Overview of Digital Detector Technology

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Disclosure

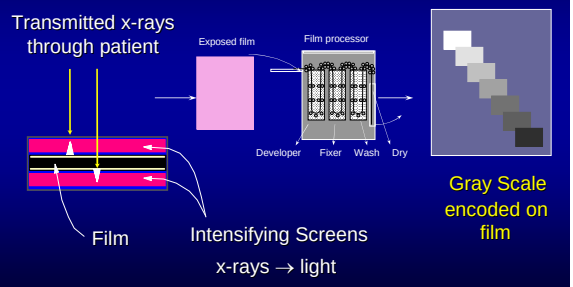
- Member (uncompensated)
  - Barco-Voxar Medical Advisory Board
  - ALARA (CR manufacturer) Advisory Board

Learning Objectives

- Describe digital versus screen-film acquisition
- Introduce digital detector technologies
- Compare cassette and cassette-less operation in terms of resolution, efficiency, noise
- Describe new acquisition & processing techniques
- Discuss PACS/RIS interfaces and features

Conventional screen/film detector

1. Acquisition, Display, Archiving



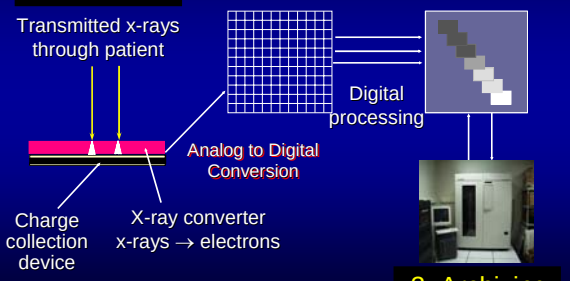
Digital x-ray detector

2. Display

Digital to Analog Conversion

1. Acquisition

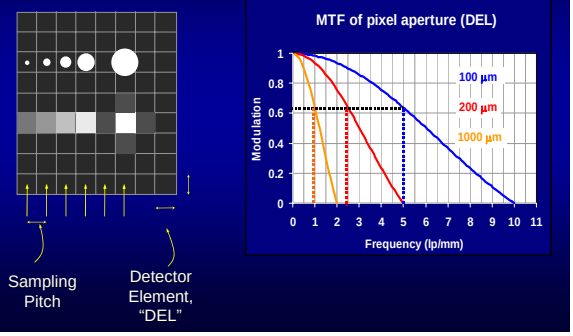
Digital Pixel Matrix



3. Archiving

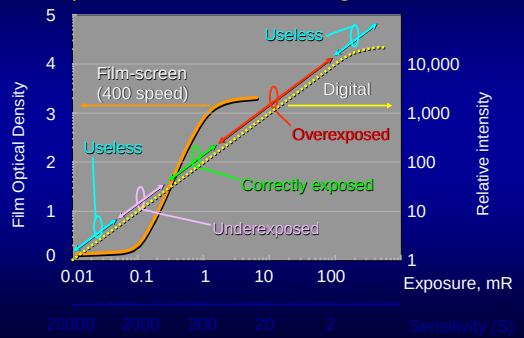
Analog versus Digital

Spatial Resolution



Characteristic Curve:

Response of screen/film vs. digital detectors

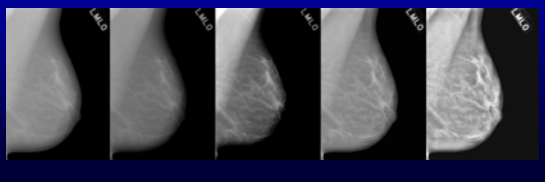


Analog versus digital detectors

- Analog
  - Coupled acquisition and display
  - Higher resolution
  - Limited dynamic range, fixed detector contrast
  - Immediate exposure feedback
- Digital
  - Separated acquisition and display
  - Lower resolution
  - Higher dynamic range and noise-limited contrast
  - Proper exposure potentially hidden

