The Challenges of Direct Digital X-Ray Detectors

A review of digital detectors in medical x-ray technology

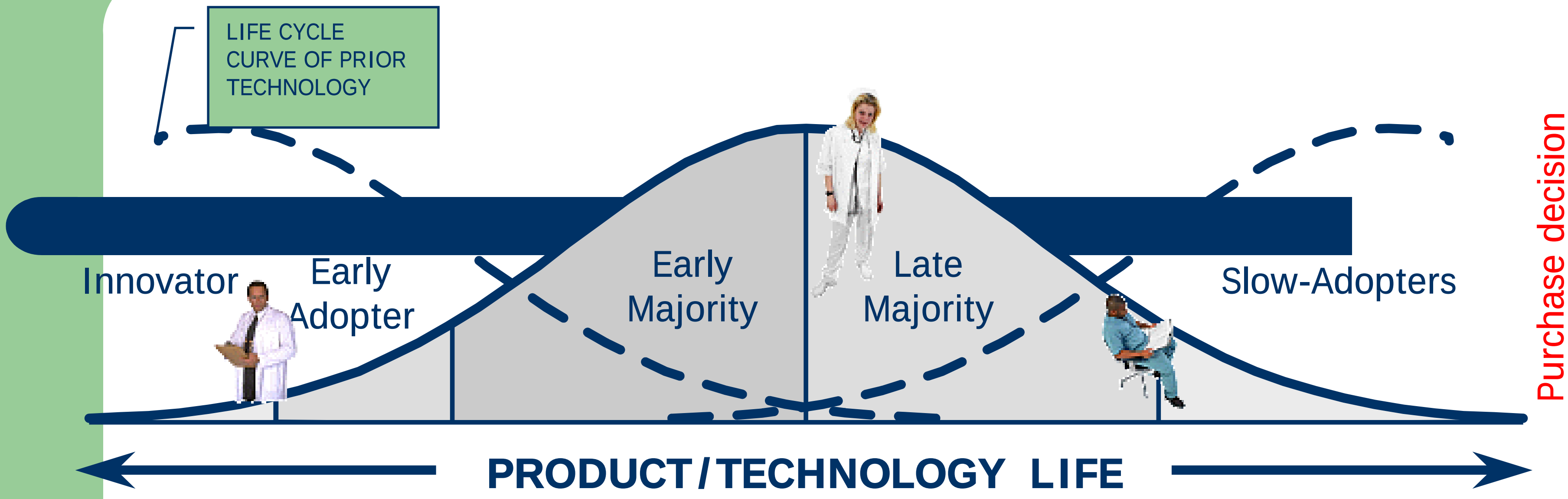
www.dondickson.co.uk

In the following slides

At least become aware and ...

- Comprehend the technology challenge
- See how commercial vendors respond
- Be aware of PACS Integration validation challenges.
- Contemplate future directions that this technology could take.

Typical Technology Adoption Cycle



DRIVERS FOR PURCHASING DECISION

- **Superior Physics**
- **Clinical Accuracy Demonstrated**
- Observer Preference
- **Patient Outcomes Obvious**
- Economic Justification
- Administration understands economic benefits

Part of your PACS solution

Initial digital detector investment should be just part of your PACS solution

When to purchase, now is the time to resolve the dichotomy

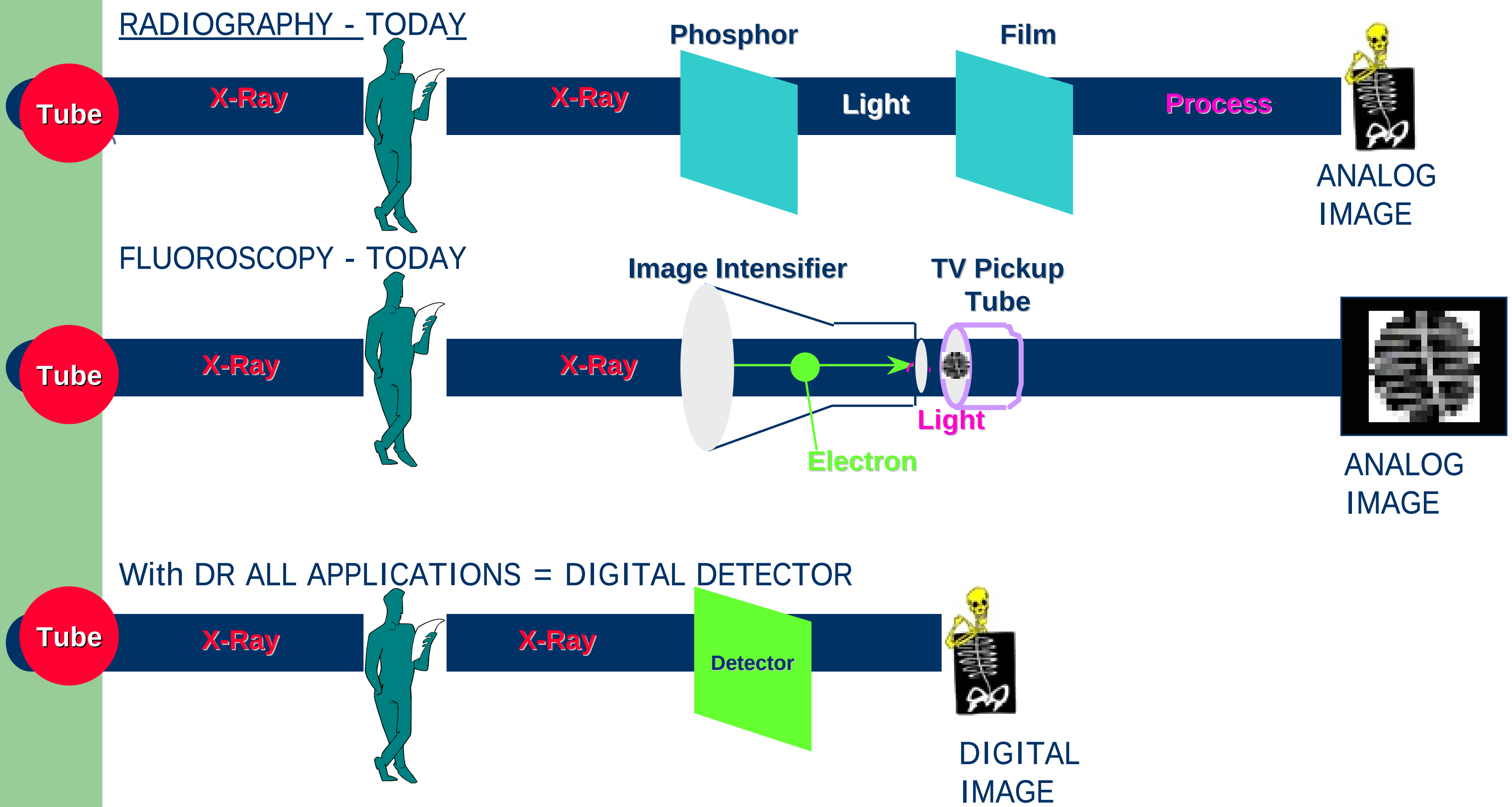
- Digital detectors can provide better detection than film, CCD, CR or image intensifier x-ray applications
  - but the initial capital purchase outlay is higher
- Digital detectors deliver lower radiation dose that satisfy ALARA criteria
- Digital detectors delivers improved outcomes for the patient
  - Improved object detection & characterisation
- Digital detectors deliver improved outcomes for the Health Care Institution
  - Workflow, faster image distribution, images “on-call”
  - Reduction of ongoing operating expense

A few thoughts! *to start with ...*

Who make direct digital detectors?

- At least twelve major system vendors are active in the industry ... but few, such as Canon (a-Si), Hologic/DirectRay (a-Se), GE (a-Si), Varian & Trixel a consortium of (Philips+Siemens+Thompson) assemble amorphous DR detectors. Most selenium detector material is supplied by Anrad, a division of a company called Analogic.
- Other digital detectors include Silicon Crystal (ASIC), CR & CCD devices
- Scintillator types include Caesium Iodide, Selenium & "Lanex" (Gd_2O_2S) Screens.
- Direct Digital Acquisition will drive many new applications, and access to those applications will ultimately drive equipment purchase decisions.

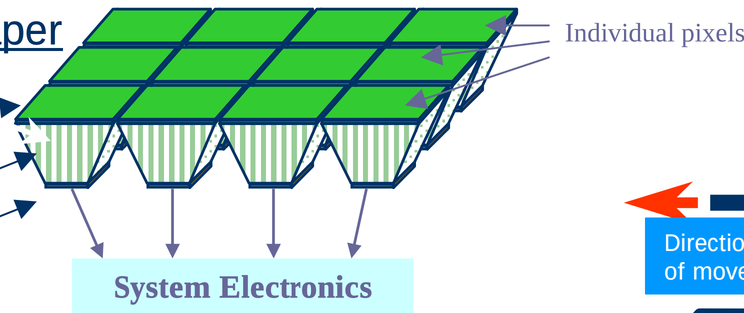
Where do detectors fit?

