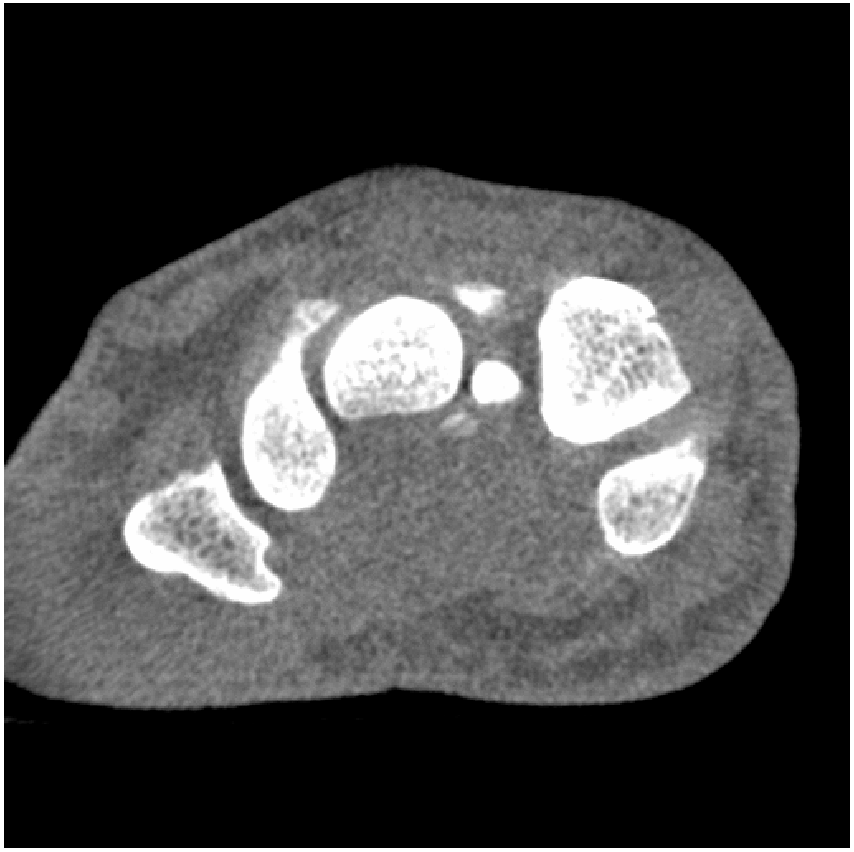
Large flat detector for general angiography: 3D reconstruction of kidney

AXIOM Artis *d*TA

Source: PD Dr. Loose, Nuremberg

First studies looking at low contrast resolution of 3-D data sets are very encouraging

