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Flat Panel Detector Technology

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Topics of Discussion

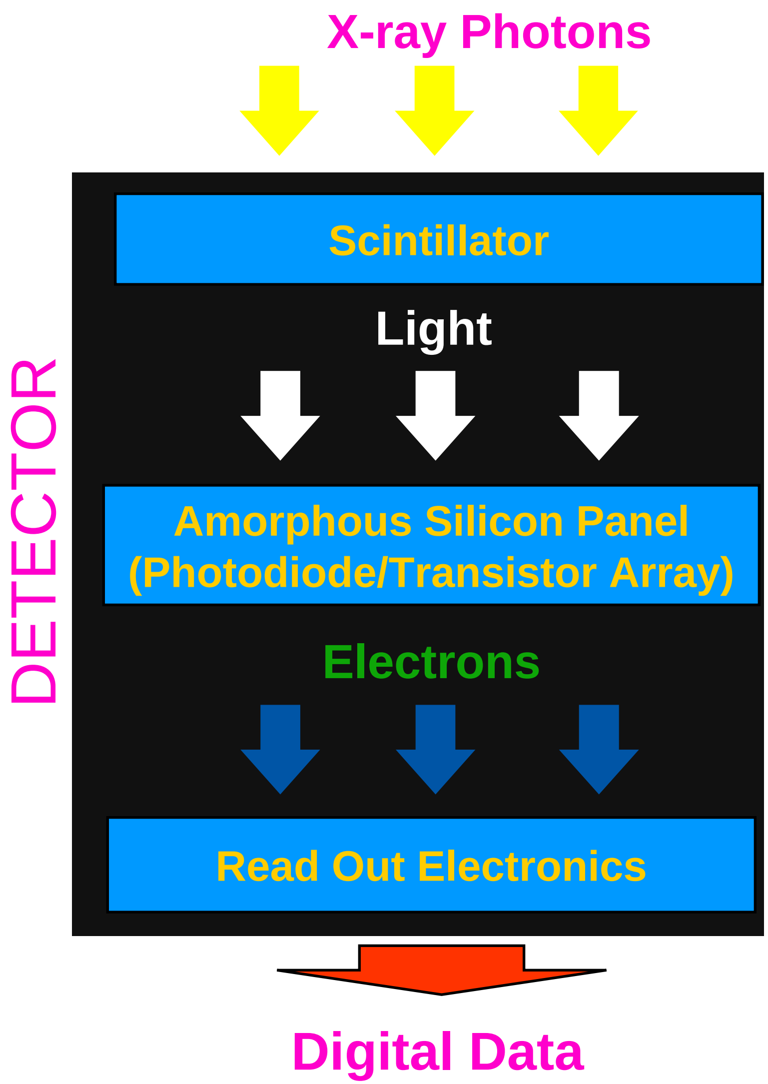
- Introduction
  - Technical history
  - How it works
- Description of the main components of a-Si FPDs
  - Scintillator
  - a-Si panel
  - Read-out electronics
  - Image calibration/correction
- Direct and indirect FPDs
- Applications of FPDs
- FPD performance comparison vs other X-ray detectors / technologies
- Conclusions

Technical History

- Idea of flat panel detectors (FPDs) derived from the LCD monitor screens
  - used thin film transistor switches to illuminate sequential pixels on LCD screen
  - arranged in a 2-D array on a glass substrate
  - charge is sent to a pixel of interest to make it glow. Reverse happens for indirect FPDs
- Photodiode arrays are predecessors to FPDs. Use of semiconductors as photo-detectors or as a switch for read out, started with photodiode arrays.
- A layer of X-ray sensitive scintillator is placed over the Si photodiode. This combination is called Linear Diode Array (still popular in some applications like baggage inspection).
- Charge Coupled Devices (CCDs) with scintillator layer were next optical sensors used for X-ray detection. CCD technology could not make large area image sensors.
- CMOS with scintillator layer is similar to CCDs x-ray detectors (with a difference in read-out mechanism). Both CCD and CMOS are susceptible to radiation damage.
- FPDs are using amorphous materials
  - construction of large area sensors possible
  - very resistant to radiation damage

FPD is Long Term Solution for most X-ray applications

How Does It Work?

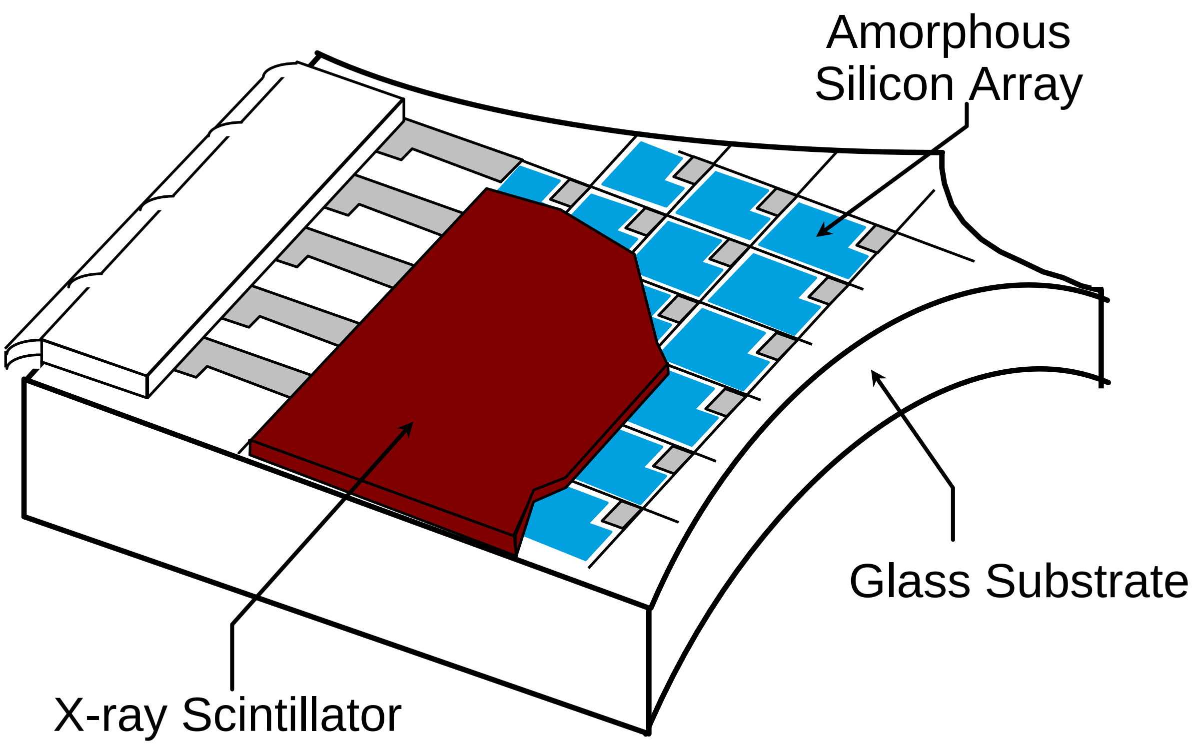


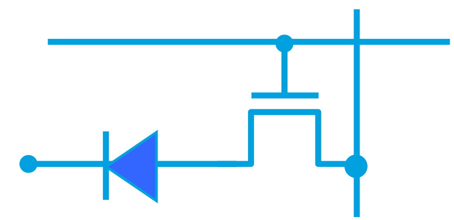
- Scintillator absorbs X-Ray photons and converts them to light.
- Photodiode array absorbs light and converts it into an electronic charge. Each photodiode represents a pixel or picture element.
- Charge at each pixel is read out by low-noise electronics.