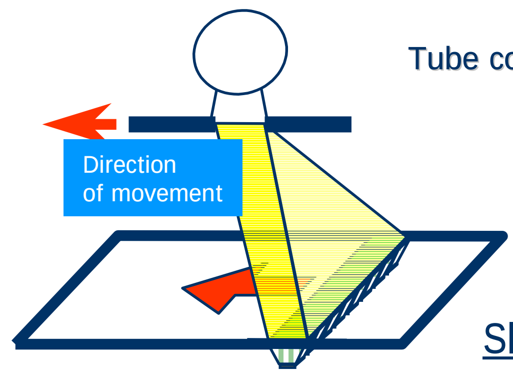


Three application examples of CCD technology in digital radiology

Image reconstruction is performed using a SW processing algorithm

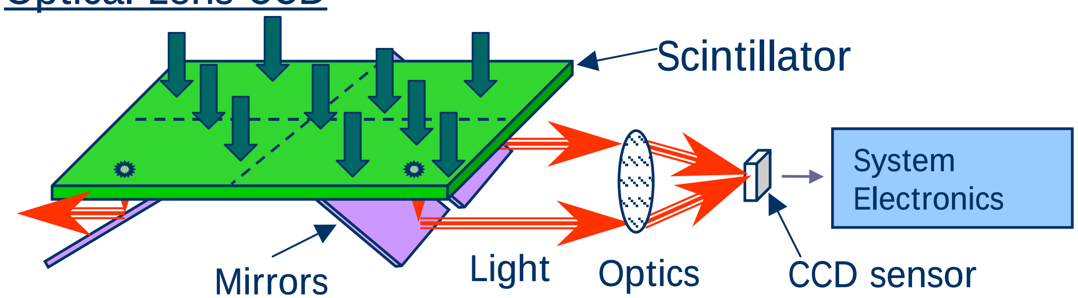
Fibre Optic Taper





Slot Scanning CCD

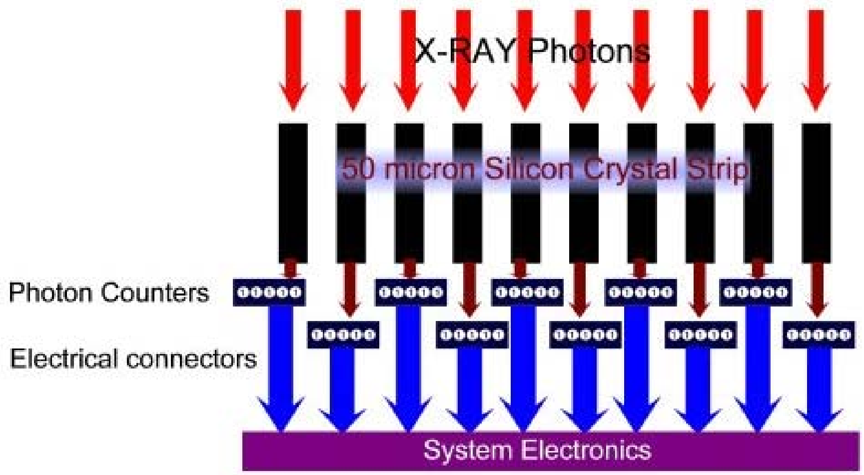
Optical Lens CCD



Crystal detectors

ASIC: - Application Specific Integrated Circuits

- The detector elements are arranged as an array
- Pixel size can be small
- The technique uses the slot scan principle for acquisition
- The structure enables very low dose exposures
- The acquisition principle is to counts photons
- Extremely efficient (97%) (no scatter)



Amorphous Detectors (Digital Flat Panels)

Using amorphous silicon / selenium it is possible to manufacture a “flat panel” photo diode / transistor array detector that absorbs, and converts photons into an electronic charge.

Each photodiode represents a pixel, or picture element, to present a true digital output from the detector.

Amorphous Detectors (Digital Flat Panels)

- There are two suitable amorphous substances.
  - Selenium (Se), a nonmetallic element
  - Silicon (Si), a metalloid element
- They have different properties and sensitivities.
- The plates are difficult to manufacture and the larger the plate size the more difficult the construction
  - To overcome the 'size' challenge some vendors utilise a *tiled* plate construction.
- They have different operating temperature limits.
  - Can require environmental control for efficient operation

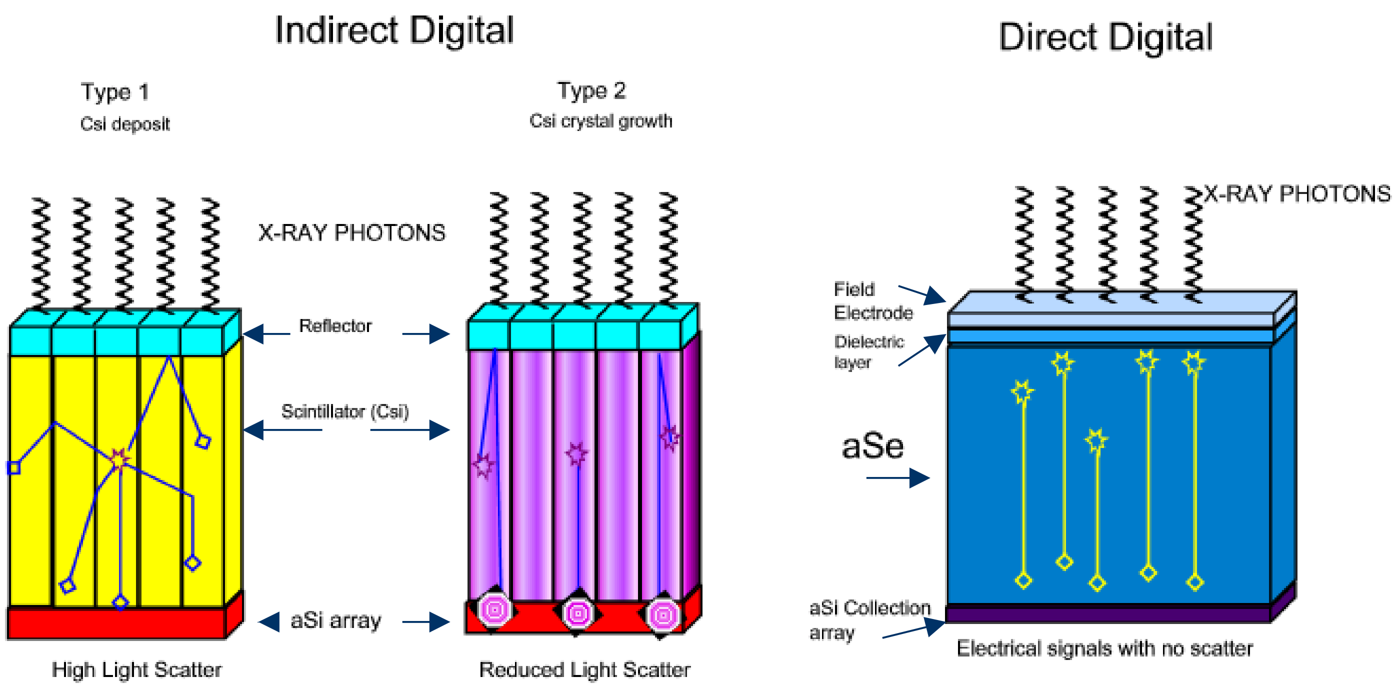
How do they work?

The scintillator converts the X-Ray photons into light, the a-Si array converts the light into an electronic charge

Selenium / A-Si array combination forms capacitor elements which converts X-Ray photons directly into an electronic charge

