

A KURSUS 2014

Diagnostisk Radiologi : ” Fysik og Radiobiologi ”

BILLEDKVALITET

OPLØSNINGSEVNE

STØJ , MTF, DQE, ROC

m.m.

Erik Andersen, ansvarlig fysiker

CIMT Medico Herlev, Gentofte, Glostrup Hospital

Billedkvalitet :

Billedkvaliteten i et radiologisk billede afhænger bl.a. af :

KONTRAST

OPLØSNING

STØJ

DOSIS

EKSPONERINGSPARAMETRE

DETEKTOR MTF og DQE

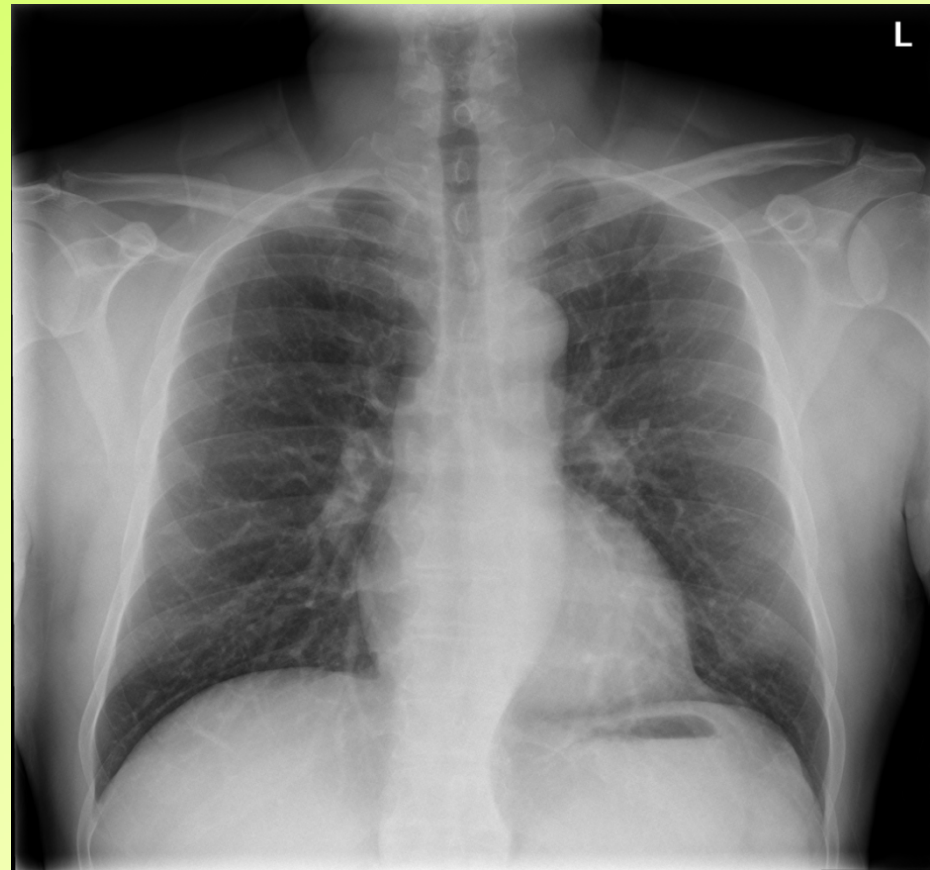
BILLEDBEHANDLING

ALGORITMER

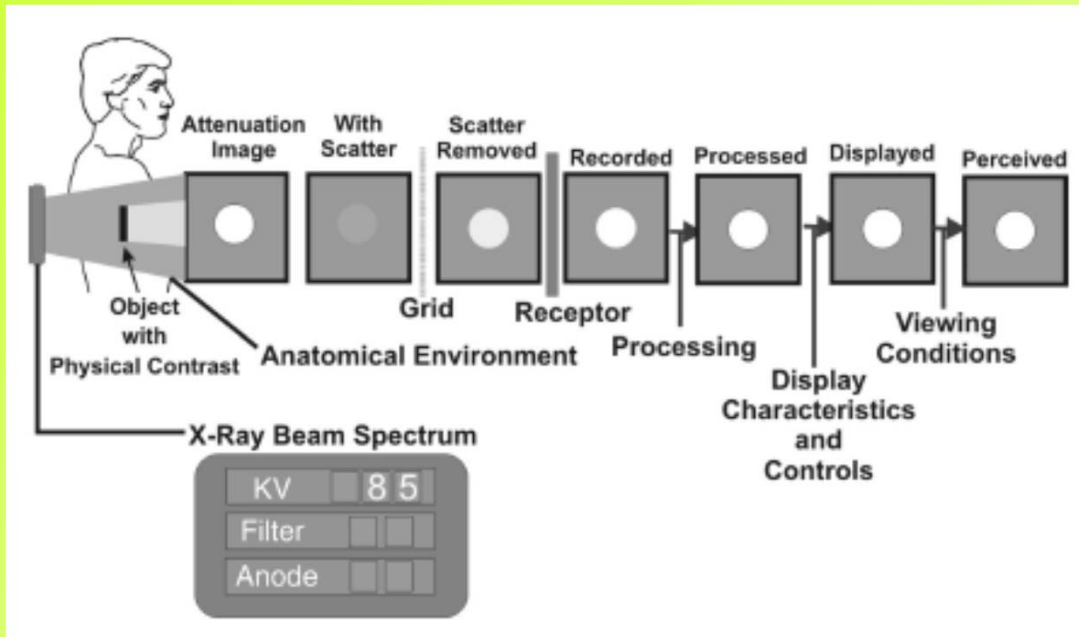
FILTRE

DISPLAY MONITORER

RADIOLOGEN (?)

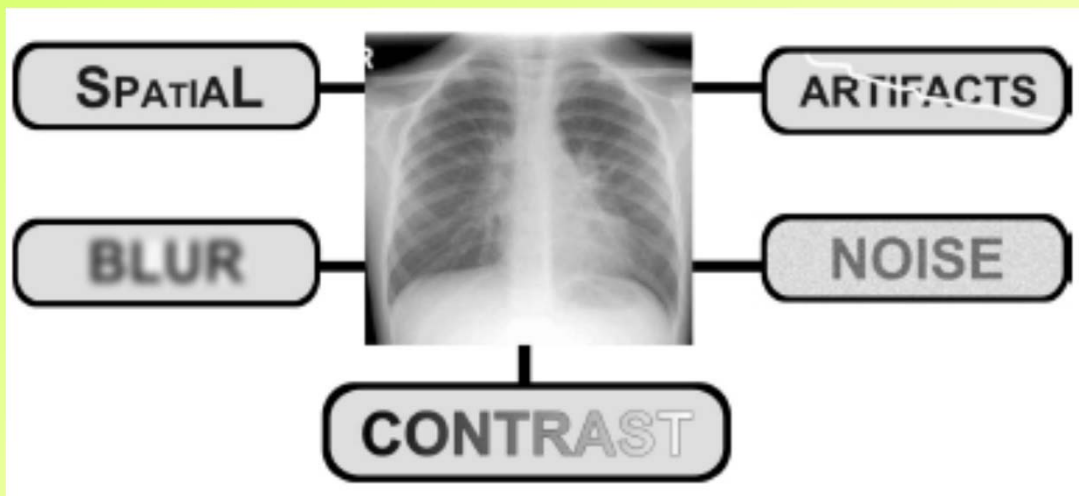


Faktorer med betydning for kvaliteten af røntgenbilledet:



Parametre for billedkvalitet:

Eksponeringsparametre
Raster
Detektor
Image processing
Diagnostik monitorer
Rumbelysning
m.m.



Parametre for billedkvalitet:

Spatial opløsning
Uskarphe
Kontrast
Støj
Artefakter
m.m.

Billeddannelse & kontrast :

Strålingsintensitet i detektor pixel (i , j) :

$$I(i, j) = N \cdot \varepsilon \cdot E \cdot \exp(-\int \mu \cdot dx) + S = P(1 + S/P)$$

Kontrast C :

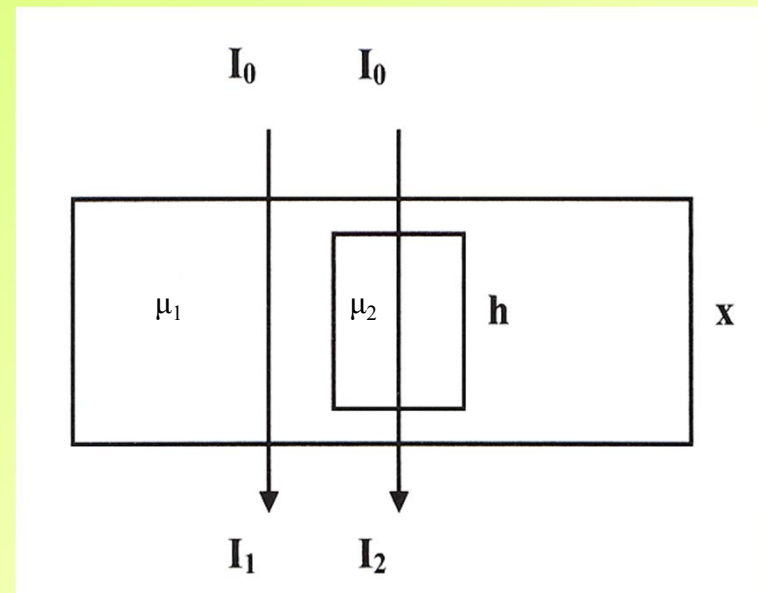
$$\begin{aligned} C &= \frac{I_2 - I_1}{I_1} = \frac{\exp((\mu_1 - \mu_2) \cdot h) - 1}{1 + S/P} \\ &= \frac{\exp(\Delta\mu \cdot h) - 1}{1 + S/P} \cong \frac{\Delta\mu \cdot h}{1 + S/P} \end{aligned}$$

hvor: I_1, I_2 = strålingsintensiteter

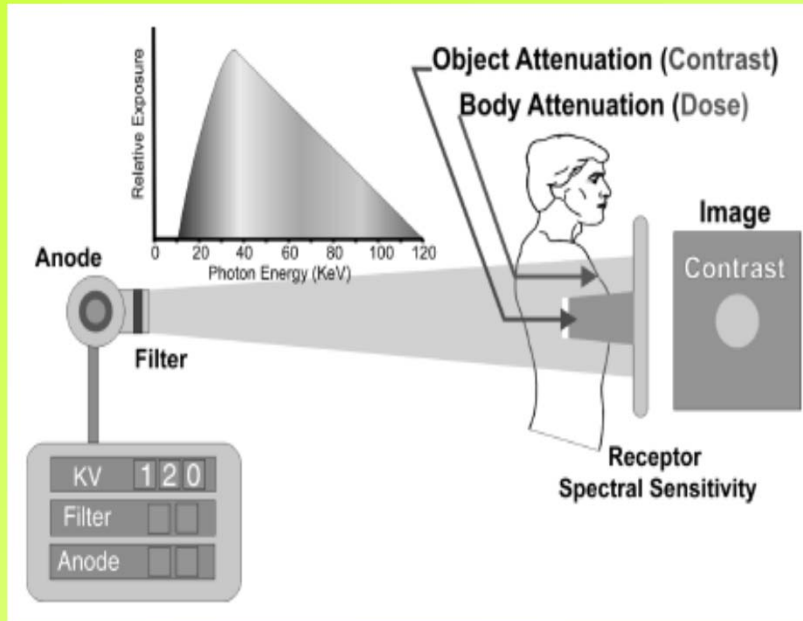
h = objektets tykkelse

μ_1, μ_2 = attenuationskoefficienter

S/P = forholdet mellem mængden af primær stråling P og mængden af spredt stråling S .

