Mammography: *Fundamental Principles, Equipment Design & Siting*

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Disclosures

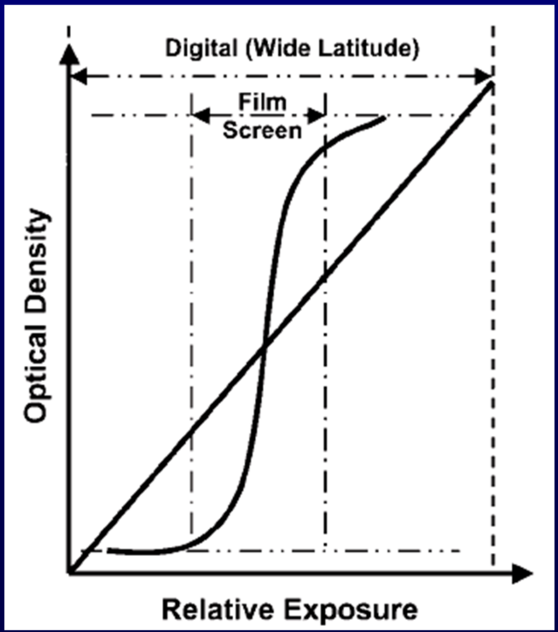
No disclosures

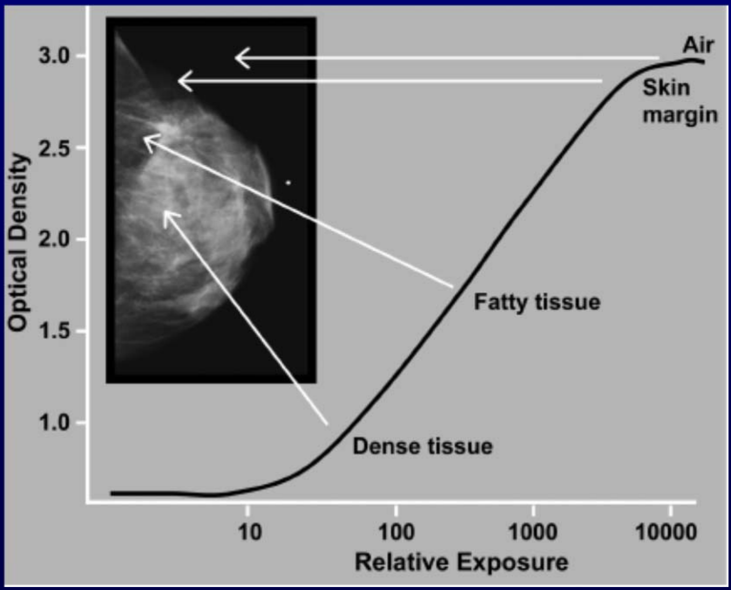
Educational Objectives

- Understand the physics of digital detector technology
- Recognize that vendors use varying detector technology in FFDM systems
- Appreciate the advantages and disadvantages of digital mammography systems
- Radiation Dose in FFDM systems
- Economics of FFDM systems

Full-Field Digital Mammography (FFDM) versus Screen-Film Mammography (SFM)

- Wide dynamic range (1000:1) compared with SFM (40:1)
- Dynamic image manipulation
- Ability to post-process
- Soft-copy read accompanied by computer-aided-diagnosis (CAD)
- 3D imaging





Radiographics 2004:24,1749

FFDM versus SFM
Digital vs. Analog

SF Mammography

- Recording — *Inherent to Film/Screen*
- Display — *Fixed Light Box*
- Archival — *Film Library*

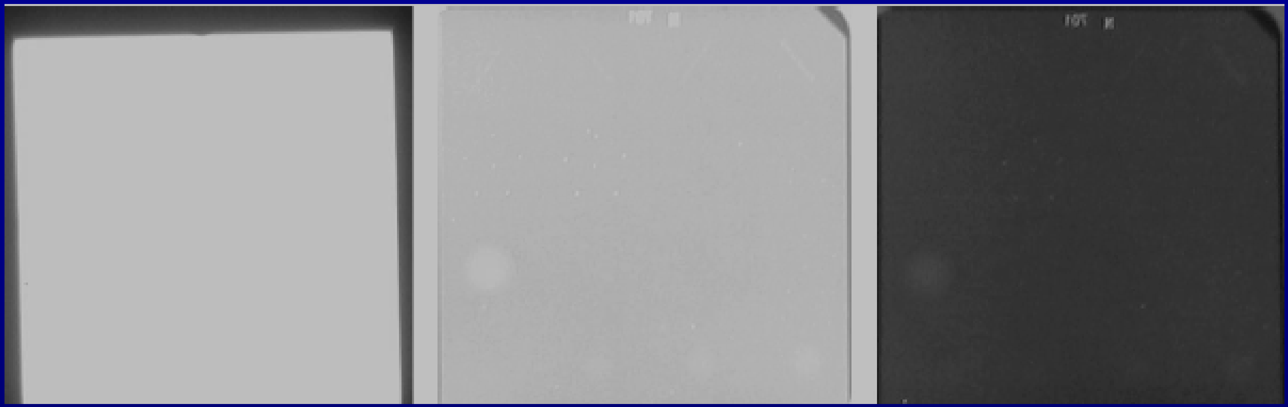
All-in-one offers simplicity, but inflexibility…

FFDM

- Recording
  - *Detector Class*
  - *System Configuration*
  - *Appropriate Technique (COMPLEX)*
- Display
  - *Image processing*
  - *Monitor calibration, read conditions*
  - *WW/WL / Magnification / ROIs*
- Archival
  - *Storage and transmission (compression)*
  - *User Interface: Hanging protocols*
  - *Tele-radiology*

Allows individual optimization of each process, but more opportunity for mistakes