Amorphous Silicon Method

Amorphous Selenium Method

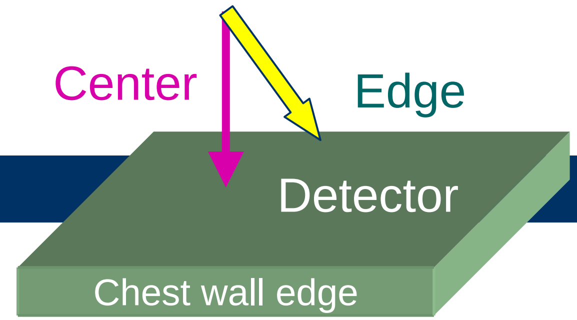


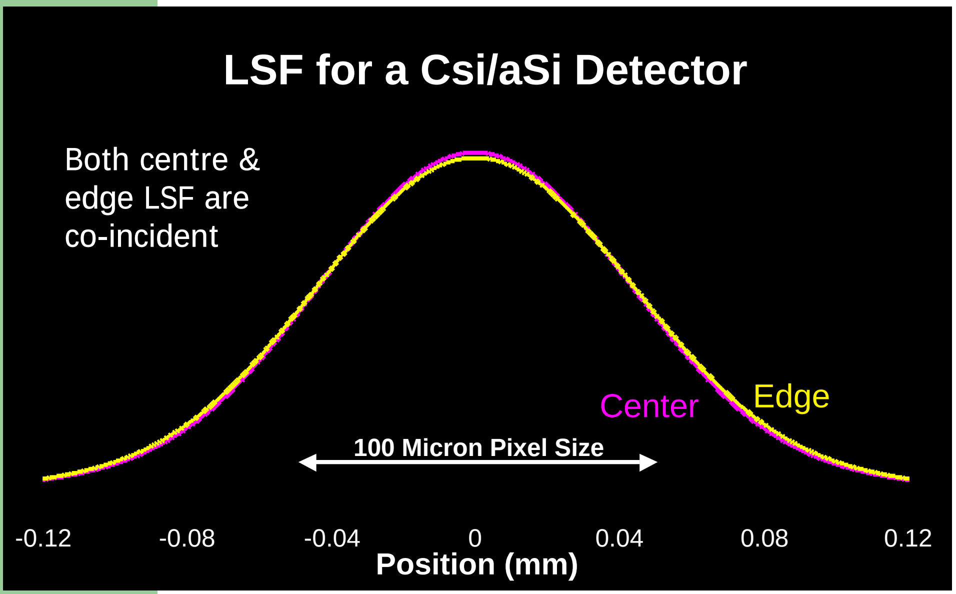
DETECTOR

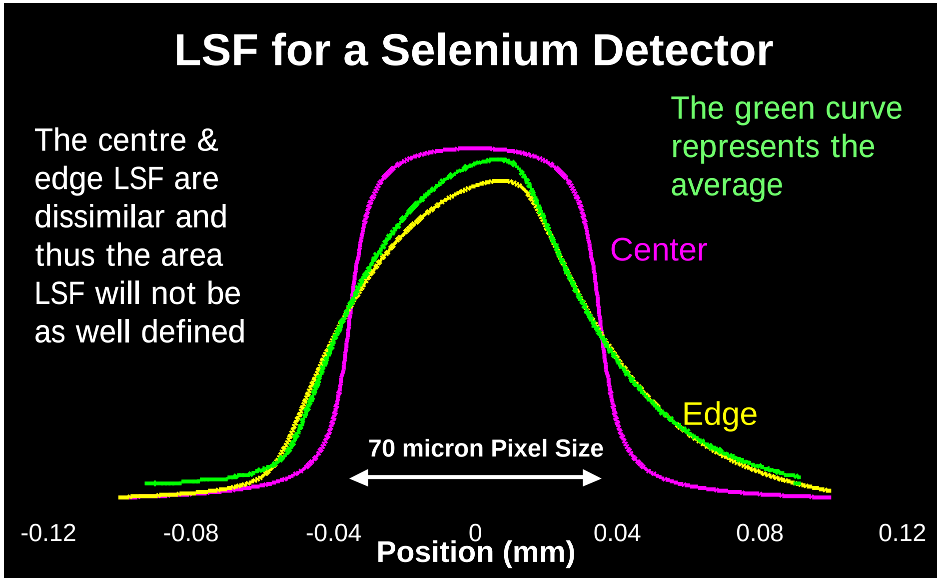
In the real world it is necessary to compare the performance at the center and edge of a detector

LSF probability in Mammography

Line Spread Function:



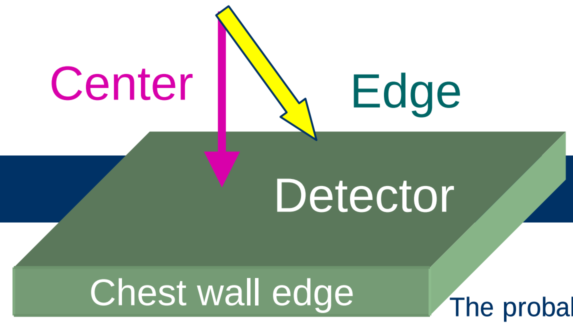




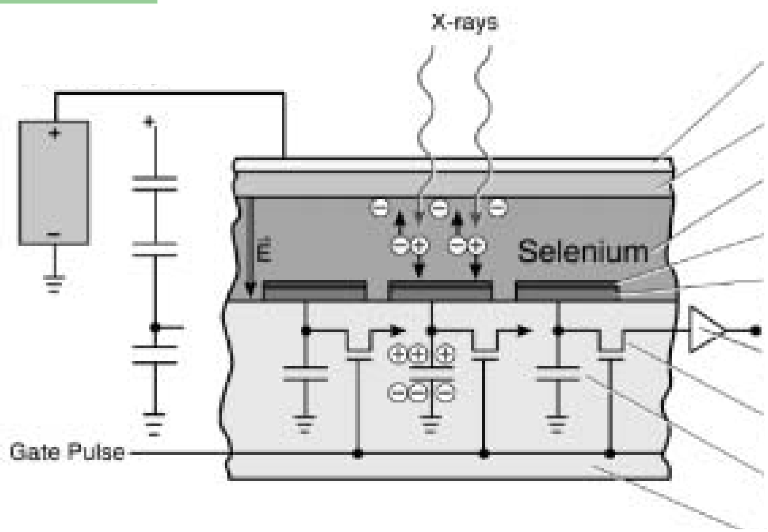
In the real world it is necessary to compare the performance at the center and edge of a detector

LSF probability in Mammography

Line Spread Function:

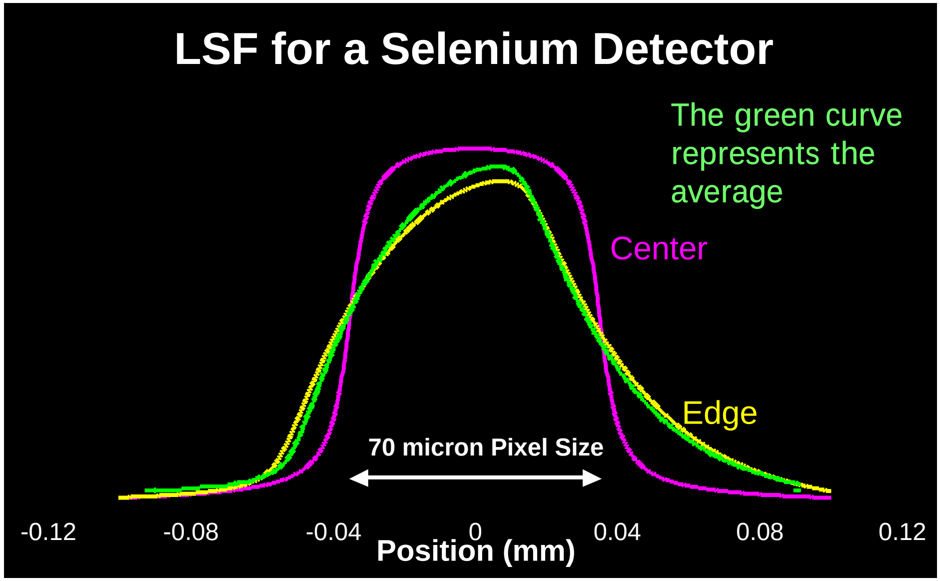


The probable cause for the change in selenium LSF will be the detector's internal electronic noise & k-edge photon effect.



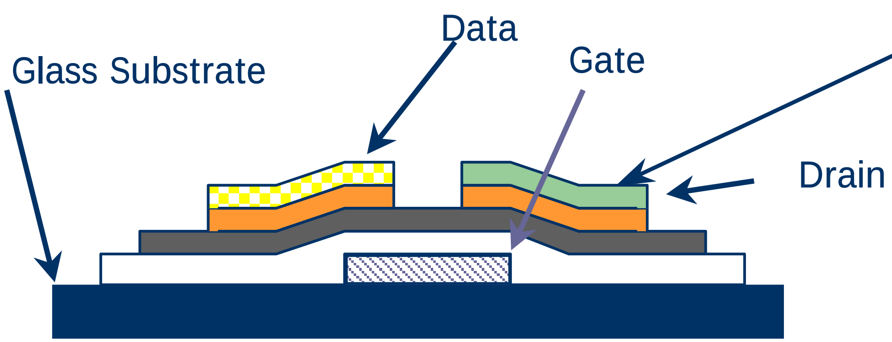
Electronic noise generation & k-edge electron cloud results in the variation of the curves

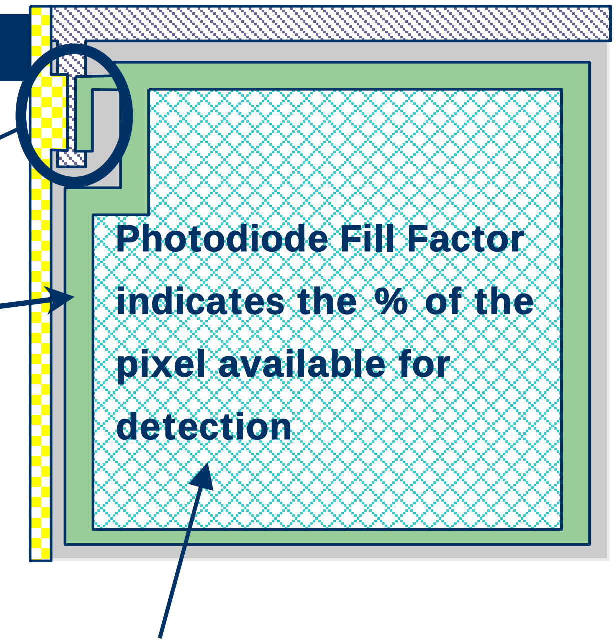
Layered structure of a selenium detector