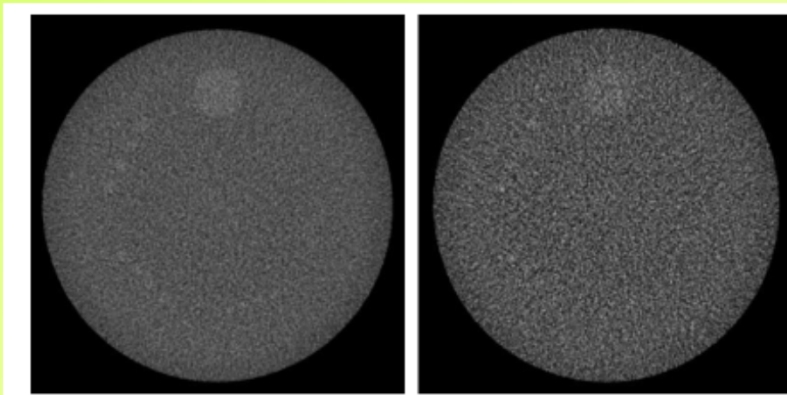
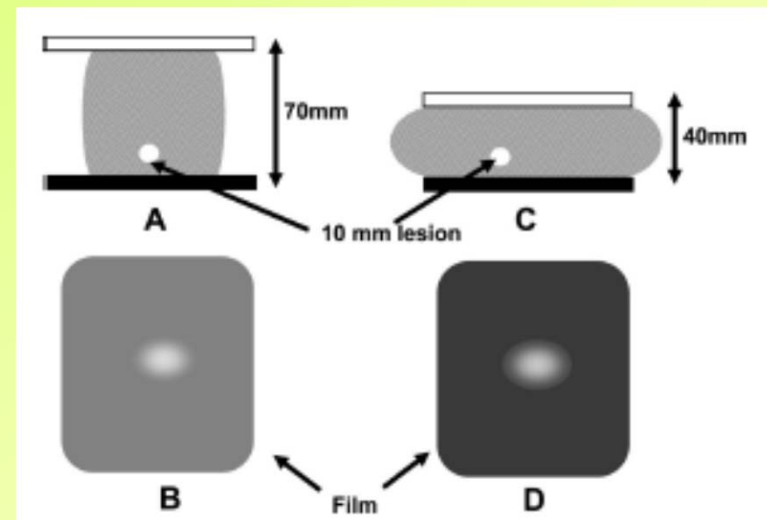


Billedkvalitet : Lavkontrast



Eks.: Mammografi

Forbedring af kontrast ved kompression:

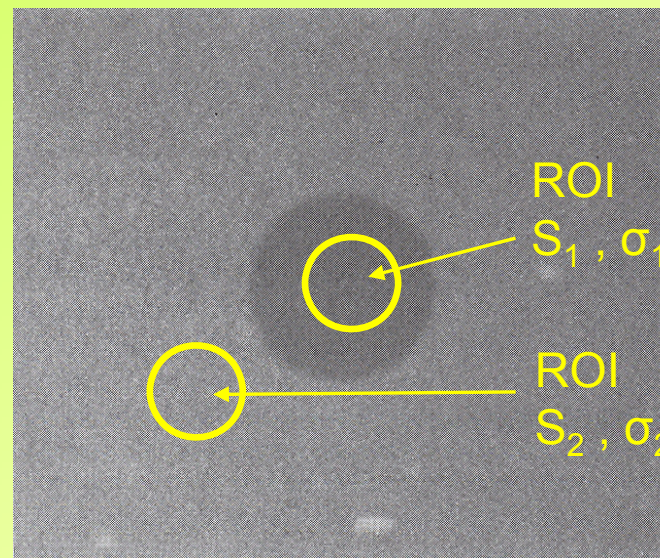


Signal difference to Noise Ratio SdNR :

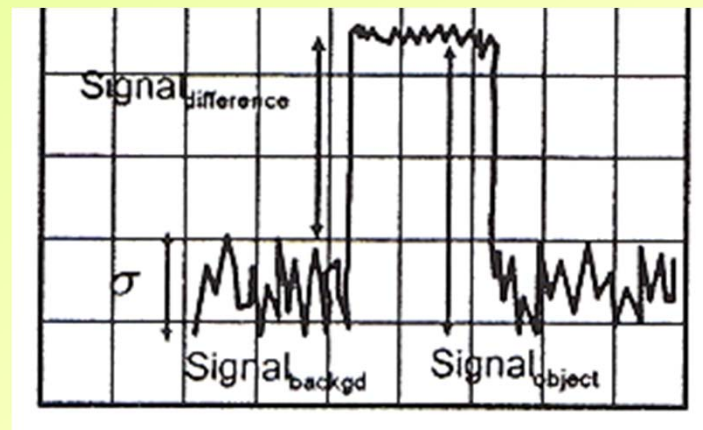
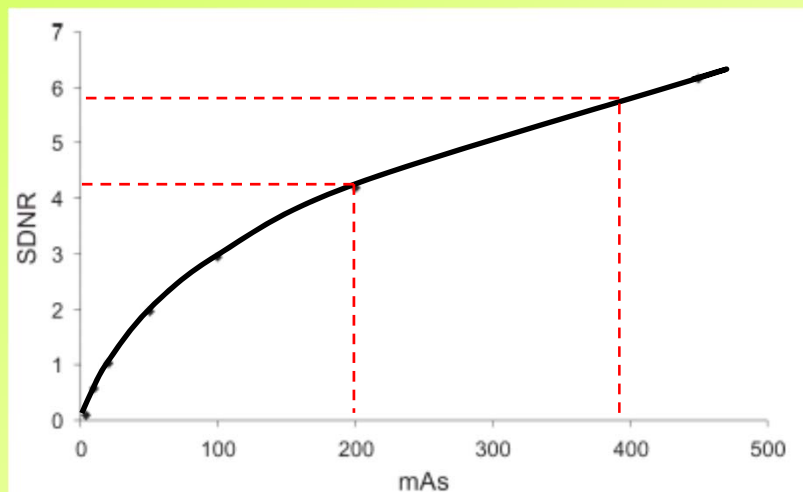
$$SdNR = \frac{S_1 - S_2}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$

hvor : S_1, S_2 = Signal Intensitet

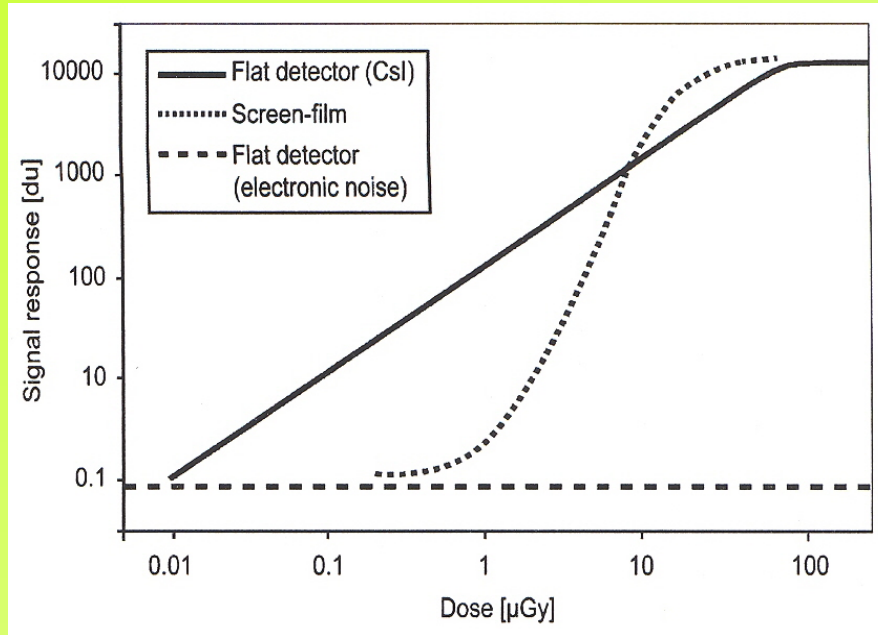
σ_1, σ_2 = Standard afvigelse ("støj")



SdNR vs. mAs



Kontrast & dosis :



Dynamikområde :

Flat panel DR detektor ca. 10000 : 1

Film – folie ca. 50 : 1

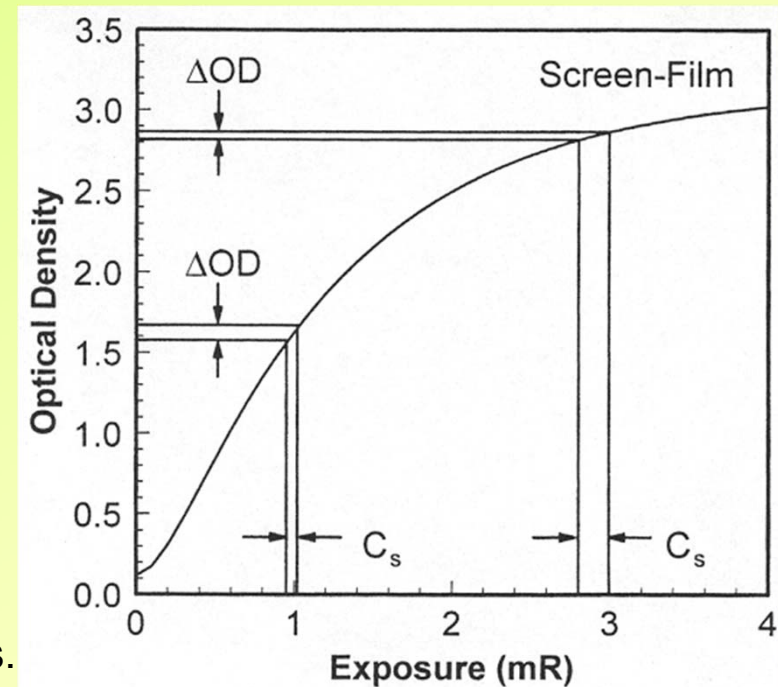
Film – folie :

Kontrasten i røntgenbilledet
afhænger af eksponeringsdosis.

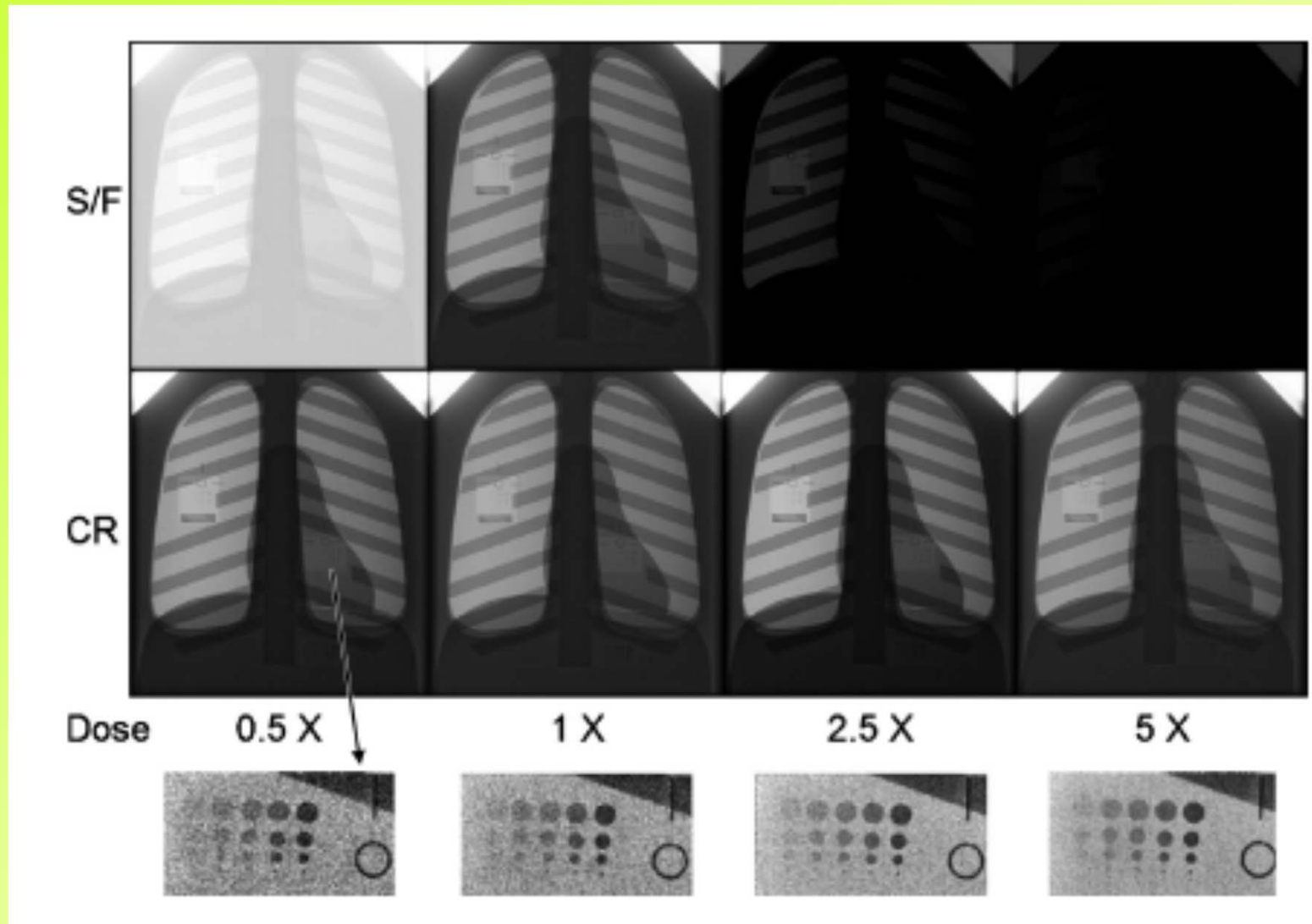
Karakteristisk S - kurve, kontrast & dosis for film-folie :

$$\text{Optisk densitet } OD = \log_{10} \left(\frac{I_o}{I} \right)$$

hvor I er strålingsintensiteten



Billedkvalitet og dosis : S/F & CR / Chest-fantom

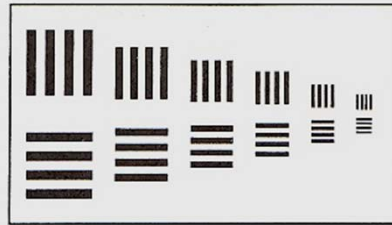


Højkontrast opløsning :

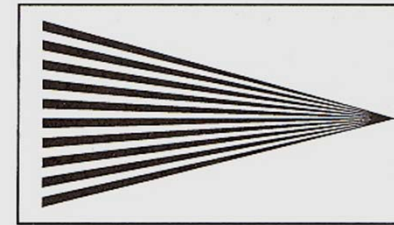


Resolution Test Pattern

Resolution / højkontrast opløsning angives i lp/mm



Line Pair Test Phantom



Section of a Star Pattern

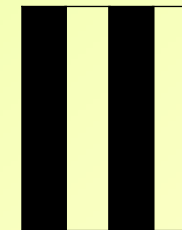
Højkontrast opløsning i liniepar pr. millimeter :

