Image Quality
Lecture 1

Resident Physics Course
March 27, 2006

UCSD

Topics

Image Contrast

Resolution

Noise

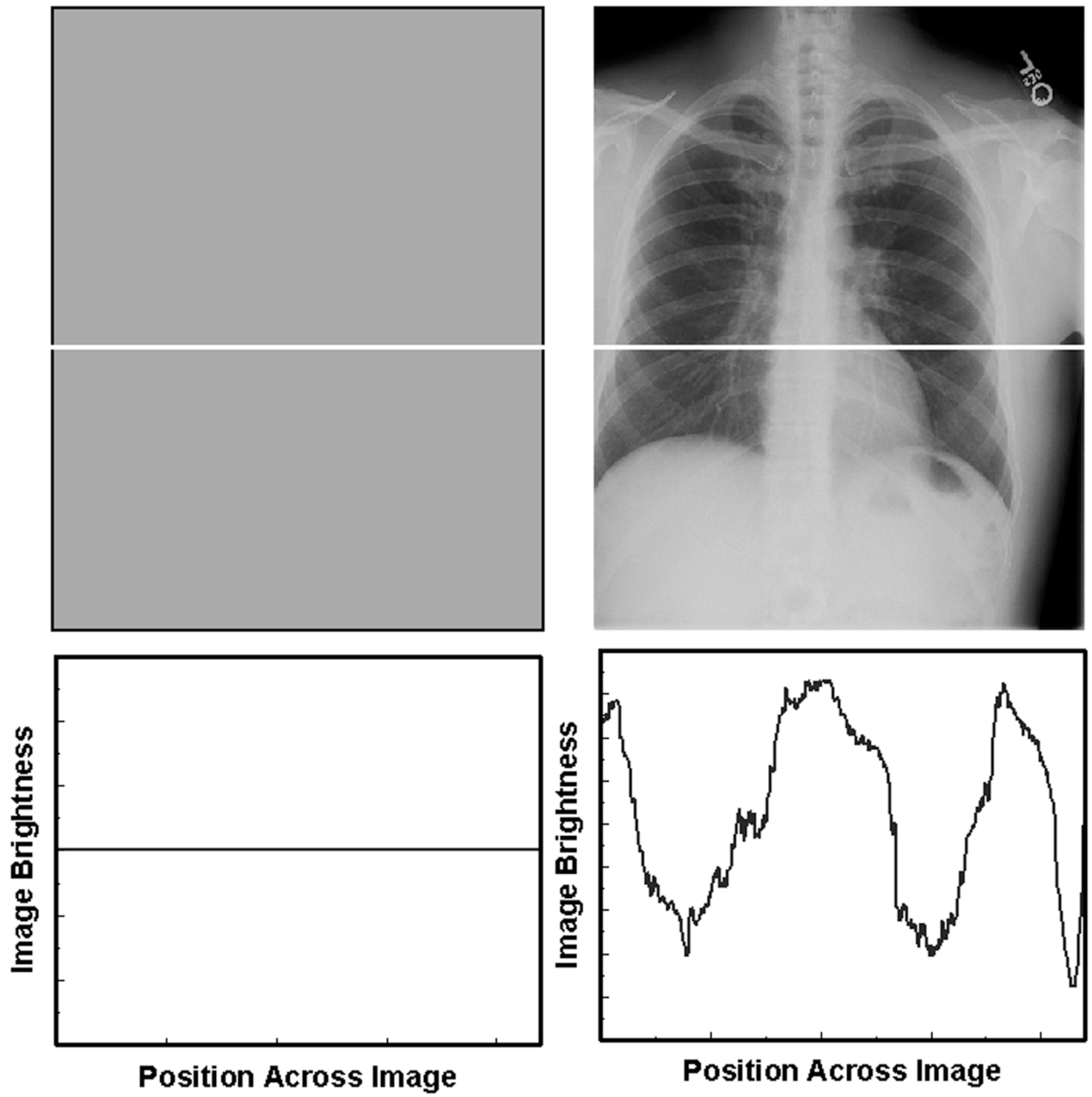
Contrast

Contrast is the difference in image gray scale between closely adjacent regions in an image.

Types of Contrast are:

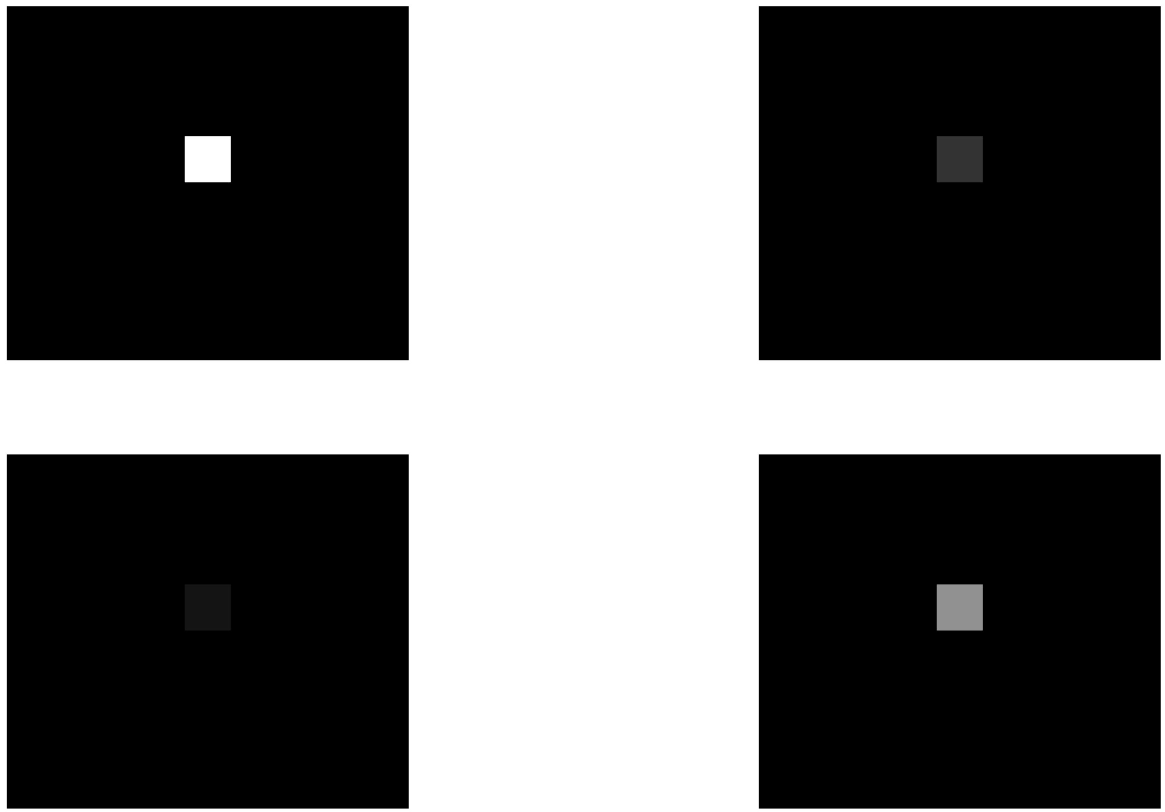
- Subject Contrast
- Detector Contrast
- Radiographic Contrast
- Digital Image Contrast
- Displayed Contrast

