Latest Advances in Digital Breast Tomosynthesis

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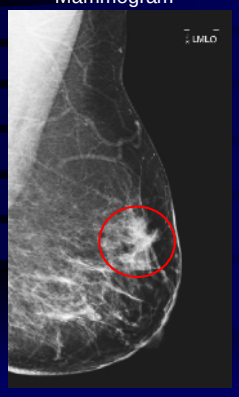
Limitation of Mammography

- False diagnoses due to superposition of breast tissue
- Solution: 3D imaging
  - Breast CT: Cone-beam CT (180°) with dedicated prone table
  - Breast tomosynthesis: modified mammo gantry with limited angular range (15°-60°)

Breast Tomosynthesis

- Fast clinical transition
- Limited angular range: 15~60°
- Slice thickness: 1mm
- Projections: 11- 50
- Dose: ~1 - 2 times single mammogram

Mammogram



Biopsy proven cancer

Tomosynthesis

Courtesy: B. Ren, Hologic

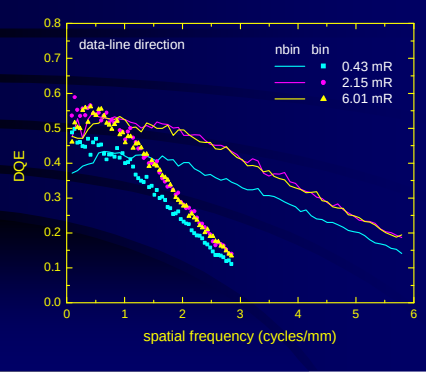
Different DBT Design

Company	System param.	Views	Detector	Scan time (s)	Recon.
GE	±20°, step/shoot (MGH, Sunnybrook)	15	CsI/a-Si 100 um	15-23	MLEM SART
	±30°, step/shoot (U. of Michigan)	21		7 s	SART
Hologic	±7.5, continuous Multiple sites	11	a-Se, 70 um 2x2 binning	10	FBP
Siemens	±22°, step/shoot Duke,Malmo,SUNY	25	a-Se, 85 um	12.5/20 Bin/full	FBP
Dexela	±12-20° (U. of Virginia)	13	Fiber optic coupled CCD	30 s	MLEM
X-counter	±13°	48	Gas counting, 48 slit, 60 um		FBP iterative
Sectra	±5.5°, 6-site trial	21	Si counting, 21 slit, 50 um	3-8 s	

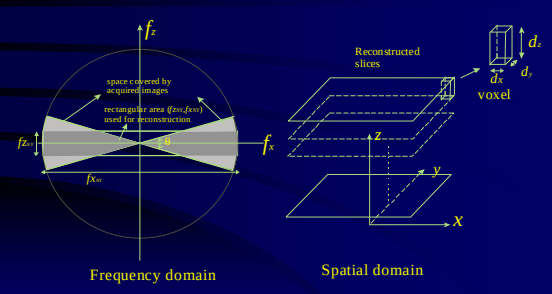
Factors Affecting Image Quality

- Detector performance
  - DQE at low dose: $1/N_{View}$
  - Temporal performance: lag and ghosting
- Imaging geometry
  - Angular range, number of views
  - Focal spot blur: continuous tube travel
- Reconstruction algorithm
  - Analytical: FBP (filter design)
  - Iterative

Detector Performance

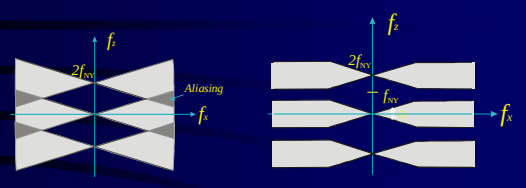


Imaging Geometry: spatial vs. frequency domain



B. Zhao and W. Zhao, Med. Phys. 2008

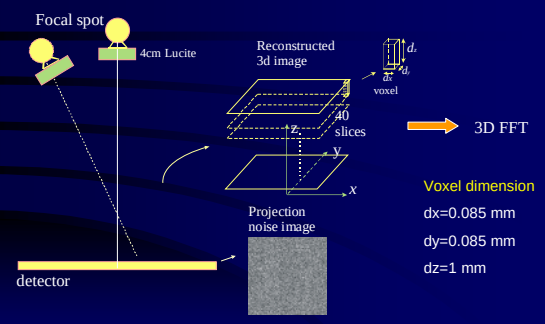
3D Image quality metrics: MTF, NPS and DQE