PIXEL PHOTODIODE/FET ARCHITECTURE

The importance of pixel fill factor





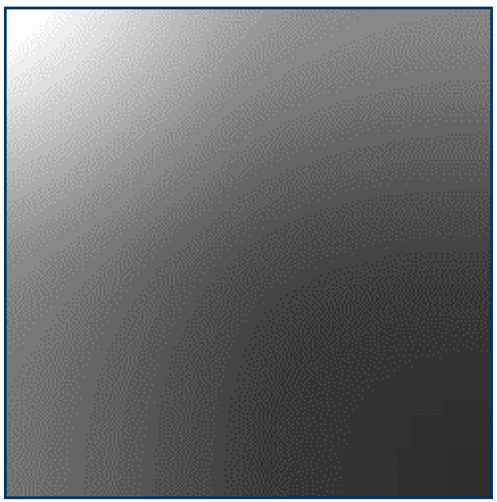
- Higher Fill Factor is better for efficiency
- Data readout done 1 row at a time
- Data readout speed governs image availability for both display and the next acquisition
- Small pixel sizes limit the size of panel that can be manufactured

A low fill factor will adversely impact detection efficiency. In some instances it can be more efficient to have a larger pixel size with higher fill factor than a smaller pixel with low fill factor

Panel architecture

Goal: To create an image without artefacts

Panel Uniformity Correction



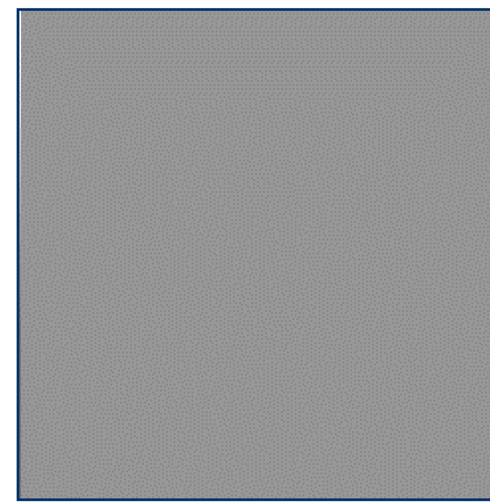
Uncorrected
(w/Brightness Non Uniformity)

An uncorrected panel would impose it's own image artefacts

Algorithm:

1. Acquire image using Flat-field phantom.
2. Calculate pixel-wise (delta) correction factor to create flat output image.

Correction Applied

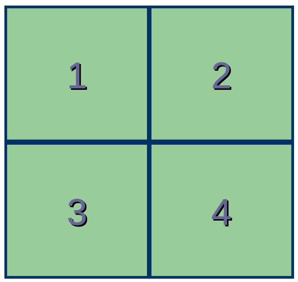


Corrected (Flat)

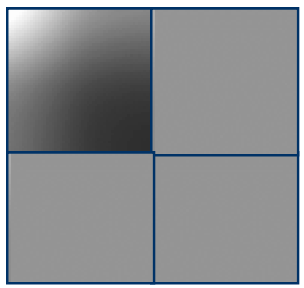
Panel architecture

Trade off between pixel size and panel size

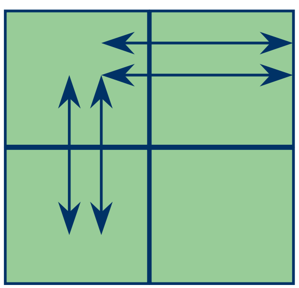
Overcoming the panel 'size' challenge



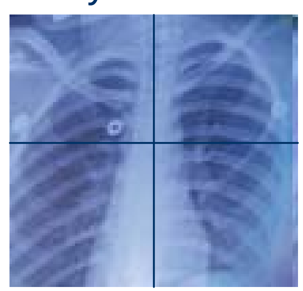
To overcome the panel size limitation imposed by small size pixels, some vendors will combine the smaller panels to make a larger size panel using a tiling process.



A typical tiled construction may involve 4 unique pieces of amorphous silicon plate, each with differing (though corrected) characteristics. A panel of this type will need regular calibration to "mimic" a single piece construction



Risk: There may be mechanical stress points at the point of bonding



The resultant image will have a two pixel-wide 'quad' line that will be removed pre display, so that it is not seen on the image.

Advantage: Using the tiling process, panel sizes up to 43 x 43 cm can be achieved

Image review

With small pixel sizes, current display technologies prevent the reviewer seeing a complete image at acquisition resolution. It is not possible to view a complete 4K image on a 2K screen

Overcoming the ‘size’ Display challenge

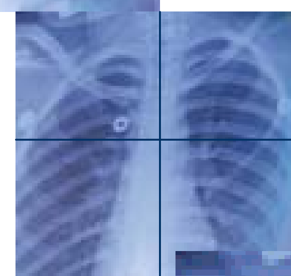
2K display screen

Display screen

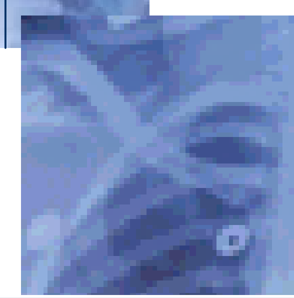
4K acquisition image

Acquired image

Minify image to fit 2K display screen



Divide image into sections



Display each section in turn

DETECTED QUANTUM EFFICIENCY (DQE)

What is DQE?

An expression of the efficiency of an imaging system's transfer, from its input to its output, as a percentage of signal to noise ratios (SNR).

DQE is the measure most representative of image quality in terms of an observer's ability to detect objects of interest in an image.

DQE has superseded reliance upon previous measurement criteria such as measuring MTF or resolution performance as a function of visible line pairs.

The key measure of image quality

$$\text{DQE} = \frac{\text{SNR}^2 \text{ at detector output}}{\text{SNR}^2 \text{ at detector input}}$$

(SNR = Signal-to-Noise Ratio)

Measures transfer of both signal

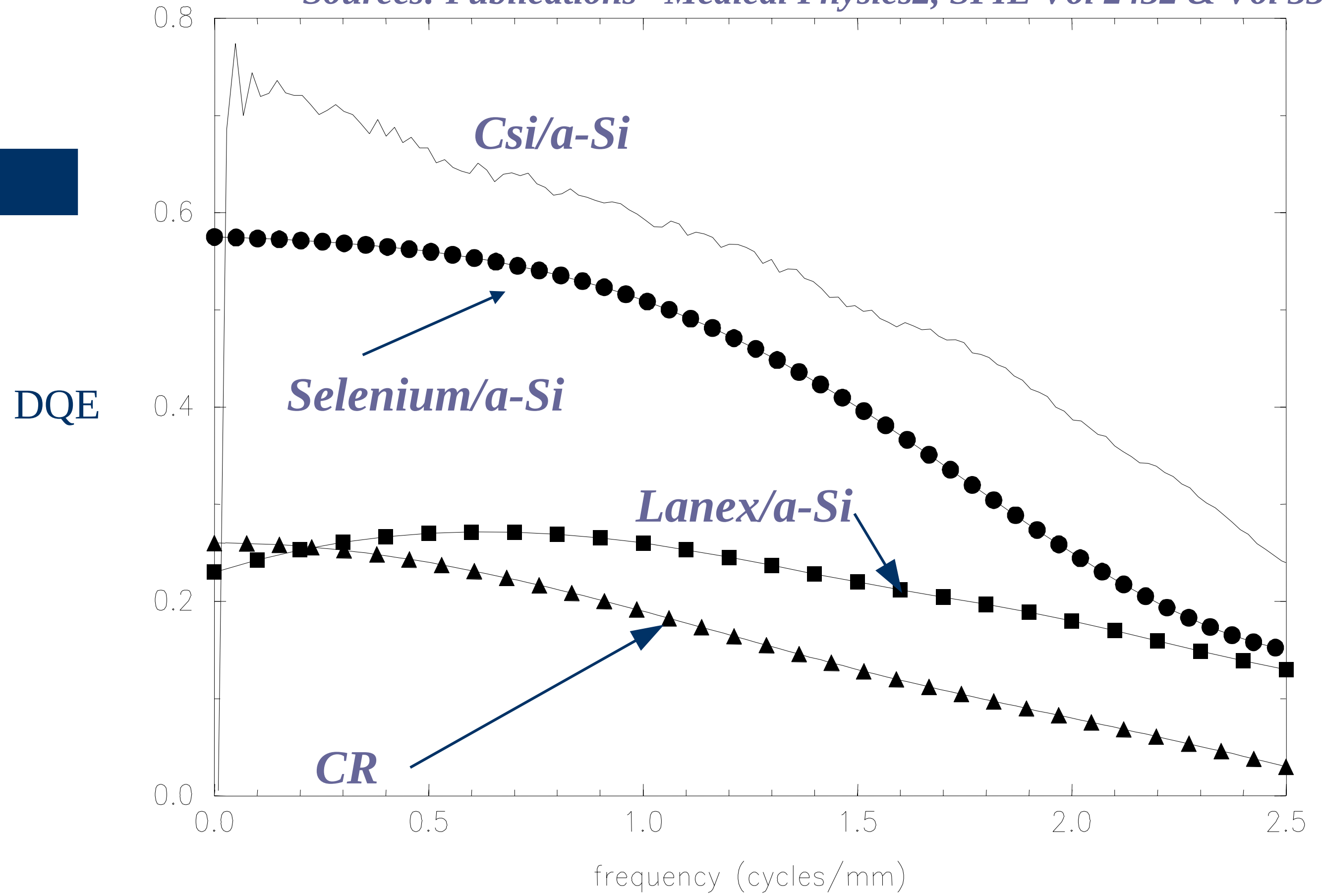
- gamma, contrast and noise (MTF)
- random variations of the signal