SFM vs. FFDM

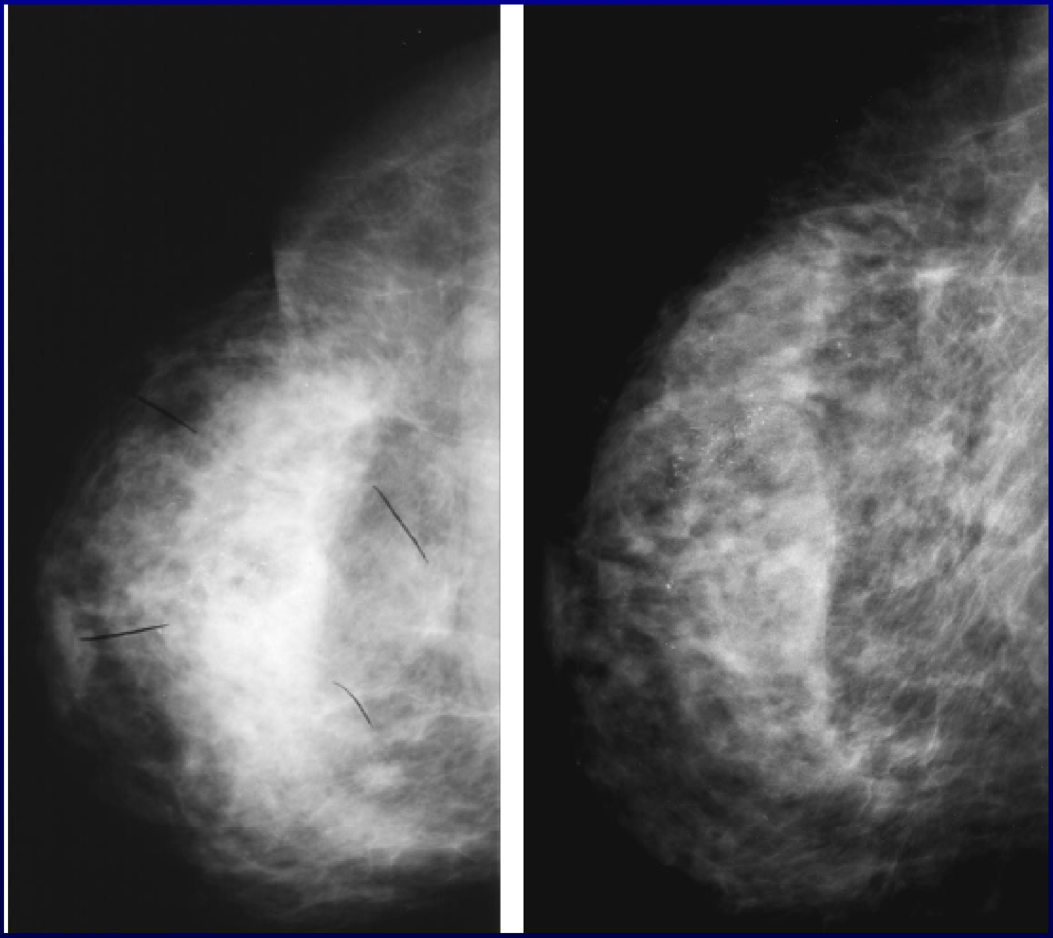


SFM: Half mAs, Automatic exposure control, Double mAs

FFDM: Same technique factors as SFM, W/L adjusted

Radiographics 2004:24,1750

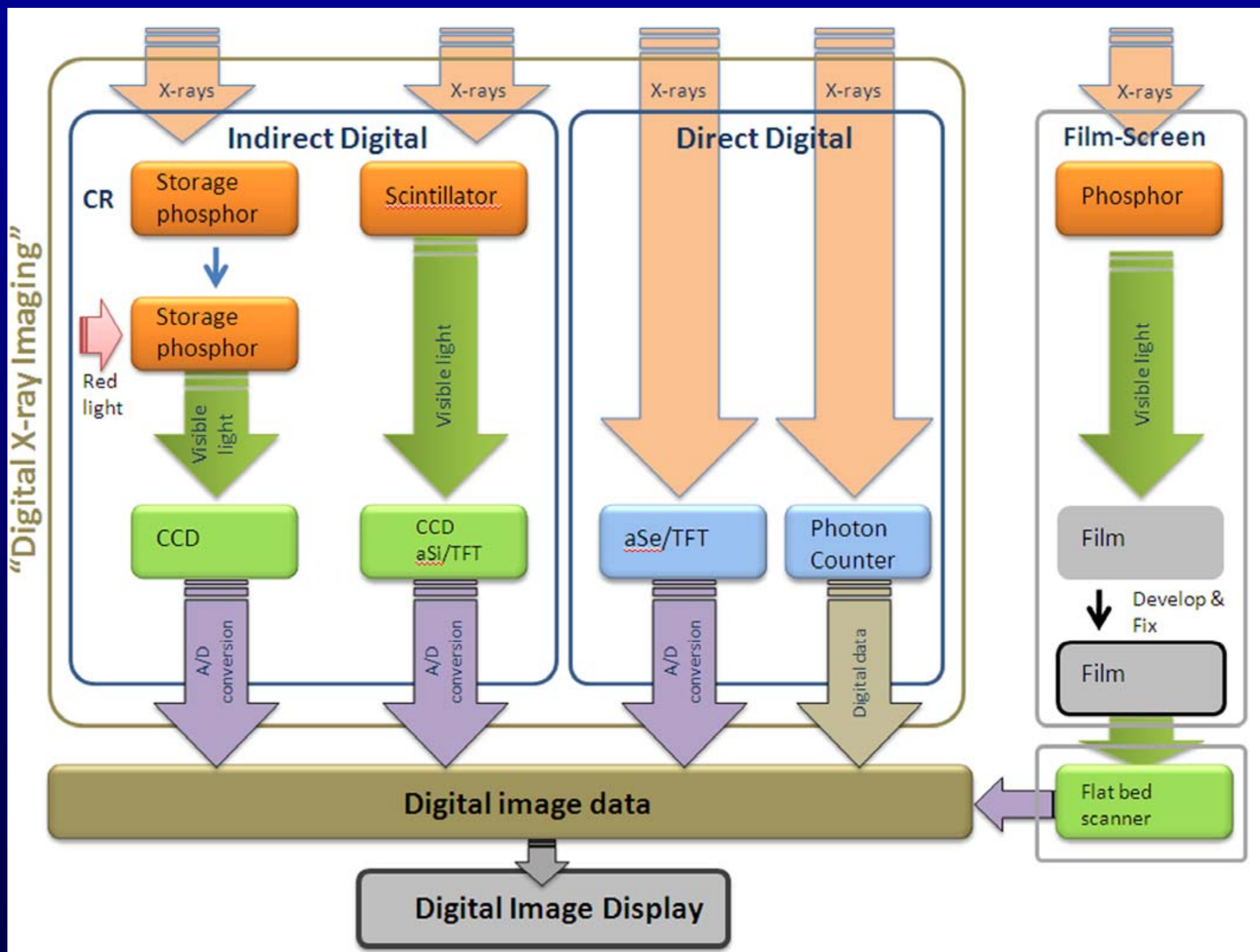
SFM vs. FFDM



SFM FFDM

Radiographics 2004:24,1751

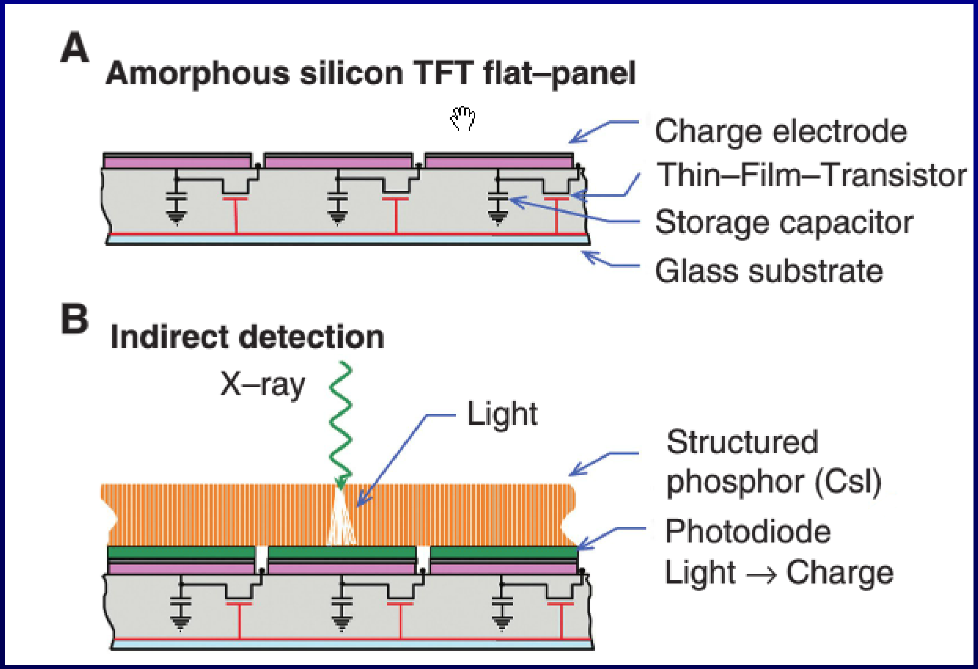
Technologies for FFDM



c.f: RSNA/AAPM Web module on Digital imaging

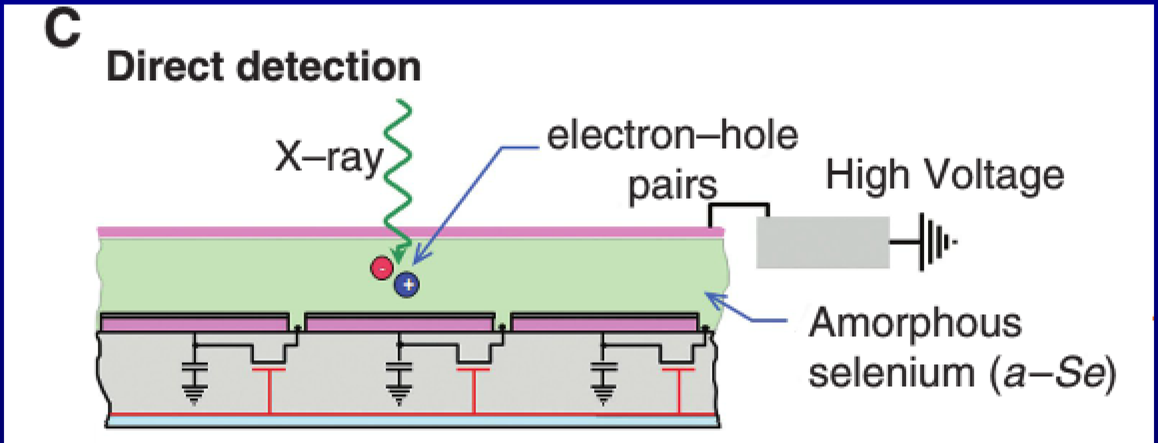
Technologies for FFDM - Indirect Capture

- A scintillator such as cesium iodide (CsI) absorbs x-rays and generates a light scintillation
- Detected by an array of photodiodes or charge-coupled devices (CCDs)
- Resolution degradation



c.f: Bushberg, Third edition, pg. 266

Technologies for FFDM - Direct Capture



- X-ray photons are captured by a photoconductor such as amorphous selenium (a-Se), which converts the absorbed x-rays directly into a electron-hole pair
- Spatial resolution limited to pixel size

c.f: Bushberg, Third edition, pg. 266

Vendor Approaches - FFDM systems

- **Indirect**
  - A single flat-panel scintillator and an amorphous silicon (a-Si) diode array – *GE*
  - Slot scanning with scintillators and CCD arrays – *Fischer Imaging, not commercially available now*
  - Photostimulable phosphor plates - *Fuji*
- **Direct**
  - A flat-panel amorphous selenium (a-Se) array – *Hologic, Siemens*
  - A dual-layer a-Se system using direct optical switching technology - *Fuji Aspire HD*

FDA and Digital Mammography

- FDA Office of Device Evaluation
- Clears FFDM for sale in US
- Approves monitors and printers for sale in US

- FDA Office of Communication, Education and Radiation Programs
- Writes and enforces MQSA regulations
- Issues MQSA certificates

FDA and Digital Mammography

- *FDA approved, cleared, or accepted the following FFDM for use in mammography facilities as indicated by date:*
  - Konica Minolta Xpress CR System on 12/23/11
  - Agfa CR System on 12/22/11
  - Fuji Aspire CR System on 12/8/11
  - Giotto Image 3D-3DL FFDM System on 10/27/11
  - Fuji Aspire HD FFDM System on 9/1/11
  - GE Senographe Care FFDM System on 10/7/11
  - Planmed Nuance Excel FFDM System on 9/23/11
  - Planmed Nuance FFDM System on 9/23/11

FDA and Digital Mammography

- Siemens Mammomat Inspiration Pure FFDM System on 8/16/11
- Hologic Selenia Encore FFDM System on 6/15/11
- Philips (Sectra) MicroDose L30 FFDM System on 4/28/11
- Siemens Mammomat Inspiration FFDM System on 2/11/11
- Hologic Selenia Dimensions 2D FFDM System on 2/11/09
- Hologic Selenia S FFDM System on 2/11/09
- Siemens Mammomat Novation S FFDM System on 2/11/09
- Hologic Selenia FFDM System with a Tungsten target in 11/2007

• Fuji CR Mammography on 07/10/06

FDA and Digital Mammography

- GE Senographe Essential FFDM System on 04/11/06
- Siemens Mammomat Novation DR FFDM System on 08/20/04
- GE Senographe DS FFDM System on 02/19/04
- Lorad/Hologic Selenia FFDM System on 10/2/02
- Lorad Digital Breast Imager FFDM System on 03/15/02
- Fischer Imaging SenoScan FFDM System on 09/25/01
- GE Senographe 2000D FFDM System on 01/28/00