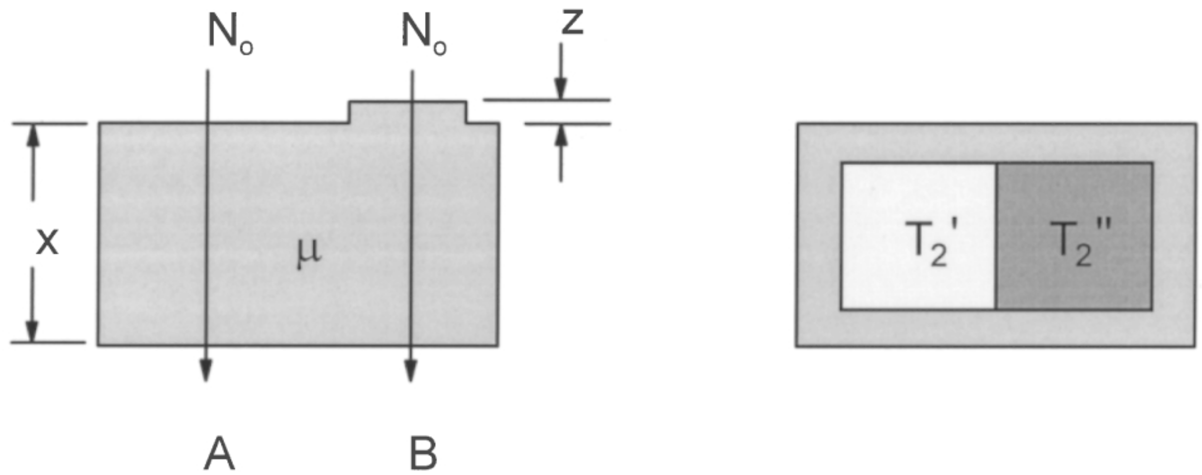
Contrast



Bushberg et al 2001

Contrast





(A) X-ray Imaging (B) MR Imaging

Bushberg et al 2001

$$A = N_0 \exp(-\mu x)$$

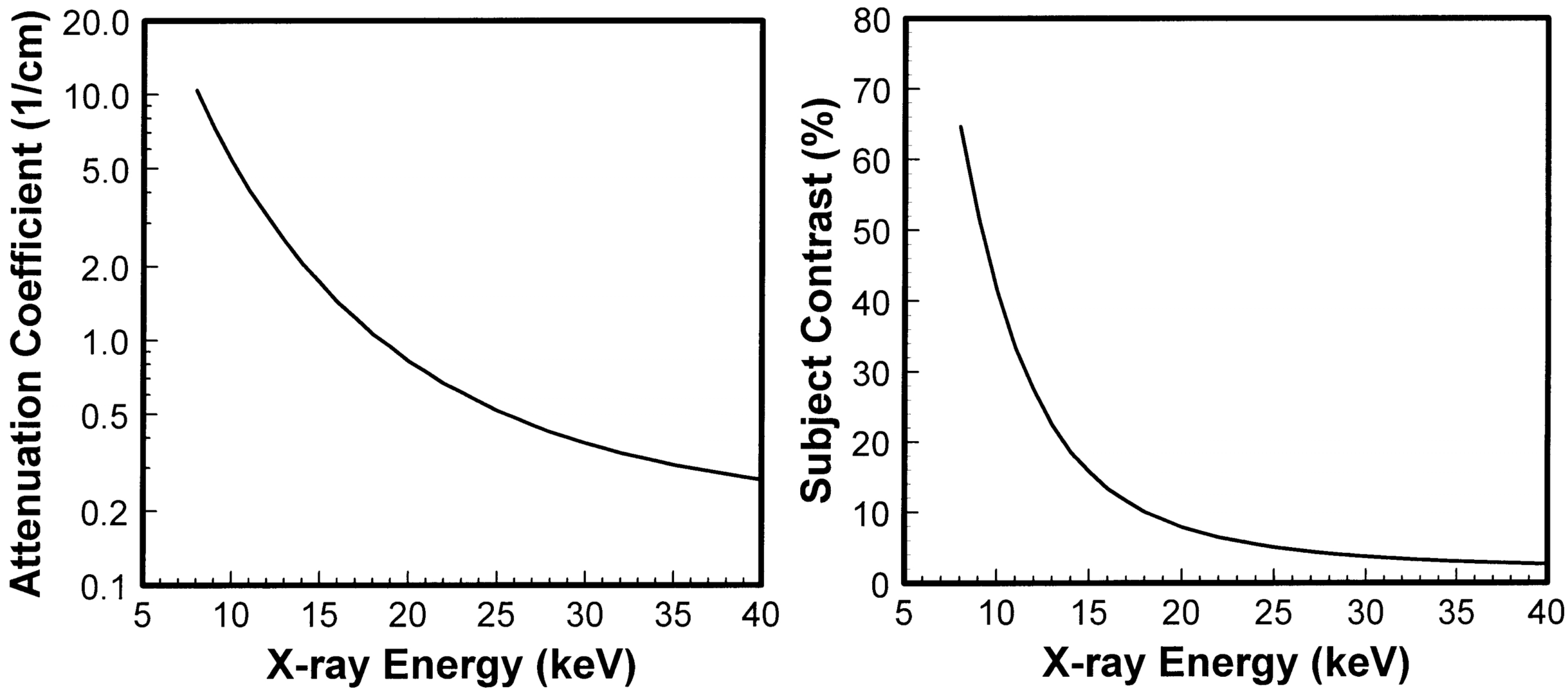
$$B = N_0 \exp(-\mu(x+z))$$

Subject Contrast

$$C_S = \frac{A-B}{A}$$

$$= \frac{N_0 \exp(-\mu x) - N_0 \exp(-\mu(x+z))}{N_0 \exp(-\mu x)}$$

$$= 1 - \exp(-\mu z)$$

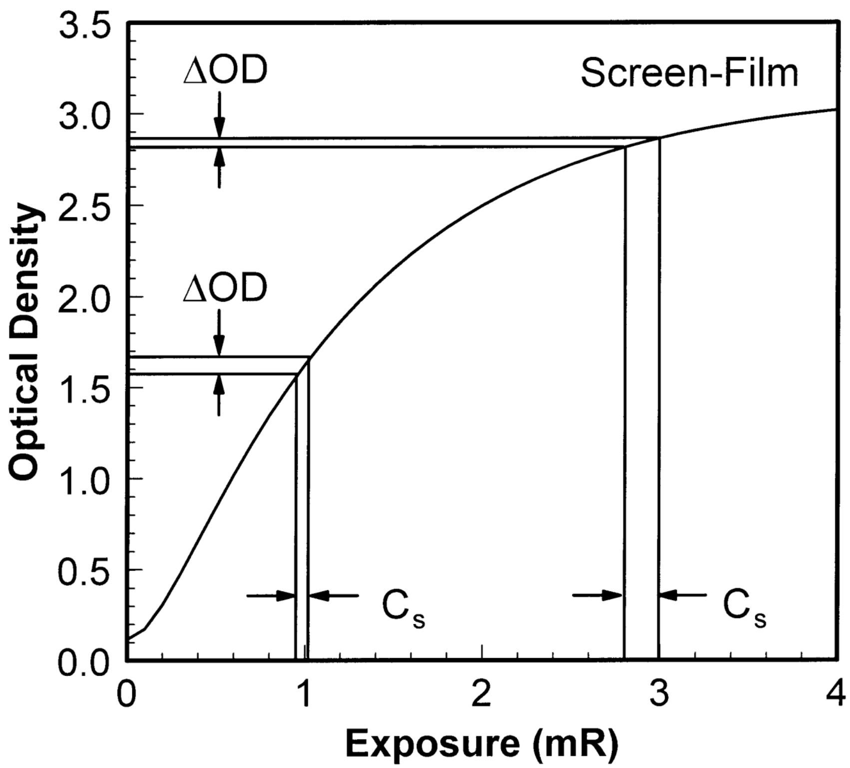


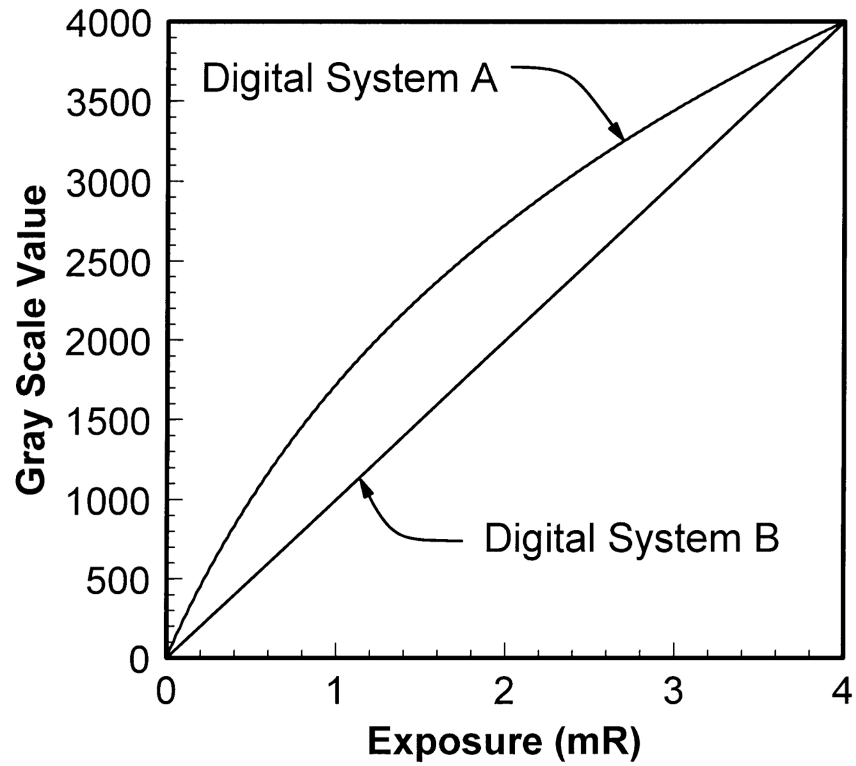
Bushberg et al 2001

$$C_S = 1 - \exp(-\mu z)$$

As attenuation increases, so does subject contrast

Characteristic Curves





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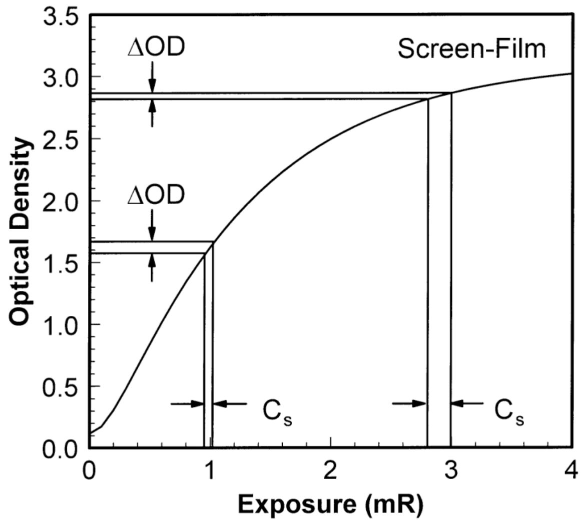
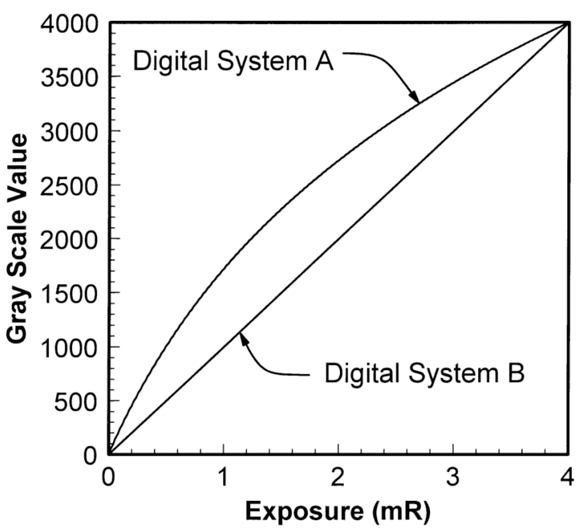
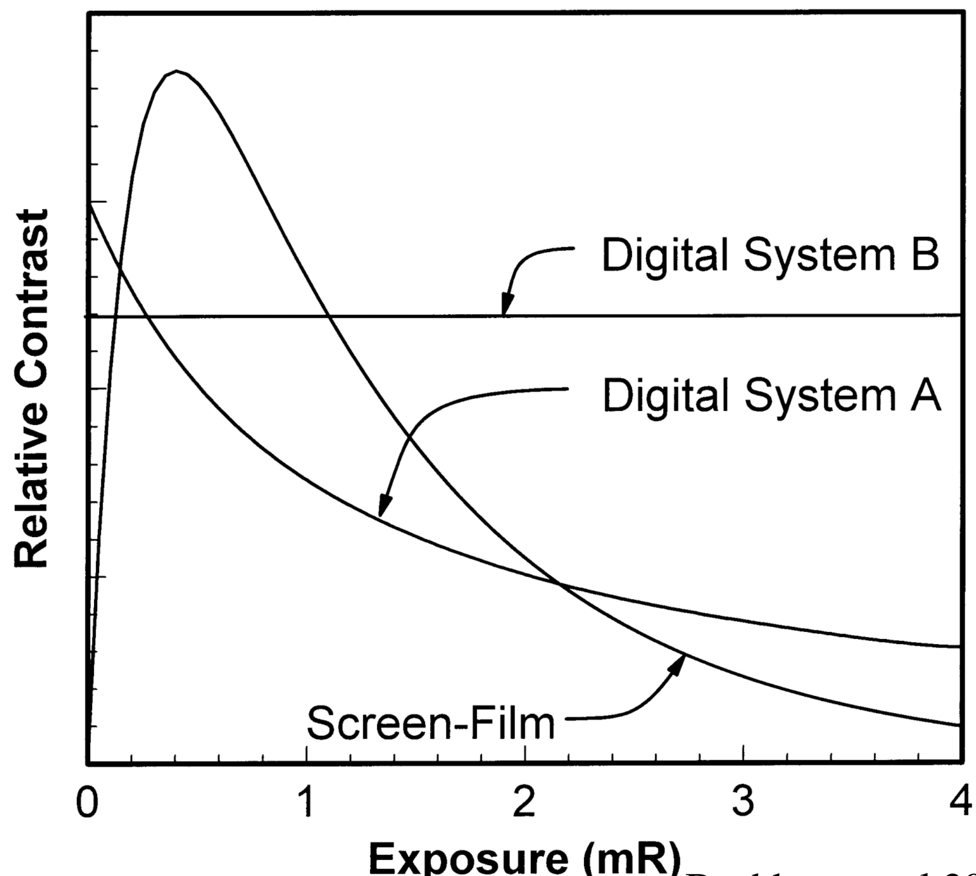
Detector Contrast = Slope of Characteristic Curve