DQE performance is limited in practice to ~70%

DQE, is now the most important parameter in Digital Imaging

Comparing DQE

Sources: Publications "Medical Physics2, SPIE Vol 2432 & Vol 3336



The higher the DQE the lower the x-ray dose per exposure

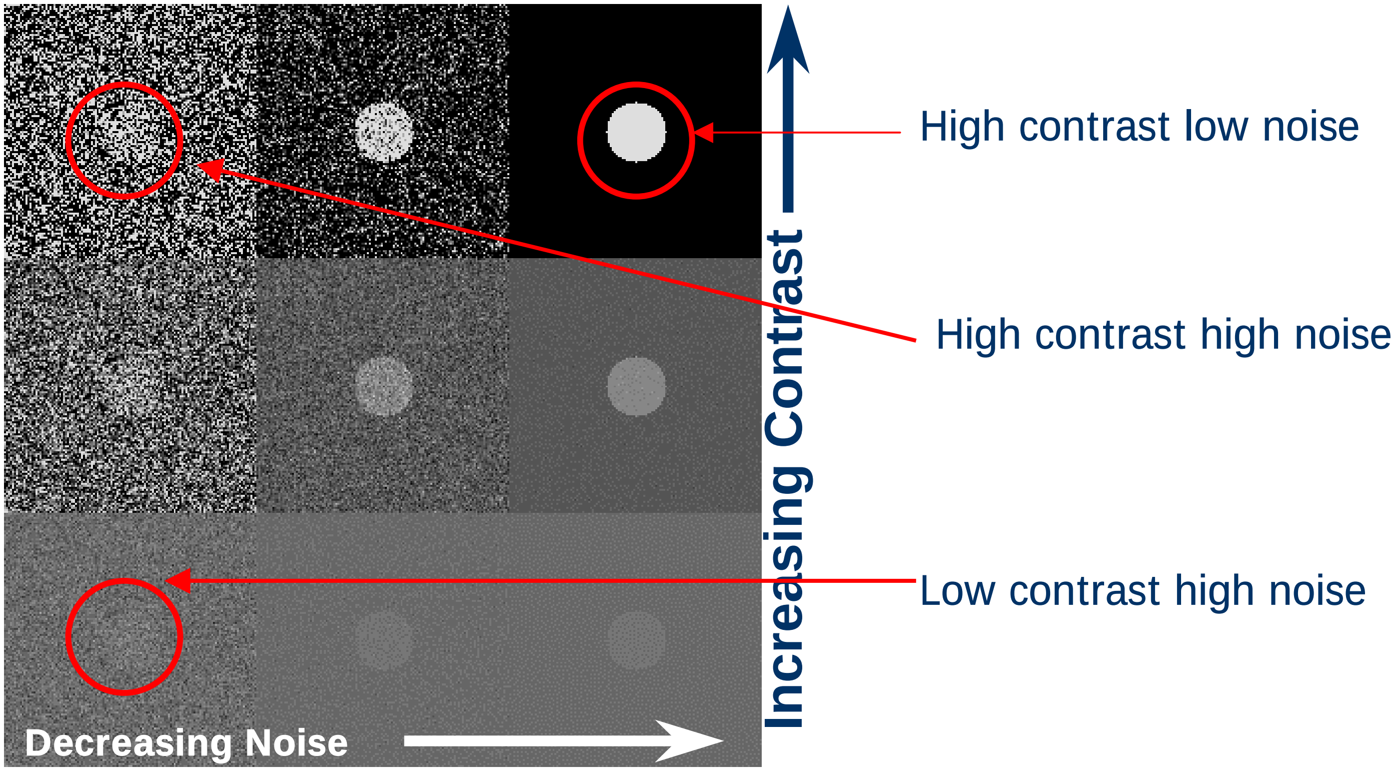
The higher the DQE the better the low contrast discrimination

Normally DQE will be expressed as a % figure

To get the benefits of a low radiation dose exposure from a direct digital detector the detection of low contrast objects in high noise is a fundamental requirement.

Within an image it can be useful to consider “Contrast to Noise Ratio” as a better way of characterising “Object” detection

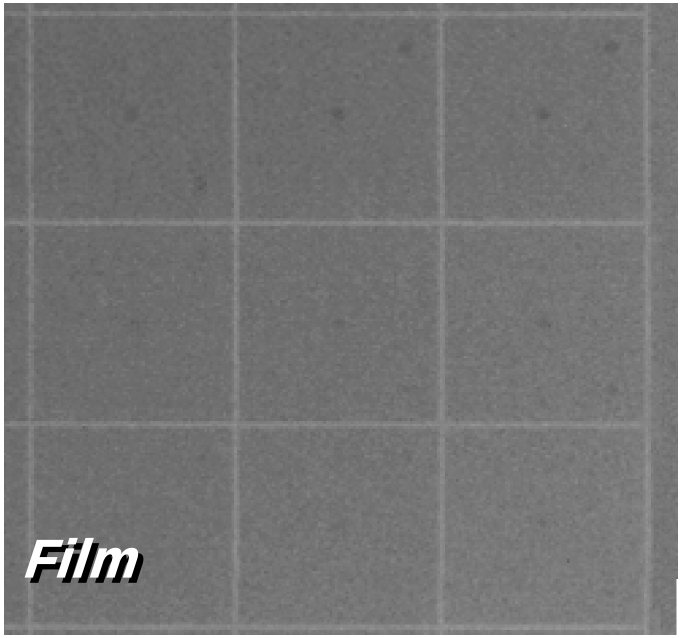
Examples of high contrast resolution and low contrast detection

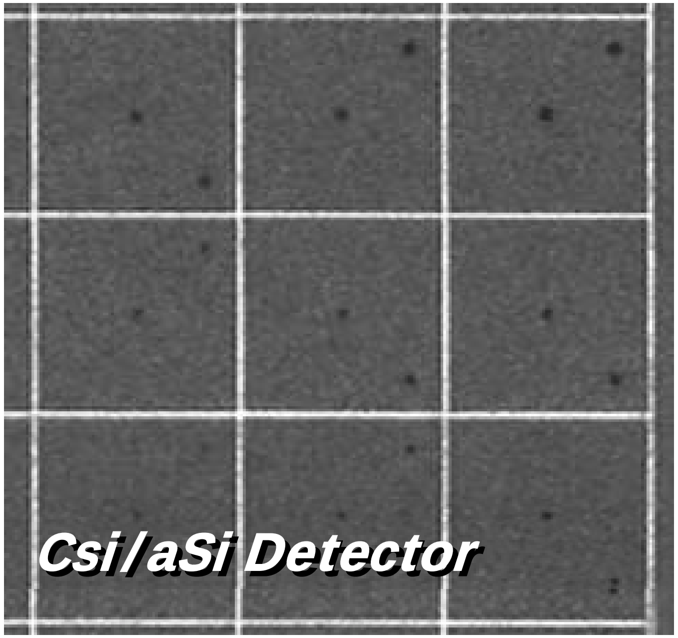


Practical example of how DQE impacts object discrimination

The same test object is exposed to x-rays on both film and a direct digital detector

High resolution low noise | **High DQE detection**



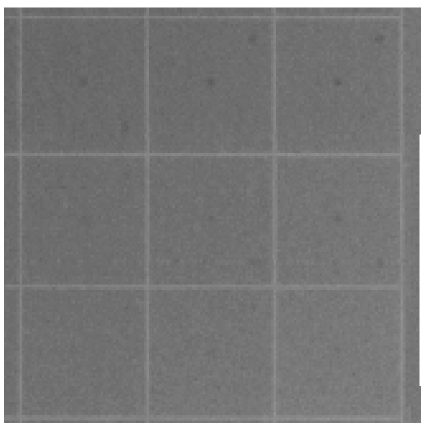


The detector with the higher DQE will show more of the visible objects as darker spots

Characterising Objects
High MTF & High DQE

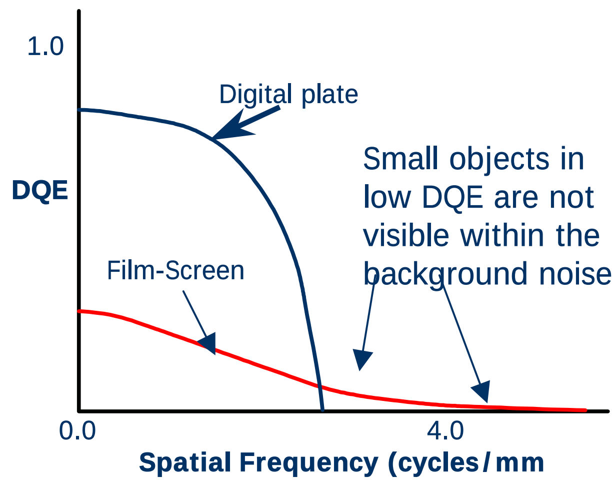
Why is this discrimination different?