MQSA Scorecard

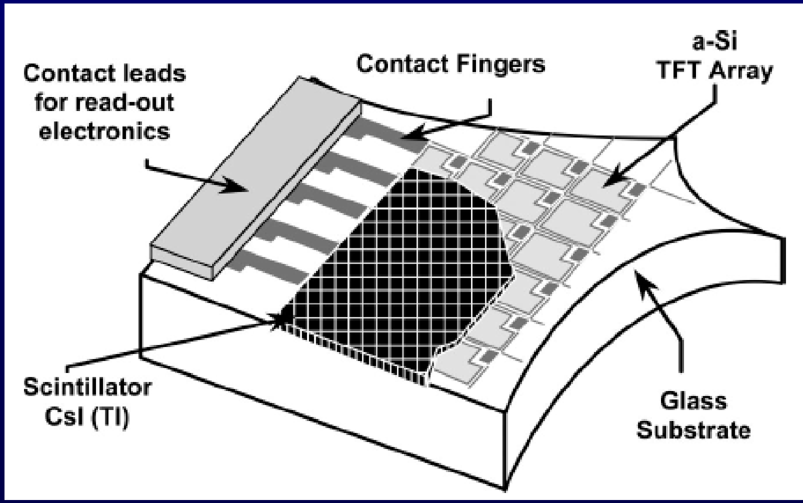
- Certification statistics, as of June 1, 2012
- Total certified facilities / Total accredited units
  - 8,626 / 12,367
- Certified facilities with FFDM units / Accredited FFDM units
  - 7,313 / 10,639
- **85%** certified facilities with FFDM units
- **86%** accredited FFDM units

http://www.fda.gov/Radiation-EmittingProducts/MammographyQualityStandardsActandProgram/FacilityScorecard/ucm113858.htm

Technologies for FFDM – Indirect Capture GE

c.f, GE FFDM manual

- In this system, the digital detector array is constructed from an a-Si thin-film transistor (TFT) matrix deposited on a glass substrate
- The CsI scintillator is deposited on the a-Si detector
- Each light-sensitive diode element is connected by TFTs
- To a control and a data line so that charge produced in the diode is read out in response to light emission from the scintillator



Radiographics 2004:24,1753

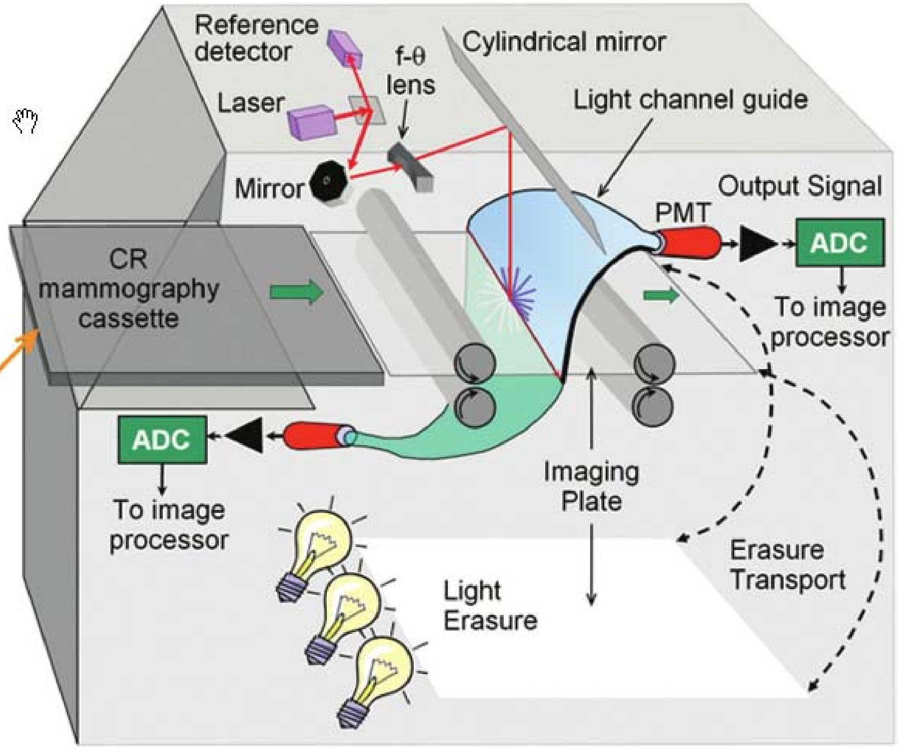
Technologies for FFDM – Indirect Capture GE

	2000D	DS	Essential
Detector size	19.2 x 23.0	19.2 x 23.0	24.0 x 30.7
Pixel size	100 µm	100 µm	100 µm
Limiting Spatial Resolution	5 lp/mm	5 lp/mm	5 lp/mm
Image size	1914 x 2294 pixels (9 MB)	1914 x 2294 pixels (9 MB)	2394 x 3062 pixels (14 MB)
Bit Depth	14	14	14

Technologies for FFDM – Indirect Capture GE –

- **Advantages and Disadvantages**
- Bonding between CsI and a-Si ensures minimal light loss
- Strong signal from the Si diode array yields higher detective quantum efficiency
- Detector is linear over a wide range (10^5)
- Limiting factor is the large pixel size (100 µm)
- Smaller pixel sizes improve spatial resolution but at the cost of increased image noise and decreased SNR for the same breast dose
- Possibility of ghosting in images

Technologies for FFDM – Indirect Capture
Fuji – CR technology



c.f: Bushberg, Third edition, pg. 266

Technologies for FFDM – Indirect Capture
Fuji – CR technology

- Fuji FCR*m*, Dual-side reader

Detector size	18 x 24 24 x 30
Pixel size	50 µm
Image size	3328 x 4096 pixels (24 MB)
Spatial Resolution	10 lp/mm
Dynamic Range	14 bits

http://www.fujimed.com/

Technologies for FFDM – Indirect Capture Fuji – CR technology

- **Advantages and Disadvantages**
- Film-screen cassettes can be replaced by CR cassettes without replacing the entire system
- Both small and large cassettes can be accommodated by the reader
- Dual side reader, 50 μm pixel size

- Effective pixel size influenced by phosphor thickness, light diffusion within phosphor, laser light scatter & diameter of laser beam
- Technologist time on processing of images
- Noise associated with the low collection efficiency of emitted light

Technologies for FFDM – Indirect Capture Fischer – SenoScan (not available now)

- A narrow slot-detector and a narrow fan beam of x-rays are scanned synchronously across the full field of view to cover the entire breast
- System consists of phosphor (thallium-activated CsI) with fiberoptic coupling to a CCD

Radiographics 2004:24,1752

Technologies for FFDM – Indirect Capture
Fischer – SenoScan (not available now)

	Fischer SenoScan
Detector material and design	Caesium iodide with 4 CCDs
Detector area (cm)	21 x 1 *
Maximum field size (cm)	21 x 29
Image acquisition time (time to display image on workstation) (s)	12 to 15
Image matrix (pixels)	4096 x 5625
Pixel pitch (μm)	25 or 50
High contrast limiting resolution (lp mm^{-1})	13 (at 25 μm) 10 (at 50 μm)

Technologies for FFDM – Indirect Capture Fischer – SenoScan (not available now)

- **Advantages and Disadvantages**
- Compact detector that is less expensive compared to others
- Excellent scatter rejection due to small volume of breast exposed at any time
- No grid needed therefore less dose
- Longer compression since scan times are longer (approx. 6 sec)
- Powerful tubes, elaborate signal readout and image reconstruction required

Comparison – Indirect Capture

	GE DS	Fischer Seno	Fuji FCRm
Detector size	19.2 x 23.0	21 x 1	18 x 24 24 x 30
Pixel size	100 µm	25 or 50 µm	50 µm
Limiting Spatial Resolution	5 lp/mm	13 lp/cm at 25 10 lp/cm at 50	10 lp/mm
Image matrix	1914 x 2294 pixels	4096 x 5625	3328 x 4096

Technologies for FFDM – Direct Capture
Hologic – Selenia

- a-Se, photoconductor is deposited directly onto the a-Si TFT substrate enabling direct capture
- The a-Se detector directly converts x-rays to electron-hole pairs
- The a-Si TFT converts the electron-hole pairs to electronic signal

http://www.hologic.com/wh/digisel.htm

Technologies for FFDM – Direct Capture Hologic – Selenia

Detector size	24.0 x 29.0
Pixel size	70 µm
Image size	3328 x 4096 pixels (24 MB)
Spatial Resolution	> 7 lp/mm
Dynamic Range	14 bits

http://www.hologic.com/wh/digisel.htm

Technologies for FFDM – Direct Capture Hologic – Selenia

- Advantages and Disadvantages
- Advantage is that the detector response function maintains its sharpness even with increasing thickness
- Potential weaknesses are the need for high biasing voltage, drifting of the dark signal and cost of detector
- Inherent sharpness of detector may also increase the severity of aliasing artifacts associated with undersampling on any digital detector

Technologies for FFDM – Direct Capture Fuji – Aspire HD

- Smallest pixel pitch of 50µm, a first in a dual-layer amorphous-selenium
- Direct Optical Switching Technology replaces the need to use TFT as in conventional DR FFDM
- Tungsten x-ray tube with a rhodium filter

http://www.fujifilmusa.com/products/medical/digital-mammography/aspire-hd/index.html#overview

Technologies for FFDM – Direct Capture
Fuji – Aspire HD

Detector size	24.0 x 30.0
Pixel size	50 µm
Image size	3328 x 4096 pixels (24 MB)
Spatial Resolution	> 7 lp/mm
Dynamic Range	14 bits

http://www.fujifilmusa.com/products/medical/digital-mammography/aspire-hd/index.html#overview

Technologies for FFDM – Direct Capture Siemens – Mammomat Novation

- a-Se, photoconductor with TFT array

Detector size	**24.0 x 29.0**
Pixel size	**70 µm**
Image size	**3328 x 4096 pixels (24 MB)**
Spatial Resolution	**> 7 lp/mm**
Dynamic Range	**14 bits**

http://www.medical.siemens.com

Comparison – Direct Capture

	Hologic Selenia	Siemens Novation	Fuji Aspire HD
Detector size	24 x 29	24 x 29	24 x 30
Pixel size	70 µm	70 µm	50 µm
Limiting Spatial Resolution	> 7 lp/mm	> 7 lp/mm	10 lp/mm ?
Image matrix	3328 x 4096 2560 x 3328	3328 x 4096	3328 x 4096

Planmed

- 85 µm pixel size
- Amorphous selenium (a-Se) direct-conversion detector
- Two detector sizes - 17x24 cm (Planmed Nuance) and 24x30 cm (Planmed Nuance Excel)
- Tungsten tube, Ag/Rh filters