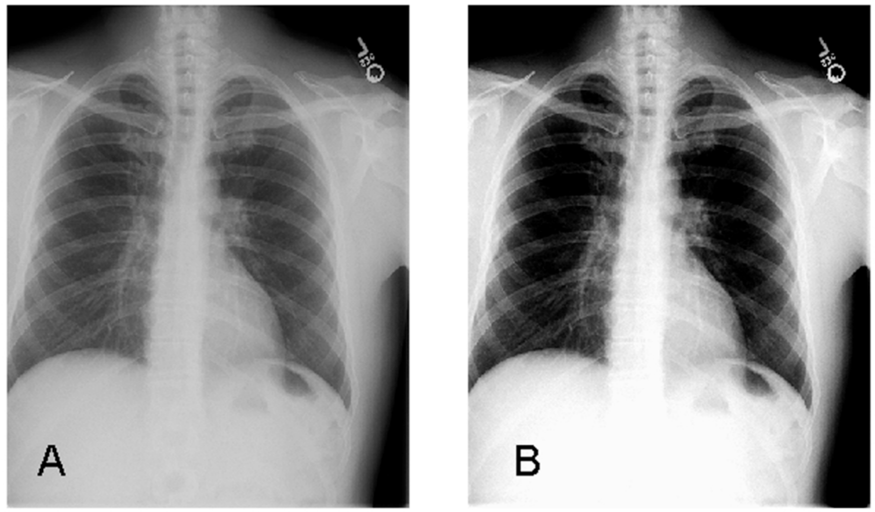


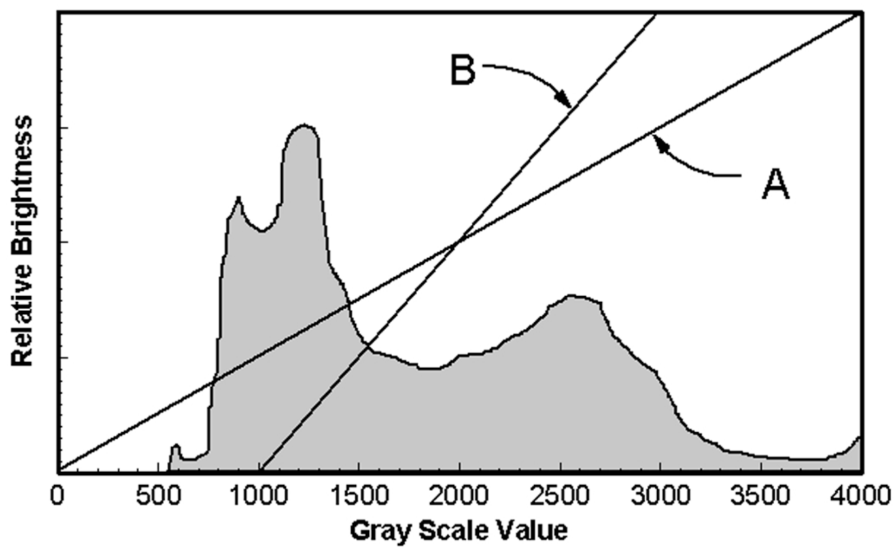




Bushberg et al 2001

Display Contrast





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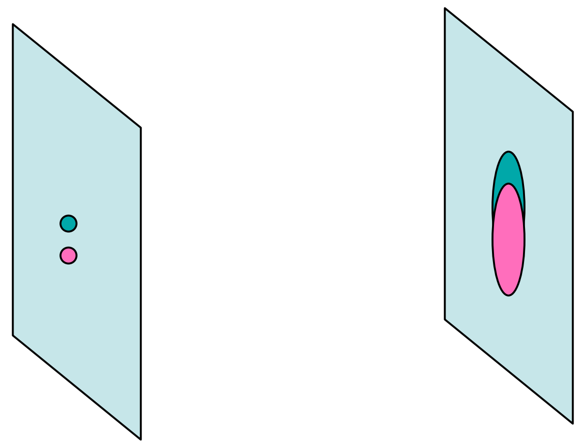
Point Spread Function (PSF)

Intuition: the PSF is the response of a system to an input of infinitesimal width and unit area.



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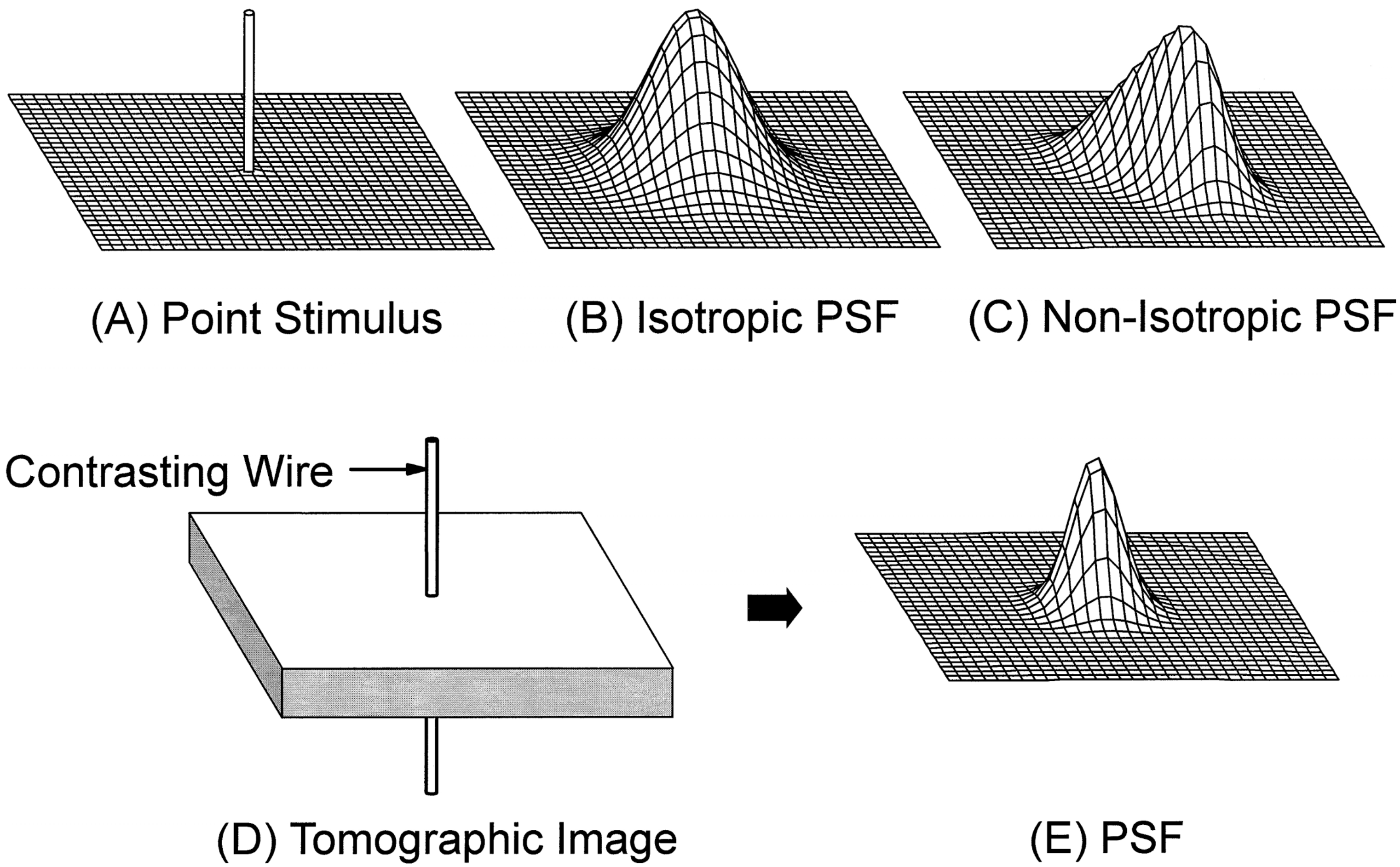
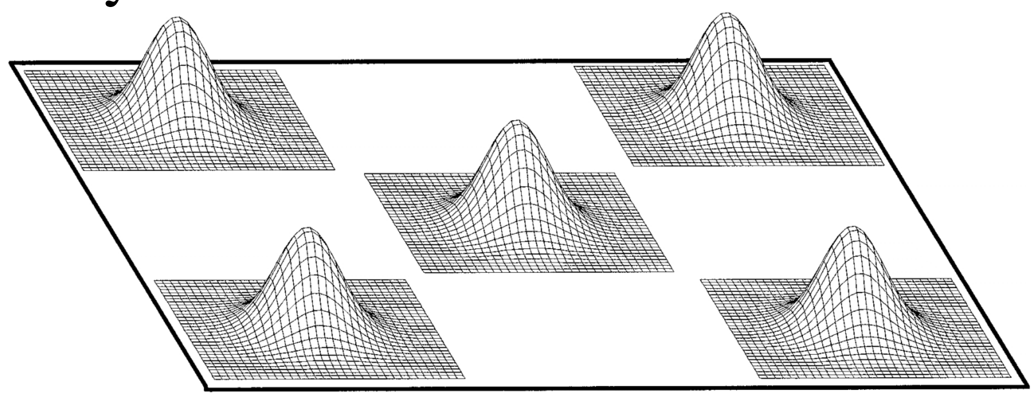
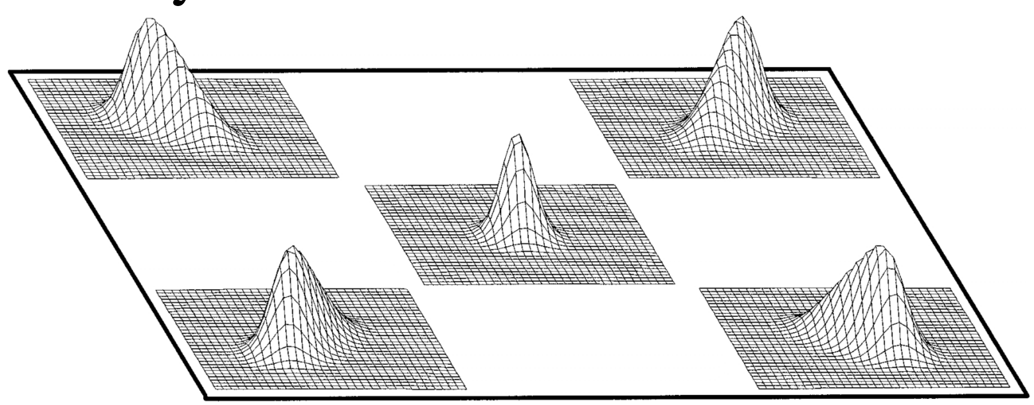


Bushberg et al 2001

Stationary PSF

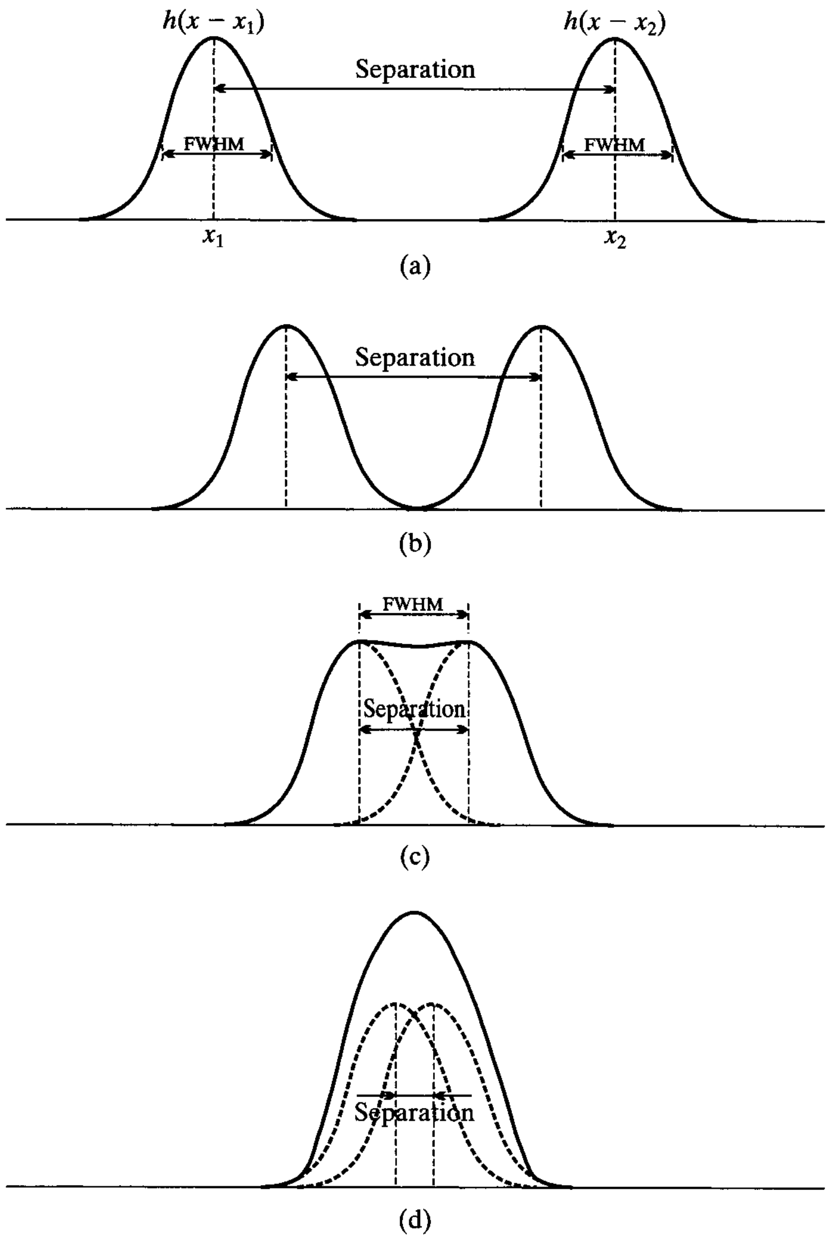


Nonstationary PSF



Bushberg et al 2001

For convenience, usually assume PSF is stationary.