Eks: $d = 0,25 \text{ mm}$

$$\text{Spatial frekvens } f = \frac{1}{d} = \frac{1 \text{ mm}}{0,25 \text{ mm}} = 4$$

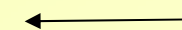
Antal liniepar pr. millimeter

$$\frac{1}{2 \cdot d} = \frac{1}{2 \cdot 0,25 \text{ mm}} = \frac{1}{0,5 \text{ mm}} = 2 \text{ lp / mm}$$



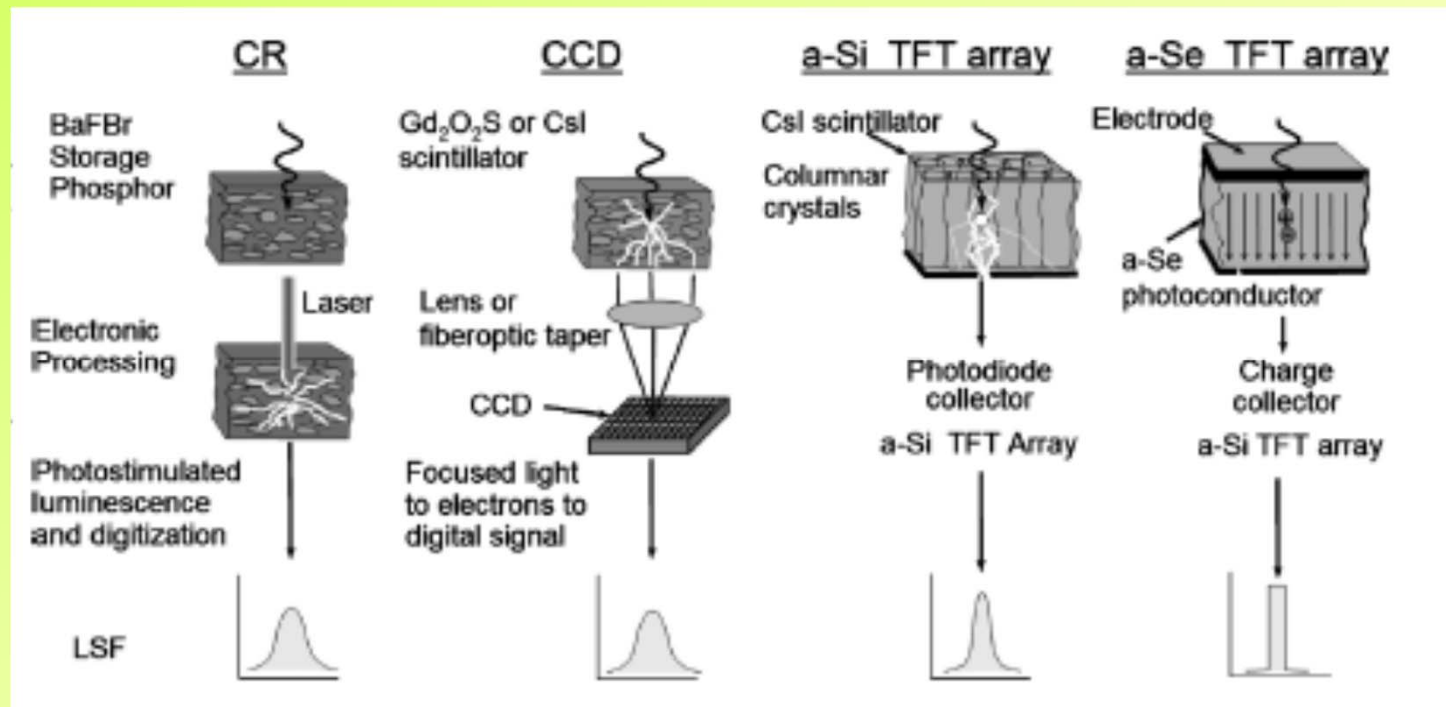
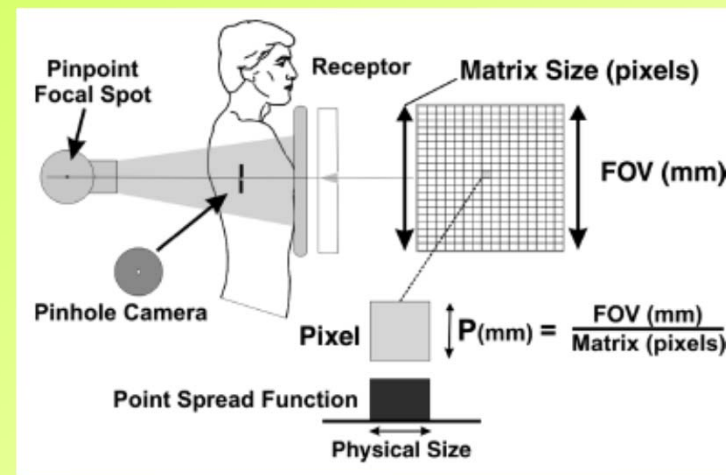
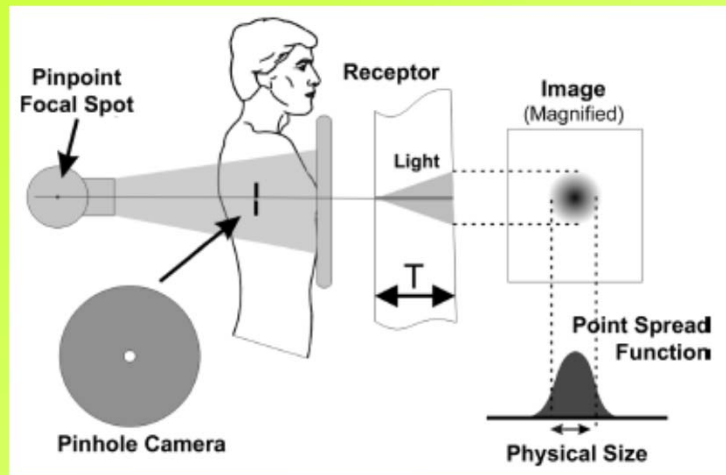
d \longleftrightarrow

liniepar \longleftrightarrow

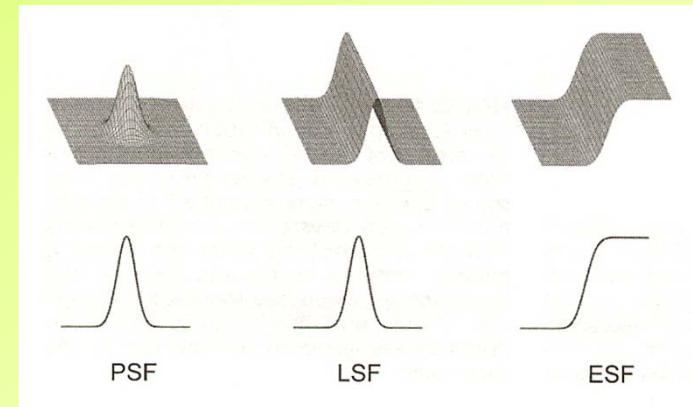
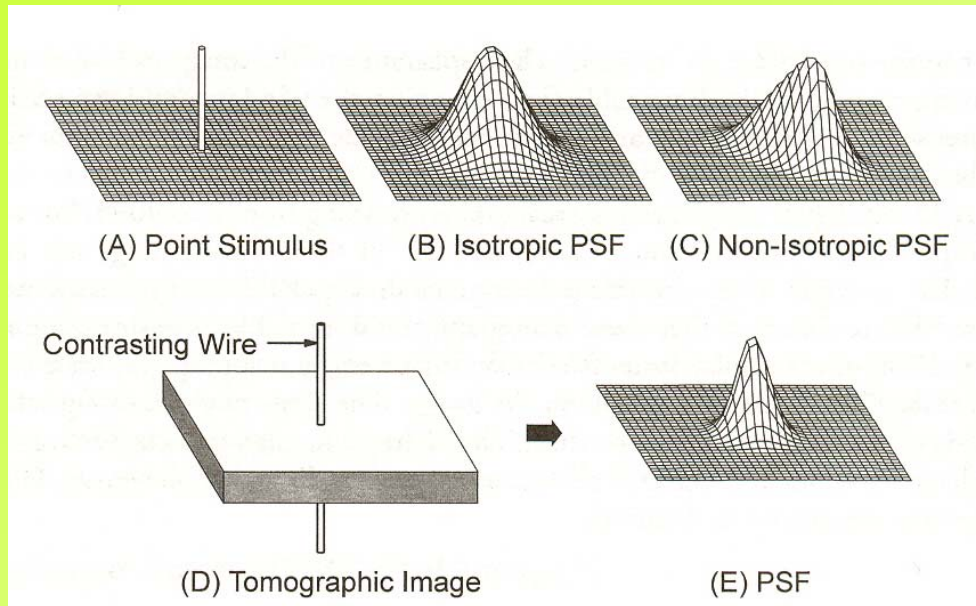


1 mm

Point Spread Funktion PSL : CR & DR detektorer



PSF, LSF, ESF, MTF :



MTF = Modulation Transfer Function

MTF kan bestemmes ud fra f.eks. LSF ved:

$$\text{MTF}(f) = | \text{FT}\{ \text{LSF}(f) \} |$$

hvor FT = Fourier Transformations operatoren.

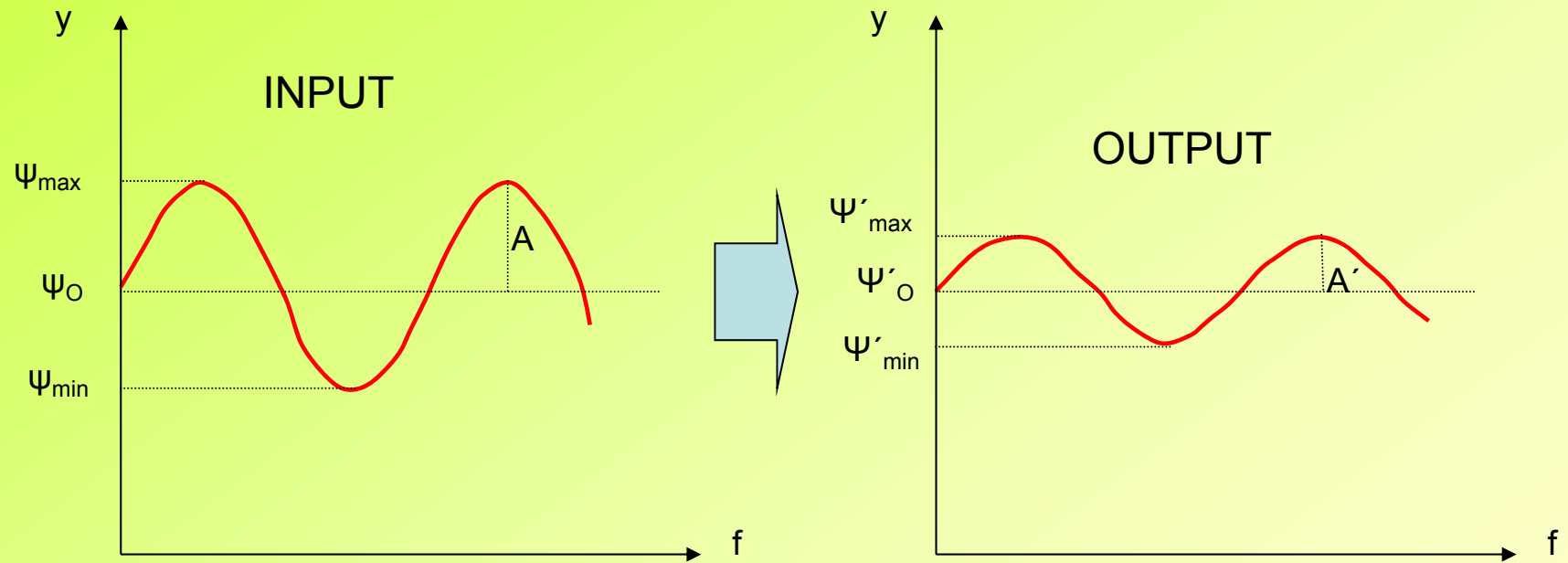
PSF = Point Spread Function

LSF = Line Spread Function

ESP = Edge Spread Function

Modulation Transfer Function MTF :

Imaging system



Modulation Input:

$$M_{\text{IN}} = (\psi_{\max} - \psi_{\min}) / (\psi_{\max} + \psi_{\min})$$

Modulation Output:

$$M_{\text{OUT}} = (\psi'_{\max} - \psi'_{\min}) / (\psi'_{\max} + \psi'_{\min})$$

Modulation Transfer Function MTF :

Harmonisk bølge : $\psi(f) = \psi_0 + A \cdot \sin(k \cdot f + \varphi_0)$

$\psi(f)$ = bølgens y-position ved den spatiale frekvens f

ψ_0 = bølgens middel y-position

A = bølgens amplitude

k = bølgetallet

φ_0 = beg. frekvens

Modulation Input:

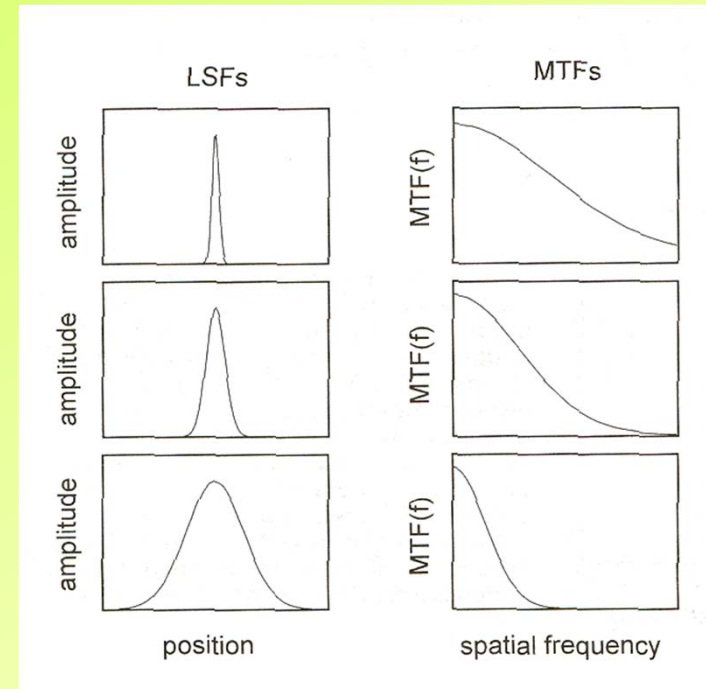
$$M_{IN} = (\psi_{max} - \psi_{min}) / (\psi_{max} + \psi_{min})$$

Modulation Output:

$$M_{OUT} = (\psi'_{max} - \psi'_{min}) / (\psi'_{max} + \psi'_{min})$$

Modulation Transfer Function :

$$MTF(f) = \frac{M_{OUT}(f)}{M_{IN}(f)}$$



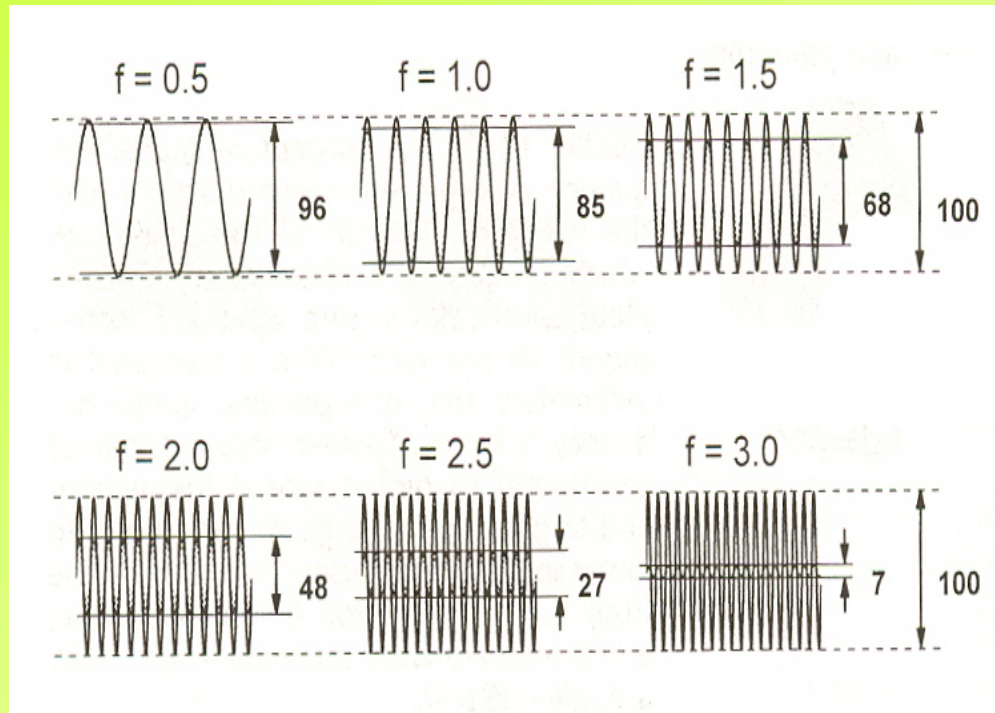
Modulation Transfer Function

$$MTF(f) = | FT\{ LSF(f) \} |$$

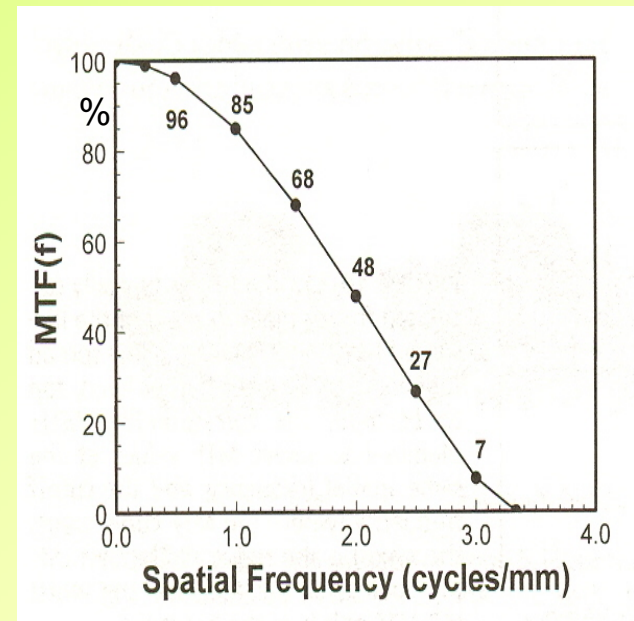
Kurveforløbet af MTF(f)
afhænger af LSF funktionens
bredde (spredning)

Modulation Transfer Function MTF :

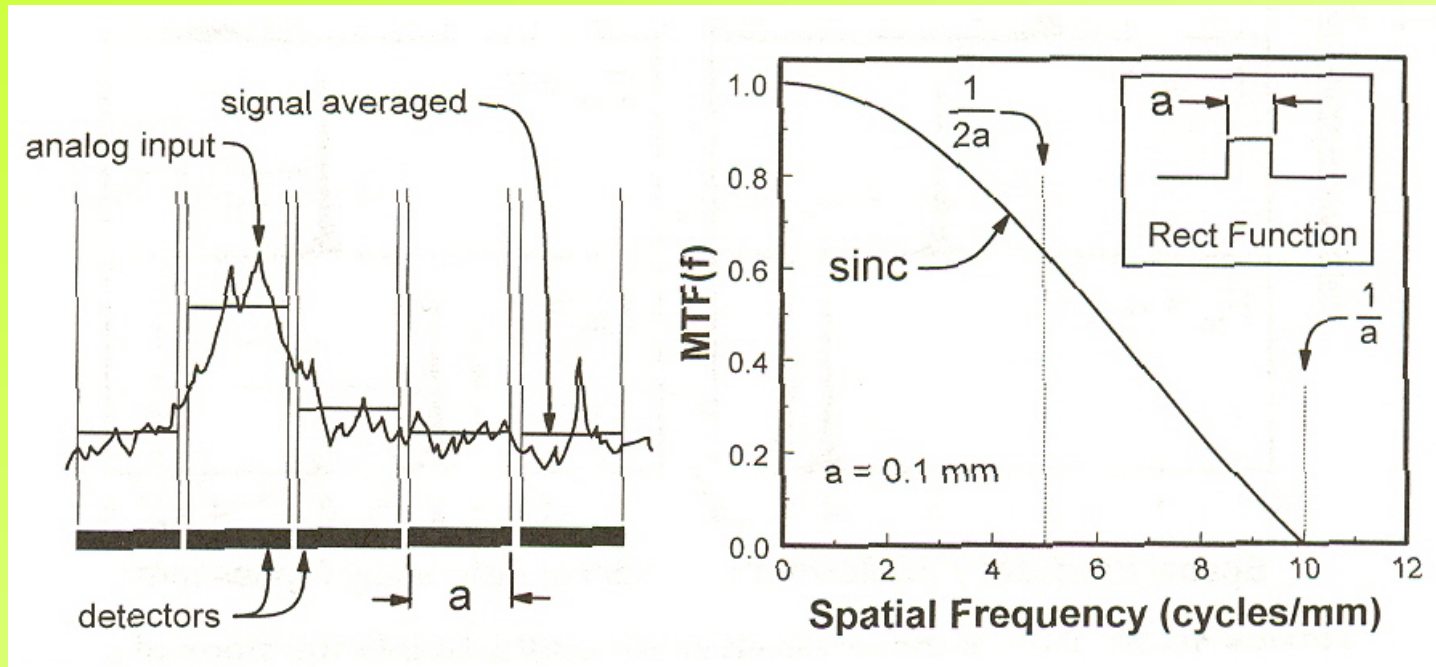
$$MTF(f) = \frac{M_{OUT}(f)}{M_{IN}(f)} = \frac{(\Psi'_{max} - \Psi'_{min}) / (\Psi'_{max} + \Psi'_{min})}{(\Psi_{max} - \Psi_{min}) / (\Psi_{max} + \Psi_{min})}$$



MTF(f) kurve (%)



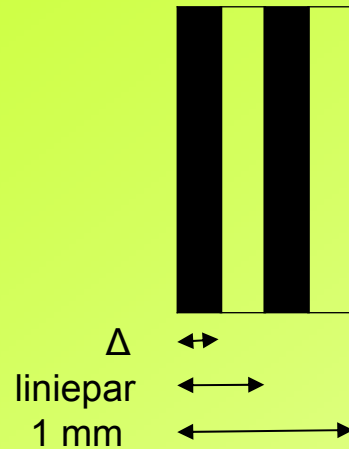
MTF for digitale detektor systemer :



$$FT \left\{ \Pi_{rect} \left(\frac{x}{a} \right) \right\} = a \cdot \text{sinc}(\pi a f) \quad , \quad \text{sinc}(x) = \frac{\sin(x)}{x} \quad , \quad MTF(0) = 1$$

a = pixel bredden, f = spatiale frekvens i mm^{-1}

Højkontrast opløsning i liniepar pr. millimeter :



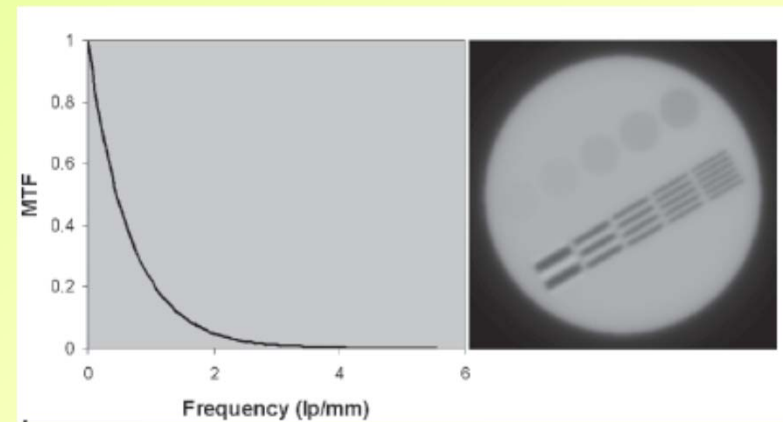
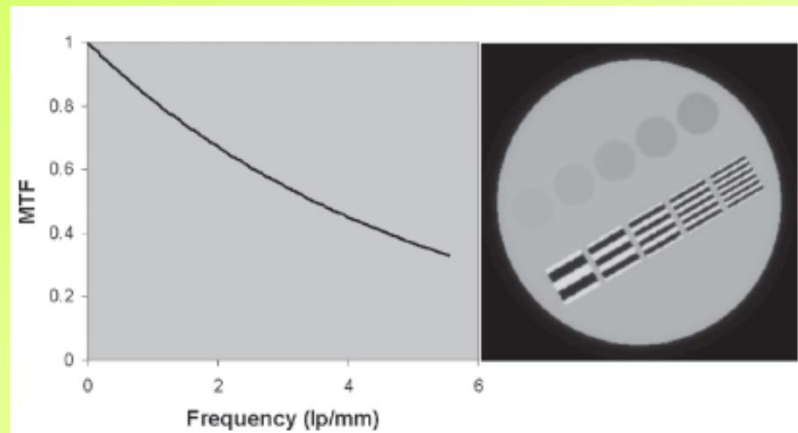
Eks.: $\Delta = 0,25 \text{ mm}$

$$\text{Spatial frekvens } f = \frac{1}{\Delta} = \frac{1 \text{ mm}}{0,25 \text{ mm}} = 4$$