Image Processing

- Crucial for optimal image presentation
- Flexibility adds potential advantage
  - Disease-specific image processing
  - Computer aided detection



Digital System Technologies
Projection Radiography

- Computed Radiography (CR)
- CCD
- CMOS
- Flat Panel (TFT) arrays

"Direct" Radiography (DR)

Consideration: "Cassette" vs. "Cassetteless" operation

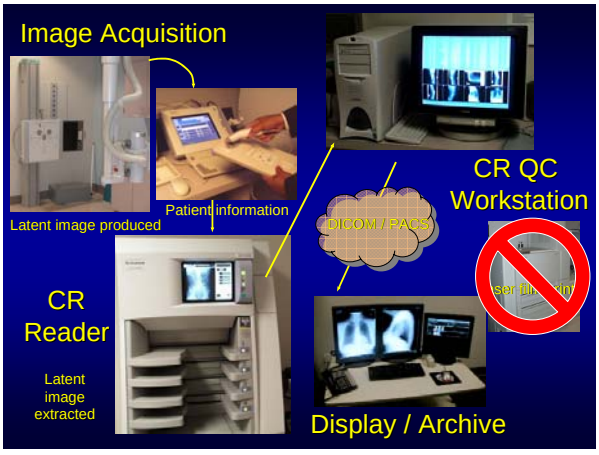
Computed Radiography (CR)

...is the generic term applied to an imaging system comprised of:

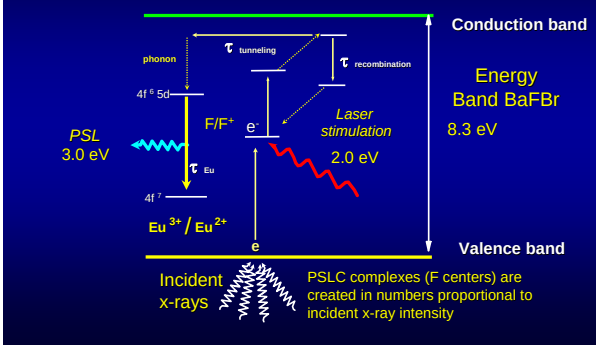
Photostimulable Storage Phosphor
to acquire the x-ray projection image

CR Reader
to extract the electronic latent image

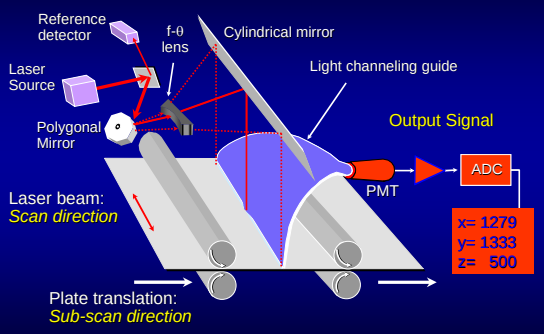
Digital electronics
to convert the signals to digital form



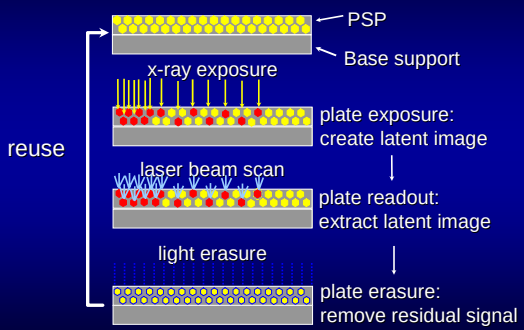
CR: Photostimulated Luminescence



CR: Latent Image Readout



Phosphor Plate Cycle



CR Innovations

- High-speed line scan systems (<10 sec)
- Dual-side readout capabilities (increase DQE)
- Structured phosphors
- Mammography applications ??
- Low cost table-top CR readers

DR: "Direct" Radiography

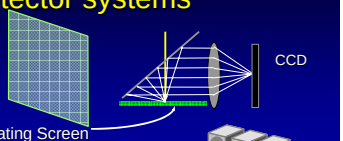
....refers to the acquisition and capture of the x-ray image *without user intervention*