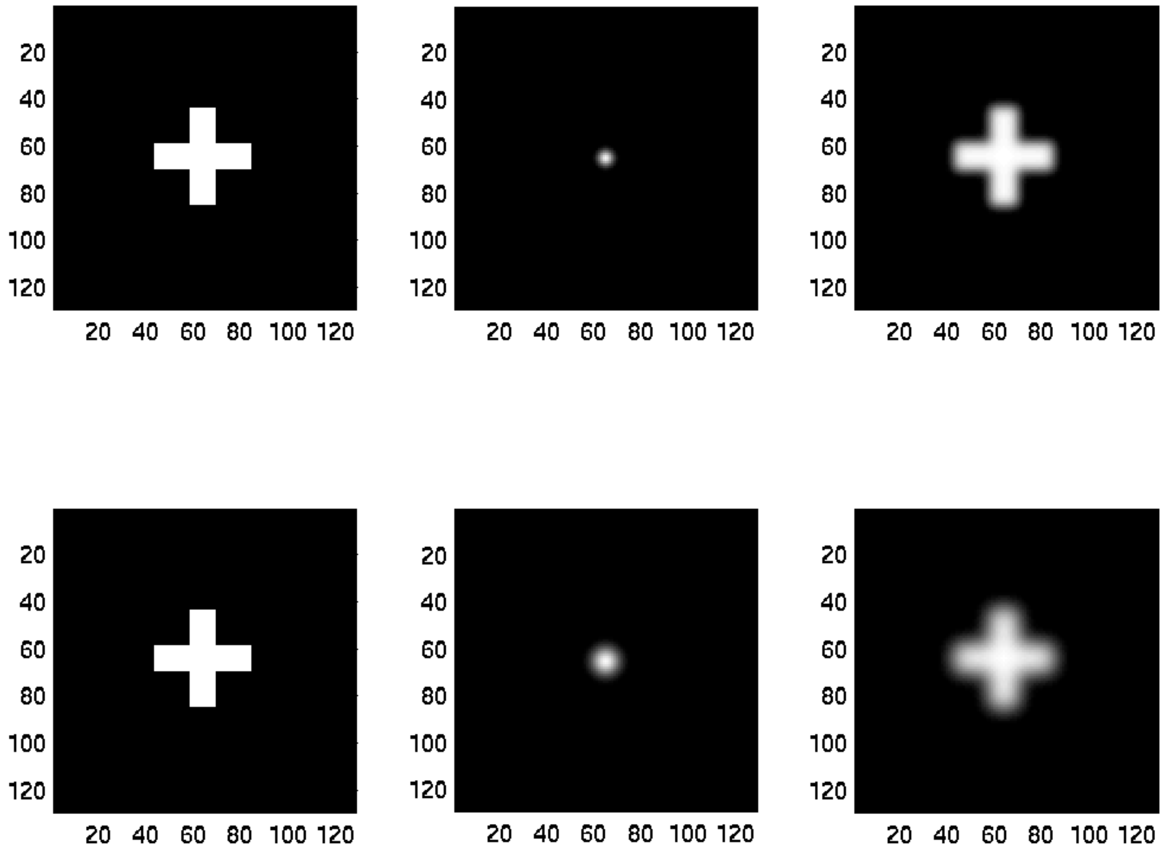


Full Width Half Maximum (FWHM) is a measure of resolution.

Figure 3.6
An example of the effect of system resolution on the ability to differentiate two points. The FWHM equals the minimum distance that the two points must be separated in order to be distinguishable.

Prince and Link 2005

Convolution



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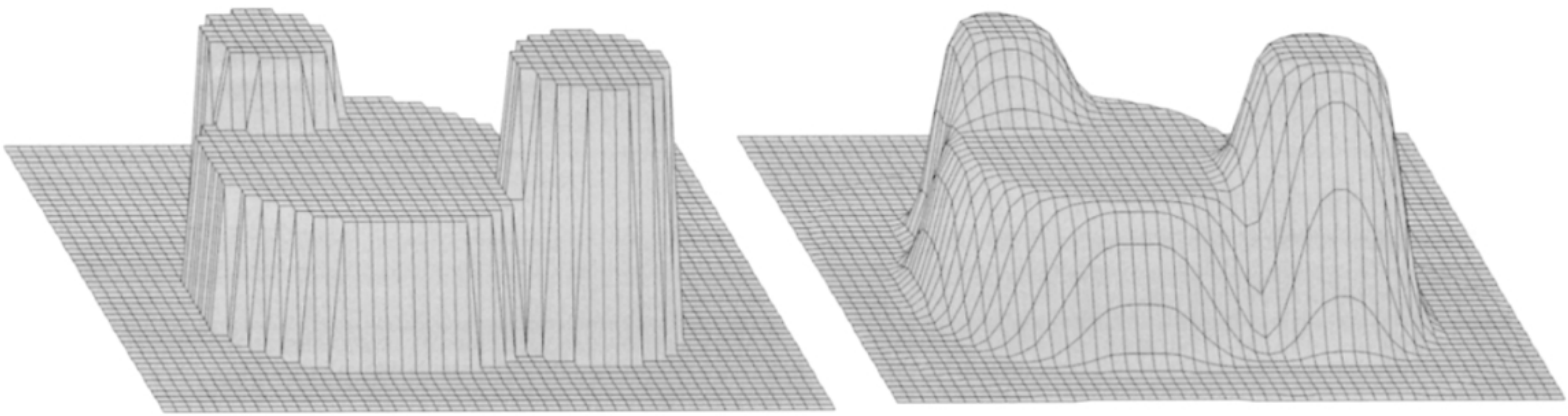
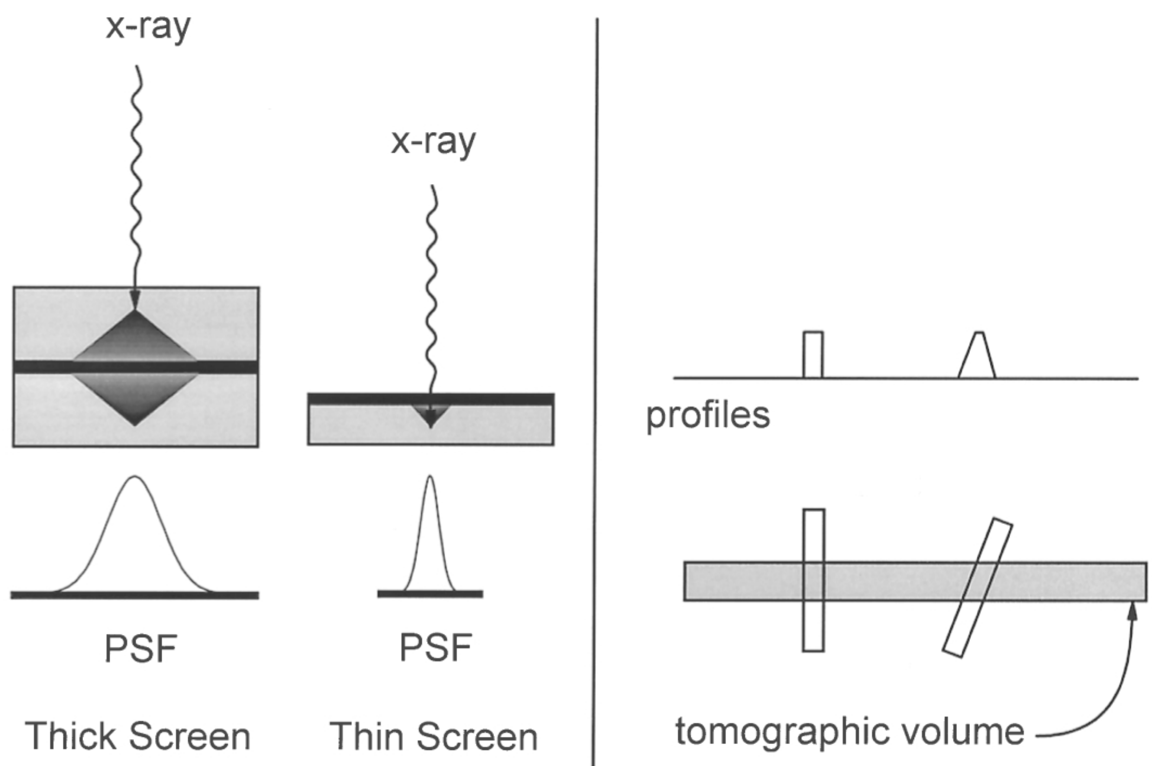
Convolution with PSF blurs object



Bushberg et al 2001

Blurring Mechanisms



Bushberg et al 2001

Figure 1:

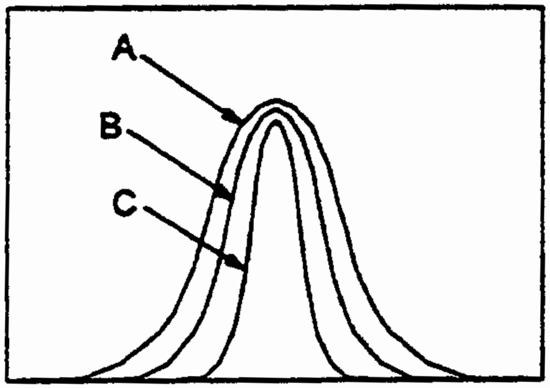
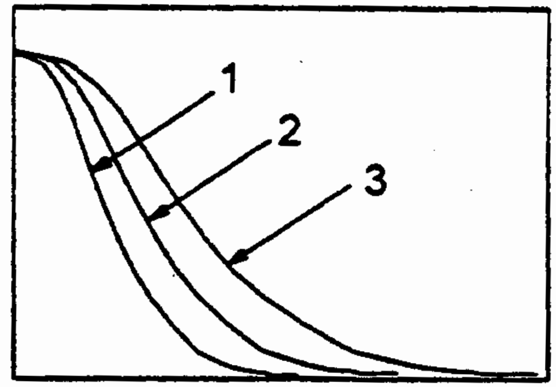


Figure 2:



8. Referring to Figure 1 (above) which demonstrates 3 different line spread functions (LSF), which LSF will yield the best spatial resolution?

9. Referring to Figure 1 showing 3 line spread functions, the best choices for the axes labels are _____ for the y-axis and ________ for the x-axis

A. frequency, amplitude
B. blur distance (mm), frequency
C. relative amplitude, frequency
D. relative amplitude, distance (mm)
E. distance (mm), relative amplitude

Figure 1:

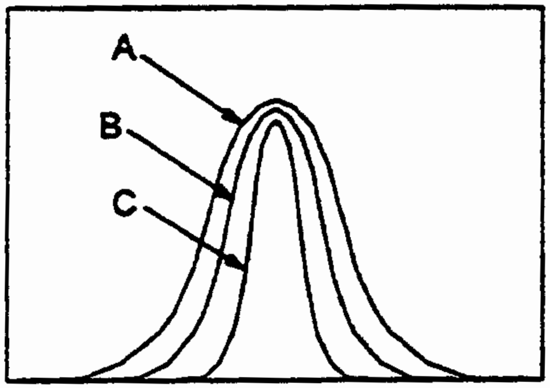
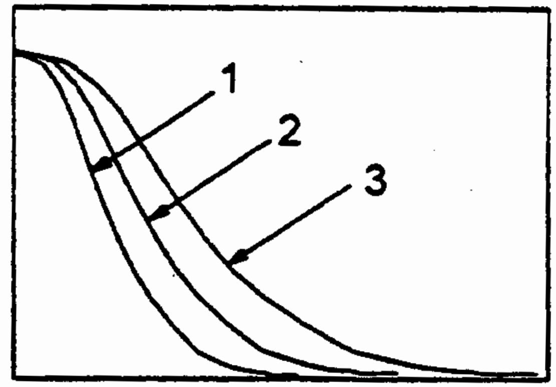


Figure 2:



10. Referring to Figure 1 which shows LSFs, and Figure 2 which shows the corresponding modulation transfer functions (MTFs), which MTF corresponds to LSF C?