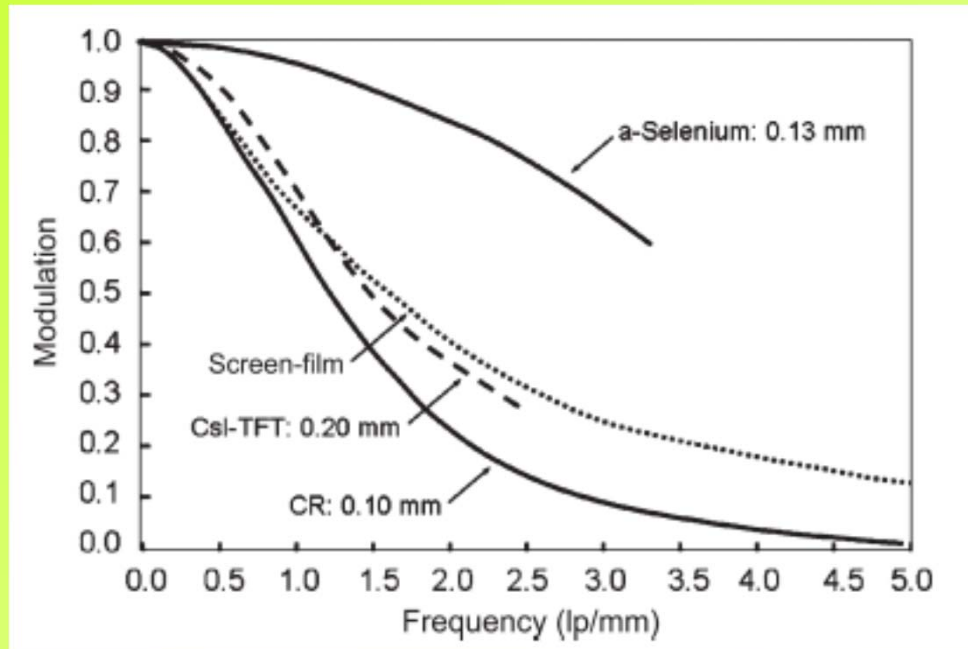
Antal liniepar pr. millimeter

$$\frac{1}{2 \cdot \Delta} = \frac{1}{2 \cdot 0,25 \text{ mm}} = \frac{1}{0,5 \text{ mm}} = 2 \text{ lp/mm}$$

MTF & Højkontrast :

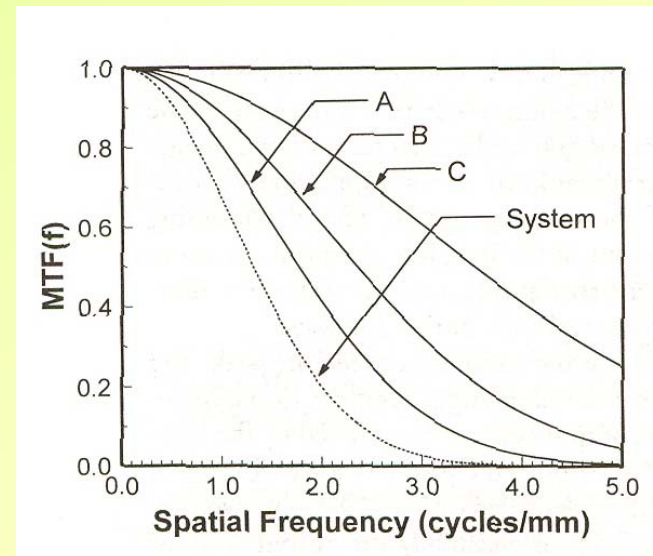


MTF for forskellige detektor systemer : DR, CR & S/F

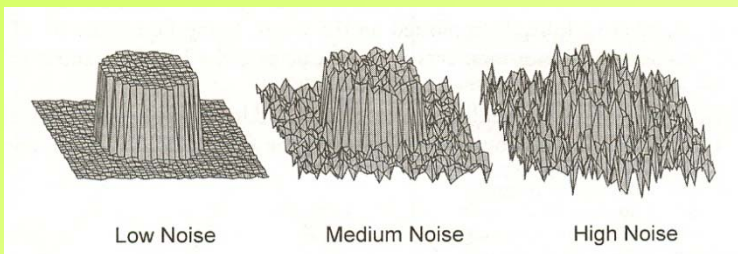
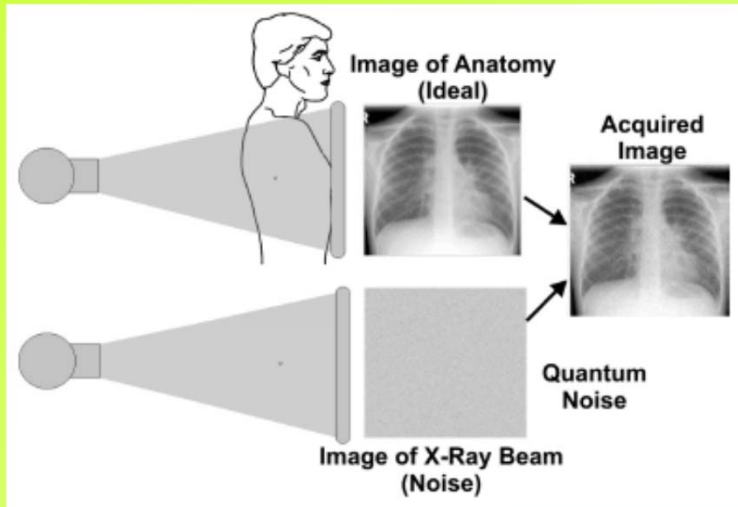


MTF for det samlede system med komponenter A, B, C og D :

$$MTF_{\text{system}} = MTF_A \cdot MTF_B \cdot MTF_C \cdot MTF_D$$



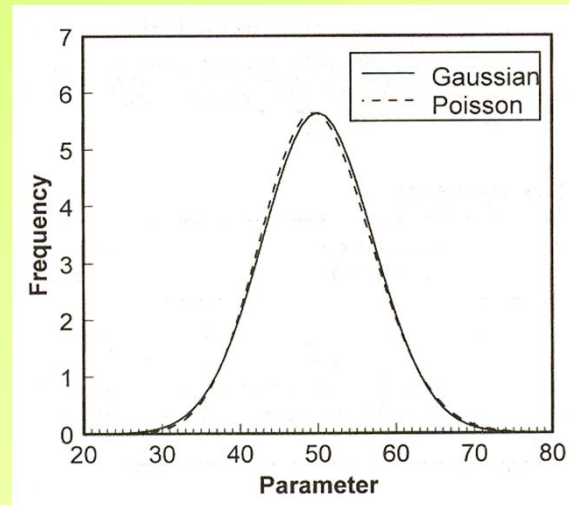
Quantum Noise / Kvantestøj :



For en Poisson fordelt stokastisk variabel (antal fotoner N) gælder :

Poisson Fordeling:

Antallet af producerede røntgenfotoner i røntgenrøret følger statistisk set en Poisson fordeling :



$$P(x) = \frac{\lambda^x}{x!} \cdot e^{-\lambda}$$

x = stokastisk variabel
 λ = middelværdien af x

Spredning $\sigma = \sqrt{N}$

Varians $\sigma^2 = N$

Quantum Noise & Dosis :

Signal to Noise Ratio SNR :

$$SNR = \frac{N}{\sigma} = \frac{N}{\sqrt{N}} = \sqrt{N}$$

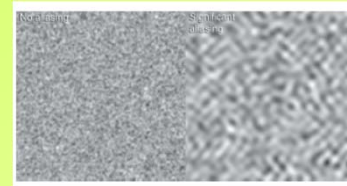
Quantum Detective Efficiency QDE :

$$QDE = \frac{N_{\text{absorberet}}}{N_{\text{incident}}}$$

Image Quality SNR :

$$SNR_{\text{image}} = \sqrt{N_{\text{detected}}} = \sqrt{QDE \cdot N_{\text{incident}}}$$

Noise Power Spectrum NPS(f) :



Quantum Noise
Detector Noise
Electronic Noise

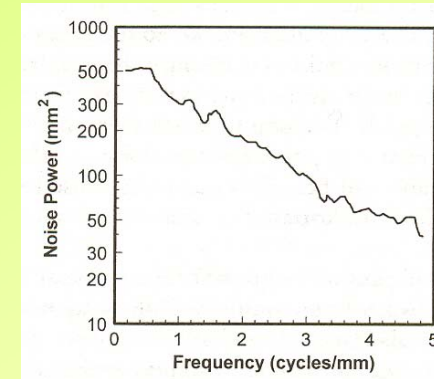


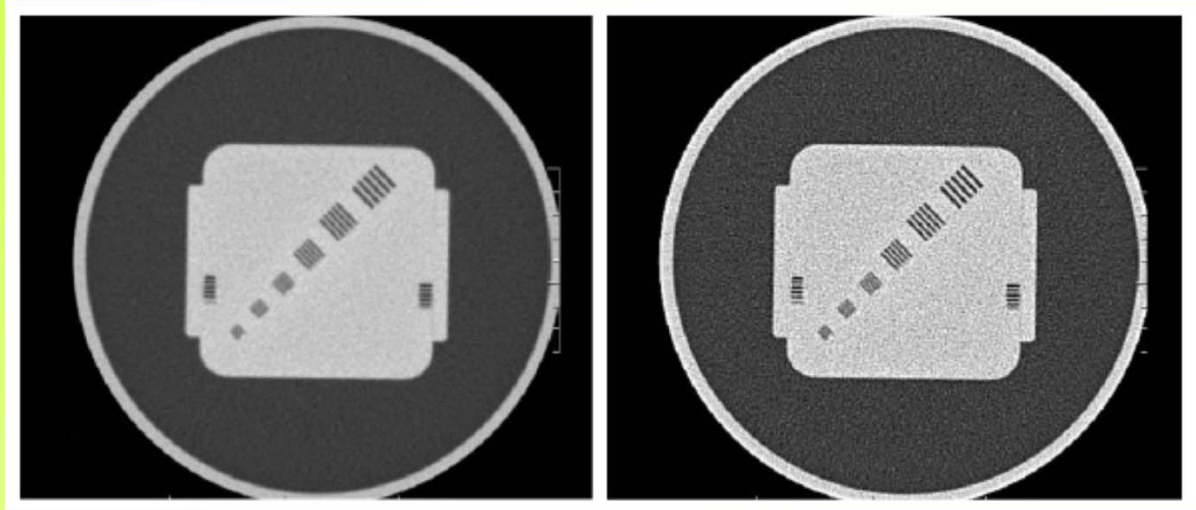
TABLE 10-1. EXAMPLES OF NOISE VERSUS PHOTONS

Photons/Pixel (N)	Noise (σ) ($\sigma = \sqrt{N}$)	Relative Noise (σ/N) (%)	SNR (N/σ)
10	3.2	32	3.2
100	10	10	10
1,000	31.6	3.2	32
10,000	100	1.0	100
100,000	316.2	0.3	316

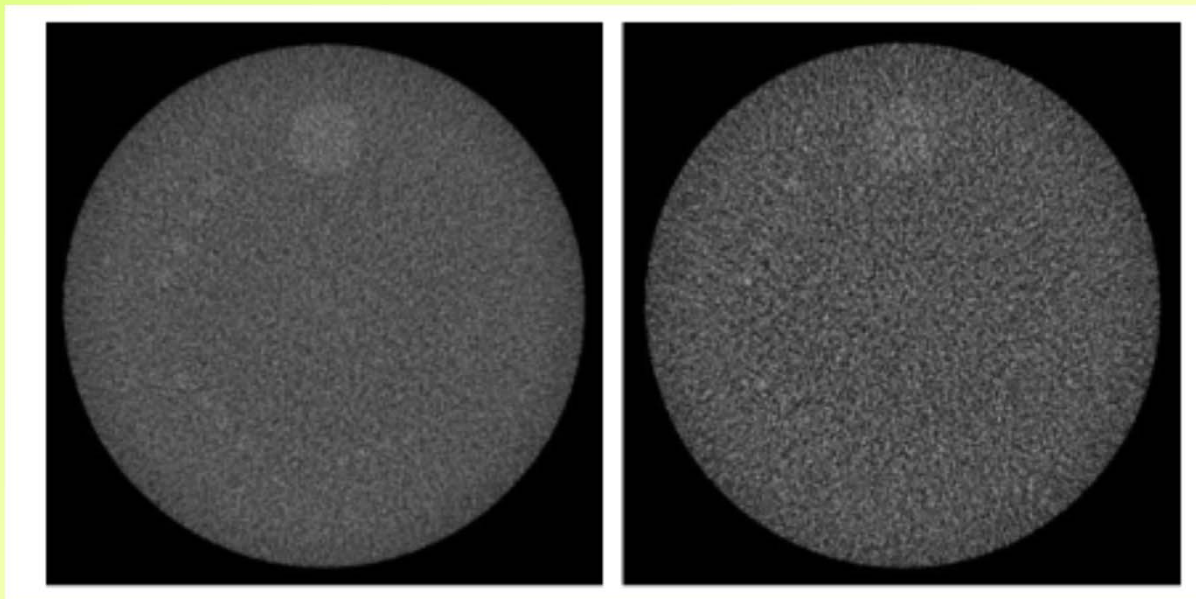
SNR, signal-to-noise ratio.