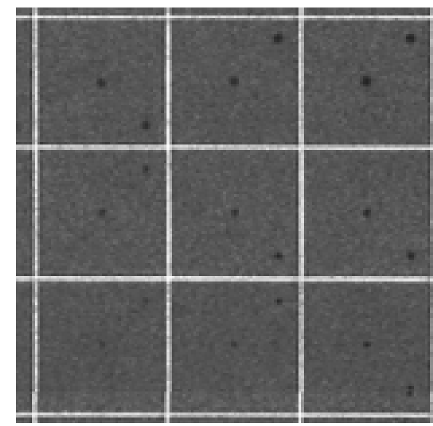
High resolution low noise | **High DQE detection**



Film

Although film has better MTF, the lower DQE reduces determination of Contrast & Small Object detail





a-Si/csi

The better DQE of a direct detector facilitates superior visual determination of Contrast & Small Object detail

Detection of micro objects

Pixel sizes chosen by commercial vendors for LFOV panels vary between ~145 – 200 micron in RF & Radiography, and between 25 – 100 micron in mammography

Pixel size and acquisition matrix

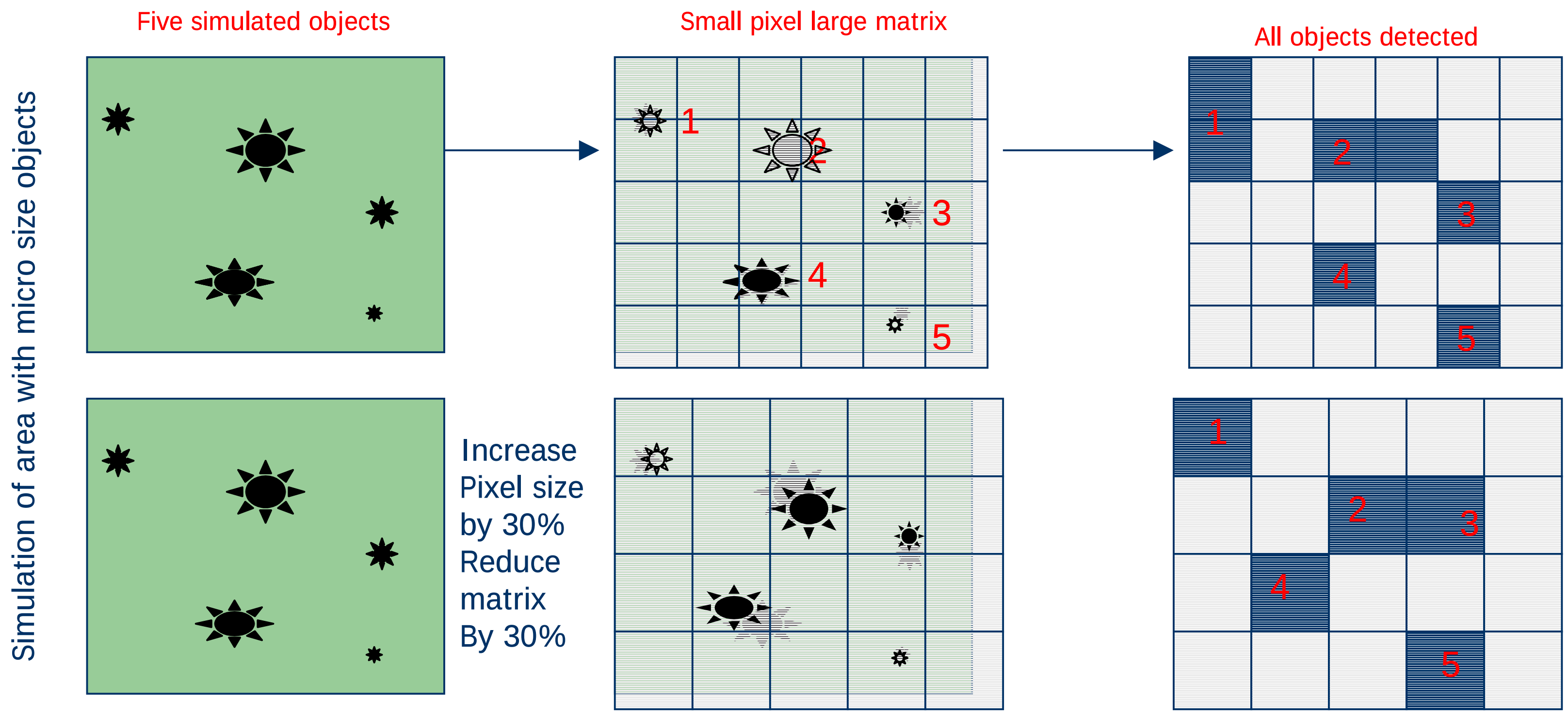


Image data presentation

Clinical – Pixel size and high resolution

In a clinical study of 100 patients‘ hands in Germany, five radiologists scored pairs of hand images using a 5-points scale on defined anatomical criteria

A 200 micron detector was compared to both Computed Radiography images and an extremity Film/Screen (100-speed)

All images were taken with matched techniques

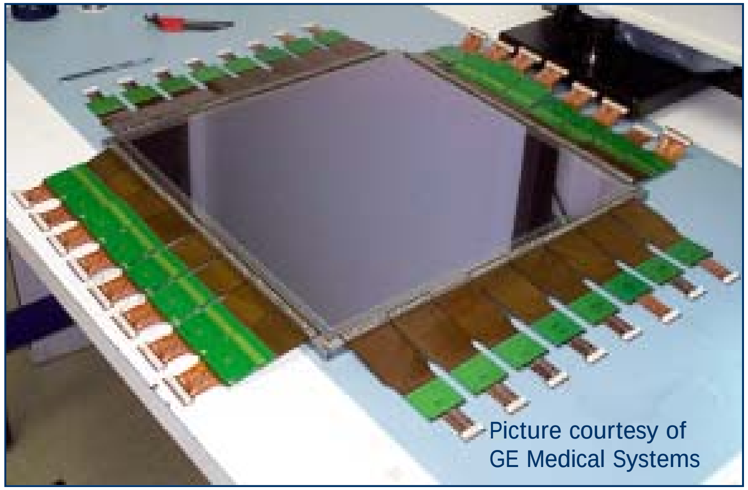
Outcome

.. the digital detector was rated statistically superior by 3 readers for cortical and trabecular structures and by 4 readers for border structures, soft tissues and overall image quality. None of the observers rated either SF or CR statistically superior to the digital detector for any category“