Main Components of a-Si FPD

X-rays → Light → Electrons → Digits

Scintillator | a-Si Photodiode | Charge Readout + A/D





Optimized for low noise and high SNR

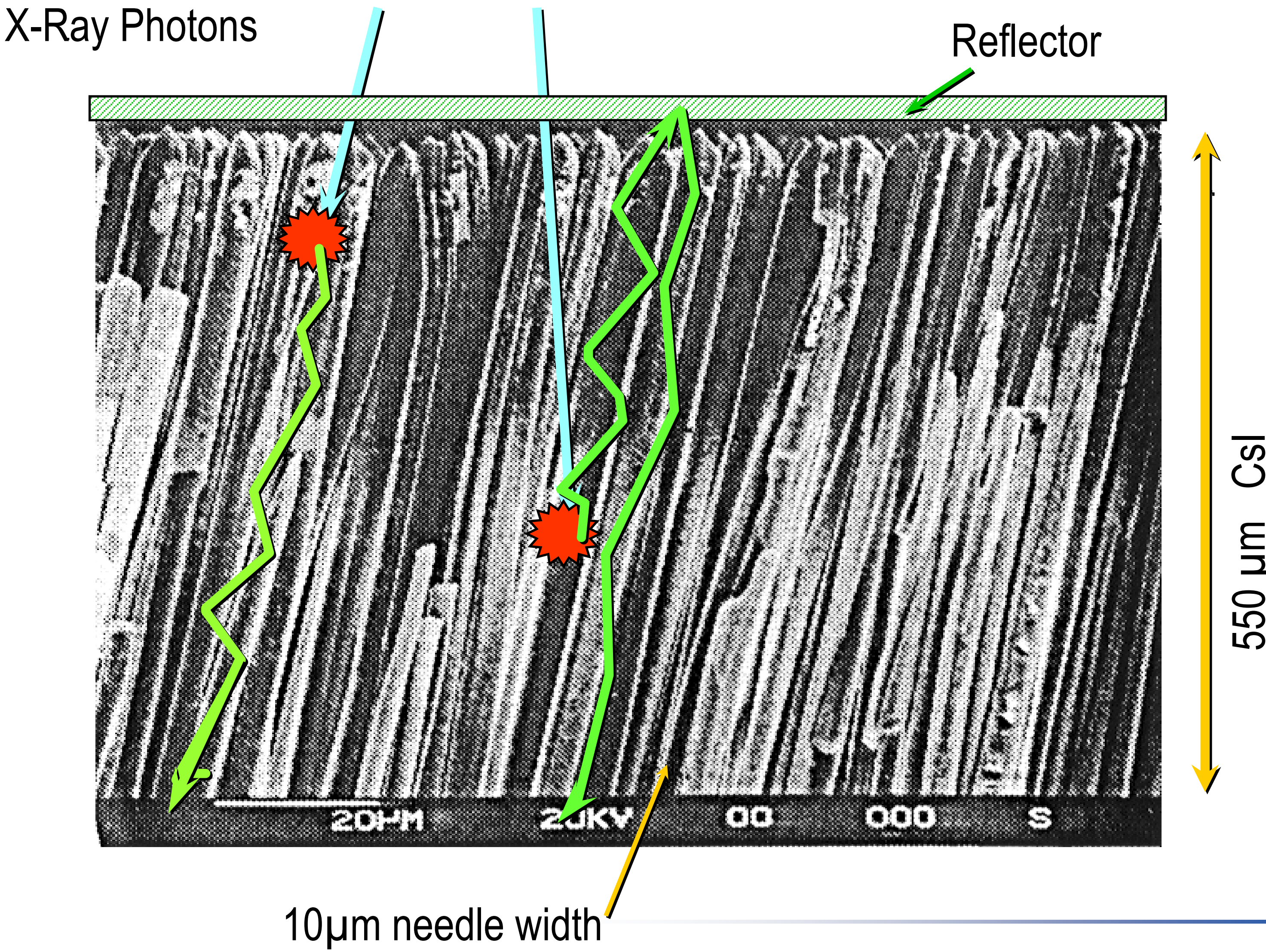
Properties of Scintillators

- Converts x-rays to light
- Scintillators used in many X-ray detectors including Image intensifiers, linear diode array, x-ray Vidicon, and a-Si flat panels.
- Main properties of scintillators influencing in imaging system performance are:
  - a) Conversion Efficiency
    - X-ray quantum efficiency
    - Light conversion per X-ray photon
  - b) MTF / spatial resolution
  - c) Light output spectrum
  - d) Light decay / after glow
- CsI:Tl and Gd_2o_2S:Tb (Gadox) are mainly used in the FPDs.

Main drivers for selecting scintillator are System/IQ specs

Scintillator:CsI(Tl)

- Vapor grown
- Grows with needle structure
- Tl doped for green emission



Scintillator: Gadox Options for KV and MV Applications

- Fine particles (powder) deposited on a substrate
- Used for MV and KV X-ray imaging
- Application and system requirements determine the scintillator type.

No	Scintillator	Normalized Sensitivity@ 70kV
1	Kodak Lanex Fast	1.00
2	Kodak Lanex Fine	0.15
3	AGFA 1070mg/cm²	1.12
4	AGFA 1240mg/cm²	1.16
5	AGFA 2770mg/cm²	1.27
6	AGFA 2970mg/cm²	1.23
7	AGFA CurixRed	1.13
8	Kyokko DRZ_High	1.43
9	Kyokko DRZ_Plus	1.02
10	Kyokko DRZ_Std	0.82
11	Kyokko PI200	1.42
12	AST Inspex_HE	1.29
13	AST SecureX HB	1.16
14	AST Inspex_M	1.29
15	AST MedeX Portal	1.74

Commercial Gadox Screen Evaluation: Presented in AAPM 2007

Scintillator: Cover and high energy build up plate

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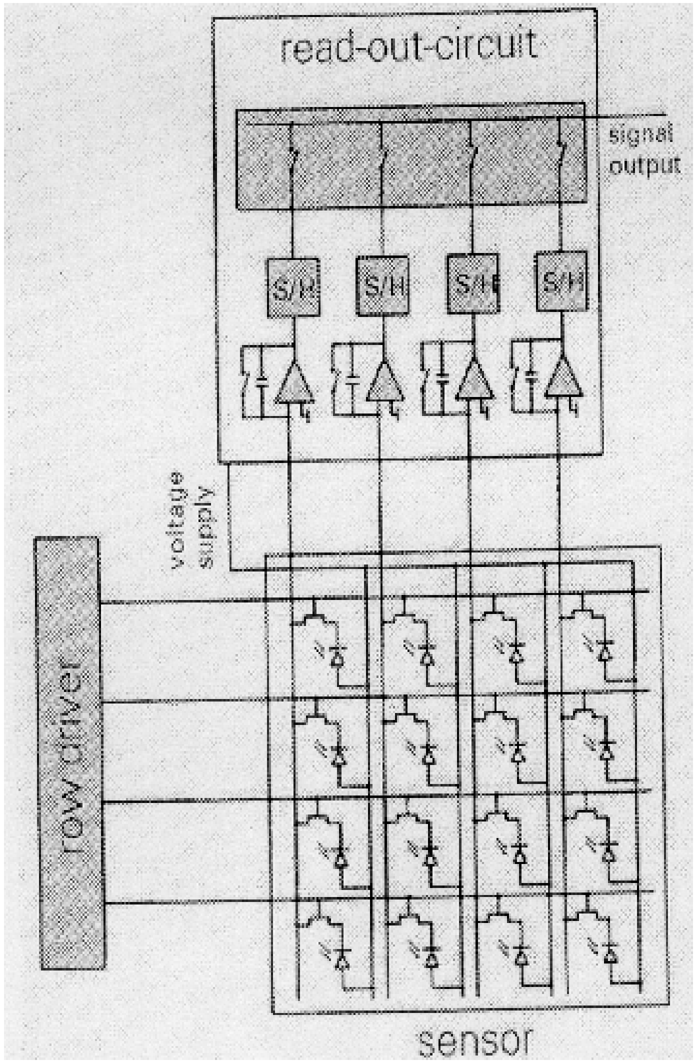
- Cover
  - Used to seal the scintillator and panel array elements
  - Must be:
    - Hermetic for CsI
    - x-ray transmissive
    - match coefficient of thermal expansion of substrate