A. MTF number 1
B. MTF number 2
C. MTF number 3

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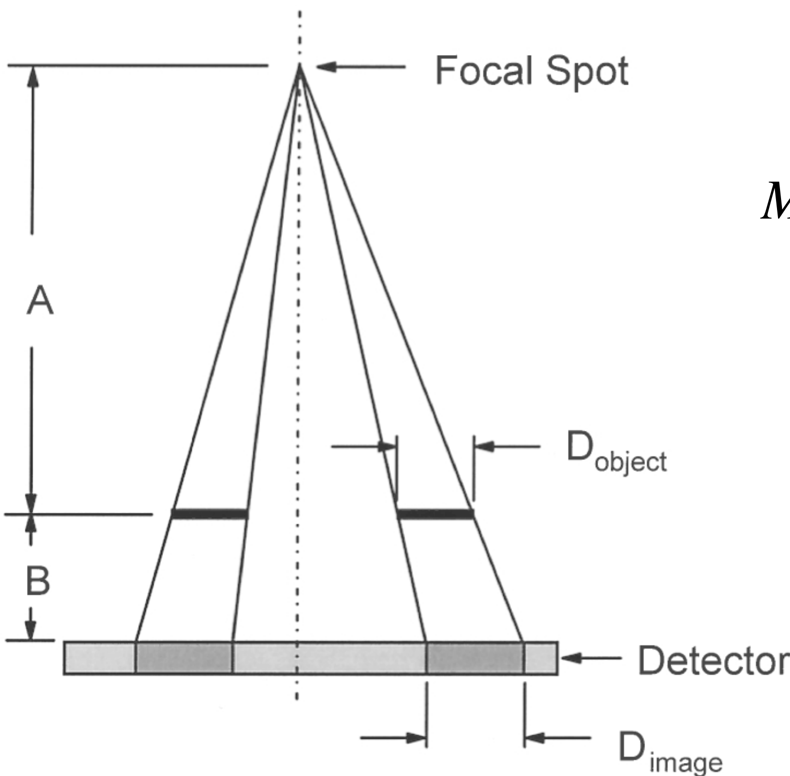
11. Referring to Figure 2 illustrating MTFs, the axes should be labeled _____ for the y-axis and ______ for the x-axis.

A. Relative amplitude, distance (mm)
B. Spatial frequency (lp/mm), distance (mm)
C. Lateral dimension (mm), Fresnel ratio
D. Relative amplitude, spatial frequency (lp/mm)
E. Relative amplitude, relative amplitude

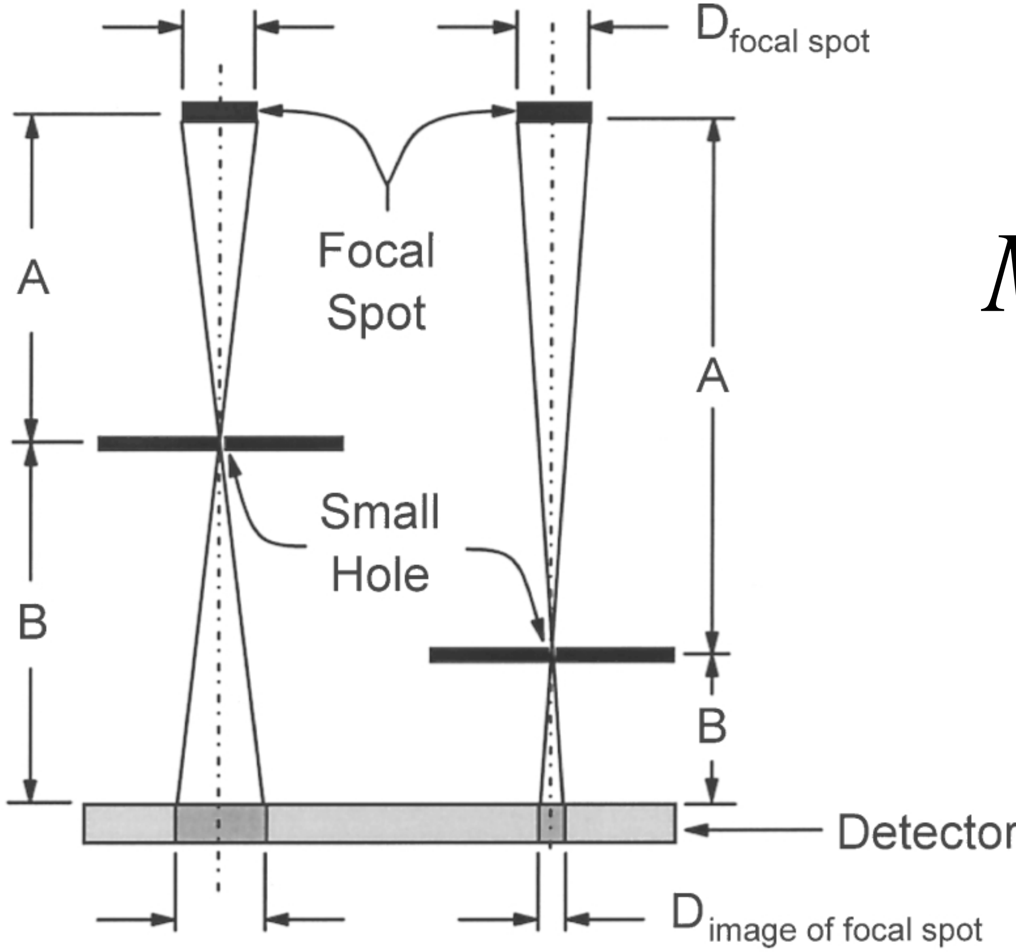
Magnification



Bushberg et al 2001

$$M_{object} = \frac{A+B}{A} = \frac{\text{Source to Image Distance (SID)}}{\text{Source to Object Distance (SOD)}}$$

Blurring due to magnification of finite source



Bushberg et al 2001

$$M_{source} = \frac{B}{A}$$

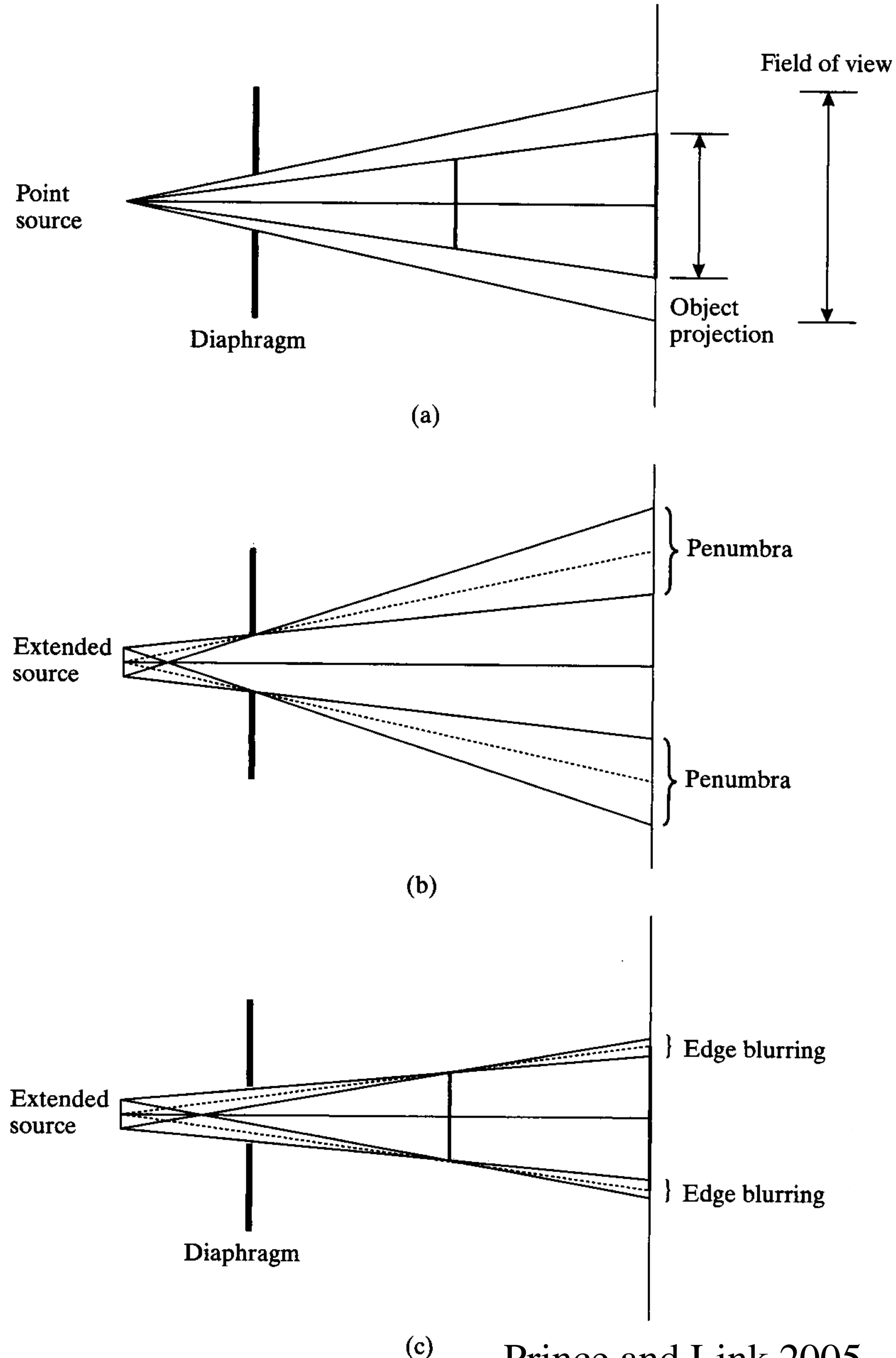


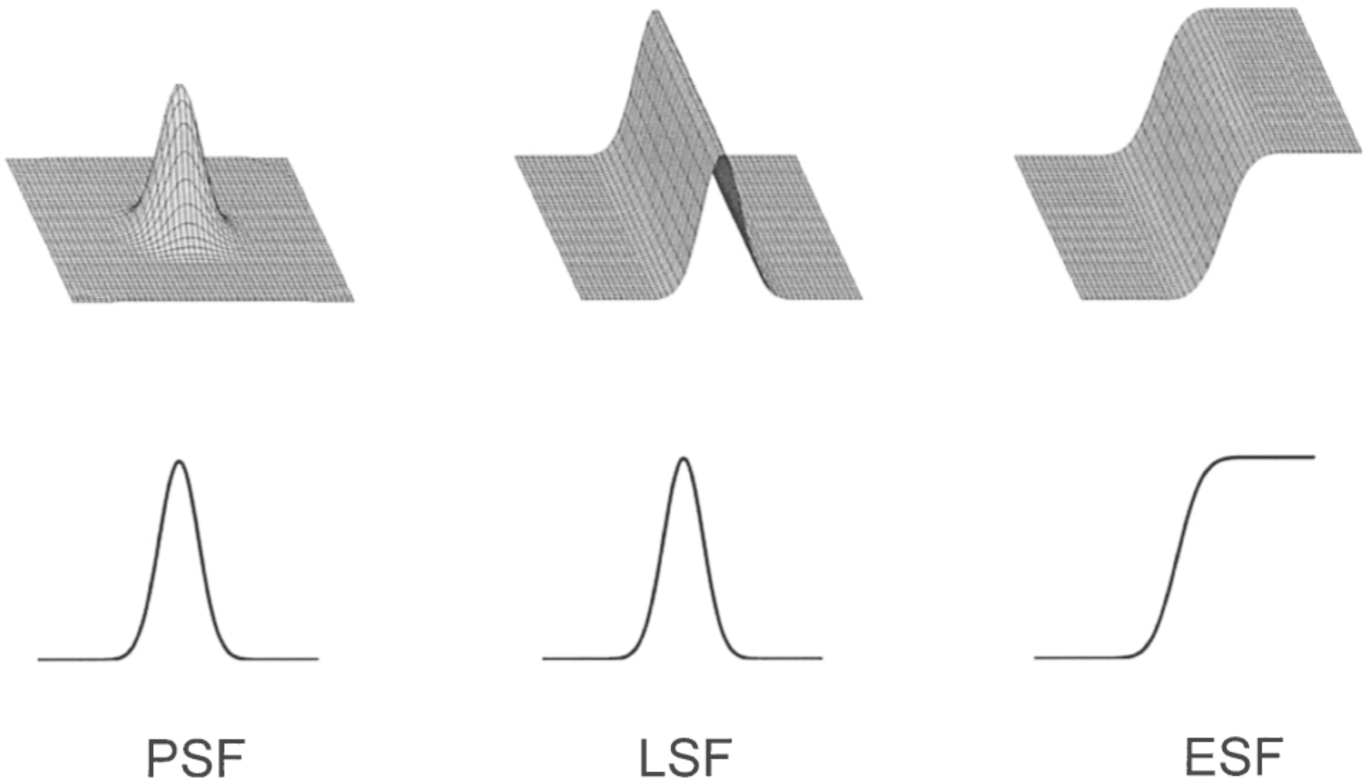
Figure 5.18
Effects of extended source. (a) Ideal field of view and object projection (with magnification). (b) Penumbra at edges of field of view due to extended source. (c) Blurred object edges due to extended source.