Image courtesy of Dresden University Hospital, Germany

Assembly and packaging

Basic panel	Hermetically sealed

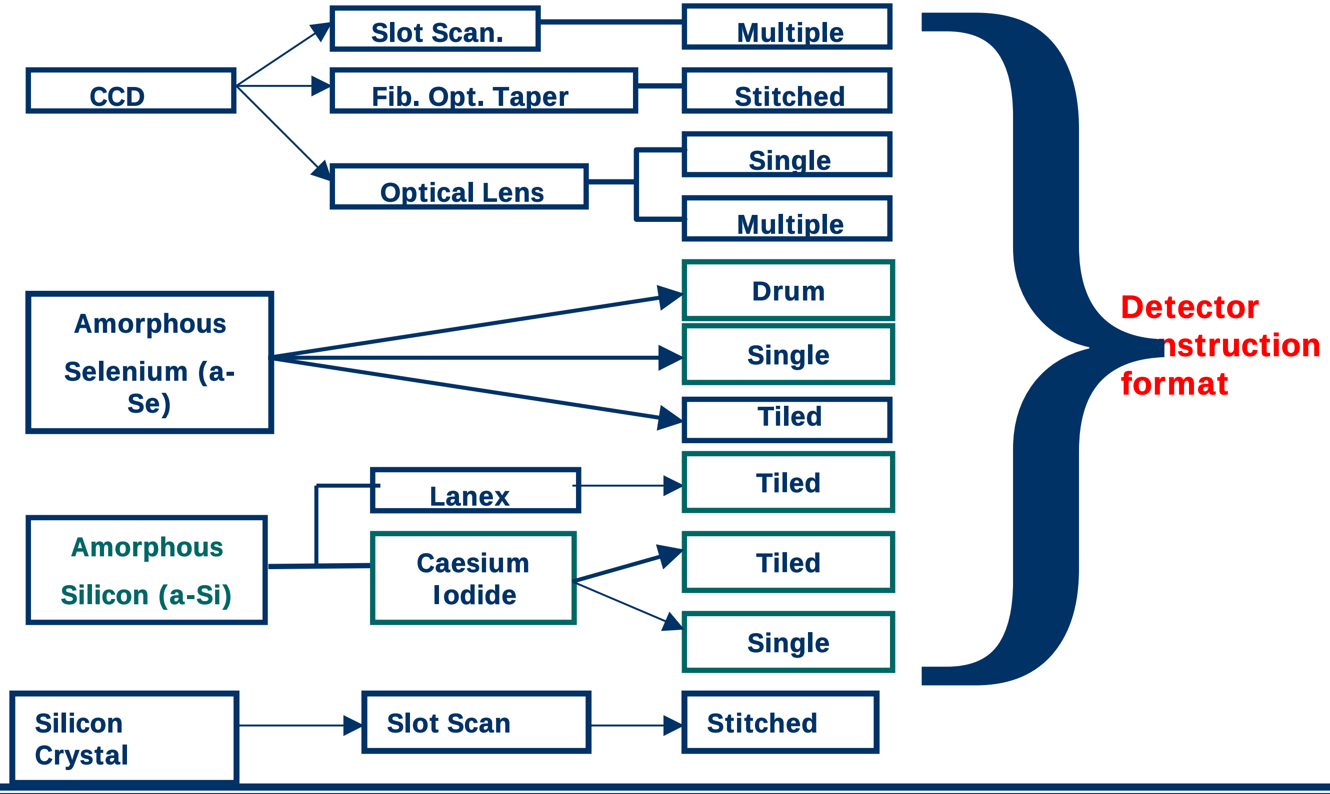


Shows an a-Si Panel with the bonded data collection modules.

Shows a packaged panel with cut-away showing a-Se receptor

The many choices facing a prospective purchaser

Digital Detector Technology Choices



Commercial Product Solutions

This is a sample of some of the major vendor's solutions to the challenge. No endorsement of any vendor is implied, the sample is not exhaustive.

43 x 43 cm a-Si/Csi	41 x 41 cm a-Si/Csi	35 x 43 cm CCD	35 x 43 cm a-Se
			
Tiled	Non-Tiled	Tiled	Non-Tiled

Type of panel construction

Type of panel construction

Choosing a vendor for direct digital requires an awareness of detector types!

Product images supplied by (left to right) Siemens, GE Medical, SwissRay & Kodak, all product and trade names are acknowledged