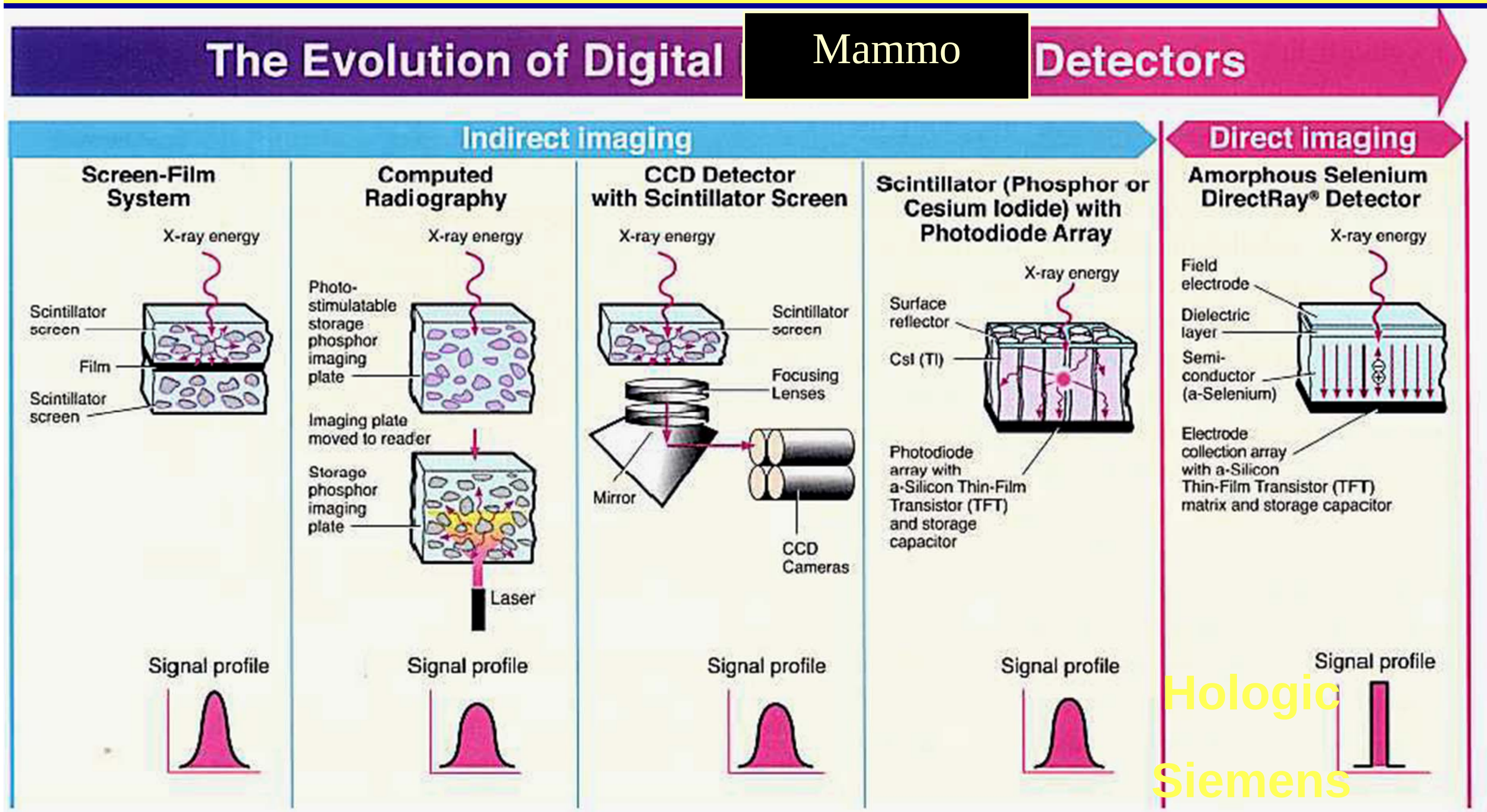
http://www.planmed.com

Giotto

- 85 µm pixel size
- Amorphous selenium (a-Se) direct-conversion detector
- Two detector sizes - 18x24 cm and 24x30 cm
- Tungsten tube, Rh filter

http://www.imsitaly.com/downloads.html

Technologies for FFDM



Direct

a-Se/
optical
switching

Fuji/Kodak/
Agfa/Philips

Fischer
(Hologic)

GE

Planmed
Giotto

Fuji
Aspire
HD

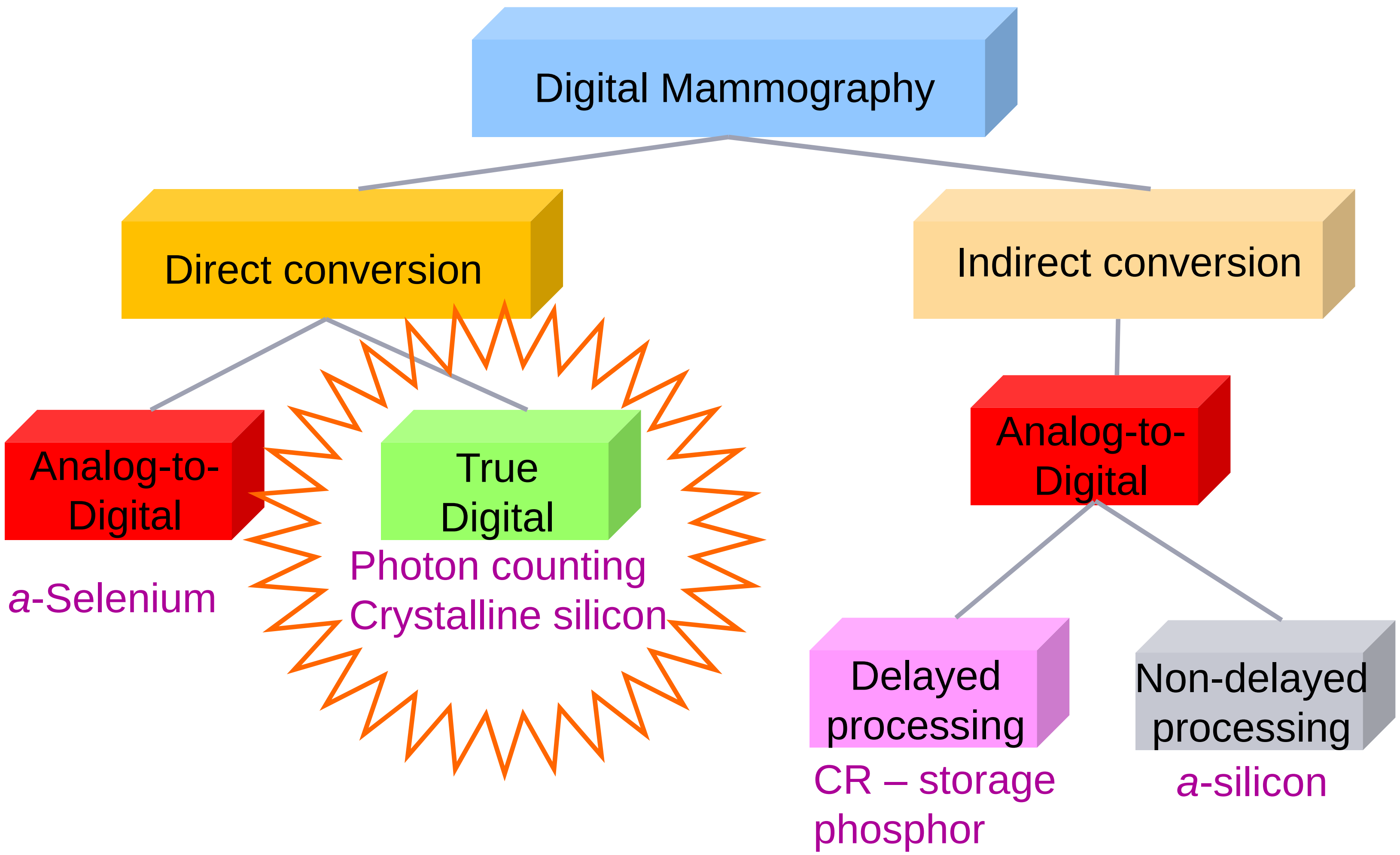
http://www.hologic.com/oem/pdf/DROverviewR-007_Nov2000.pdf