– "Indirect" detector: a conversion of x-rays into light *and then* light into photoelectrons

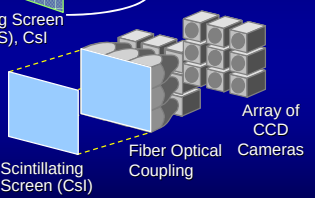
– "Direct" detector: a conversion of x-rays to electron-hole pairs with direct signal capture

CCD detector systems

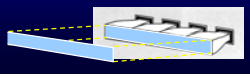
- Area Scintillator / lens coupling



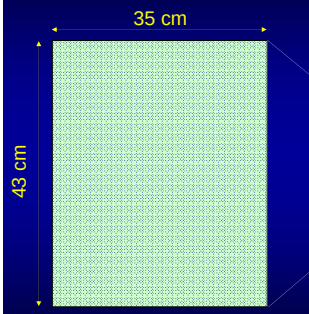
- Area Scintillator / fiberoptical coupling



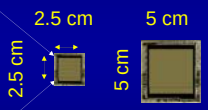
- Slot scintillator linear array fiberoptical coupling



CCD area detector



High fill factor ~ 100 %
Good *light conversion* efficiency (~85%)



4 to 16 megapixels
Optical de-magnification
Lens efficiency?
Secondary Quantum Sink

Optically coupled CCD systems

- Technology improvements are overcoming quantum sink issues (lens / phosphor)
- Low cost systems for budget-limited situations
- Capable imaging systems

Scanning slot chest x-ray system

- CCD array
- Fiberoptic coupling
- **No grid**
- Reduced scatter
- Low dose

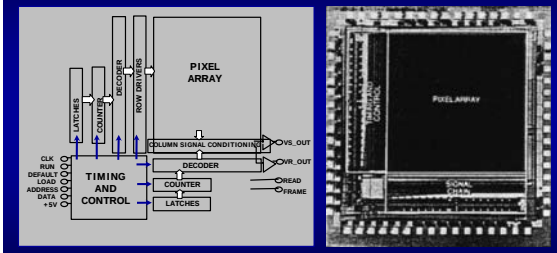
- "Effective" DQE compares to flat-panel systems

CMOS

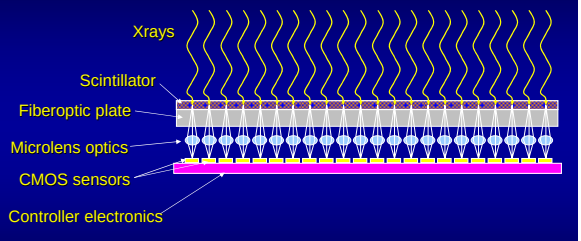
- “RAM” with photodiode converter
- Random access readout
- Low voltage operation (5V)
- ? NOISE ……
- Large FOV detector available (tiled CMOS)

CMOS

Complementary Metal Oxide Semiconductor



Array of tiled CMOS sensors



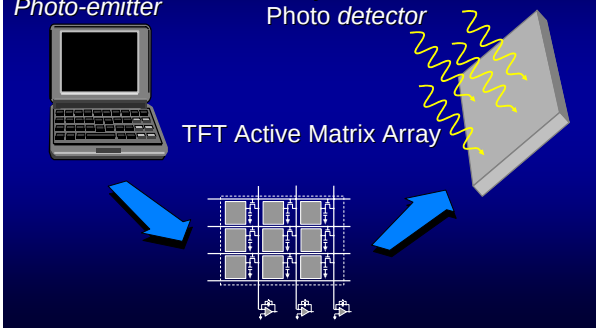
7000x7000 element array, 17” x 17” FOV for one implementation