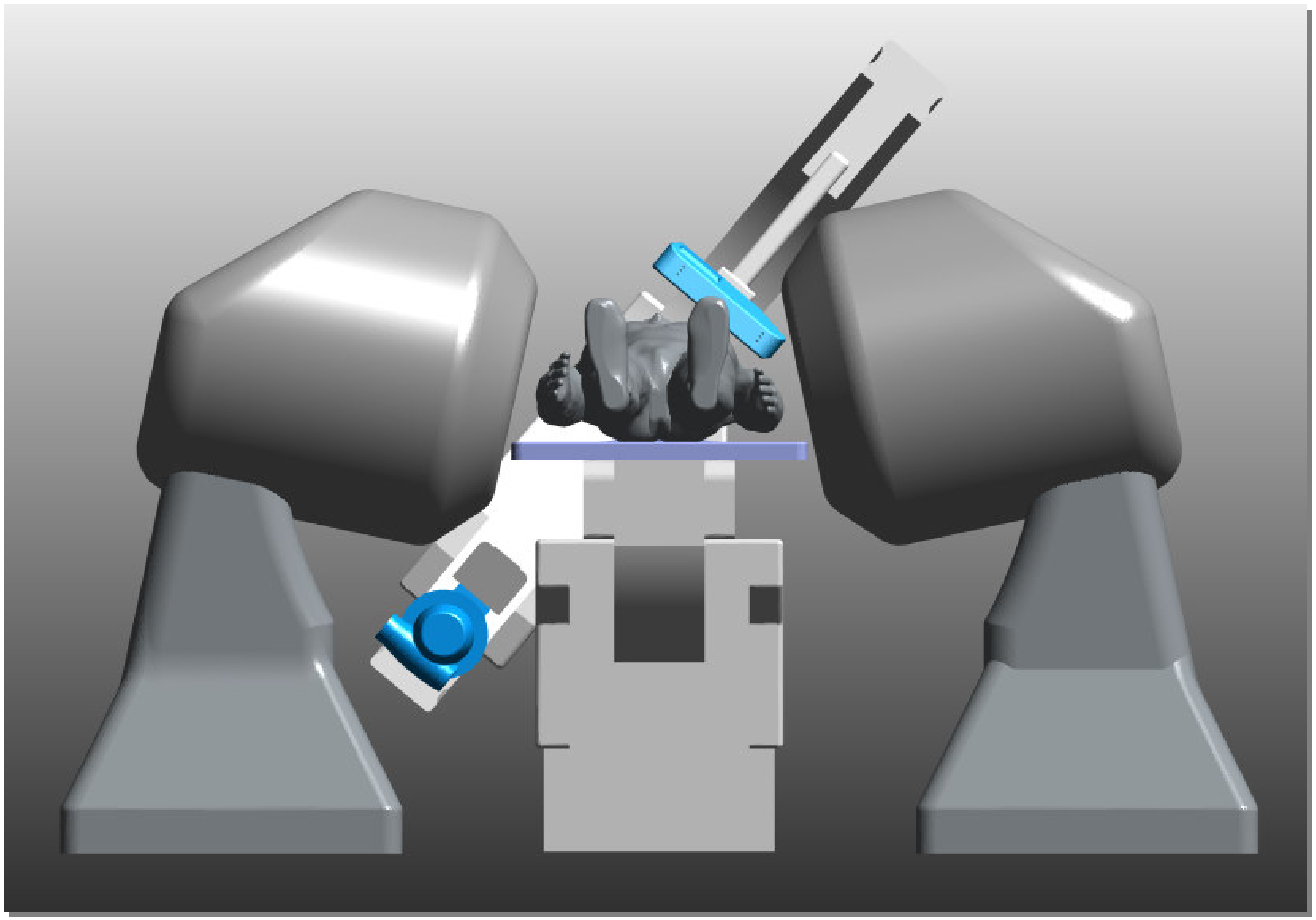
Large flat detector: 3D reconstruction of a hand[1)]



Source: AX PLM-CW 1) Left: 3D image; Right: Cross section with nicely visible muscles and fat tissue

Magnetic navigation is a new application area where X-ray systems have to operate in magnetic fields

Magnetic navigation in cardiac angiography: Principles



Areas of interest:

- Magnetically guided catheter and guide wire for navigation
- Fixation of ferromagnetic embolic at target sites