Photon Counting Technology

- Slides are Courtesy of Dr. Eric Berns and Philips

PHILIPS

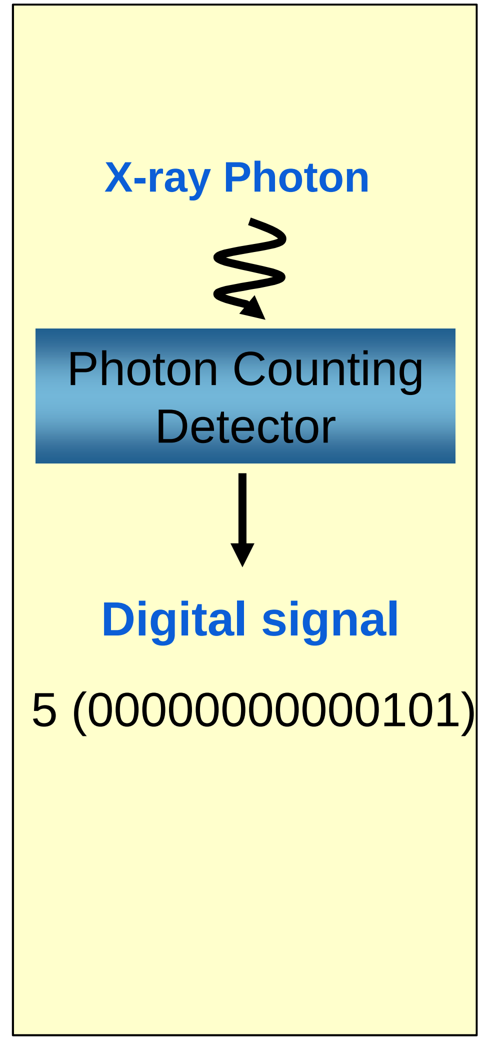
Digital Mammography
Technology Overview



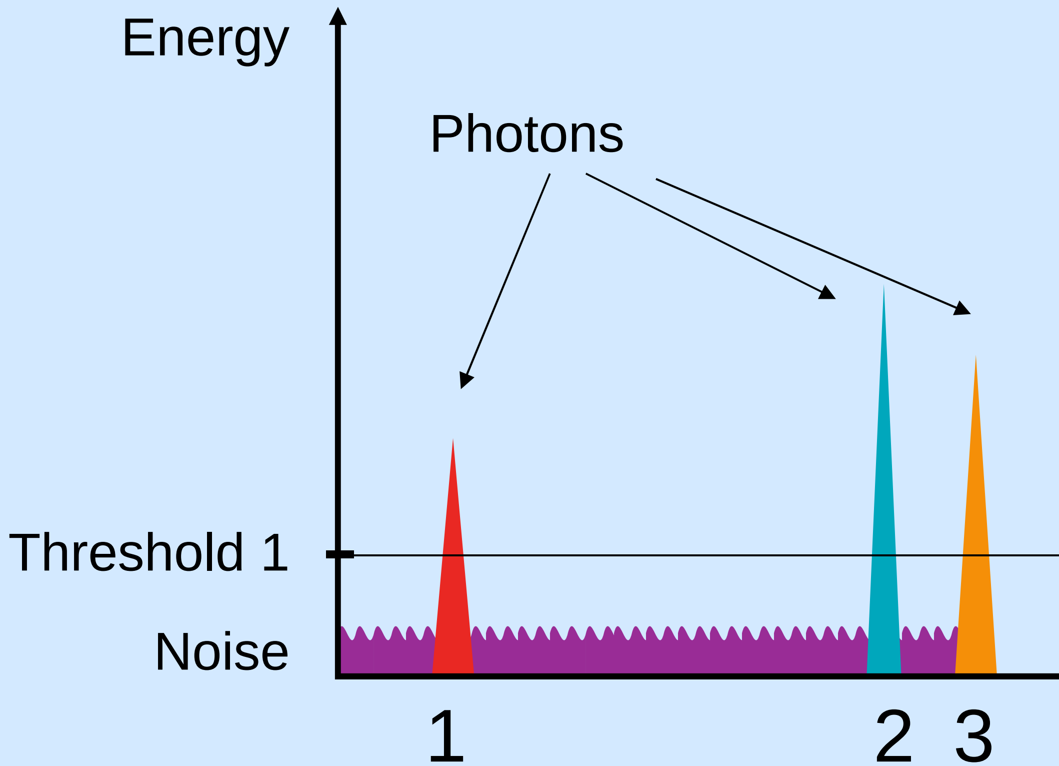
PHILIPS

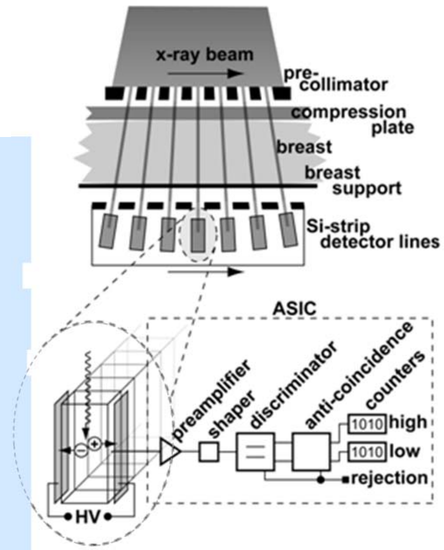
Photon Counting Technology

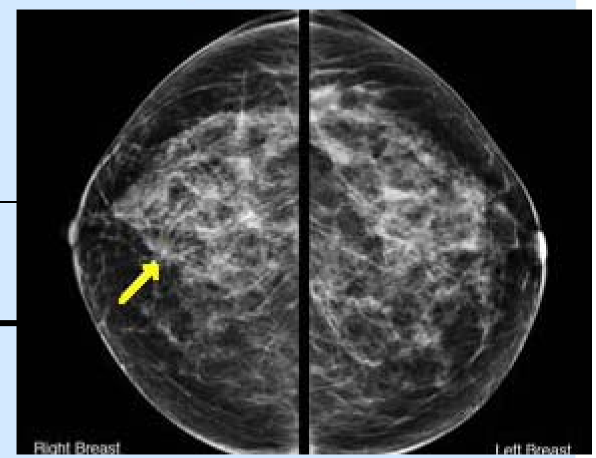
- Direct multi-slit scanning
- Crystalline silicon detector



Electronic Noise Removal







No anti-scatter grid required

Multi-slit detector module scans the breast

Module contains 50 um detector elements, 21 detector lines

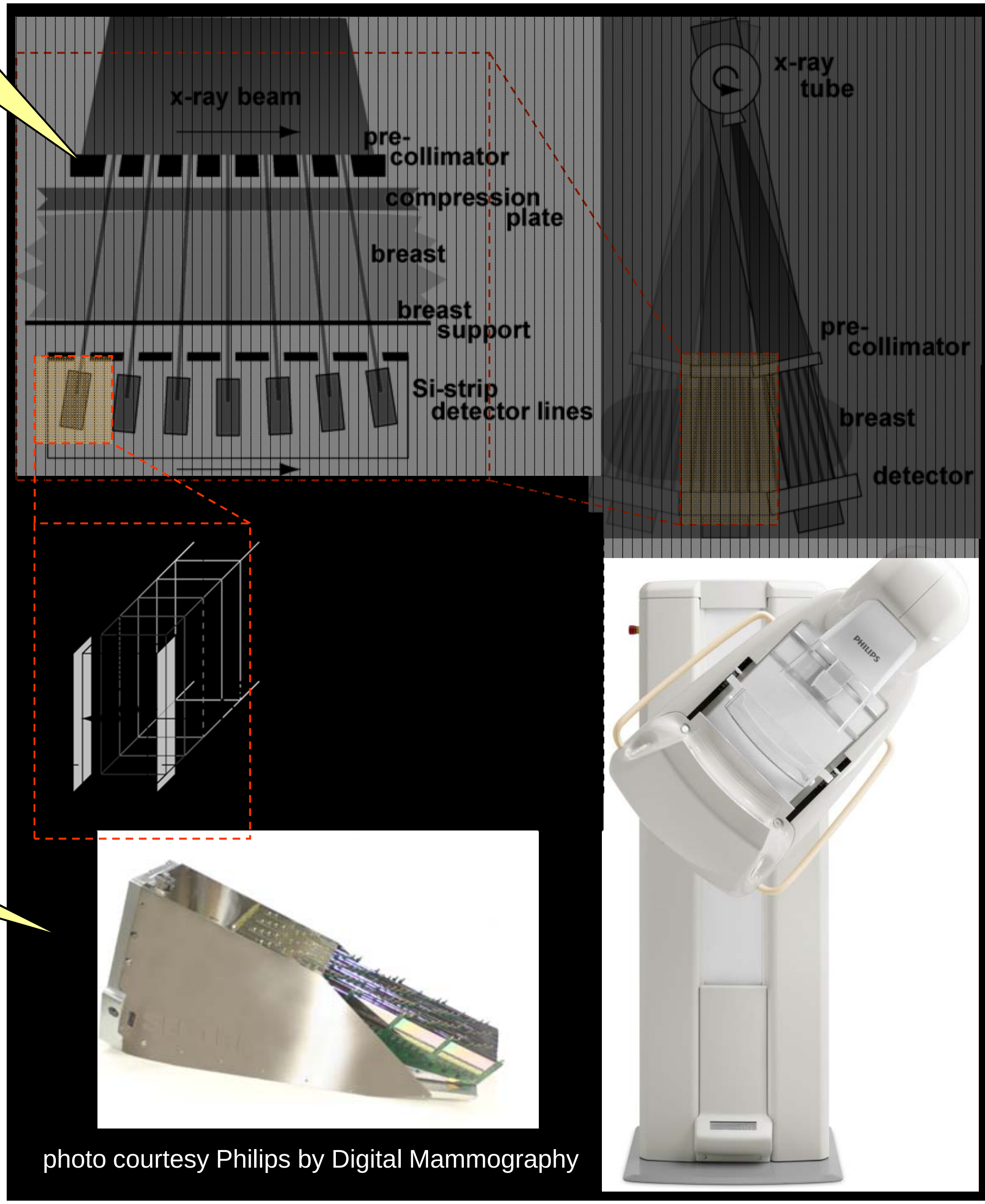
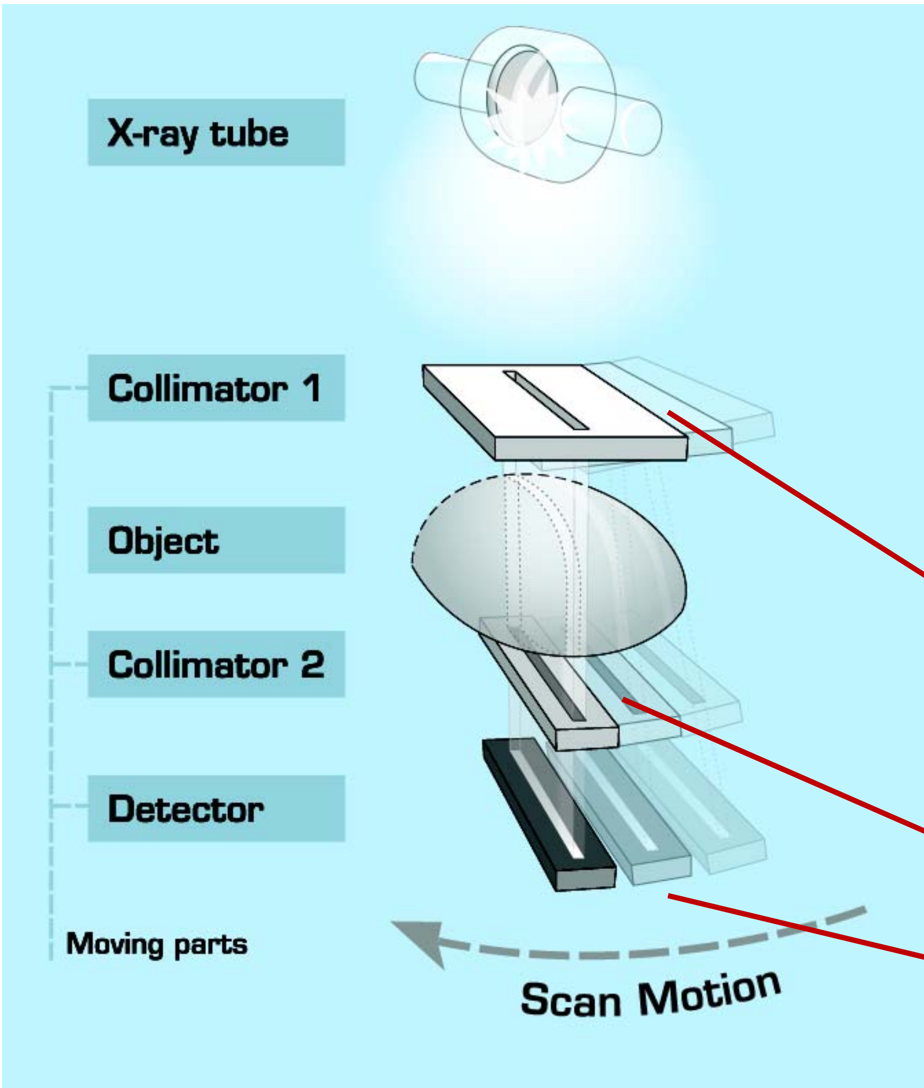