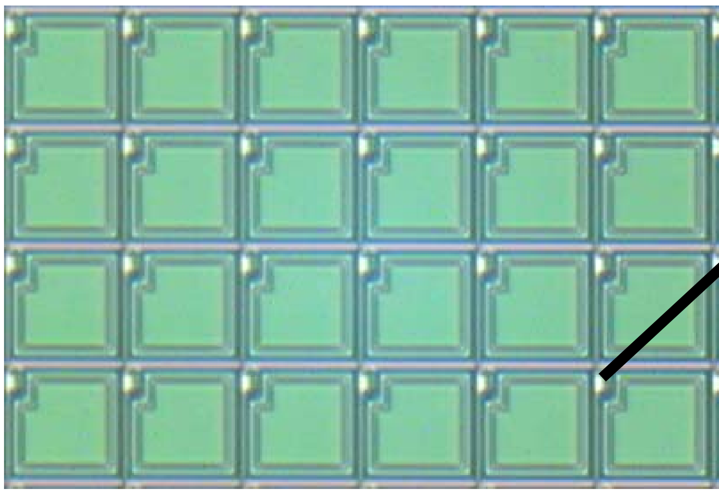
- High energy / MV build up plate
  - Generates high speed electrons to increase sensitivity
  - Reduce X-ray scatter

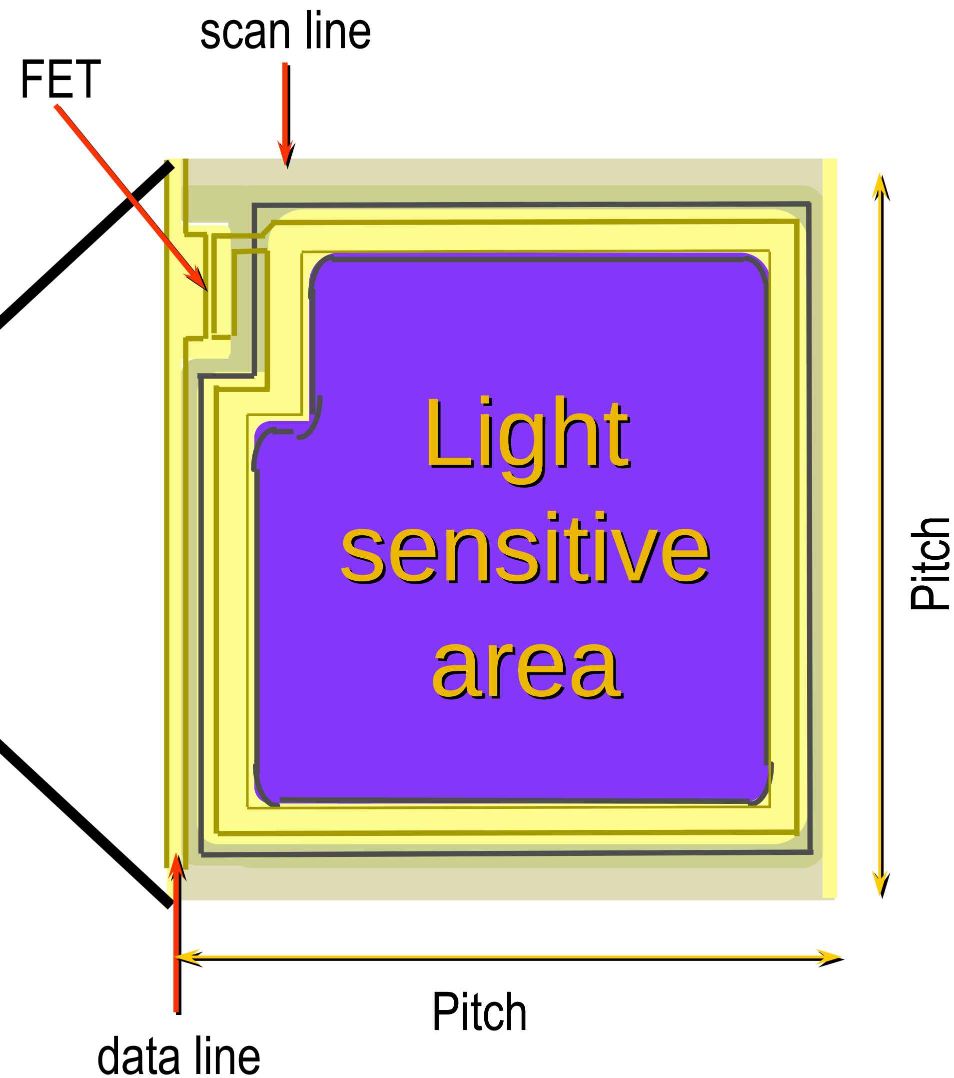
Structure of a-Si Flat Panel Detector

- Flat panel detector is fabricated in large sizes using thin film technology on glass panels.
- Contains arrays of pixels.
- Each pixel consists of an a-Si photodiode connected to a TFT.
- a-Si photodiodes are sensitive to visible light
- Generated charges are transferred to read-out circuits by TFT.



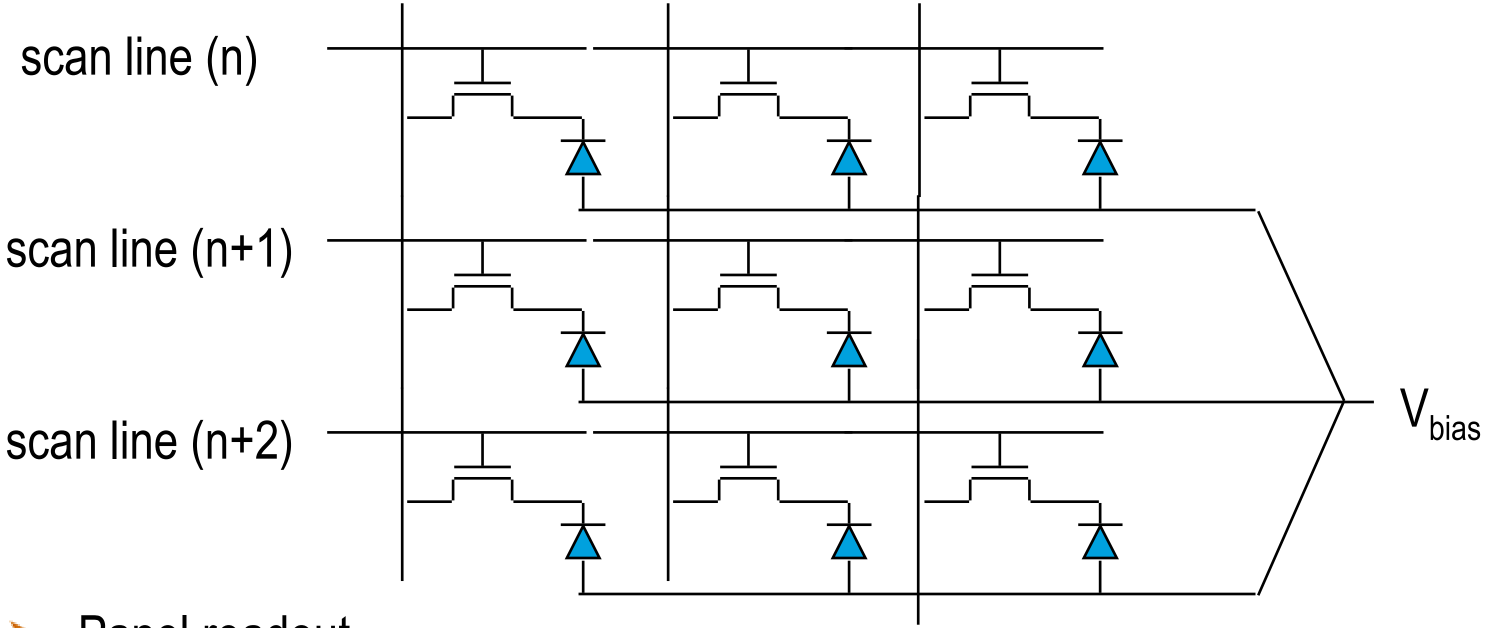
a-Si Panel: Each Pixels is a Light Sensor