Prince and Link 2005

D8. Geometric magnification can improve the detection of high contrast objects. The fundamental limitation on useful magnification is:

A. Blurring due to focal spot size.
B. Blurring due to removal of the grid.
C. H&D curve of the image receptor.
D. MTF of the image receptor.
E. Size of the image receptor.

D8. A Penumbra, caused by a finite focal spot, increases with magnification. Eventually this dominates the image. The grid, H&D curve, and size have no effect on magnification. The receptor's MTF becomes less important as magnification increases.

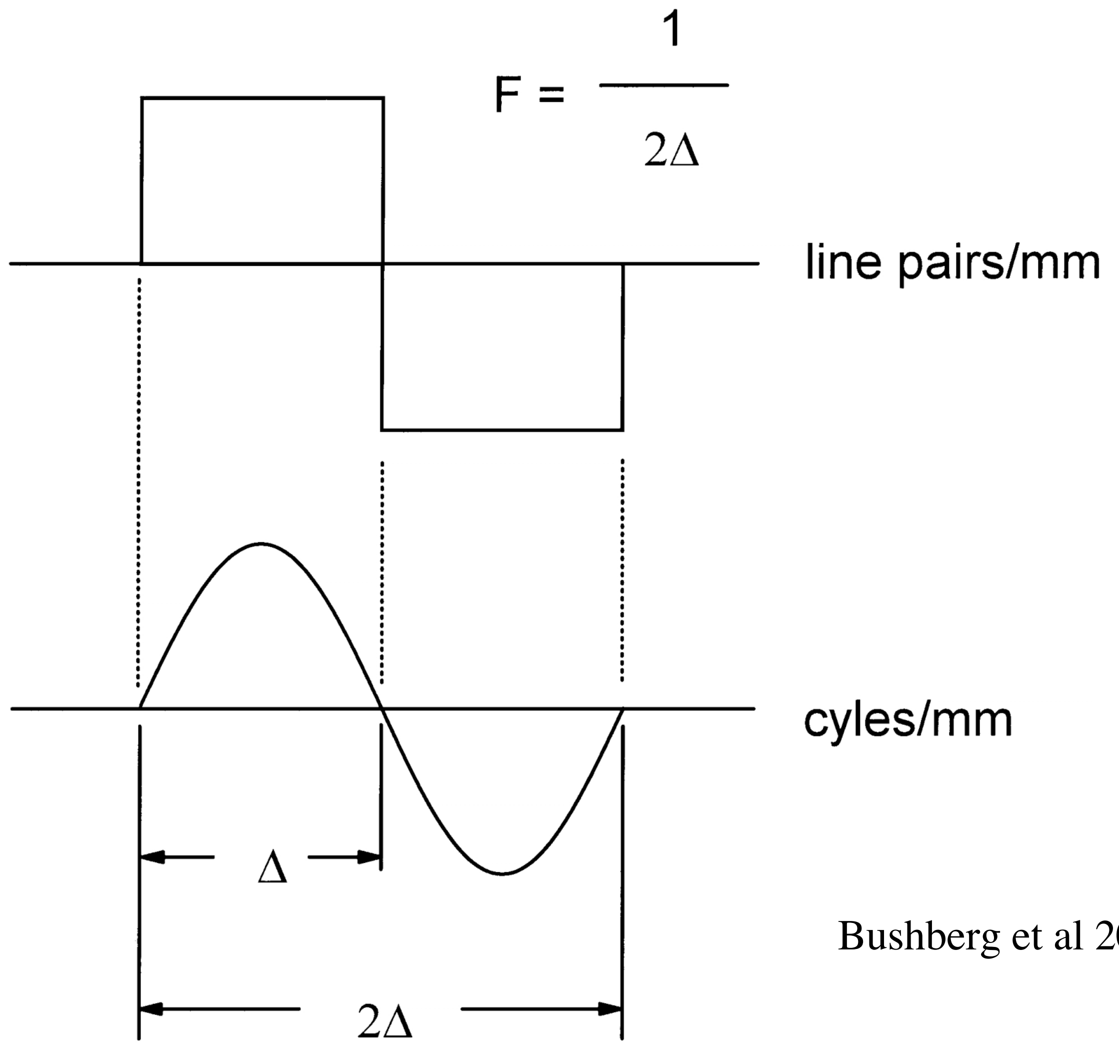


Line Spread Function

Edge Spread Function

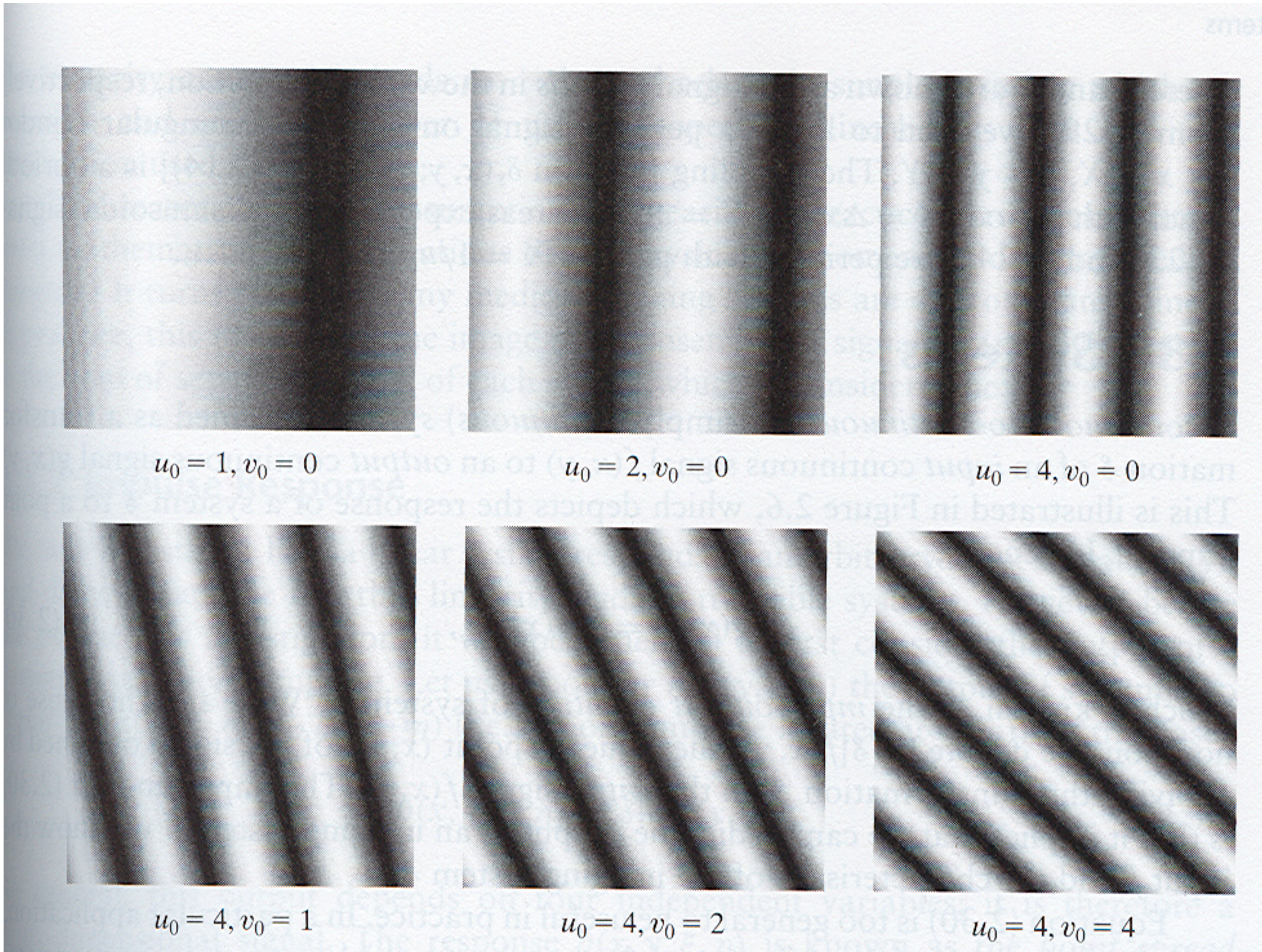
Bushberg et al 2001

Spatial Frequency



Bushberg et al 2001

Spatial Frequencies