Slice thickness 1 mm:
Noise aliasing in *z*

Slice thickness filter:
eliminate aliasing

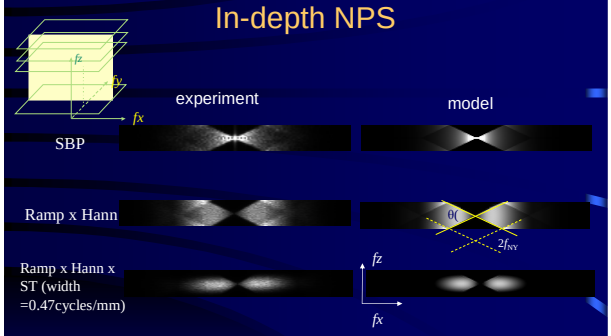
Noise Measurement



Voxel dimension
dx=0.085 mm
dy=0.085 mm
dz=1 mm

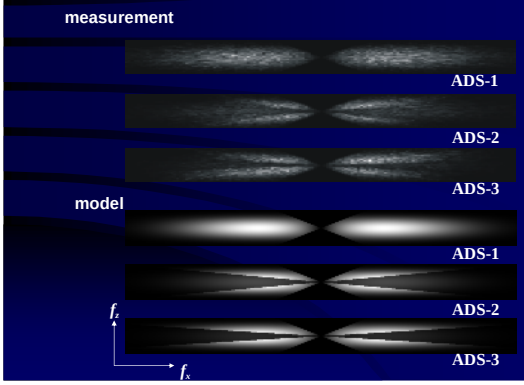
B. Zhao et. al, Med. Phys. 2009

In-depth NPS

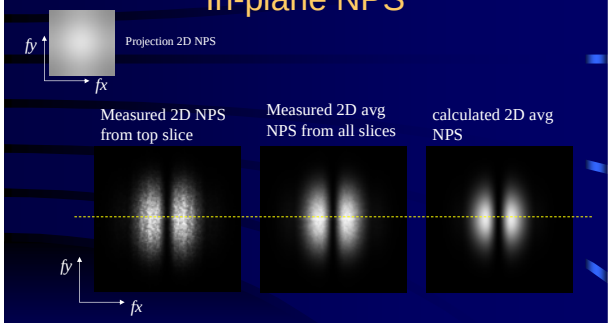


- Effect of angular range θ
- Effect of reconstruction filters
- Effect of 3D sampling, ST filter