$$\text{Fill Factor} = \frac{\text{Sensitive Area}}{\text{Pitch x Pitch}}$$

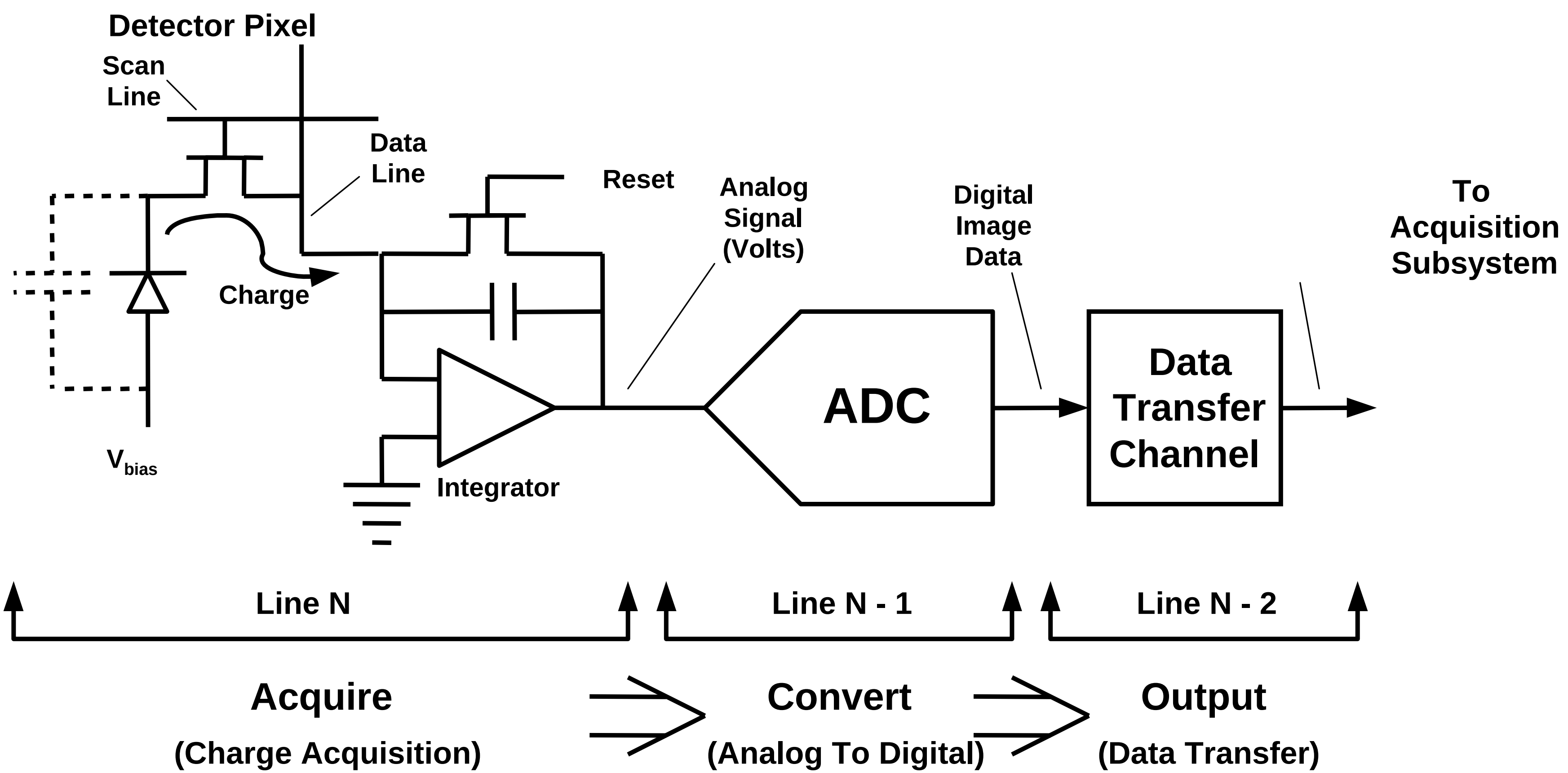
a-Si Panel: Readout Electronics



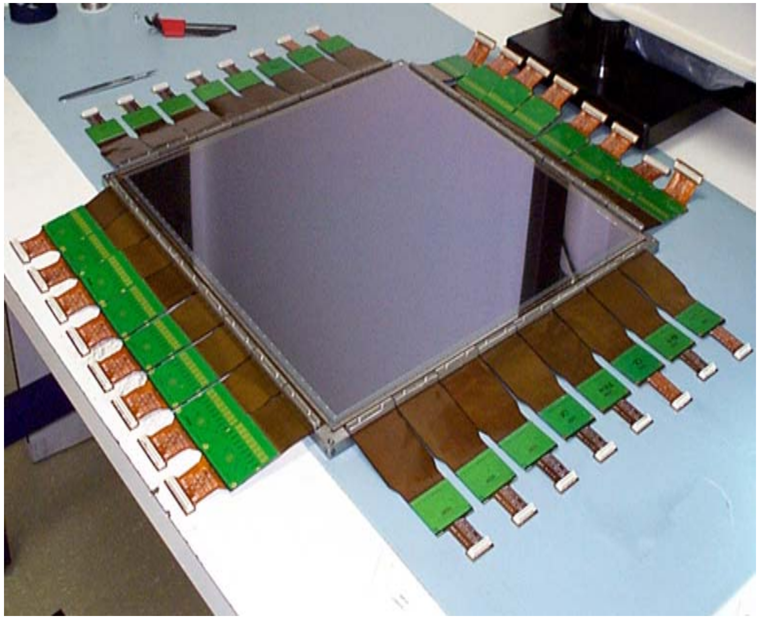
- Panel readout
  - Scan line activated and FET is turned on. Photodiode is charged.
  - Scan line deactivated and FET is turned off (Scan lines are turned on sequentially).
  - Light creates electron-hole pairs in photodiode (partially discharge).
  - For turned-on row, all photodiodes are re-charged in parallel and amount of charges for each diode transferred by data lines to readout electronics.
  - Amount of discharge is measured by readout electronics.

Pipe-lined Readout

- Contains three simultaneous processes.
- The longest process dictates the scan line time.



Detector after row/column bonding and housing

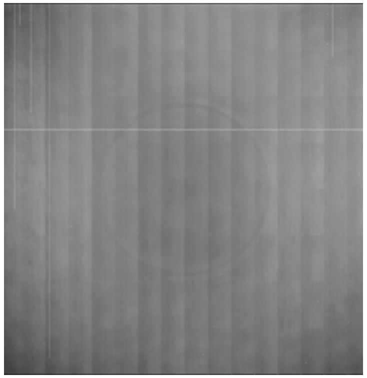


a-Si flat panel with read-out electronics

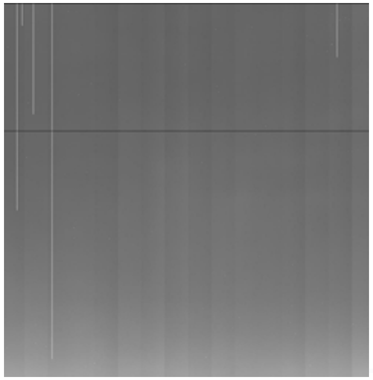
a-Si detector after housing

Calibration / Correction

- Difficulties caused by amorphous silicon compared to single-crystal silicon
  - 100 to 1000 x increase in defects
  - mobility reduced by ~ 1000 x (affects switching speeds)
  - defects give rise to complicated lag and offset behaviors
- Difficulties are overcome by
  - calibration
  - careful management of detector timing for all applications
- Calibration Images
  - Offset: corrects for the dark current of each pixel
  - Gain: homogenize differences in pixel sensitivities and X-ray beam non-uniformity
  - Bad pixel map: software correction of defective pixels