This application can only be performed with flat detectors but not with I.I.s

Source: AX PLM-I

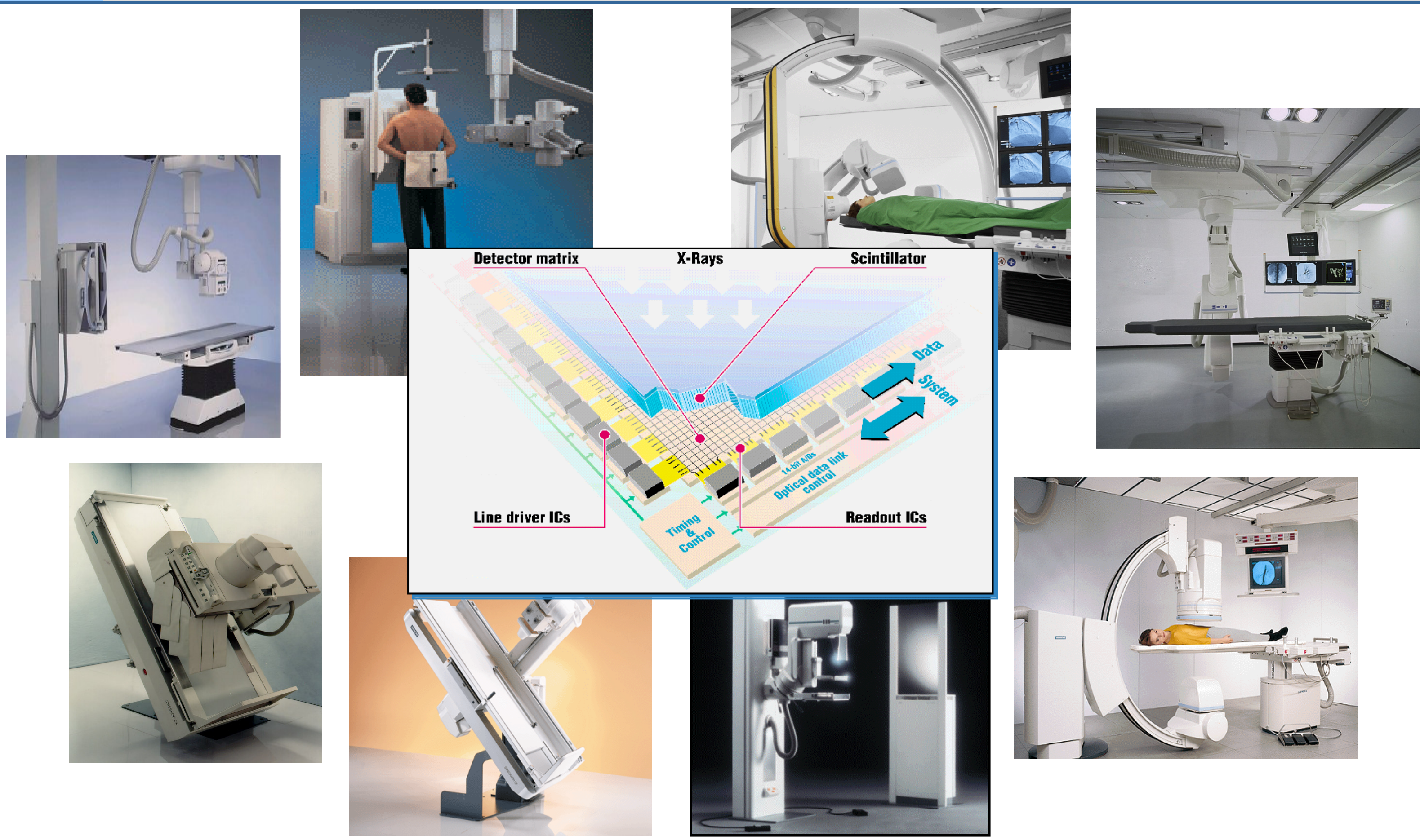
With magnetic navigation the catheter can be navigated freely by adjusting external magnets

Magnetic navigation in cardiac angiography: Steering of catheter

Source: AX PLM-I

Our vision: flat detectors will finally be introduced in all X-ray systems

Flat detectors: strategic role



Summary

- Flat detectors, specifically designed for a given application, provide the basis for high image quality (dynamic range, DQE, MTF)
- Digital image processing techniques greatly help to enhance the diagnostic content of the image
- To ensure reliable and constant image quality, the system has to be set up properly (automatic exposure control, kV-dependence) and constancy tests need to be applied (spatial resolution, contrast resolution, exposure index)
- Flat detectors allow to probe into new diagnostic and interventional fields which were not accessible so far