Billedkvalitet og billedstøj :

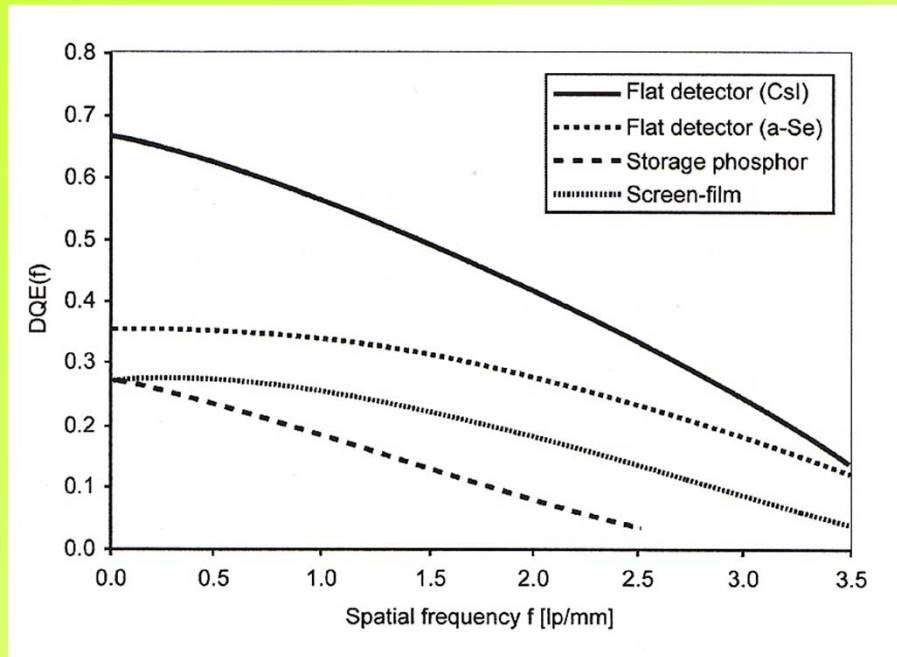
Støj & højkontrast :



Støj & lavkontrast :



Detective Quantum Efficiency DQE :



NEQ = Noise Equivalent Quantum

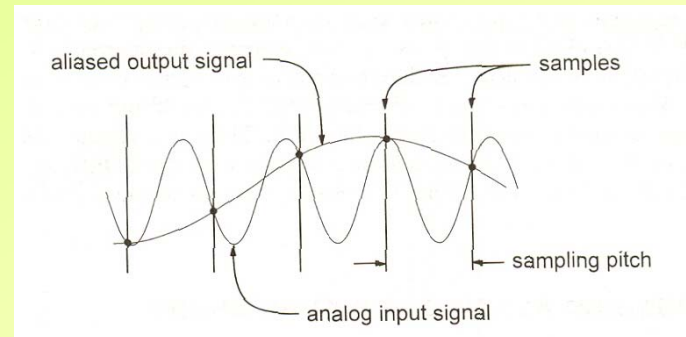
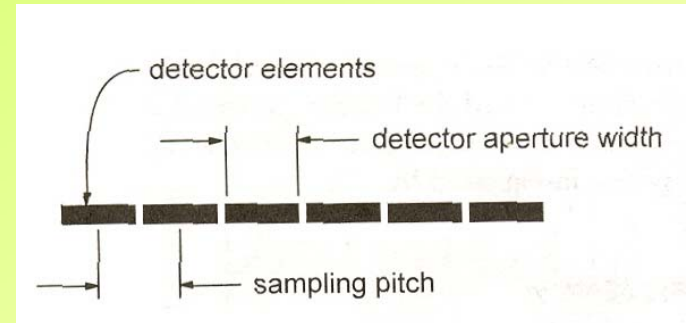
SNR = Signal to Noise Ratio

NPS = Noise Power Spectrum

G = Gain Factor

$$DQE(f) = \frac{SNR_{actual}^2}{SNR_{ideal}^2} = \frac{NEQ}{SNR_{ideal}^2(f)} = \frac{G^2 \cdot MTF^2(f)}{NPS(f) \cdot SNR_{ideal}^2(f)}$$

Sampling & Aliasing :



Sampling & Aliasing :

Nyquist frekvens F_N : $F_N = \frac{1}{2\Delta}$

$\Delta = 100 \mu\text{m}$, $F_N = 5,0 \text{ lp/mm}$
"Foldning" om F_N

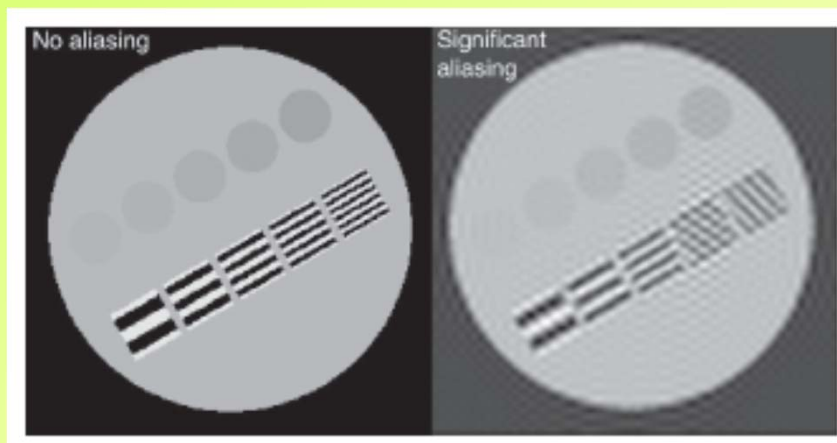
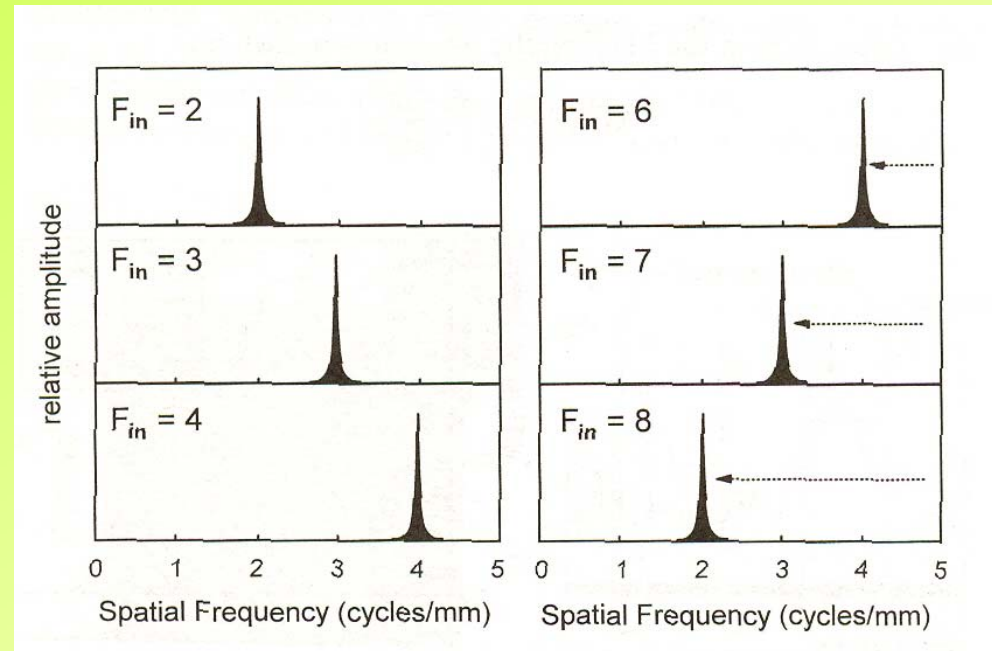
Eks.:

DR receptor CsI:TI

$\Delta = 143 \mu\text{m}$, $F_N = 3,5 \text{ lp/mm}$

CR billedplade receptor

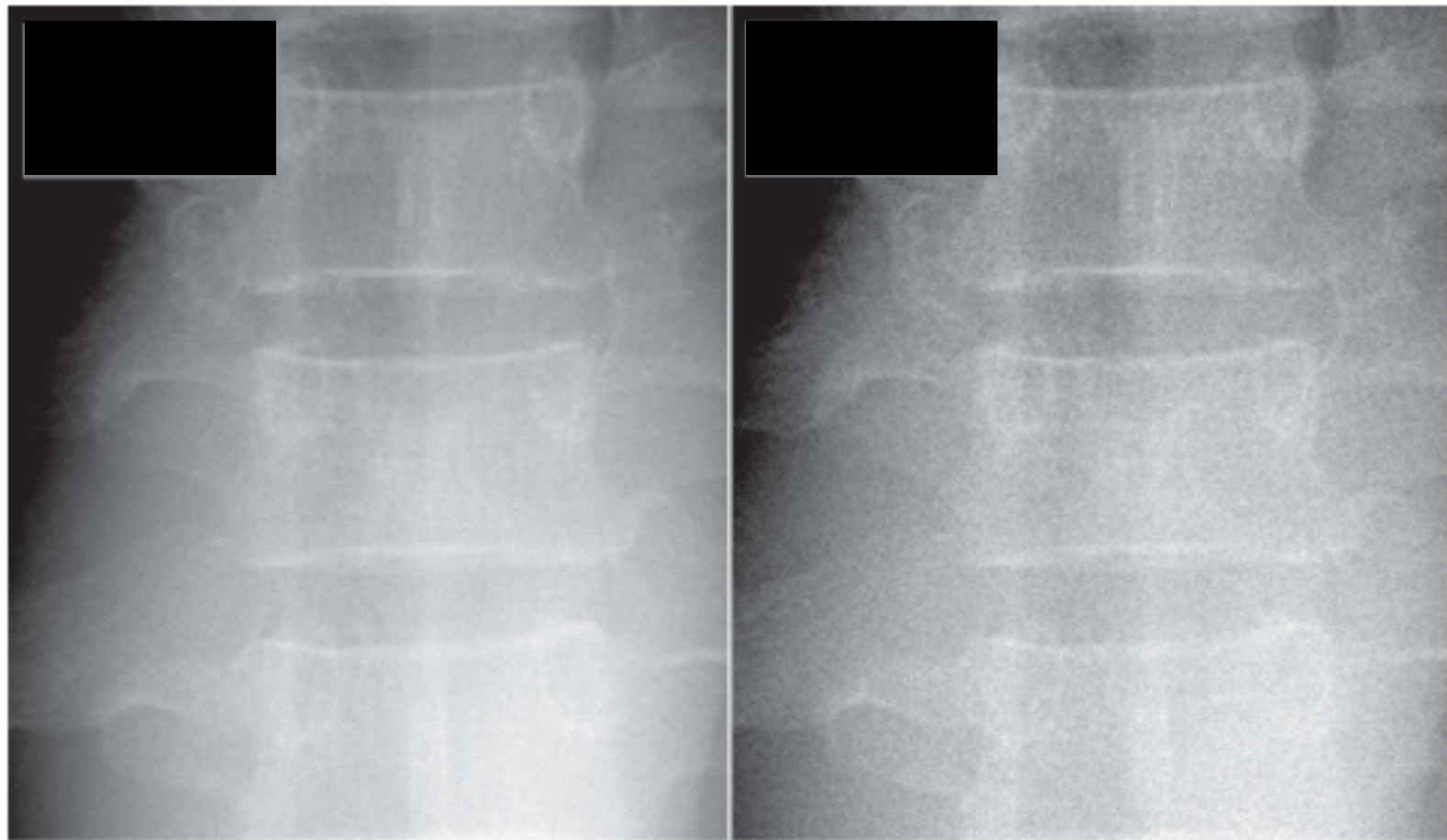
$\Delta = 200 \mu\text{m}$, $F_N = 2,5 \text{ lp/mm}$



Aliasing :

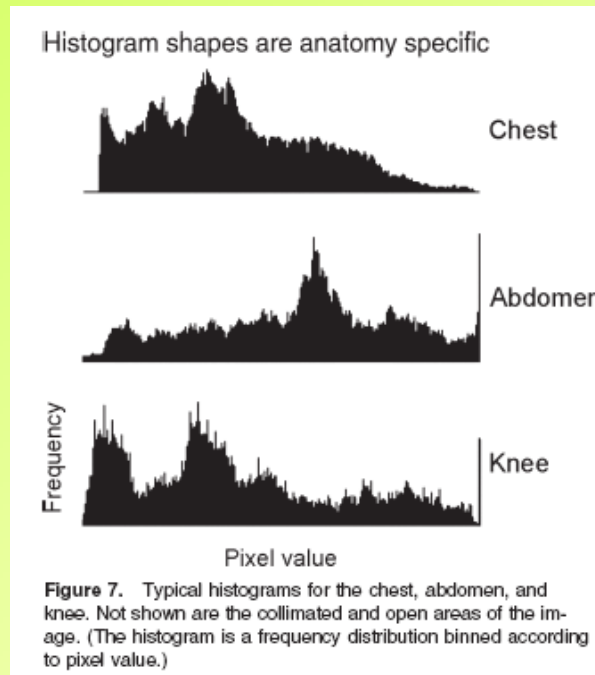
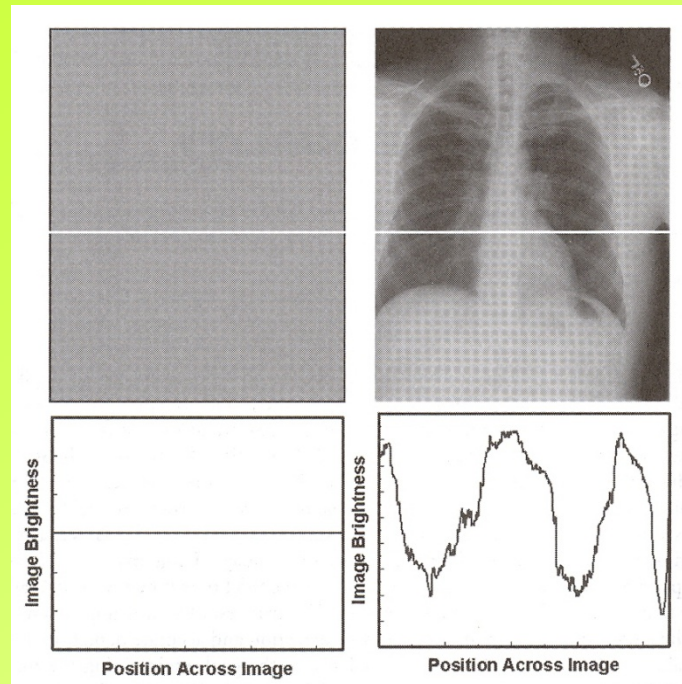
Højkontrast & Lavkontrast