Offset Image

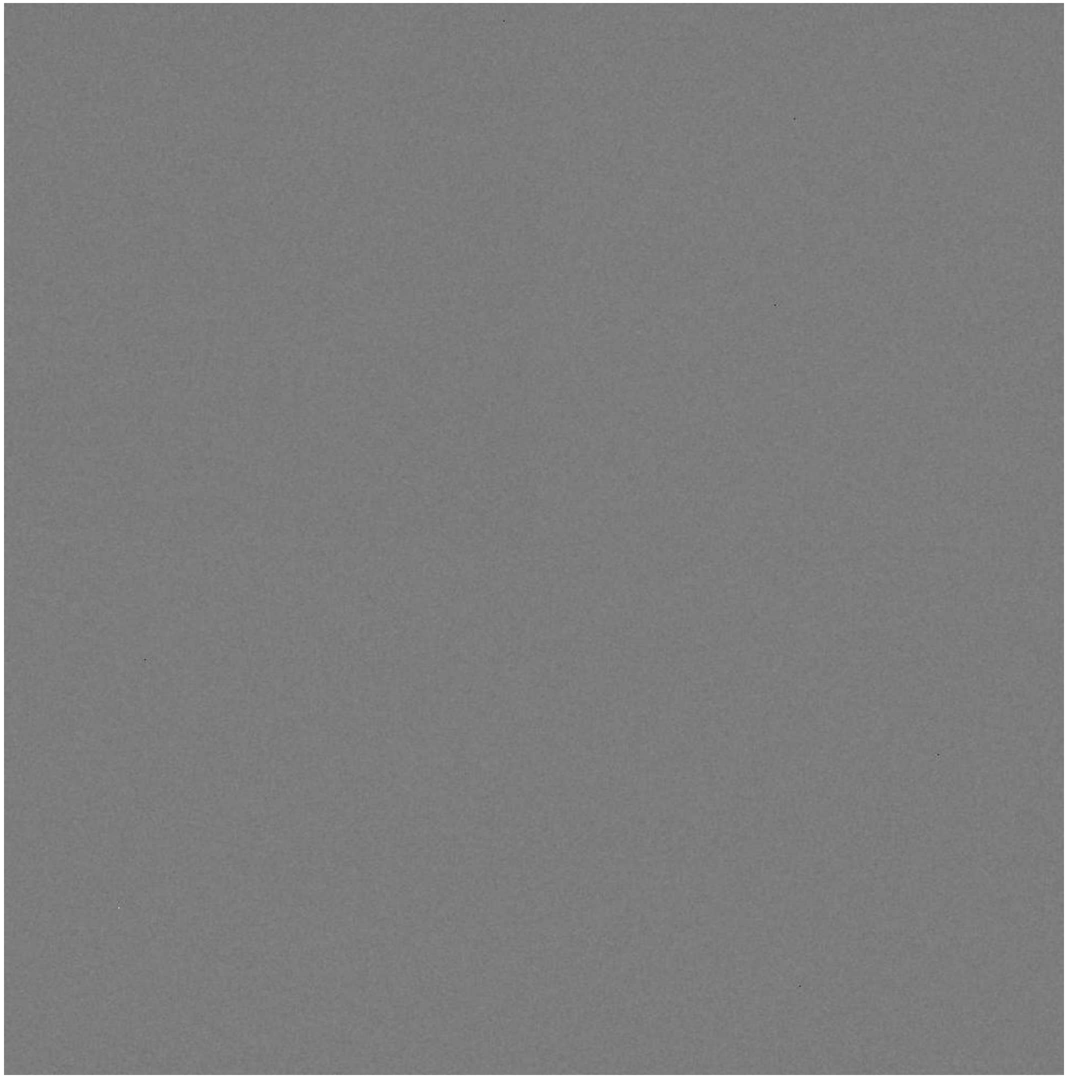


Gain Image

BPM Image

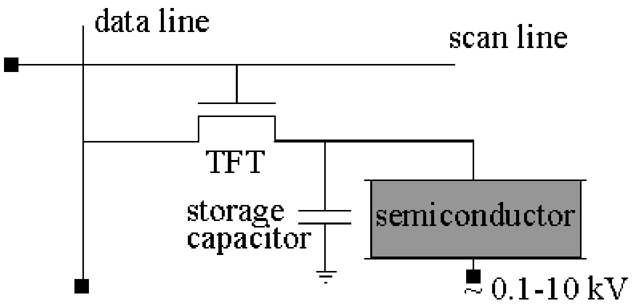
Calibration /Correction (cont.)

Fully Corrected Flat Field Image



Direct and Indirect FPDs

- Indirect a-Si FPD construction was needed due to inefficient absorption of x-rays by silicon. But some materials like Selenium have much better stopping power. Se also has photo-conductive properties. This resulted in construction of Direct type FPD.
- On absorption of x-ray energy, a-Se produces charge pairs.
- No separate scintillator is required.
- With a bias voltage, electron and holes travel to respective electrodes. TFT structure is similar to indirect type and storage capacitor for each pixel is provided.



- Lateral spread of light is absent for a-Se FPD (there is no scintillator). The resolution is determined by pixel geometry.
- Se has a limited stopping power and therefore it mainly used for low energy X-ray (up to about 100 – 150 kV).
- At higher X-ray energy, Se layer thickness would become impractically thick. Hence, alternative materials like CdTe, HgI_2 and PbI_2 are being explored as they have better stopping power.

Main choice for high energy imaging is indirect FPD

Detective Quantum Efficiency (DQE): measure of image quality

- DQE measures the transfer of signal and noise for a detector
- DQE defined as:

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

SNR = signal to noise ratio

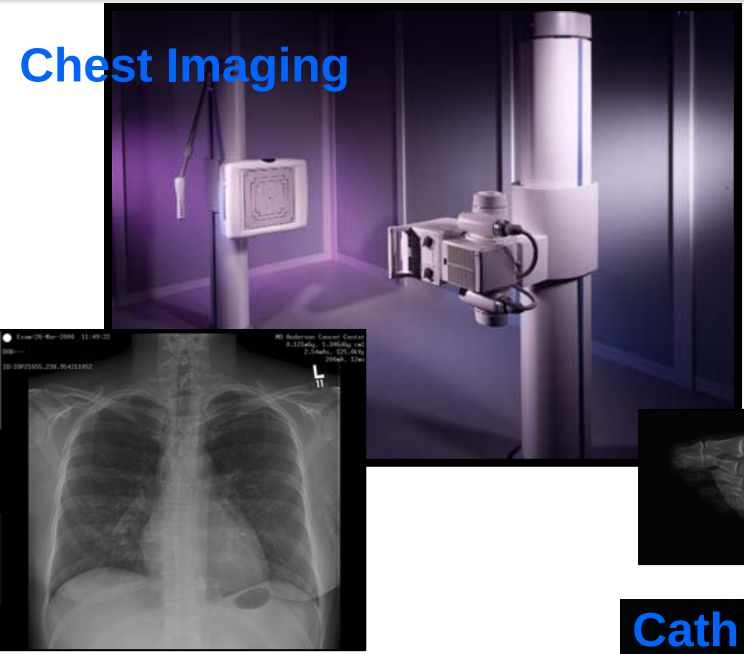
- DQE(f) is used as object-independent indicator of detector contrast to noise ratio performance.