Thin-Film-Transistor Array

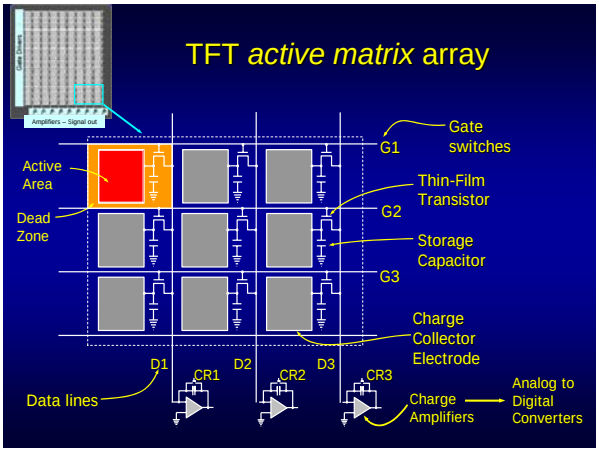
Laptop LCD display
Photo-emitter

X-ray converter
Photo *detector*

TFT Active Matrix Array

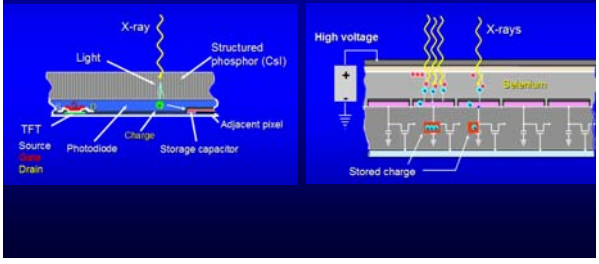


TFT *active matrix* array



Thin-Film-Transistor Array

- Indirect (CsI scintillator + photodiode)
- Direct (*a*-selenium)

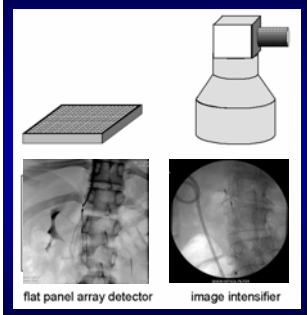


Indirect / Direct flat panel
detector systems

Flat-panel Fluoroscopy / Fluorography

- Based upon TFT charge storage and readout technology
- Thin-Film-Transistor arrays
  - Proven with radiography applications
  - Now available in fluoroscopy
    - CsI scintillator systems (indirect conversion)
    - a-Se systems (direct conversion)

Flat panel vs. Image Intensifier



Field coverage / size advantage to flat panel

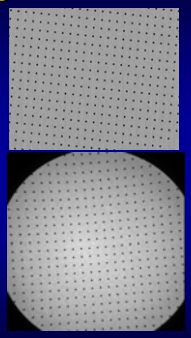
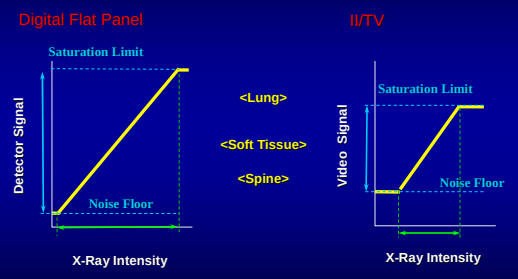


Image distortion advantage to flat panel

Flat vs. Fat

	Digital Flat Panel	*Conventional II*
Dynamic Range	Very Wide (5-10 times more than conventional)	Narrow (TV camera limit)
Distortion	No Distortion	Distortion from curved input surface of II
Detector Size	Weight and thickness much lower	Heavy, bulky detector
Image Area	41 cm x 41 cm square	Round area is more than 20% smaller area for same diameter
Image Quality	Good resolution, high DQE	Good resolution, high DQE

Dynamic range



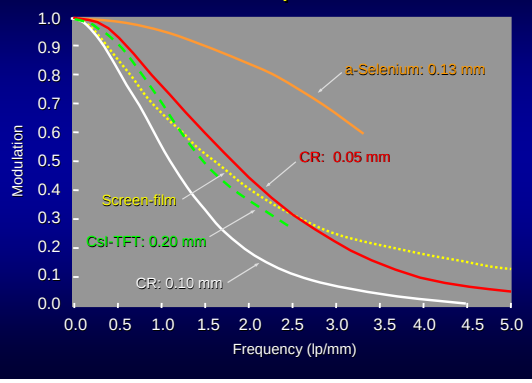
Flat panel vs. Image Intensifier

- Electronic noise limits flat-panel amplification gain at fluoro levels (1-5 μr/frame)
- Pixel binning (2x2, 3x3) offers improvements
- Low noise TFT's are slowly being produced; variable gain technologies on the horizon
- II's will likely go the way of the CRT…….