NPS vs. angular dose distribution

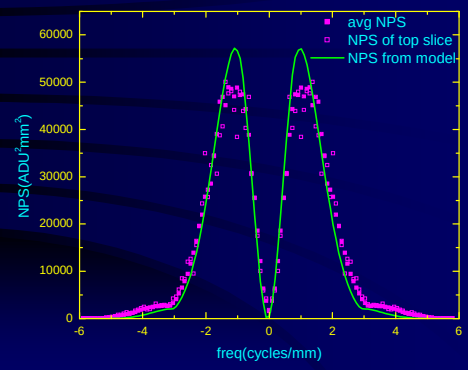


In-plane NPS

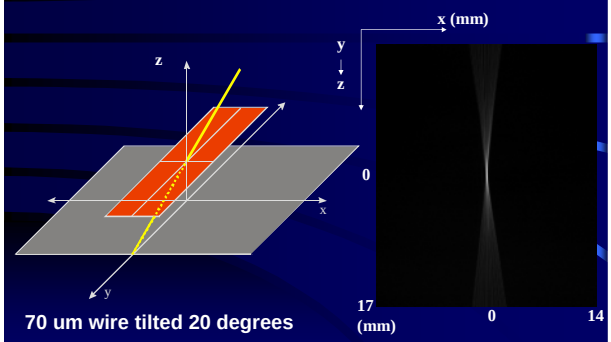


•Reconstruction: Ramp + Hanning

3D NPS



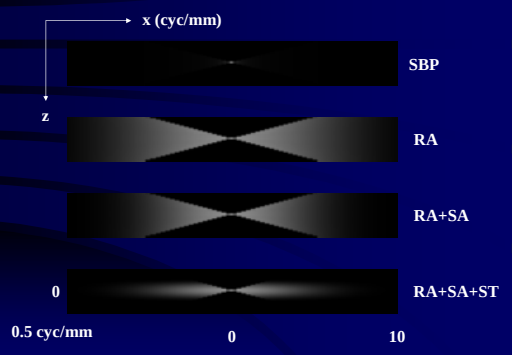
Oversampled Point Spread Function (PSF)



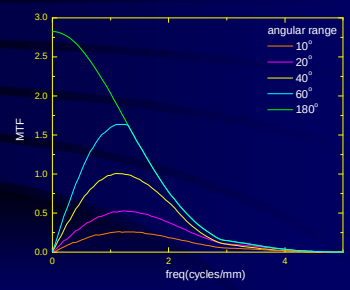
70 um wire tilted 20 degrees

PSF/artifact vs. Angular Range

MTF – Dependence on Filters

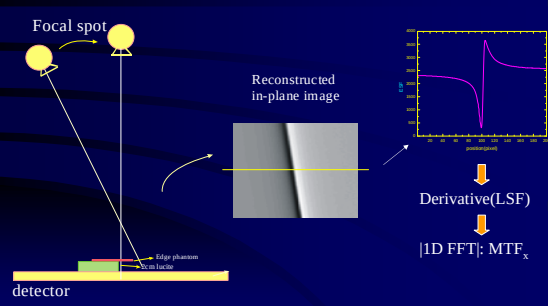


Impact of Angular Range on In-Plane MTF



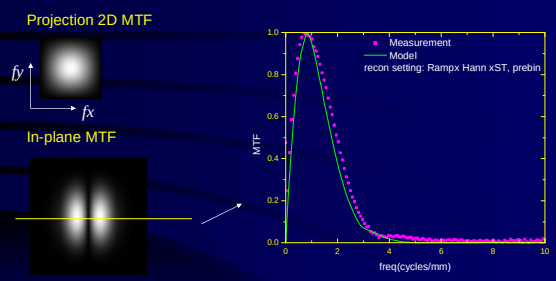
• Increasing angular range improves MTF at low frequencies