Applications of a-Si FPDs

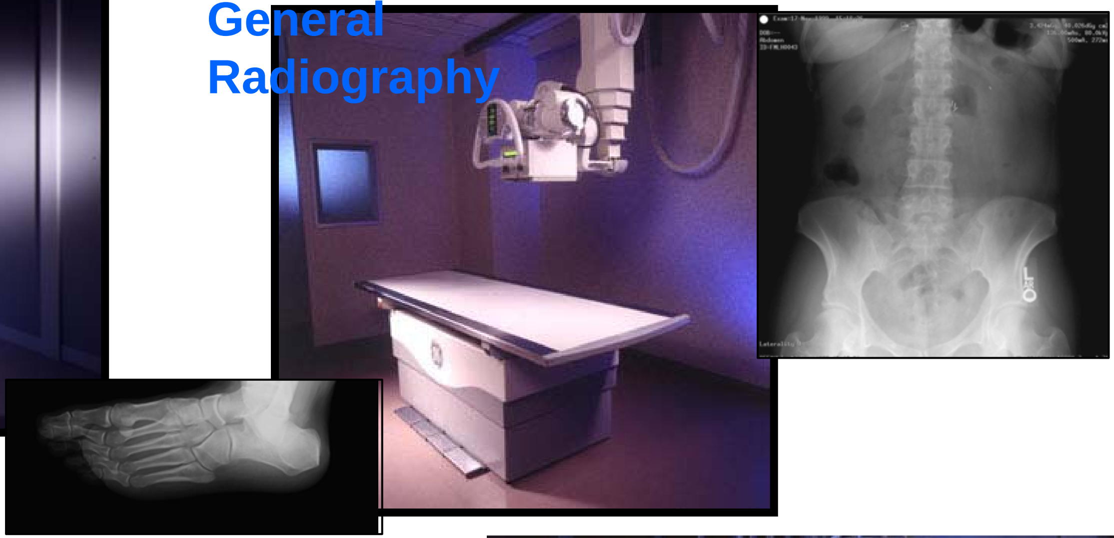
- Medical
  - Diagnostic X-ray imaging
    - Radiography
      - Human
      - Veterinary
    - Fluoroscopy
      - Cardiovascular (cardiac catheterization, angiography)
      - Surgery (Surgical C-arms)
      - Gastrointestinal
    - Mammography
  - Radiation Oncology
    - Simulation CBCT
    - Image guided radiation therapy
    - Radio surgery
    - Proton Therapy
  - Dental
    - Cone Beam CT and Panoramic
  - Biomedical Tissue Characterization
- Industrial NDT
  - Dynamic Imaging
  - Static Imaging

Medical Diagnostics Systems

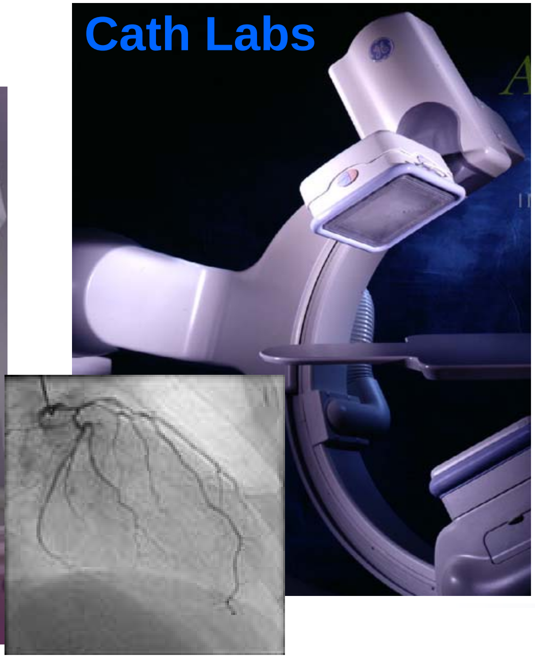
Chest Imaging



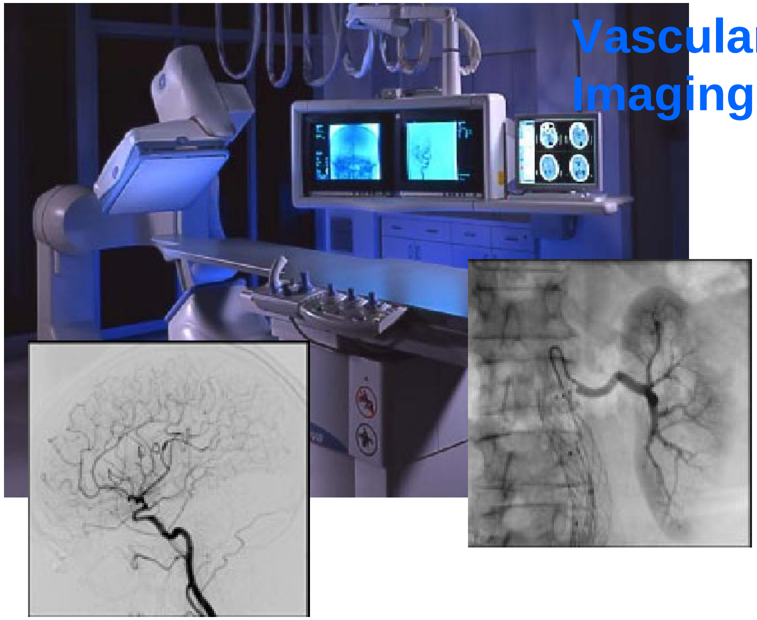
General Radiography



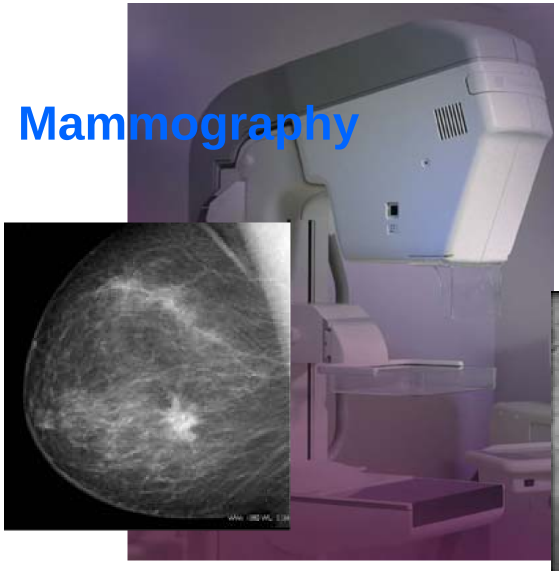
Cath Labs



Vascular Imaging



Mammography



Medical Customer Benefits

	Clinical	Productivity
Radiography & Mammography	Image Quality ⇧ Dose ⇩ New Applications Computer Aided Det.	Exam Time ⇩ Film/Chemical Cost ⇩
Fluoroscopy	Image Quality ⇧	
Radiation Therapy	Image Quality ⇧ Dose ⇩ New Applications Effective Treatment	Patient Positioning Time ⇩

Better Patient Care and Higher Productivity

Industrial NDT Applications and Benefit of Using FPDs

- Dynamic Imaging
  - Microelectronics inspection (2D and 3D CBCT imaging)
    - Wide dynamic range and bit depth: detect tiny voids in µBGA and lack of solder wetting.
    - Large SNR: Low dose 2D and 3D Cone Beam CT
    - Large area detector: enables large PCB inspection
    - Fast frame rate: real time imaging and faster CBCT acquisitions
    - High quality CBCT with improved contrast, less noise and reconstruction artifacts
  - Welding inspection
    - Wide dynamic range and bit depth
    - Large SNR
      - High quality low dose imaging (Increase efficiency and decrease re-work time, reduce operator exposure dose)
    - Maintaining high image quality at Wide range of X-ray energies for various pipe sizes/thicknesses
    - X-ray energy range from kV to MV
  - Casting inspection
  - X-ray Crystallography
  - Neutron Imaging
  - Metrology
  - Wheel inspection

Industrial NDT Applications and Benefit of Using FPDs

- Static Imaging
  - Low performance film replacement applications in Portable security, Field pipeline inspection, Composite structure (Aerospace, Automotive)
    - Higher dynamic range and bit depth
    - High SNR
      - Excellent image quality
      - Compensate the aging of isotopic radiation source
      - Potential of replacing isotopic sources with low power/low energy portable X-ray source
    - Higher productivity
      - Faster image acquisition and processing (shorter exposure time and no developing need)
      - Increase efficiency and decrease re-work time. On-site image analysis
    - Maintaining high image quality at Wide range of X-ray energies for various applications
    - Increased operator safety: Significant reduction in exposure time and exposure dose
    - Environmentally friendly (no use of chemical).