Commercial Responses
Image Presentation aSi

Lateral
in flexion

Lateral
in extension

A-Si/Csi
Digital Detector

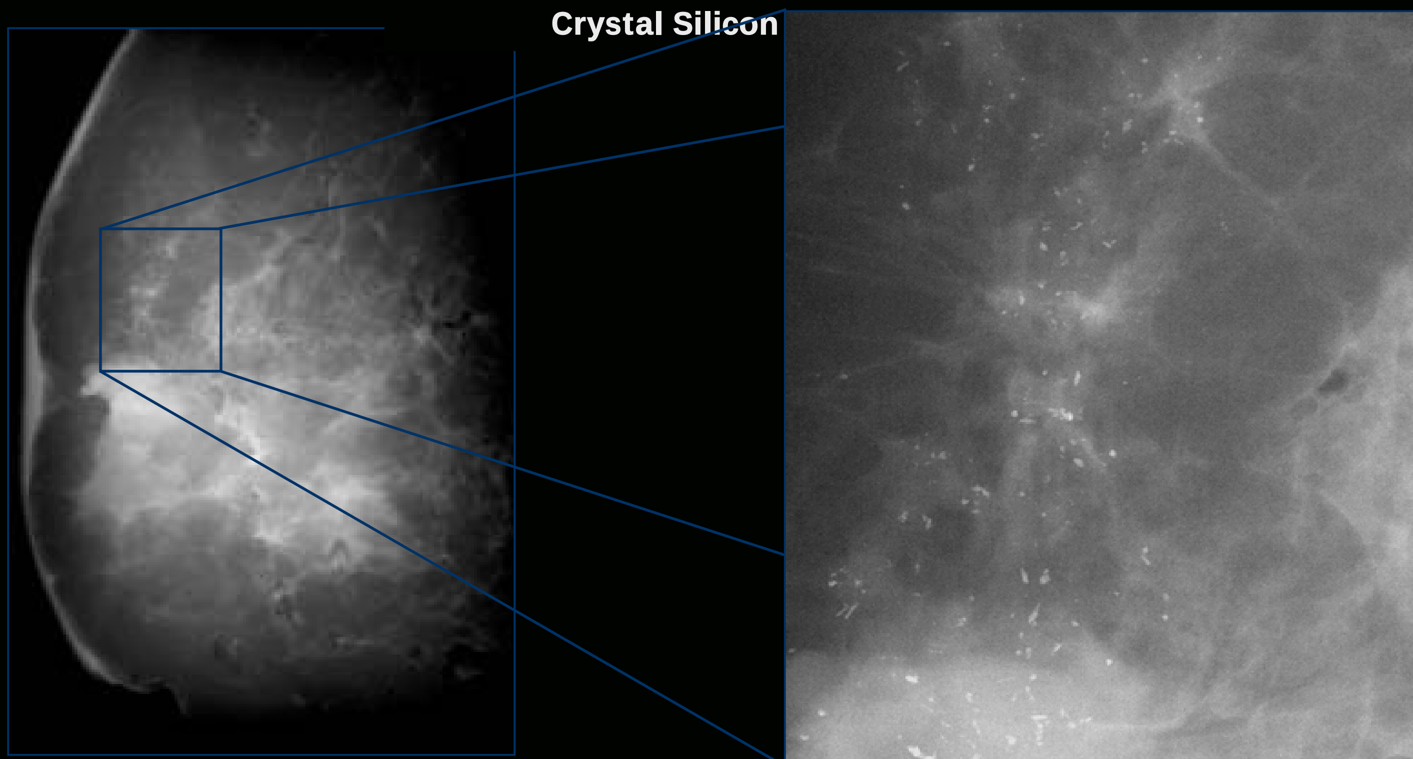
C7

T1

0.11 mGy (AGD) image provided courtesy of SECTRA

ASIC Mammography image

Crystal Silicon



Minified **Electronic Magnification**

aSi images

1 Exposure - Multiple Views

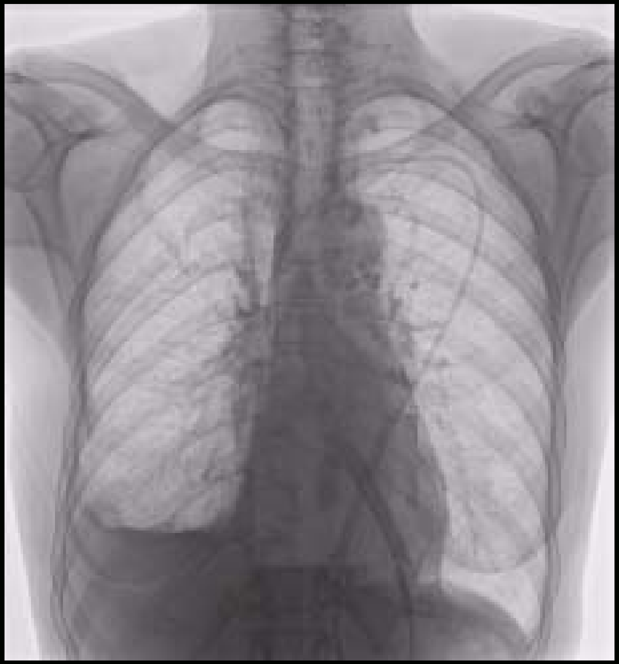
Raw Data

Processed Image

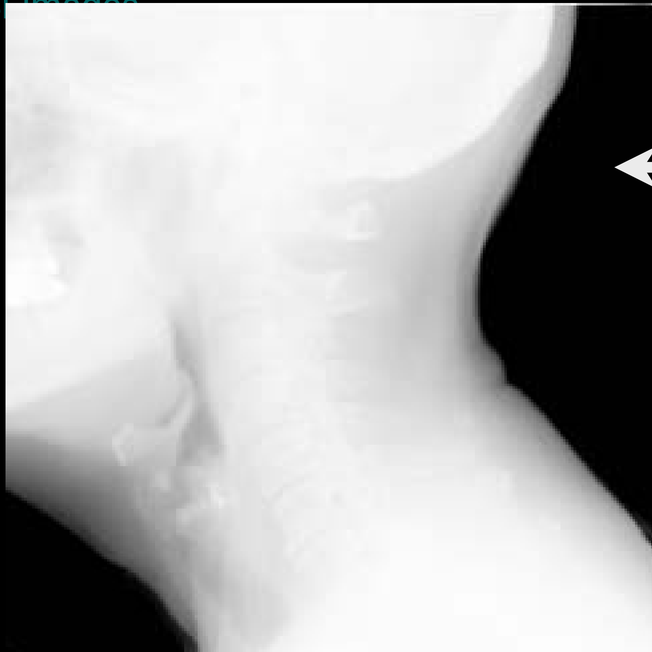
Examples of Post Processing

High Contrast

Zoom & Invert

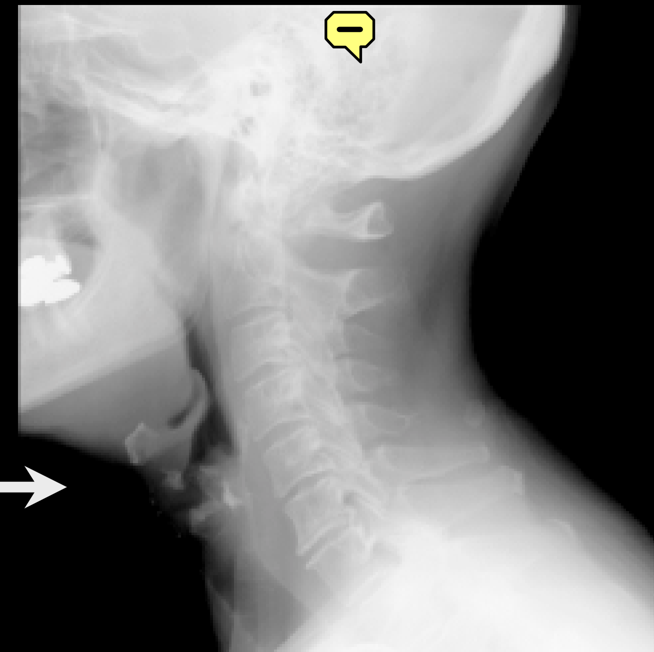


aSi images



Raw data in system memory

Image presented as ‘Film Look’



C-Spine

Image presented as ‘Soft Tissue’ Look’

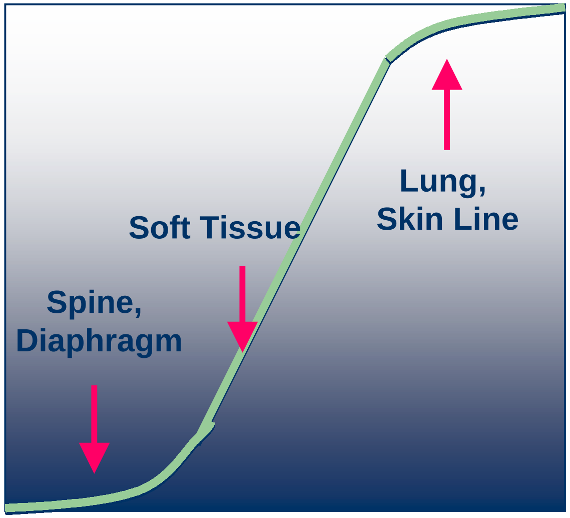
Image presented as ‘Bone Look’

Advanced Image processing

A digital detector has a wide dynamic range that facilitates it's use with sophisticated image processing to display more information than could be obtained from a single exposure

Before Tissue Equalization – A standard radiographic result from a film look

- Exposure parameters are chosen to show detail of primary interest.
- A standard exposure produces a typical gamma curve which results in under penetrated areas within the x-ray images



Film 'look' mimics a radiographic film / screen presentation

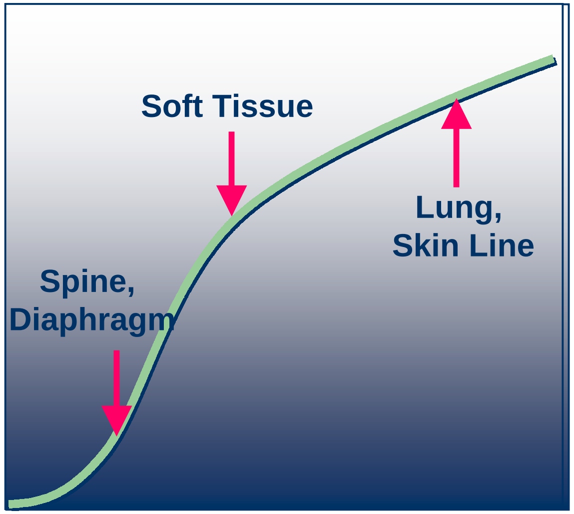
Images courtesy of GE Medical

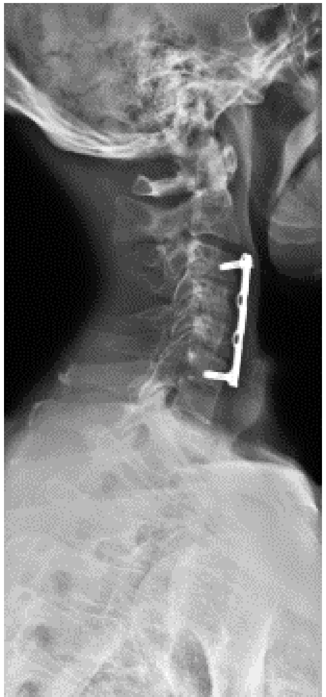
Advanced Image processing

Using image processing algorithms the shape of the gamma curve is altered to enhance both the soft tissue and spine. Thus from a single exposure more soft copy information is presented to the viewer.

Benefits of advanced image processing

- Better visualization of throat and C7-T1
- Reduction of total dose for C-spine
- Probability of less repeat exams





Images courtesy of GE Medical

The shape of the gamma curve is modified by image processing software to reveal more diagnostic information

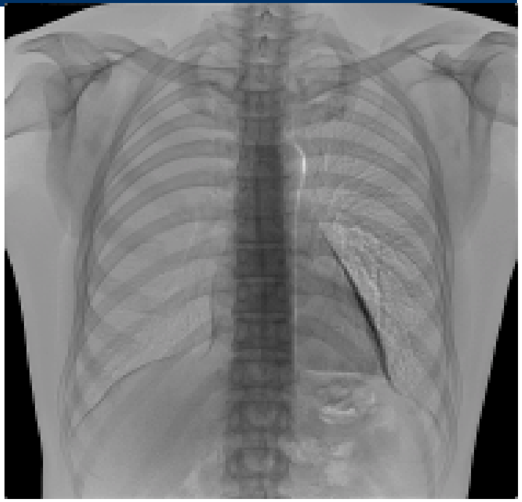
aSi knee image

Example of image presentation

A digital detector image can show both bone and soft tissue from a single exposure

One vendor manufacturers a detector that provides a very fast data readout that permits a second exposure to be initiated within 200 milliseconds. This feature can be used to perform dual energy exposures, one high kVp and one low kVp. The system image processor is used to perform image subtraction to enable the clinical reviewer to see either the low or high energy image reconstruction, in addition to the non-subtracted image.

Dual Energy image Subtraction using a DFP



Soft-tissue image probable outcomes

- **Increase nodule visibility**
- **Better visualization of tracheo-bronchial abnormalities**
- **Better visualization of pulmonary vascular diseases**
- **Increased sensitivity**

Dense-tissue image probable outcomes

- **Show calcifications to distinguish between benign/malignant nodules**
- **Better visualization of rib lesions**
- **Increased specificity**

Most purchasers know that a key question involves DICOM 3.0 integration within a product, so they ask vendors “Are you DICOM compliant?”.

Your own Direct Digital Detector challenge

- The vendors typical response is “Yes, we have DICOM 3.0”
- But make sure you know what you want to do with your processed digital images on your network because there is a choice of DICOM image formats that can be used by vendors.
  - The ‘CR’ format the ‘DX’ and the ‘DM’ format
  - Both store and transfer images, the difference is the way additional data (such as annotations or measurement) is transferred
  - DX & DM is the more efficient in terms of post image transfer data manipulation.
- Go to a vendors’ web sites and download the Direct Digital Radiography DICOM conformance documentation and read them!
- Vendors are not responsible for validating DICOM compliance with your PACS, you are!

Two simple validation checks can save you anguish at a later date!

Your own Direct Digital Detector challenge

- Check detector calibration intervals, they can vary from once a year to once a week or every day!
- Check the vendor's product data and validate the upper temperature limit for operation, this can vary by vendor between 25^0 C to 35^0 C. It does not take long to reach 25^0 C in an imaging suite on a hot day in some countries.

Thanks for taking the time to view this presentation!

Conclusion

Today with Direct Digital Technology ...
already applications include Mammography, Radiography, Angiography & Cardiac ... and more progress will happen.

Exciting times are ahead!

THINK NOT HOW YOU WORK TODAY

BUT

HOW YOU WILL WORK TOMORROW