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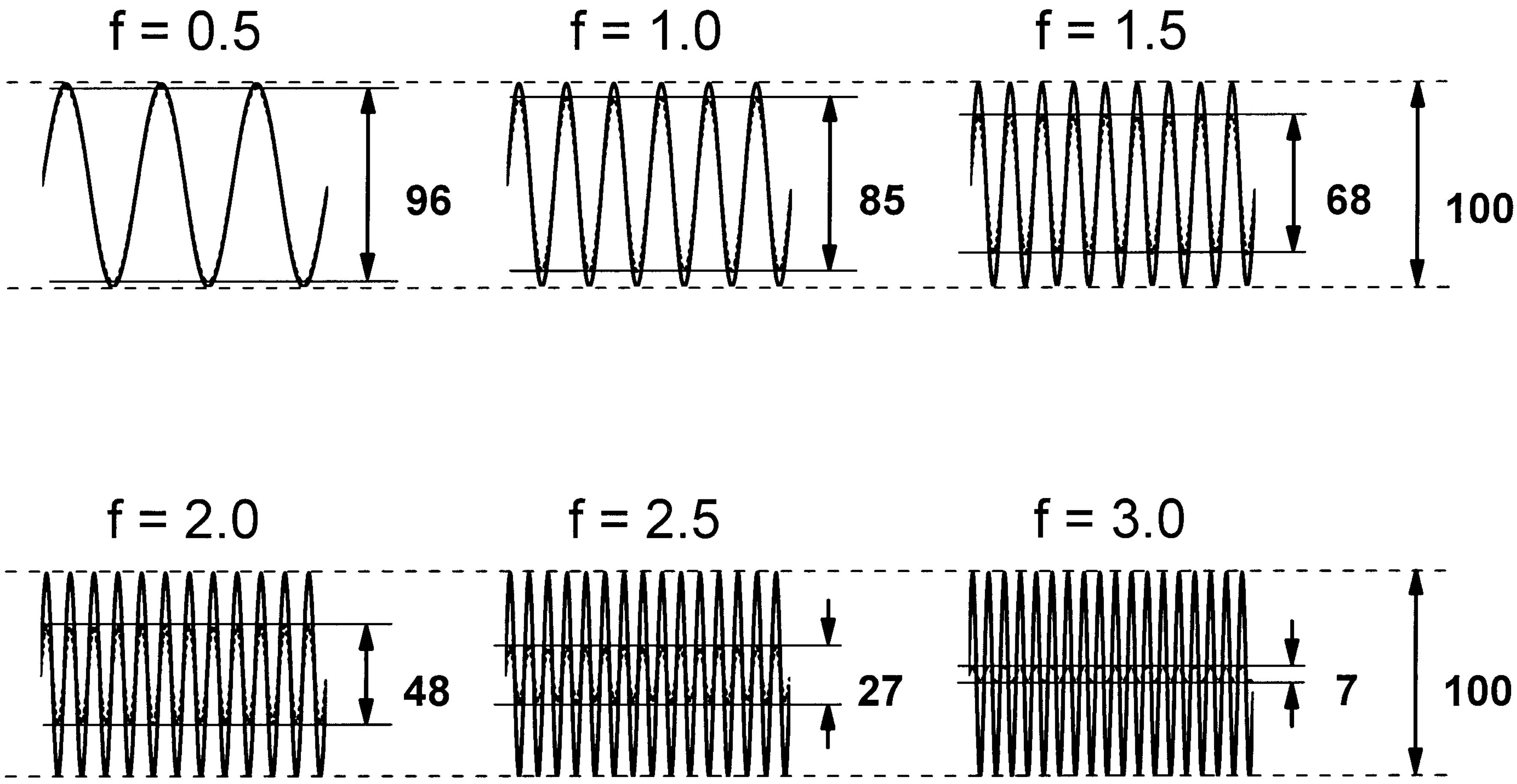
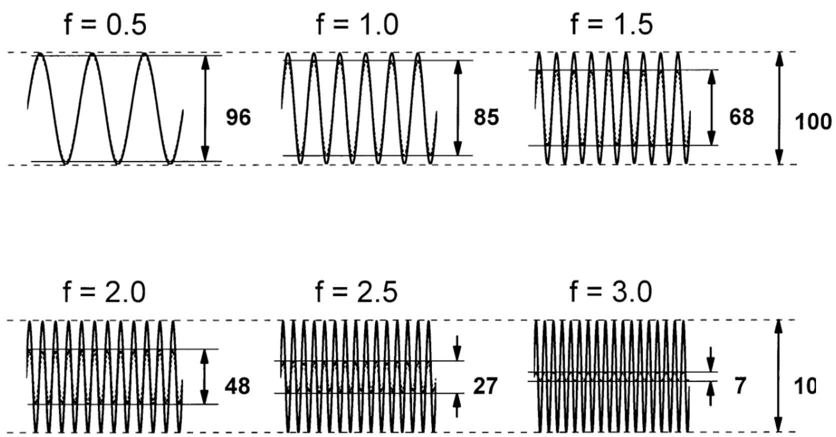
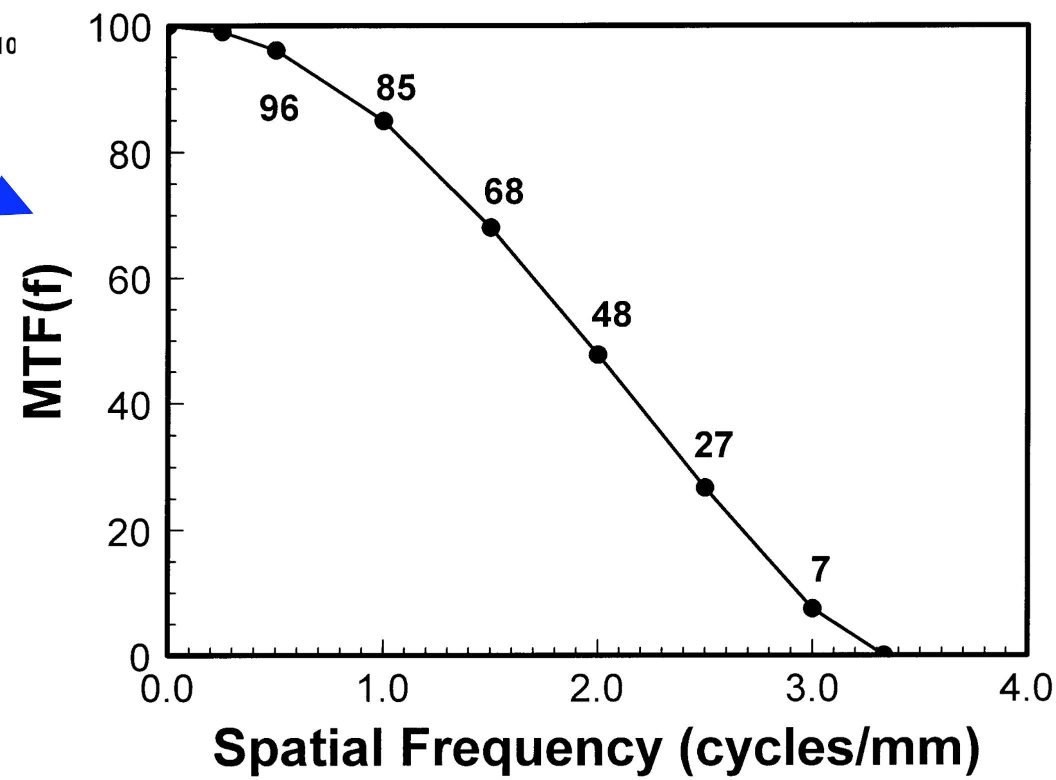
Modulation Transfer Function (MTF) or Frequency Response



Bushberg et al 2001

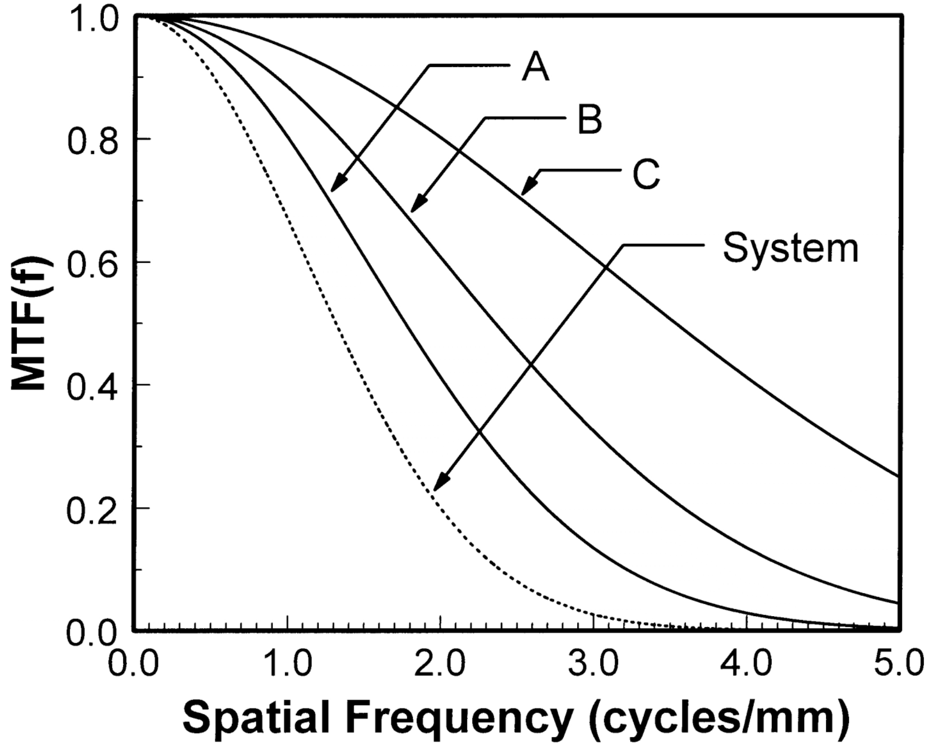
Modulation Transfer Function





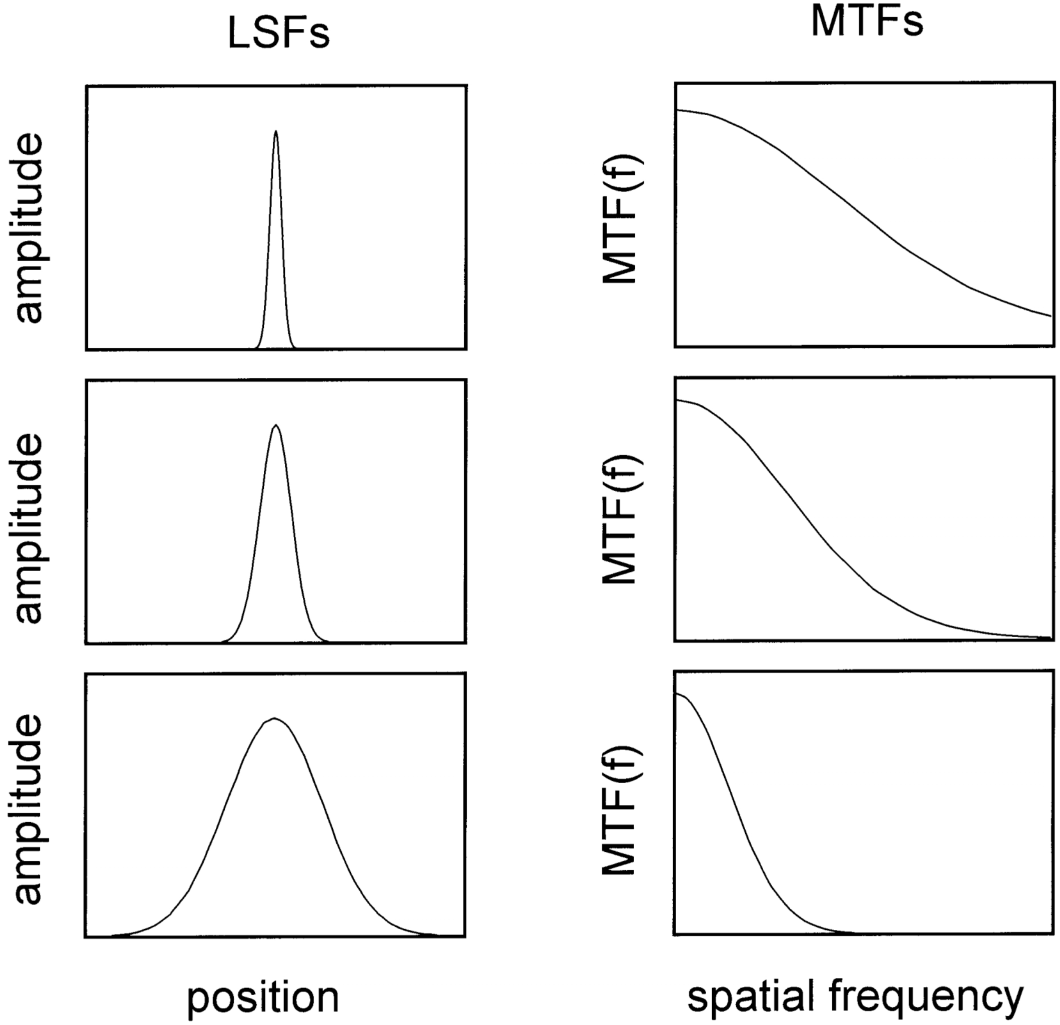
Bushberg et al 2001

System MTF = Product of MTFs of Components



Bushberg et al 2001

MTF = Fourier Transform (LTF)



Bushberg et al 2001

Useful Approximation

$$FWHM_{System} = \sqrt{FWHM_1^2 + FWHM_2^2 + \cdots FWHM_N^2}$$

Example

$$FWHM_1 = 1mm$$

$$FWHM_2 = 2mm$$

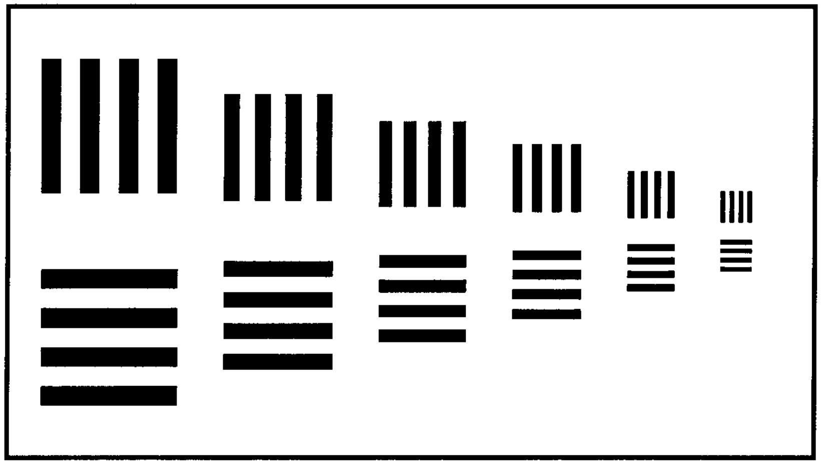
$$FWHM_{system} = \sqrt{5} = 2.24mm$$

D74. The intrinsic resolution of a gamma camera is 5 mm. The collimator resolution is 10 mm. The overall system resolution is ______ mm.