photo courtesy Philips by Digital Mammography

PHILIPS

Photon Counting in Practice

MicroDose



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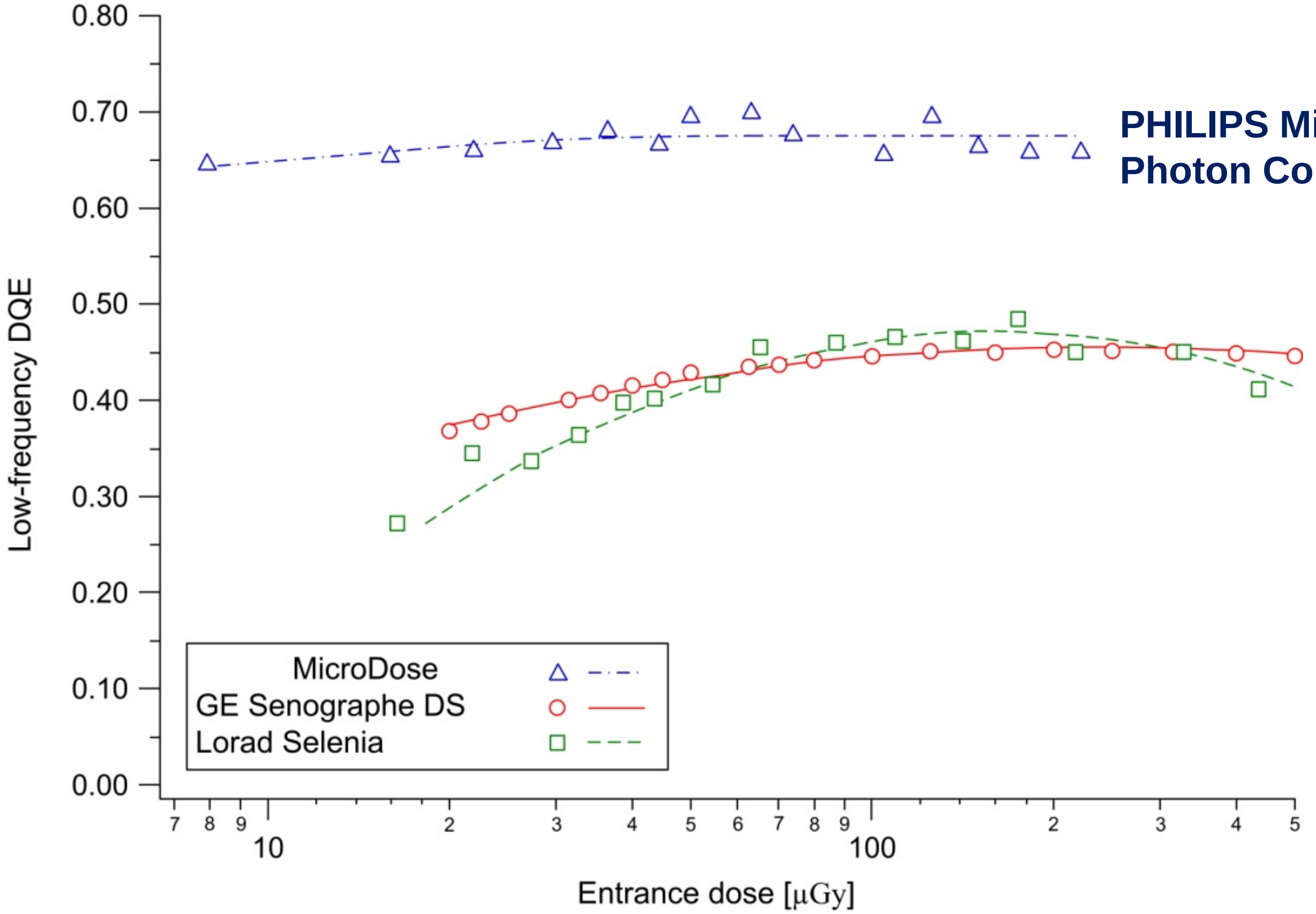
DQE – A Measure of Dose Efficiency