Billedkvalitet og billedstøj :



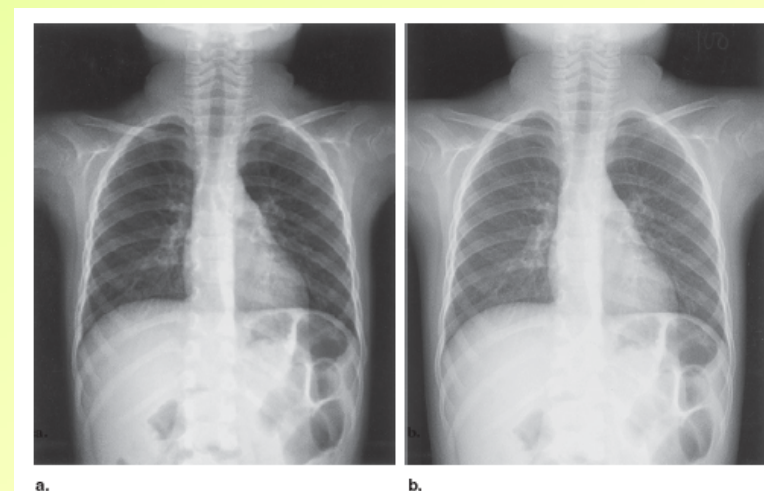
Se Direct Digital Radiographs: Chest Phantom, AP Spine

Histogram over pixel værdier :



Post – processing :

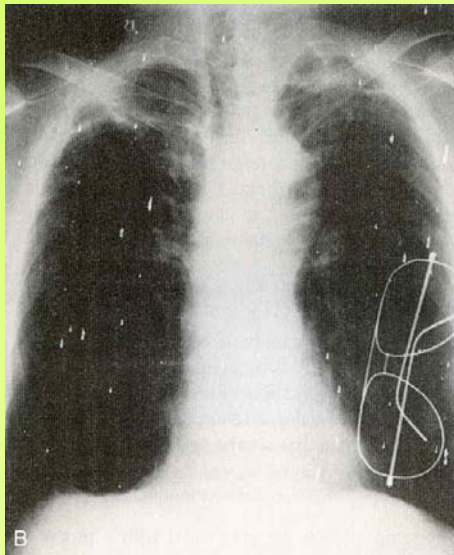
- a) Adult postprocessing software
- b) Pediatric postprocessing software



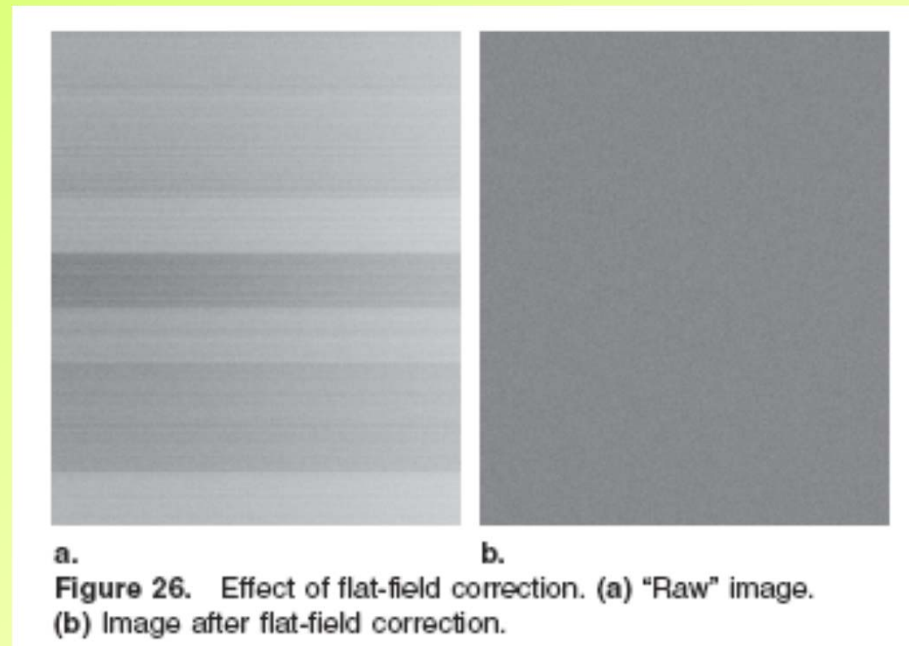
Eksempler på artefakter :



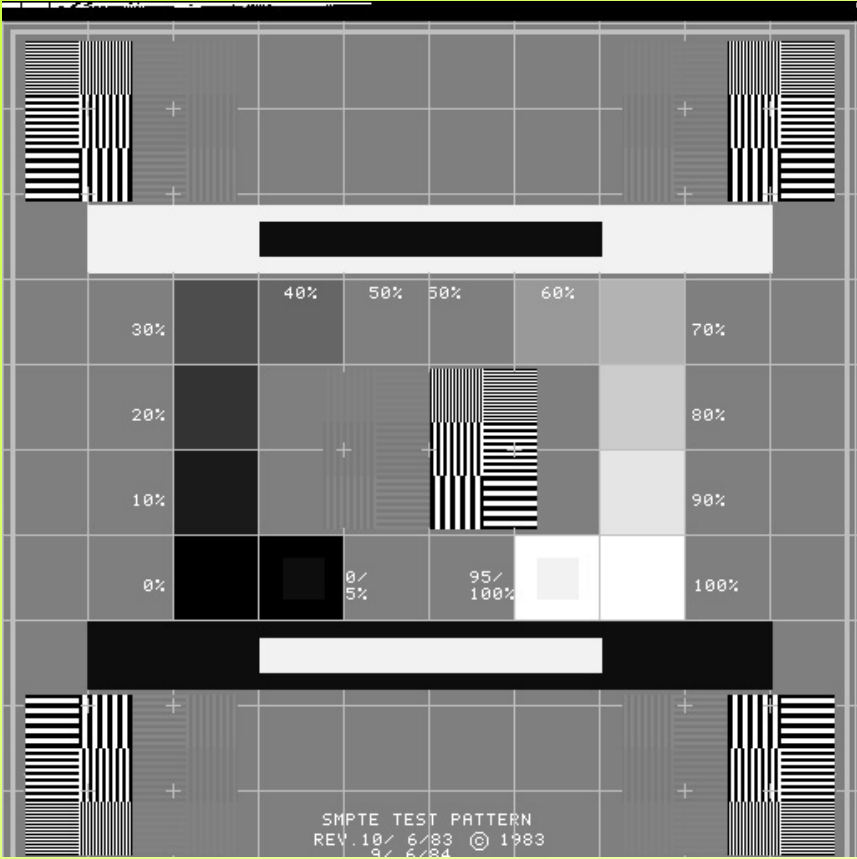
Moiré pattern



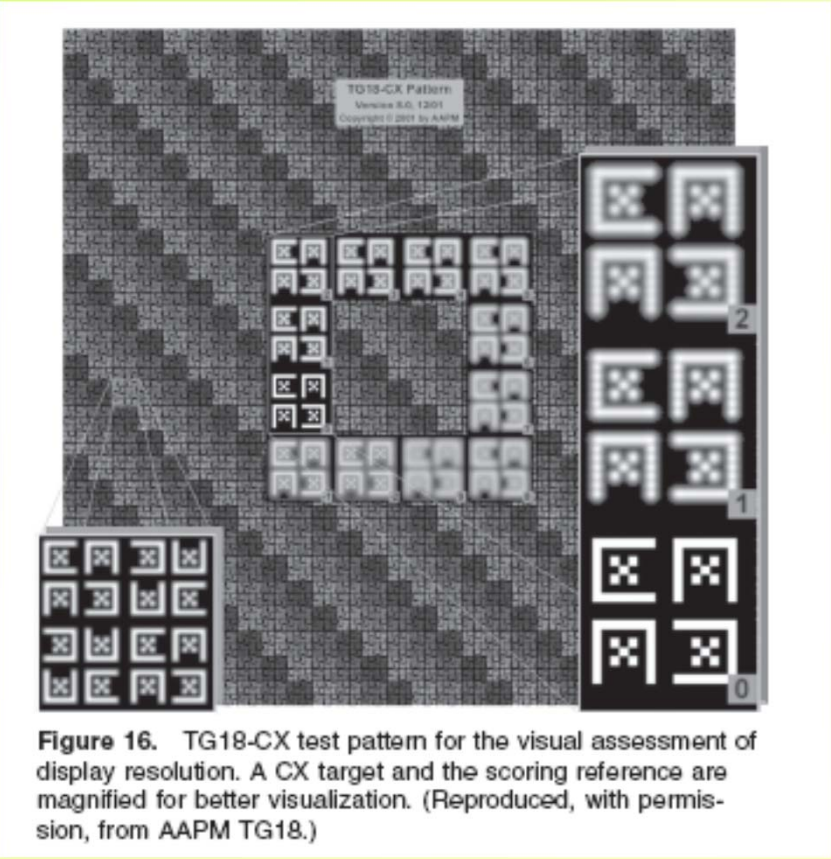
UPS !!!



Diagnostik monitorer: Kvalitetskontrol



SMPTE test billede



AAPM TG18 test billede

Diagnostik monitorer : Ambient light, Reflections, Viewing angle, etc.

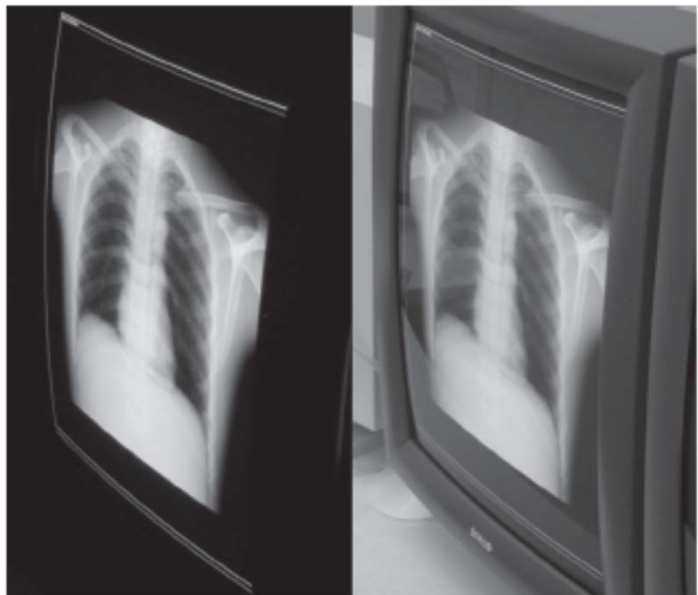


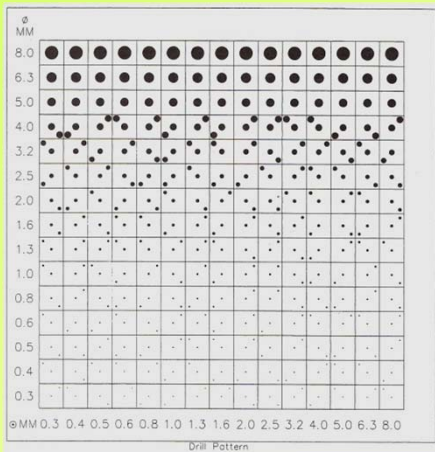
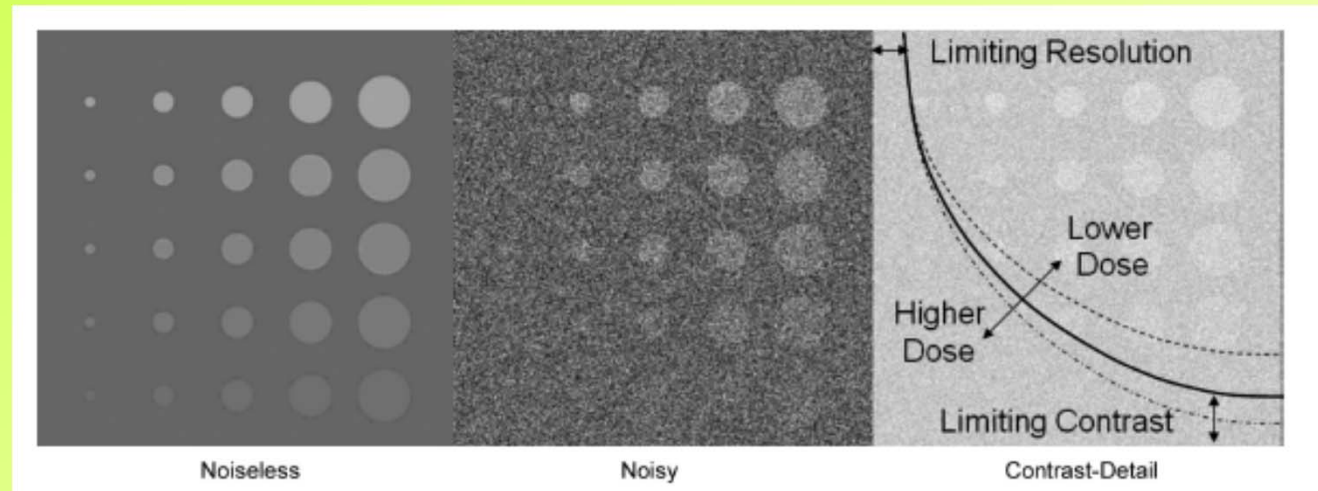
Figure 8. Reduction of image contrast (right image) caused by specular reflection (visible as shadows of bright objects) and diffuse reflection (manifested as an overall contrast reduction of the chest radiograph).