In-Plane MTF Measurement



Edge phantom: 0.2mm Al

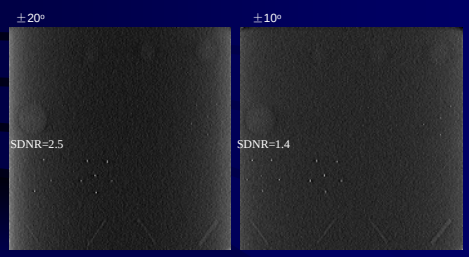
In-Plane MTF



Low *f* drop caused by ramp filter and limited angular range

High *f* drop caused by other reconstruction filters

Dependence on Angular Range

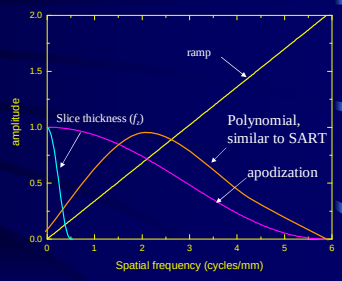


ACR phantom imaged at 28kVp, W/Rh, 1.7mGy

Recon: FBP with ST filter

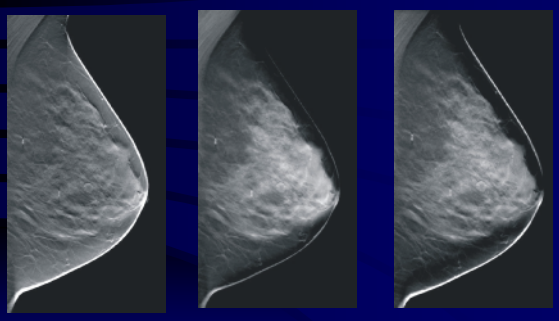
Reconstruction filter designs

- Ramp + limited angle: loss of low frequency (breast density)
- Modified filters: recovers density, but increased out-of-plane blur
- Iterative recon: improvement at the cost of computation



J. Zhou et. al. Med. Phys. 2007; Ludwig et. al. IWDM2008; B. Ren, et. al. SPIE 2009

Reconstruction filter comparison



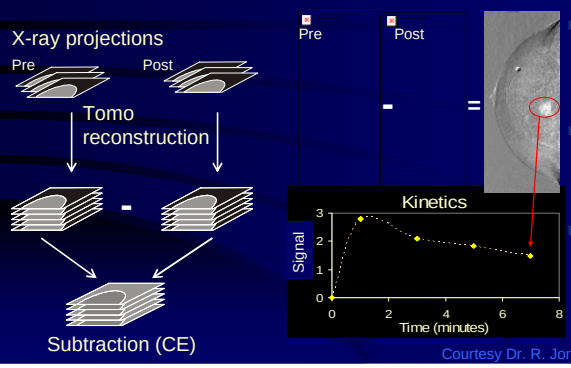
FBP with Ramp **SIRT** **Polynomial**

Adapted from Ludwig et. al. (IWDM 2008)

Clinical Application of DBT

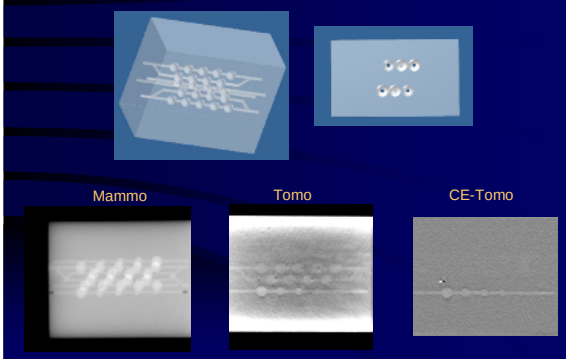
- Screening/diagnosis
- Contrast enhancement: angiogenesis
- Multimodality imaging:
  - DBT + automated ultrasound (AUS)
    - P. Carson et. al. U. Michigan
  - DBT + optical tomography
    - Boas et. al. MGH
  - DBT + limited angle SPECT
    - M. Williams et. al., U. Virginia

Dynamic Contrast-Enhanced (CE) Tomosynthesis



Courtesy Dr. R. Jong

CE-Tomosynthesis

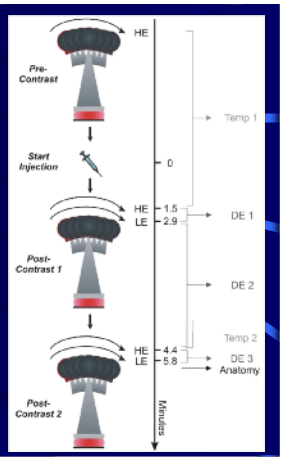


Courtesy M. Hill and J. Mainprize

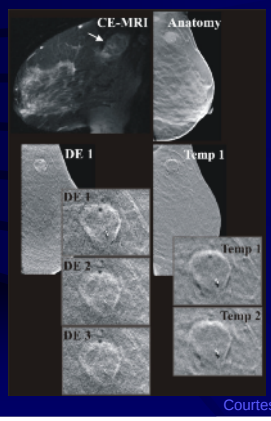
Temporal vs. Dual-Energy CE-DBT

- DS DBT system, GE Medical Systems
- Automated tube motion
- No anti-scatter grid
- HE:
  - Rh target - 0.25 mm Rh + 0.25 mm Cu filter
  - 49 kVp
- LE
  - Rh target – 0.25 mm Rh filter
  - 32 kV
- 7 projections: 40° arc, 6.7° apart
- Dose per HE/LE data set ~single mammographic view (~2 mGy)
- Filtered backprojection