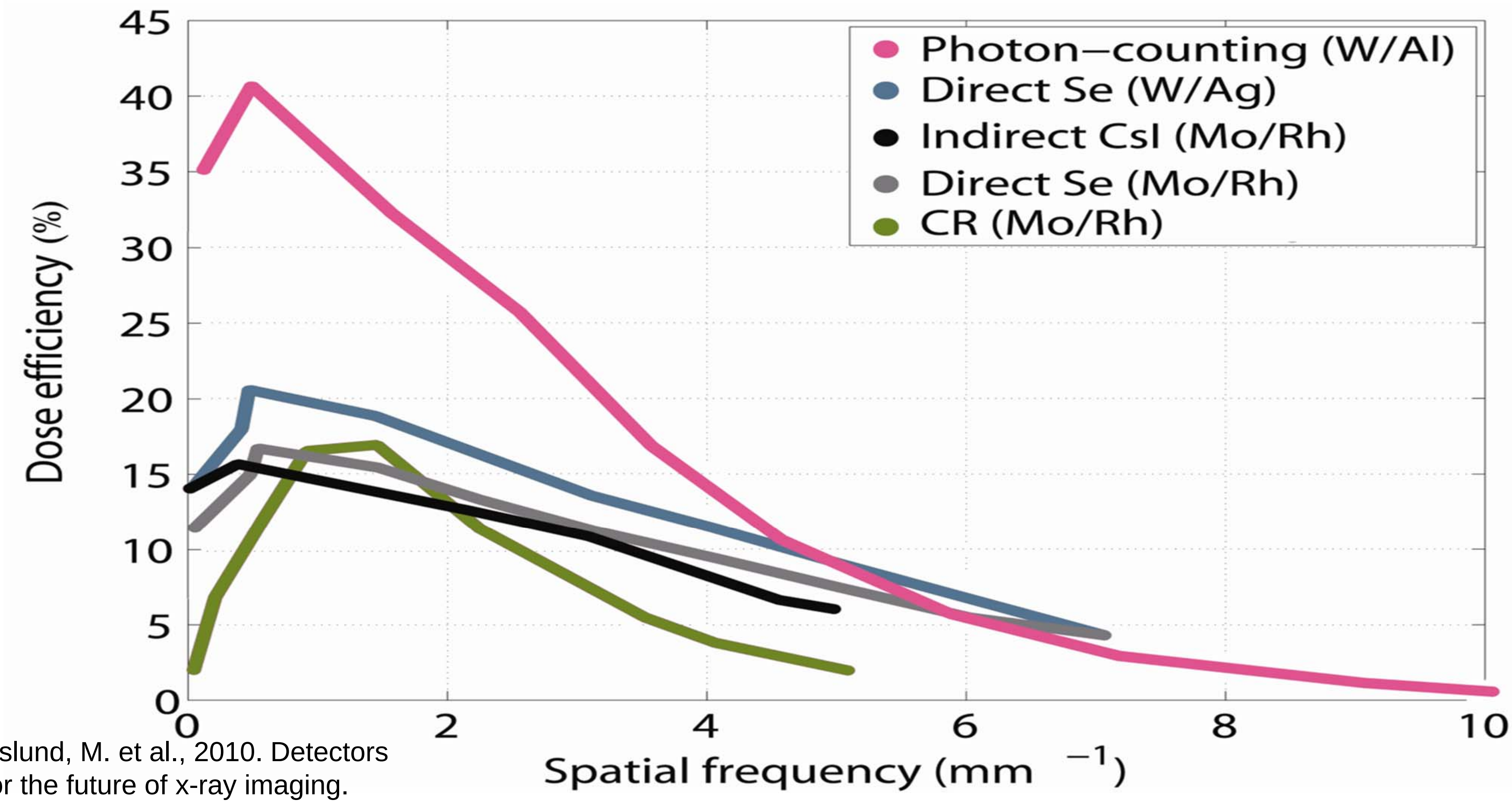


PHILIPS MicroDose Photon Counting

Monnin et al., Med. Phys. (34) 2007

PHILIPS

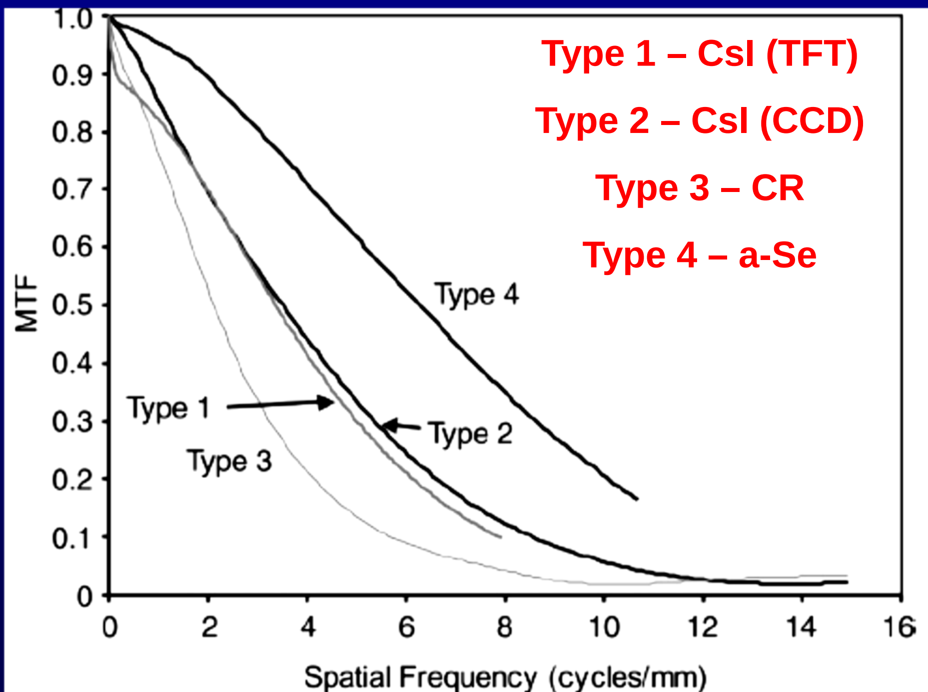
Dose Efficiency

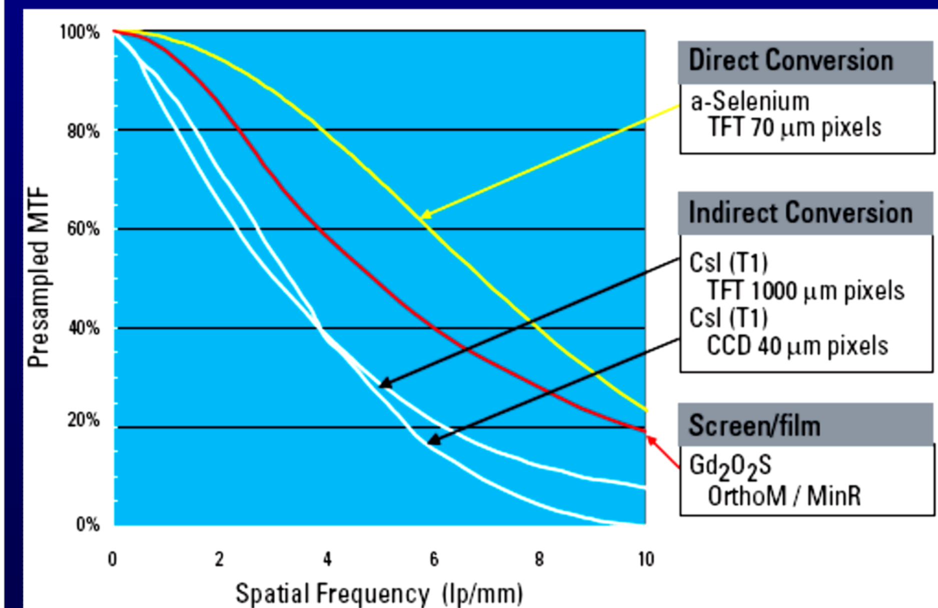


Åslund, M. et al., 2010. Detectors for the future of x-ray imaging. *Radiation Protection Dosimetry*, 139(1-3), pp. 327-333

Modulation Transfer Function (MTF)

- MTF is a measure of signal transfer over a range of frequencies and quantifies spatial resolution



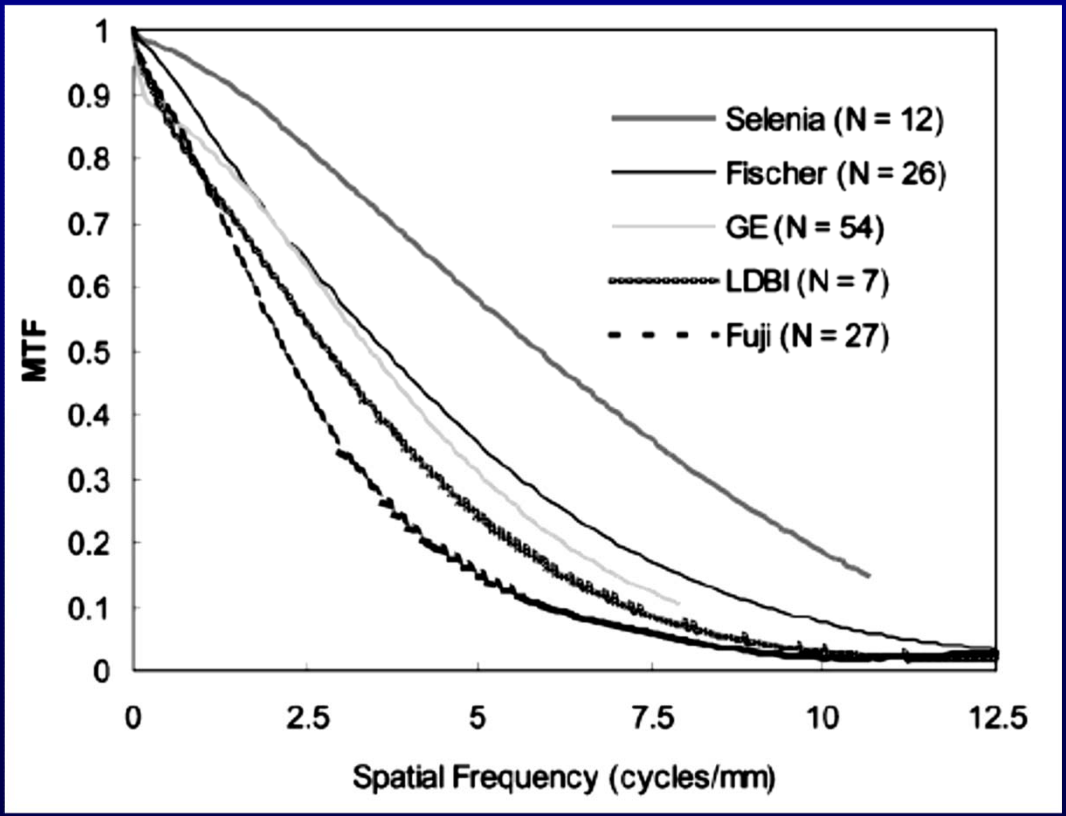


Yaffe - Radiology 2005:234,353

http://www.hologic.com/wh/pdf/R-LM-016_Radiology_Management.pdf

Modulation Transfer Function (MTF)

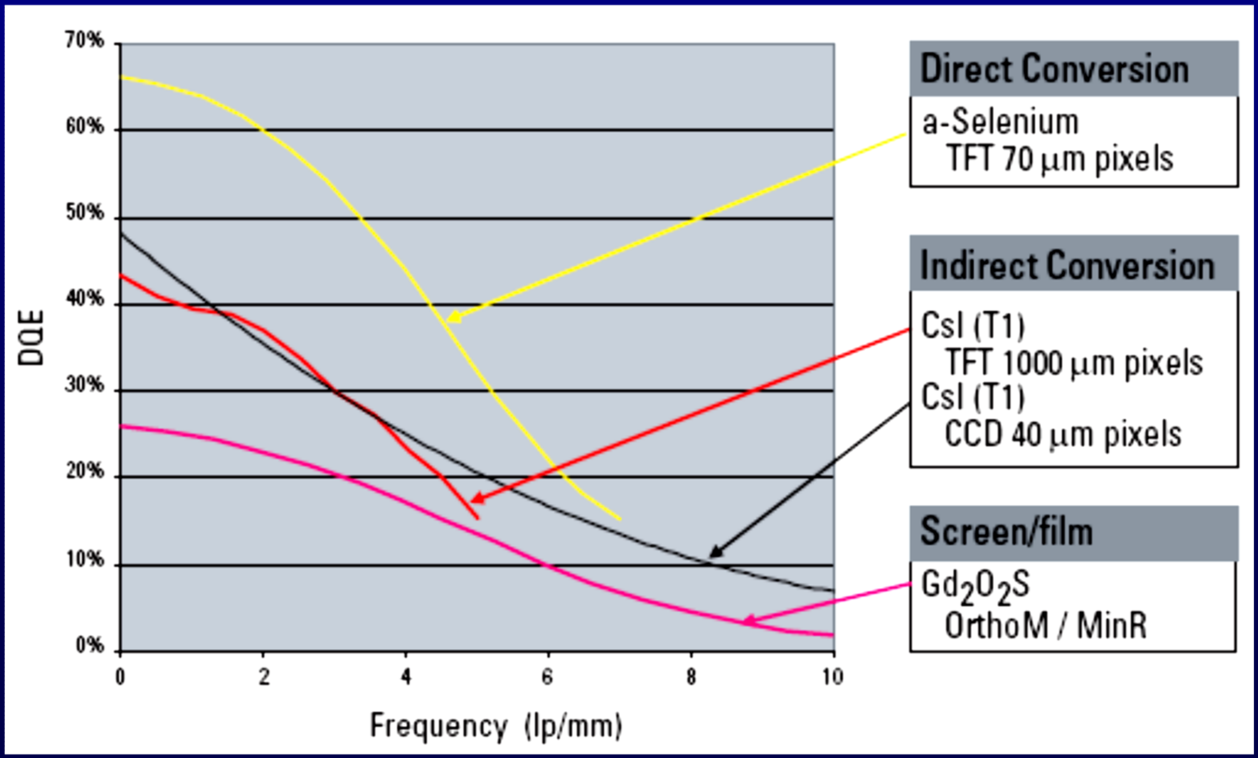
- Bloomquist et al - DMIST trial



Bloomquist – Medical Physics 2006:33 (3), 719

Detective Quantum Efficiency (DQE)

- Detective Quantum Efficiency (DQE) measures SNR transfer through the system as a function of spatial frequency and is a good measure of dose efficiency



http://www.hologic.com/wh/pdf/R-LM-016_Radiology_Management.pdf

FFDM – Radiation Dose

- Bloomquist et al - DMIST trial

TABLE XIV. Mean glandular dose for the standard breast (*N* is measurements from separate inspections).