LCD Flat Screen monitorer

Billedkvalitet & Contrast Detail kurver :

Vurdering af billedkvalitet ved ændring af dosis / støj for et detektor system:



CD RAD 2.0

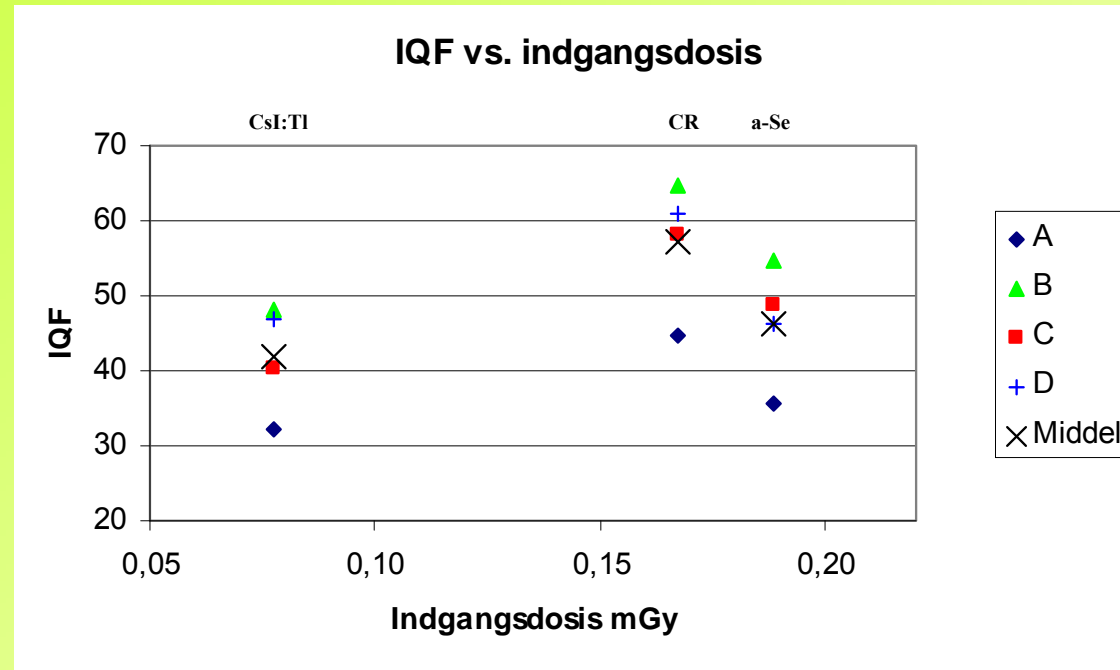
Image Quality Figure

$$IQF = \sum_{i=1}^{15} h_i \cdot d_i$$

Billedér vurderet på diagnostik monitorer.
 Brug af forstørrelse/zoom tilladt
 Ændring af Window / Level niveauer tilladt

CD RAD fantom, IQF - værdier, 4 observatører :

Eks.:



				Observatør							
				A		B		C		D	
	mGy	IQF	σ	IQF	σ	IQF	σ	IQF	σ	IQF	σ
a - Se	0,1886	46,24	7,80	35,47	2,79	54,59	3,00	48,80	1,10	46,10	5,28
CsI:TI	0,0775	41,90	7,13	32,26	3,53	48,21	2,65	40,34	4,04	46,77	2,34
CR	0,1673	57,05	9,28	44,61	5,35	64,58	6,79	51,09	6,55	61,01	3,76

Receiver Operating Characteristics ROC :

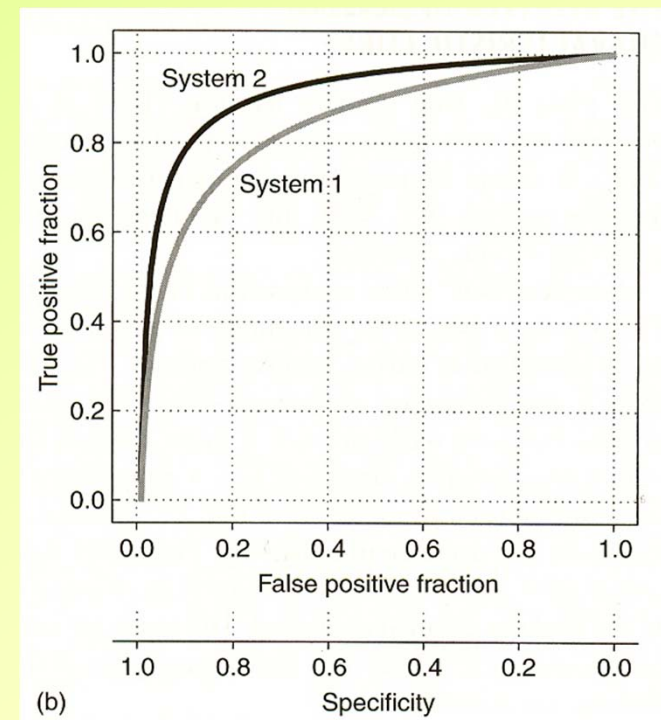
Decision 2 x 2 matrix	Actually Abnormal	Actually Normal
Diagnosed as Abnormal	True Positive TP	False Positive FP
Diagnosed as Normal	False Negative FN	True Negative TN

True Positive Fraction $TPF = \frac{TP}{TP + FN}$

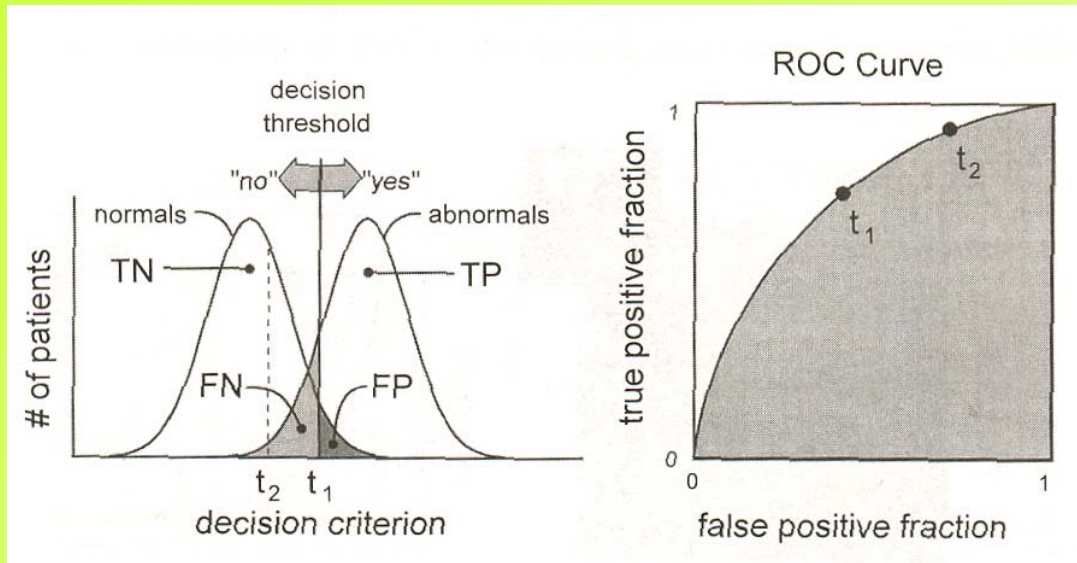
False Positive Fraction $FPF = \frac{FP}{FP + TN}$

Sensitivity = TPF

Specificity = $\frac{TN}{TN + FP}$

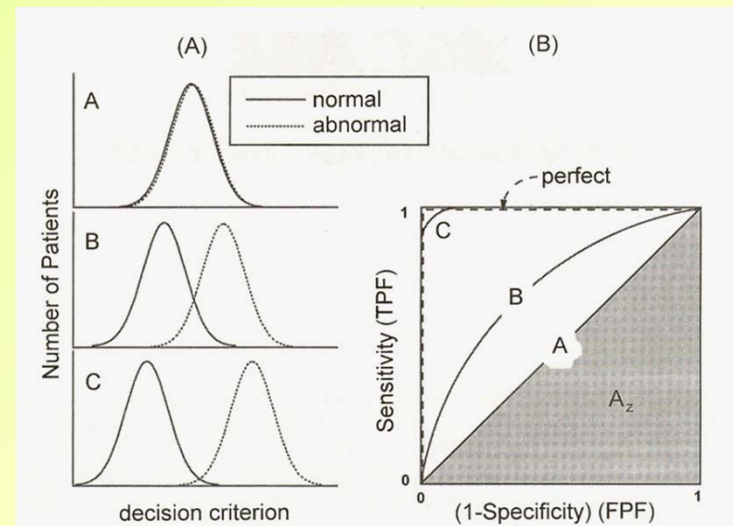


Receiver Operating Characteristics ROC :



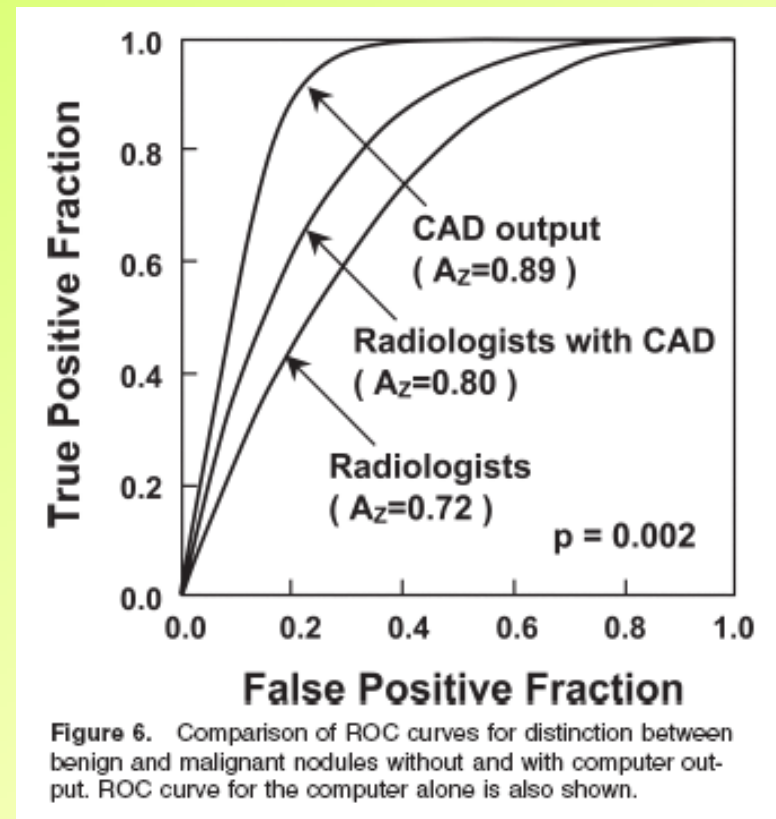
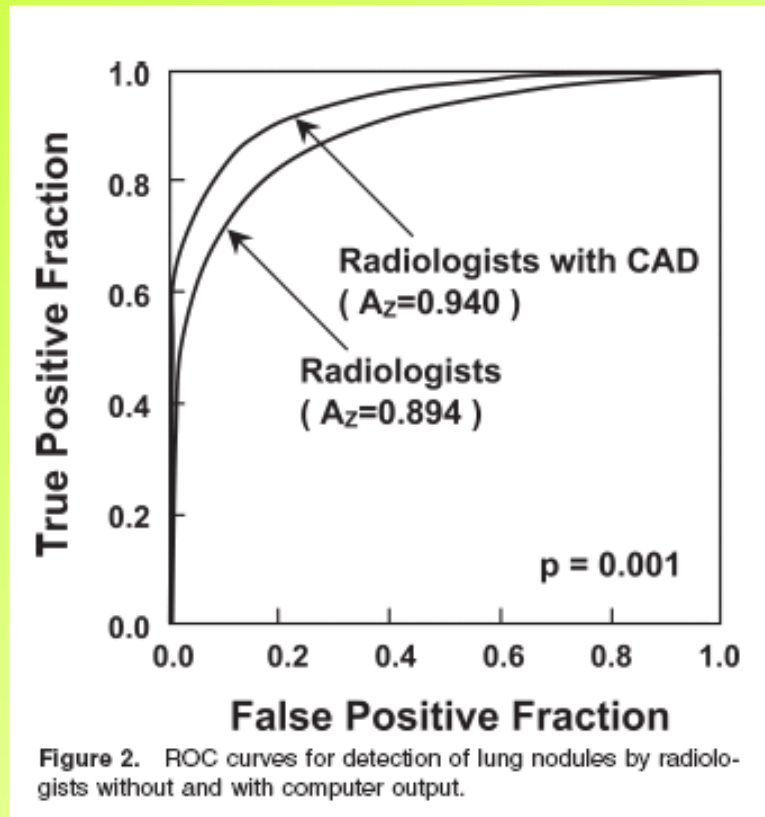
Decision thresholds t_1 , t_2 & ROC kurve

Areal under ROC kurve
 A_z ($\frac{1}{2} < A_z < 1$)



ROC kurver :

Lung nodules - m/u. CAD (Computer-Aided Diagnosis)



The End !