Industrial Customer Benefits

	Productivity	End User care
Static Imaging	Image acquisition time ↓ Image processing time ↓ On-site image analysis ↓ Efficiency ↑ New applications	Image quality ↑ Dose ↓ Operator safety ↑
Dynamic Imaging	Efficiency ↑ New applications	2-D Image Quality ↑ 3-D Image Quality ↑ Dose ↓ Operator safety ↑

Higher Productivity and Better End User Care

New Advanced Applications

- Medical
  - Diagnostic X-ray
    - Digital Tomosynthesis
    - Dual energy subtraction / Energy resolved method
      - Will have applications in NDT such as baggage inspection
    - Multi-modality imaging
    - Breast digital subtraction angiography
    - Replacing fan beam CT with Cone beam CT using FPD (like dental CBCT)

  - Radiation therapy
    - Image guided radiation therapy
    - Dose guided radiation therapy / Linear accelerator physics QA
    - Radio-surgery

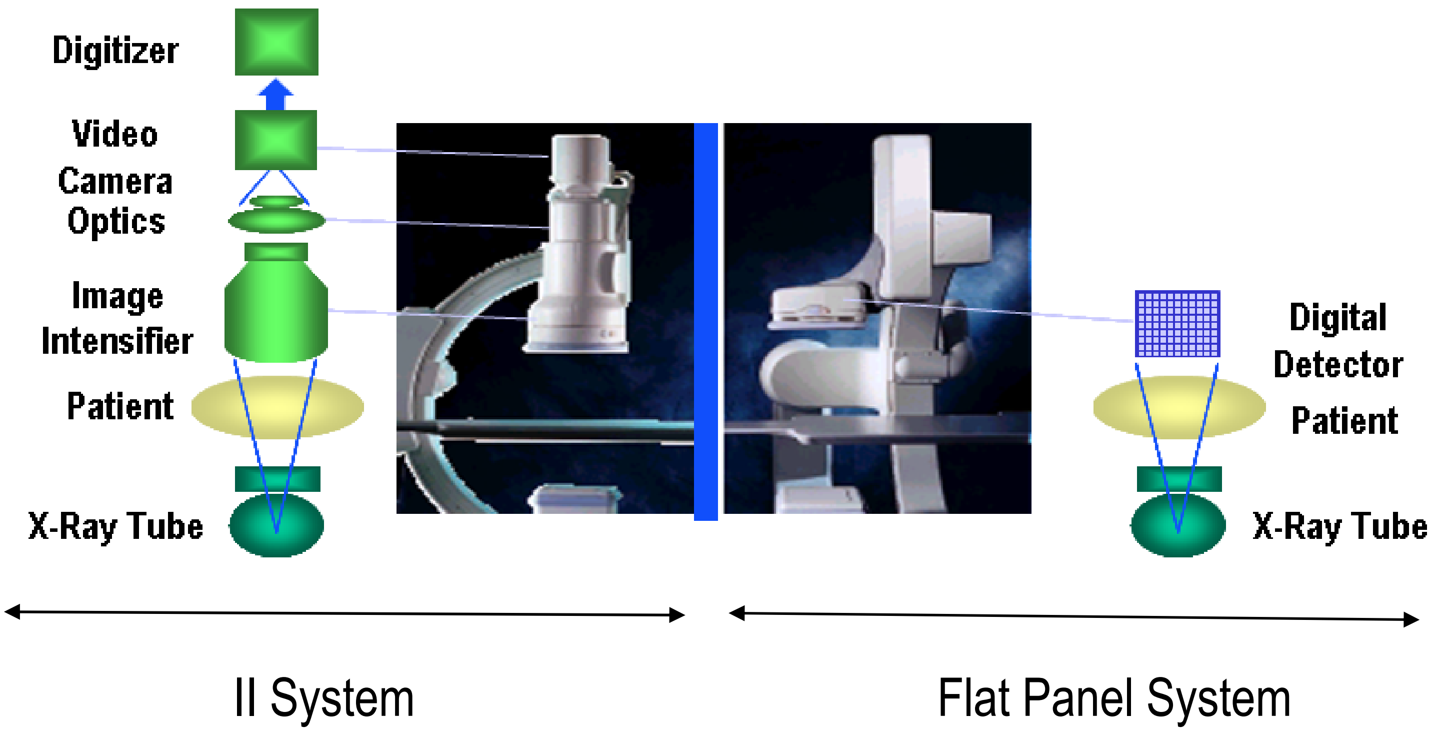
Imaging Technology Comparisons

- Dynamic Imagining
  - FPD vs X-ray Image Intensifier (II)

- Static Imaging
  - FPD vs Computed Radiography (CR)
  - FPD vs Film

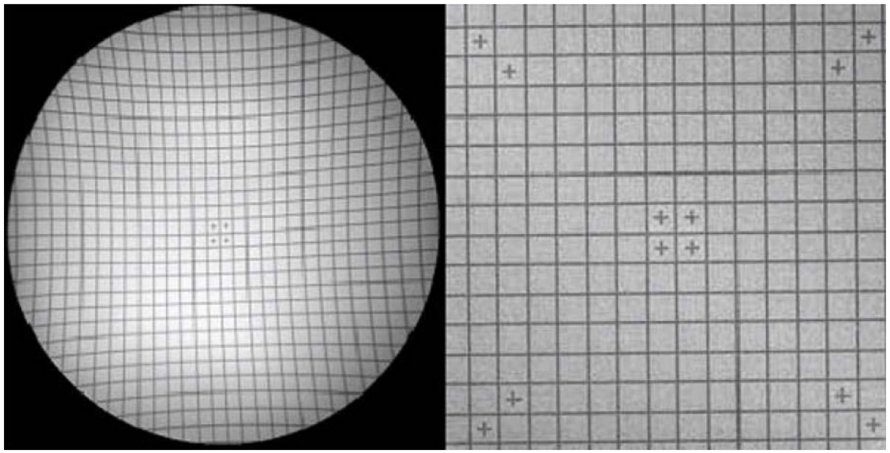
Performance Comparison: FPD vs II

- System Simplification



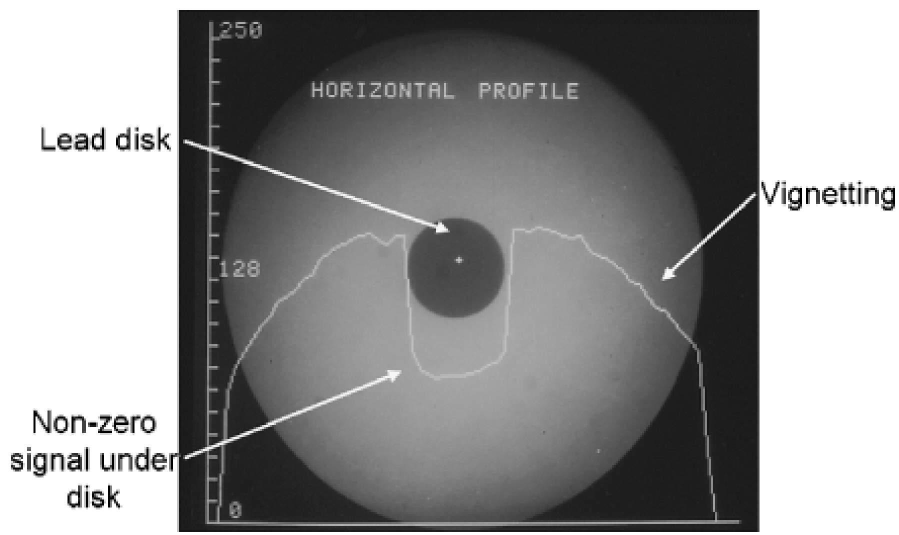
Performance Comparison: FPD vs II (cont.)