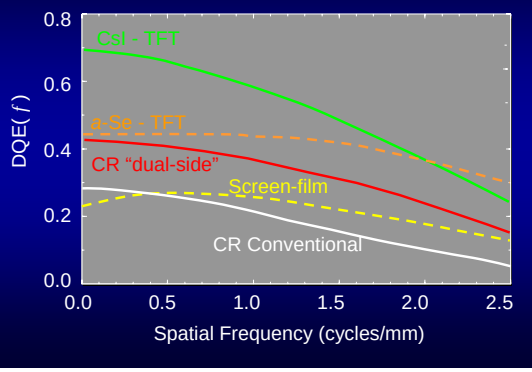
Detector Characteristics

- MTF
- NPS
- DQE

"Pre-sampled" MTF



Detective Quantum Efficiency, Radiography



Equipment considerations

- Specific applications
  - Fluoroscopy
  - Pediatrics
  - Trauma and ED
  - Orthopedics multi-film studies (scoliosis, etc)
  - Dental panorex
  - Operating room
  - Mammography
  - Radiation Therapy

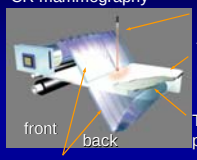
Escape

Dental Panorex example

Integration into “digital” paradigm often requires creative ideas, e.g., modification of cassette for CR

Technological Advances

CR mammography



50 μm spot

Thicker phosphor layer

Transparent phosphor base

2 light guides

Line-scan CR array reader with “structured” phosphor

Portable DR Device

Resurgence of “slot-scan” systems
- No grid, great scatter rejection
- Low patient dose

CR systems with DR form factor

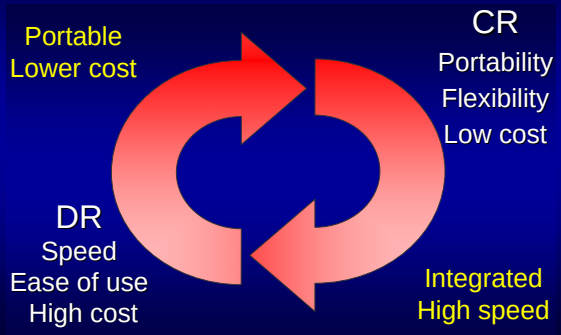
Pros and Cons: CR vs. DR

- CR
  - Flexibility*
    - portables, multiple rooms, mammography -- direct replacement
  - Proven technology*
    - 2 decades of experience
  - Screen-film paradigm
    - extra steps for processing
- DR
  - Single room use
    - Dedicated chest, bucky
    - C-arm / U-arm
  - New technology
    - experience is expanding
  - Acquire and display*
    - no extra steps
    - ↑ patient throughput

Pros and Cons: CR vs. DR

- CR
  - Limited DQE
    - Higher dose for same SNR
  - Integration/interfacing
    - PACS +++
    - x-ray system +
  - Range of systems and * costs to match needs
- DR
  - Higher DQE *
    - Better dose efficiency
  - Integration/interfacing *
    - PACS +++
    - x-ray system +++
  - Higher costs for detector and x-ray source $$$

Less distinction between CR / DR
"cassette" vs "cassetteless"