Courtesy Ann-Katherine Carton



Case 1: poorly differentiated invasive ductal carcinoma



Courtesy Ann-Katherine Carton

U. Michigan

GE Gen II Research Tomo Unit

60º angle
21 projections
7.5 sec

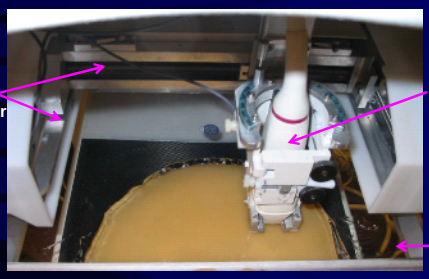
GE Logiq 9 US system

Dual-modality compression paddle

Stationary digital x-ray detector

Courtesy: Drs. P. Carson and M. Goodsitt

Automated US Scanning System



xy translator

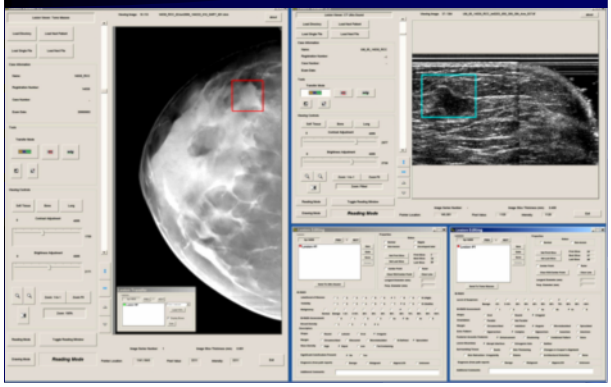
US transducer

TPX paddle

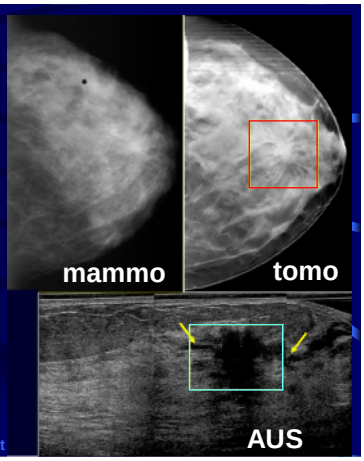
- Translator & transducer are flipped up out of field for tomo acquisition
- Translator & transducer flipped down for AUS acquisition

Courtesy: Drs. P. Carson and M. Goodsitt

Co-location Reader Study Display GUI showing Corresponding VOI's in DBT & AUS



Invasive Cancer



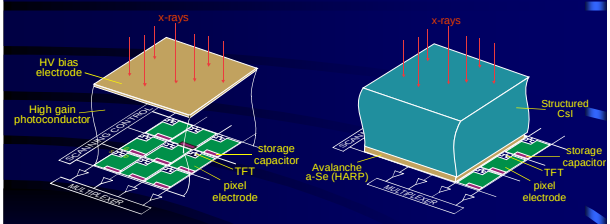
- AUS-suggested ductal extension

Courtesy: Drs. Carson & Goodsitt

Further Development for DBT Systems

- Gantry:
  - Faster scan, more views
- Generator/tube:
  - dual-energy, shorter pulse/less focal spot blur
- Detector:
  - Better low dose performance, faster readout
  - photon-counting

New detectors: Improve low dose performance



Direct FPI:
Photoconductor with higher gain

Indirect FPI:
Avalanche photodetector

Summary

- Physics of DBT: 2D→3D
  - Optimization of acquisition and recon.
- New clinical applications:
  - Contrast enhanced CEDBT
  - Multimodality imaging
- Challenges for further system development

Acknowledgements

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