- Geometrical distortion of II



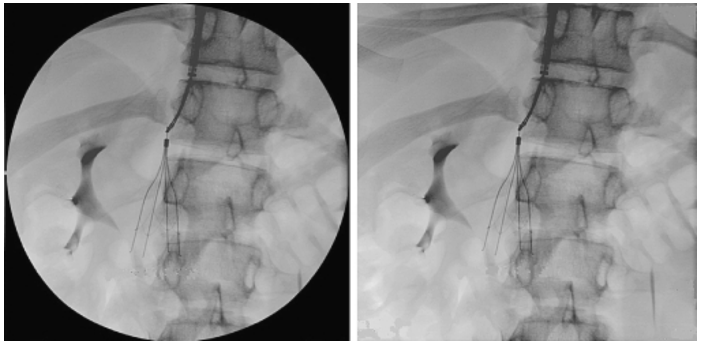
Comparison of geometrical distortion and brightness non-uniformity between a 12 inch image intensifier and 8 inch flat panel detector.

- Vignetting of II



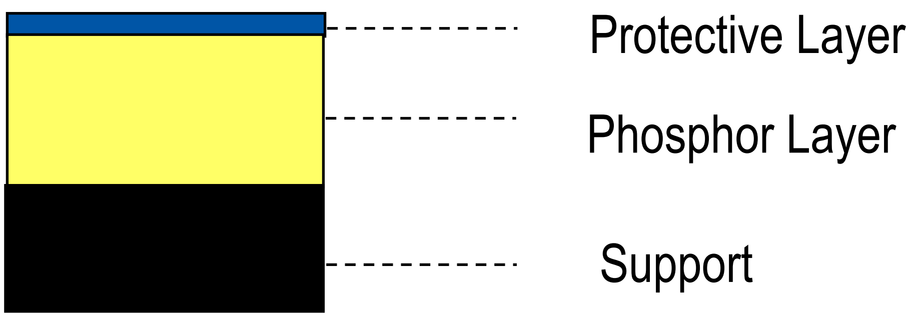
Performance Comparison: FPD vs II (cont.)

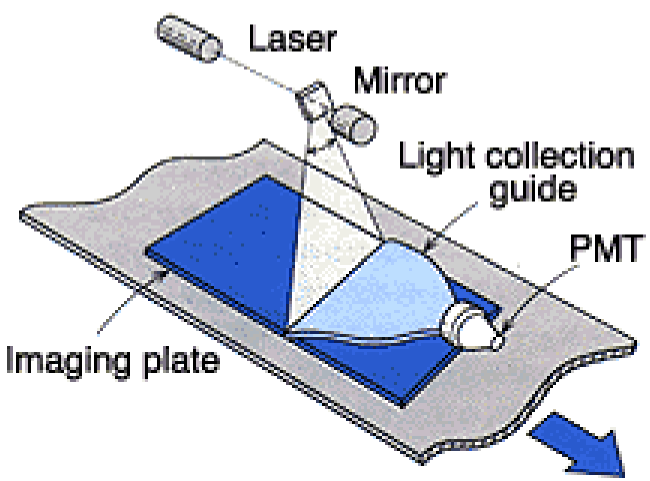
- Image format

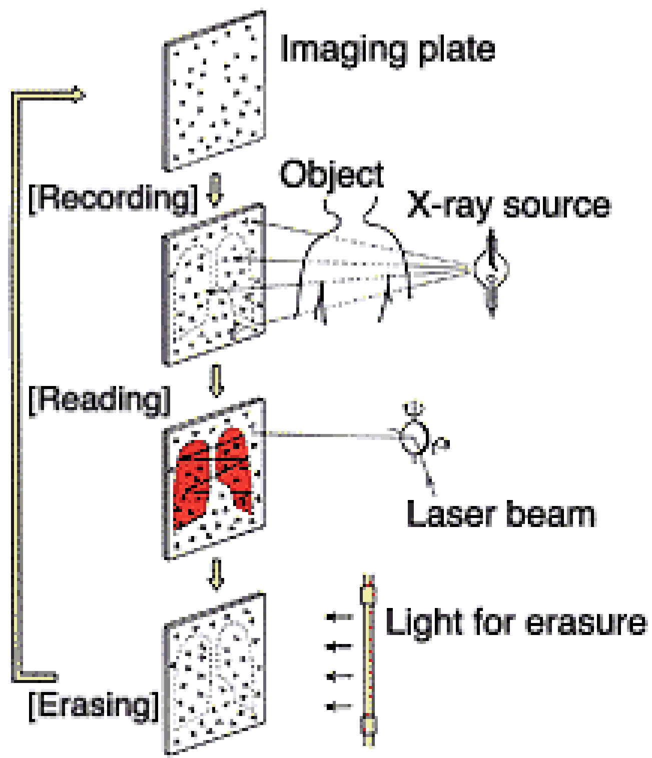


- Veiling glare of II
- Blooming of II
- Size / weight
- FPD distortion free and not subject to magnetic fields due to moving metal parts
- Image Lag

CR Technology







Performance Comparison: FPD vs CR

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a-Si FPD	CR
Higher DQE. Better image quality at lower radiation dose	Lower DQE
Higher dynamic range	Lower dynamic range
Static and real time dynamic imaging	Static imaging only (no dynamic/real time applications). Require manual processing.
Capable of Fluoro, CBCT, and advanced applications	No potential for advanced application
Higher productivity	Lower productivity
Higher cost	Lower cost

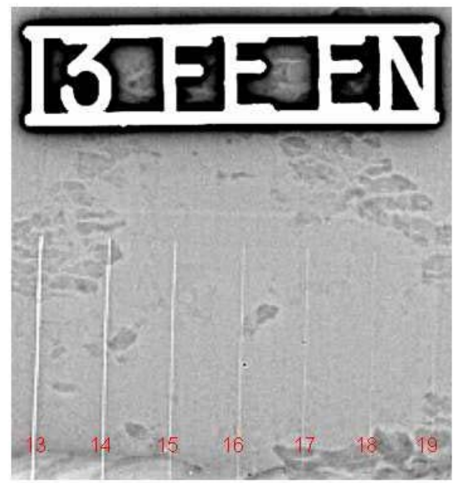
Performance Comparison: FPD vs Film

- Film is very similar to CR (except film is used in place of phosphor plate)
- Film has the same disadvantages of CR plus it requires dark room and chemical for developing film

C1 film:
wire ~16 visible
100µm contrast resolution

highpass filtered

Draht Ø
EN 462-1
W13 200µm
W14 160µm ← class B
W15 130µm
W16 100µm
W17 80µm
W18 63µm
W19 50µm



DDA (magnification = 1):
W19 = 50µm contrast resolution

200µm pixel size!

Comparison of visibility of wire type IQIs according to EN 462-1 for film (left) and FPD (right) at 8mm wall thickness. The higher SNR of the FPD allows to detect the wire W19 (50 µm diameter) at a pixel size of 200µm.

Higher SNR enables detection of defects smaller than pixel size

Performance Comparison: FPD vs Film (cont.)

- System Simplification

Film Cassette

Developer

Digitizer

Digital Detector

Film System

Digital System

Conclusions

- FPDs are digital detectors used in medical and industrial NDT applications and are replacing existing film, CR, and II technologies.
- FPDs benefits are increased productivity and better end user care compared to other technologies.
- Higher quality of FPDs resulted in new application development in X-ray imaging.
- Flat panel technology is the clear long term solution for most X-ray applications.

Thank You

References:

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