System	*N*	Entrance exposure μC/kg	Entrance exposure mR	Range mR	MGD mGy	Range mGy
Fischer	26	144	560	400–750	1.31	0.81–1.79
Fuji	25	278	1080	270–1660	1.87	0.79–2.69
GE	46	196	760	410–1410	1.49	0.84–2.53
Lorad DBI	11	294	1140	540–1610	1.98	1.10–2.70
Lorad Selenia	13	273	1060	620–1830	1.85	1.09–2.98
All	121	219	850	270–1830	1.62	0.79–2.98
Screen-film	149	304	1178	708–1810	1.90	1.24–2.72

Bloomquist – Medical Physics 2006:33 (3), 719

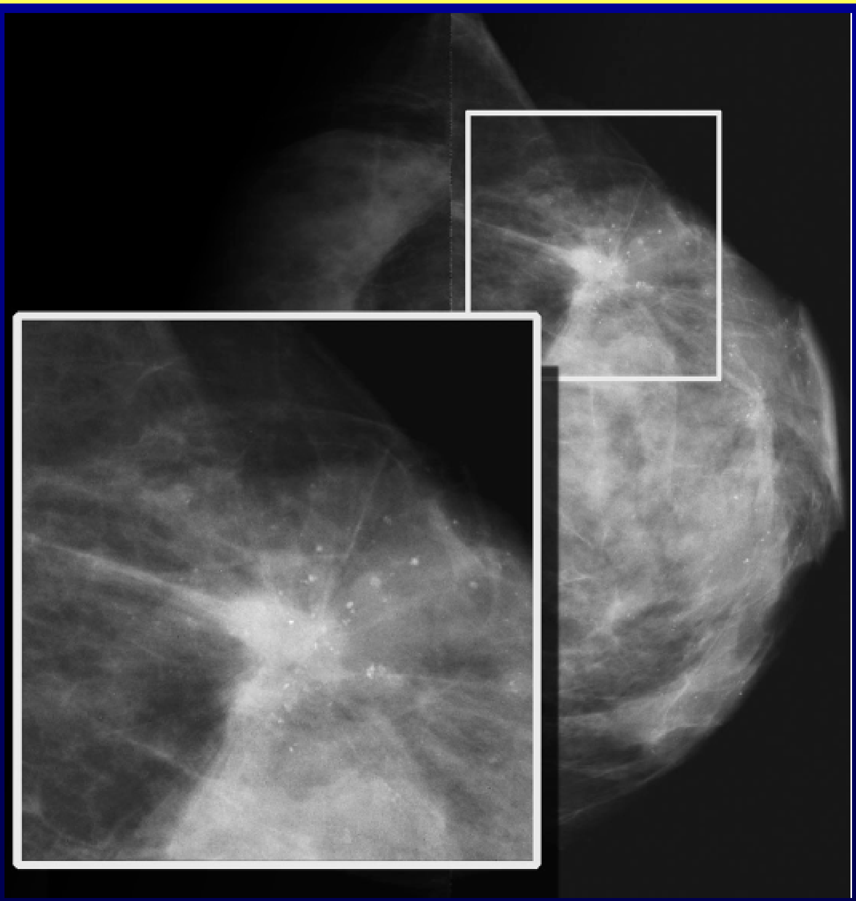
Storage of Digital Images

TABLE 8-6 DIGITAL IMAGE SIZE FOR MAMMOGRAPHY SCREENING EXAMS

DETECTOR TYPE	FOV (cm)	PIXEL SIZE (mm)	IMAGE SIZE (MB)	EXAM SIZE (MB)	+3 Y PRIORS (MB)
Indirect TFT	19 × 23	0.10	9	35	140
Indirect TFT	24 × 31	0.10	15	60	240
Direct TFT	18 × 24	0.07	18	70	280
Direct TFT	24 × 29	0.07	27	108	432
CR	18 × 24	0.05	32	128	512
CR	24 × 30	0.05	50	200	800

c.f: Bushberg, Third edition, pg. 267

Display of Digital Images



Radiographics 2004:24,1757

Economics of FFDM

- SFM systems cost well under $100,000
- FFDM systems cost in the range of $300,000 - $450,000

FFDM Reimbursement

CPT/HCPCS Code	Description	2011 National Medicare Payment
G0202	**Screening mammography, digital** Technical (TC) Professional (26)	**$140** $105 $35
77057	**Screening mammography, film** Technical (TC) Professional (26)	**$81** $46 $35
77052	**Computer-aided detection (CAD), screening** With film or digital mammography Technical (TC) Professional (TC)	**$12** $8 $3
G0206	**Diagnostic mammography, digital (unilateral)** Technical (TC) Professional (26)	**$133** $98 $35
G0204	**Diagnostic mammography, digital (bilateral)** Technical (TC) Professional (26)	**$168** $125 $43
77055	**Diagnostic mammography, film (unilateral)** Technical (TC) Professional (26)	**$87** $52 $35
77056	**Diagnostic mammography, film (bilateral)** Technical (TC) Professional (26)	**$111** $67 $44
77051	**Computer-aided detection (CAD), diagnostic** With film or digital mammography Technical (TC) Professional (TC)	**$12** $8 $3

www.cms.gov

Expected Benefits of FFDM

- The costs of FFDM systems should be compared along with the inherent benefits of the digital technology prior to the purchase:
  - Reduced recall rates
  - Increased patient throughput
  - Increased early detection of breast cancer
  - Decreased false-negative biopsy results
  - Decreasing film and processing costs
  - Increasing the caseload of each mammography room

Clinical Trials and Phantom Studies

- Larger screening study screened 49,500 women
- *Digital Mammographic Imaging Screening Trial* (DMIST), funded by NCI and conducted by ACRIN (http://www.acrin.org/6652_protocol.html)

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 OCTOBER 27, 2005 VOL. 353 NO. 17

Diagnostic Performance of Digital versus Film Mammography for Breast-Cancer Screening

CONCLUSIONS

The overall diagnostic accuracy of digital and film mammography as a means of screening for breast cancer is similar, but digital mammography is more accurate in women under the age of 50 years, women with radiographically dense breasts, and premenopausal or perimenopausal women. (ClinicalTrials.gov number, NCT00008346.)

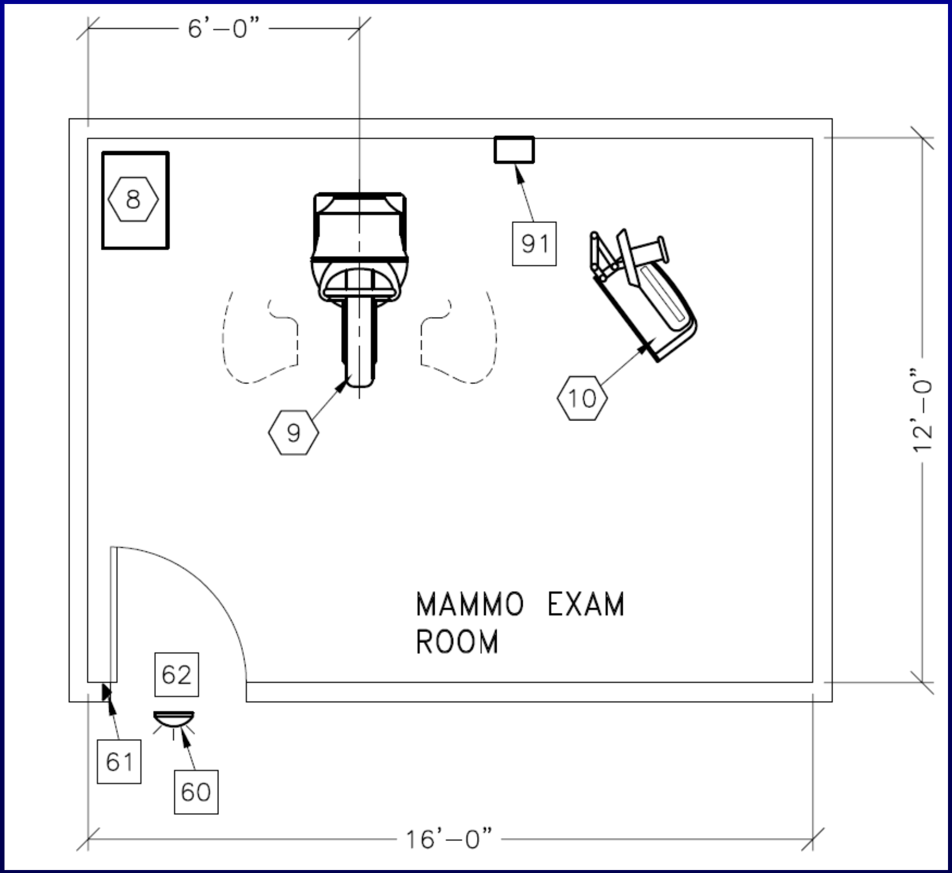
Advantages and Disadvantages

- Advantages
  - Optimize post-processing of images
  - Permit computer-aided detection to improve the detection of lesions
  - Storage of images easier
- Disadvantages
  - Image display and system cost
  - Limiting spatial resolution is inferior to film, 5-13 lp/mm vs. 20 lp/mm
  - Superior contrast resolution

Siting Requirements

- Room dimensions and power requirements needed depend on vendor equipment
- Breast support provides adequate primary barrier for radiation
- Typically 2 sheets or 28 mm of gypsum wallboard (sheetrock) provide adequate secondary shielding
- Technologist protected by lead shield, 0.3mm lead
- Wood doors attenuate less than gypsum wallboard, may need metal doors or solid-core wood doors
- "X-ray on" light typically required on the door (in outside room/hallway)

Example – One Vendor



ROOM DIMENSIONS	LENGTH & WIDTH	CEILING HEIGHT
MINIMUM:	10'–0" x 12'–0" [3.5m x 3.7m]	8'–0" [2.4m]

Educational Objectives

- Understand the physics of digital detector technology
- Recognize that vendors use varying detector technology in FFDM systems
- Appreciate the advantages and disadvantages of digital mammography systems
- Radiation Dose in FFDM systems
- Economics of FFDM systems

TAKE HOME POINTS

- Different technologies exist for digital systems – indirect and direct
- Commercially available FFDM systems vary in technology
- Many advantages exist for FFDM in comparison to FSM
- Dose is lower with FFDM compared to SFM

Resources

- Digital Mammography: An overview – *Dr. Mahesh* (Radiographics 2004;24:1747-1760)
- Fundamentals of Digital Mammography Primer – *Dr. Smith* (Hologic Inc)
- Digital Mammography – *Pisano and Yaffe* (Radiology 2005; 234:353-262)
- Bloomquist and Yaffe – Med Phys 33 (3), 2006
- MHRA report 05037: Comparitive Specifications of Full Field Digital Mammography Systems
- http://www.fda.gov/Radiation-EmittingProducts/MammographyQualityStandardsActandProgram/FacilityCertificationandInspection/ucm114148.htm

THANK YOU