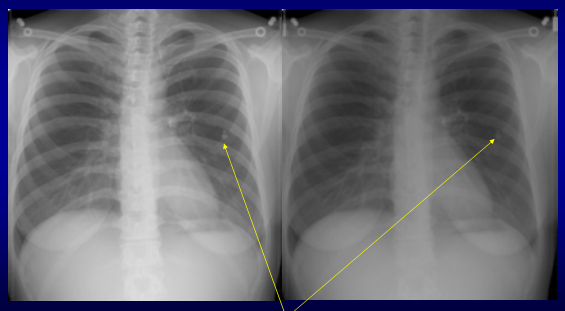


Advanced Acquisition & Processing Techniques

- Dual energy imaging
  - Tissue selective imaging
  - Differential attenuation with energy
- Digital tomosynthesis
  - Acquisition from several projection angles
  - Reconstruction of tomographic slices

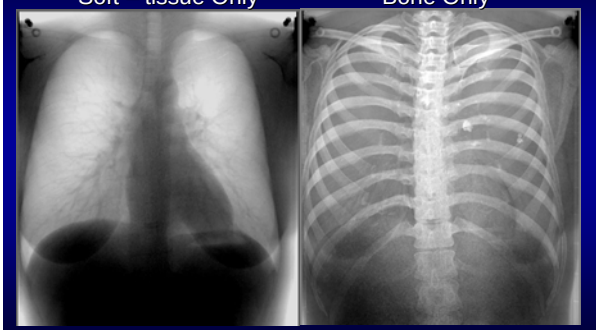
Dual Energy Image Pair

Low kVp High kVp



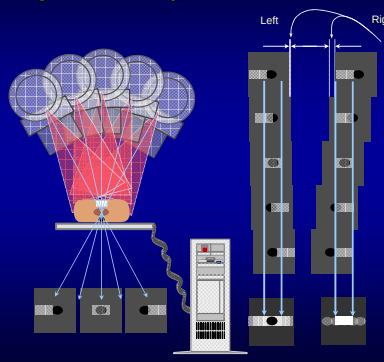
Tissue-selective Images

Soft – tissue Only Bone Only



Nodule *not* in soft tissue image → Nodule calcified

Digital Tomosynthesis: *reduce* structured noise



Shift images to select plane
Add to create tomogram

- 3 cm above detector
- 9 views, + to - 30°
- 1.4 x dose

Tomographic ramp

Niklason, L.T. et.al. Radiology 205:399-406

QC tools, phantoms, exposure data

- Consider systems with a simple yet robust QC phantom and *automated analysis*
- Look for a system having exposure information with database mining capabilities
- Find out about preventive maintenance and unscheduled maintenance procedures
- Provide for adequate quality control support!!
- QC Workshop: Wednesday, Room 608

Escape

CR / DR Implementation

- PACS and DICOM
  - Digital Imaging COmmunications in Medicine
  - Provides standard for modality interfaces, storage/retrieval, and print
- Modality Worklist (from RIS via HL-7 "broker")
  - Reduce technologist input errors
- Technologist QC Workstation
  - Image manipulation and processing
  - "For Processing" vs "For Presentation"
  - VOI LUT

CR/DR implementation

- Robust PACS/Network System
  - Image Size: Storage Needs
    - 8 - 32 Mbytes uncompressed
      - 10 Pixels/mm
      - 4300 x 3560 x 2 Bytes
    - 3 - 13 Mbytes: 2.5:1 *Lossless* Compression
    - Lossy compression???
  - Network Transmission
    - 100 Mbit/sec minimum (diagnostic workstations)

CR/DR implementation

- *Uniformity* Among CR/DR images *and* Display Monitors
  - Acceptance Testing
    - Measurement of Performance
    - Correction of Substandard Performance
  - Calibration of CR/DR Response
  - Calibration of Monitors
    - Maximum brightness
    - Look-up-Tables, DICOM GSDF, Part 14
  - Heterogeneous environment more difficult…. IHE?

Conclusions

- CR is the most *flexible and cost-effective* technology for digital acquisition
- *Direct* digital radiographic devices have advantages in efficiency and throughput
- Real-time imaging & advanced processing are clinically relevant considerations