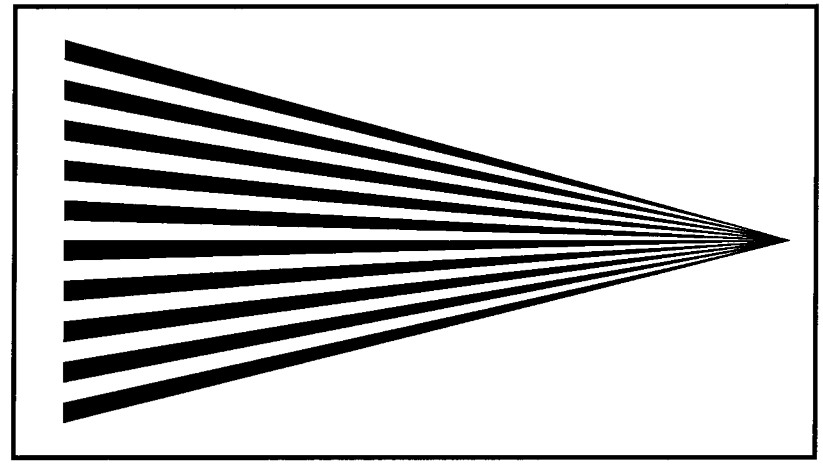
A. 15
B. 11.2
C. 7.5
D. 5.0
E. 0.5

D74. B System resolution is given by:

$(\text{system resolution})^2 = (\text{intrinsic resolution})^2 + (\text{collimator resolution})^2$



Line Pair Test Phantom



Section of a Star Pattern

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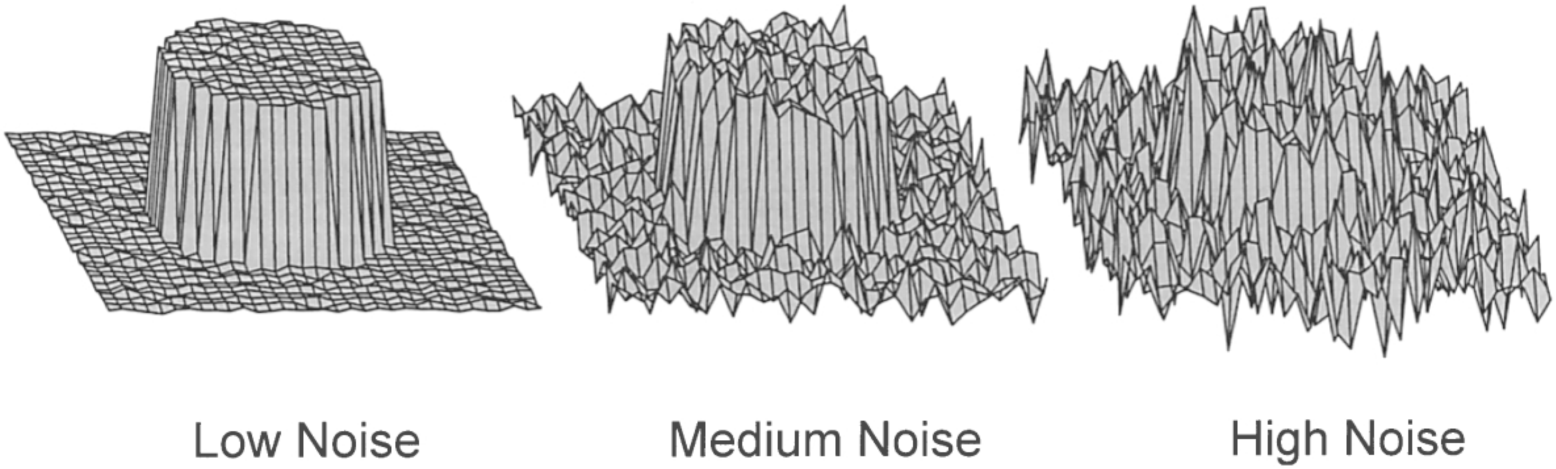
D79. **Methods of assessing spatial resolution of an imaging system include all of the following *except:***

A. **Bar patterns.**
B. **Step wedges.**
C. **Wire mesh pattern.**
D. **Hole pattern.**
E. **Wire impulse response.**

Answer: B; step wedges are used to create a gray scale which can be used to evaluate the contrast of the image receptor system

Noise and Image Quality



Bushberg et al 2001

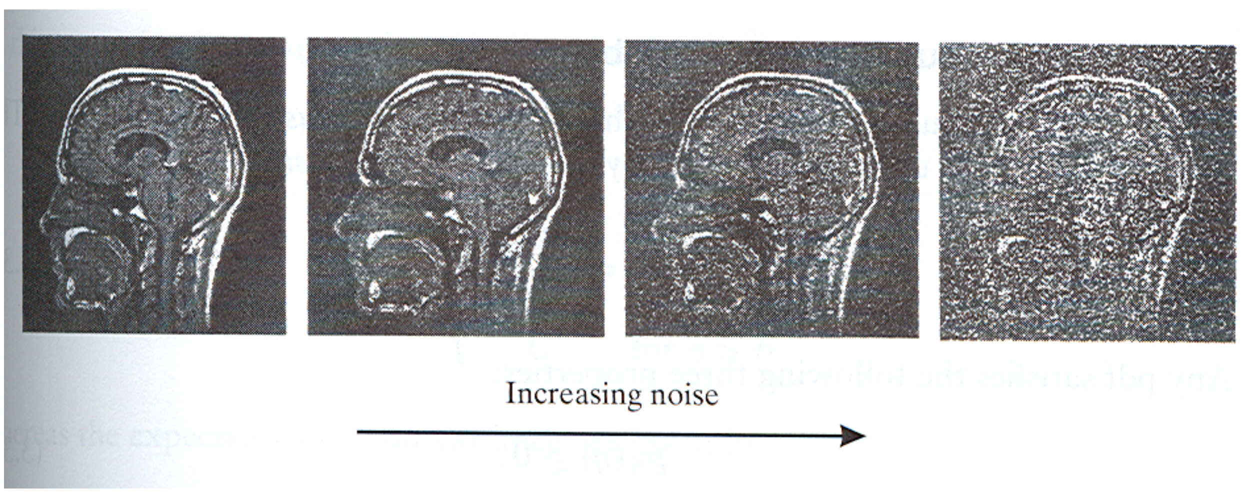


Figure 3.10
The effect of noise on image quality: image quality decreases rapidly with increasing noise contamination.

Prince and Links 2005

What is Noise?

Fluctuations in either the imaging system or the object being imaged.

Quantization Noise: Due to conversion from analog waveform to digital number.

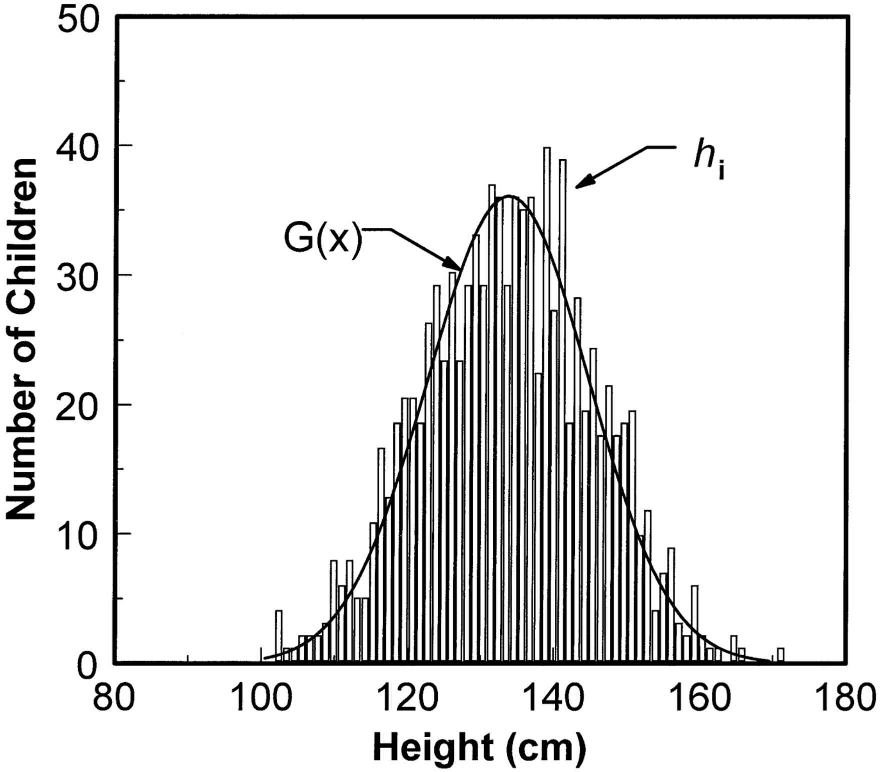
Quantum Noise: Random fluctuation in the number of photons emittted and recorded.

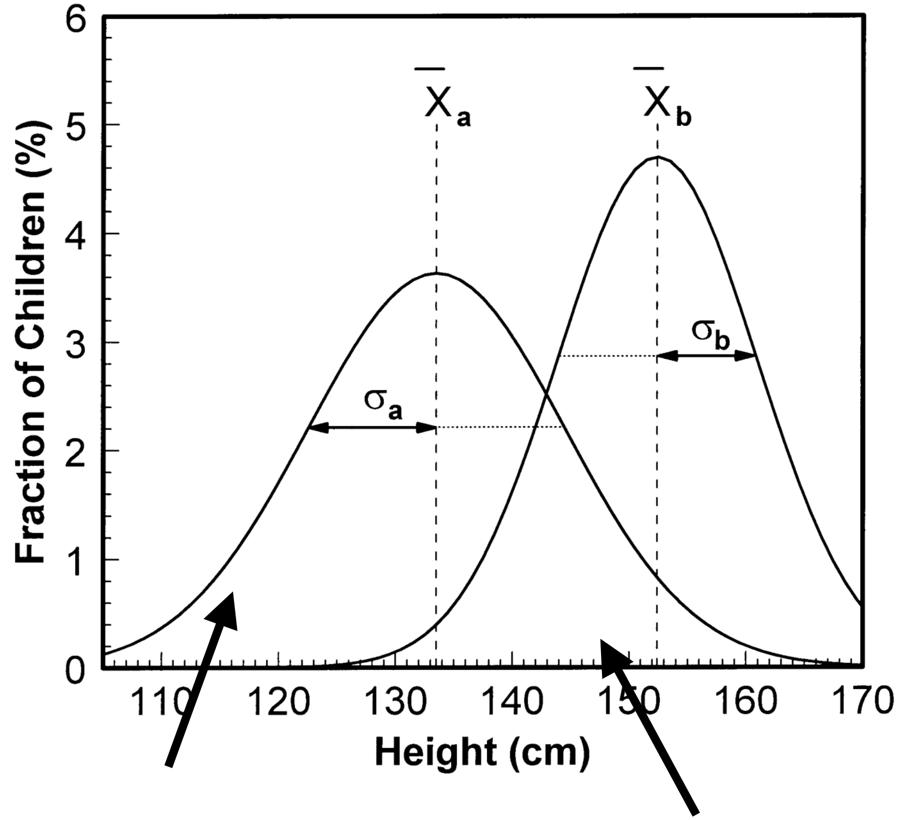
Thermal Noise: Random fluctuations present in all electronic systems. Also, sample noise in MRI

Other types: flicker, burst, avalanche - observed in semiconductor devices.

Structured Noise: physiological sources, interference

Histograms and Distributions

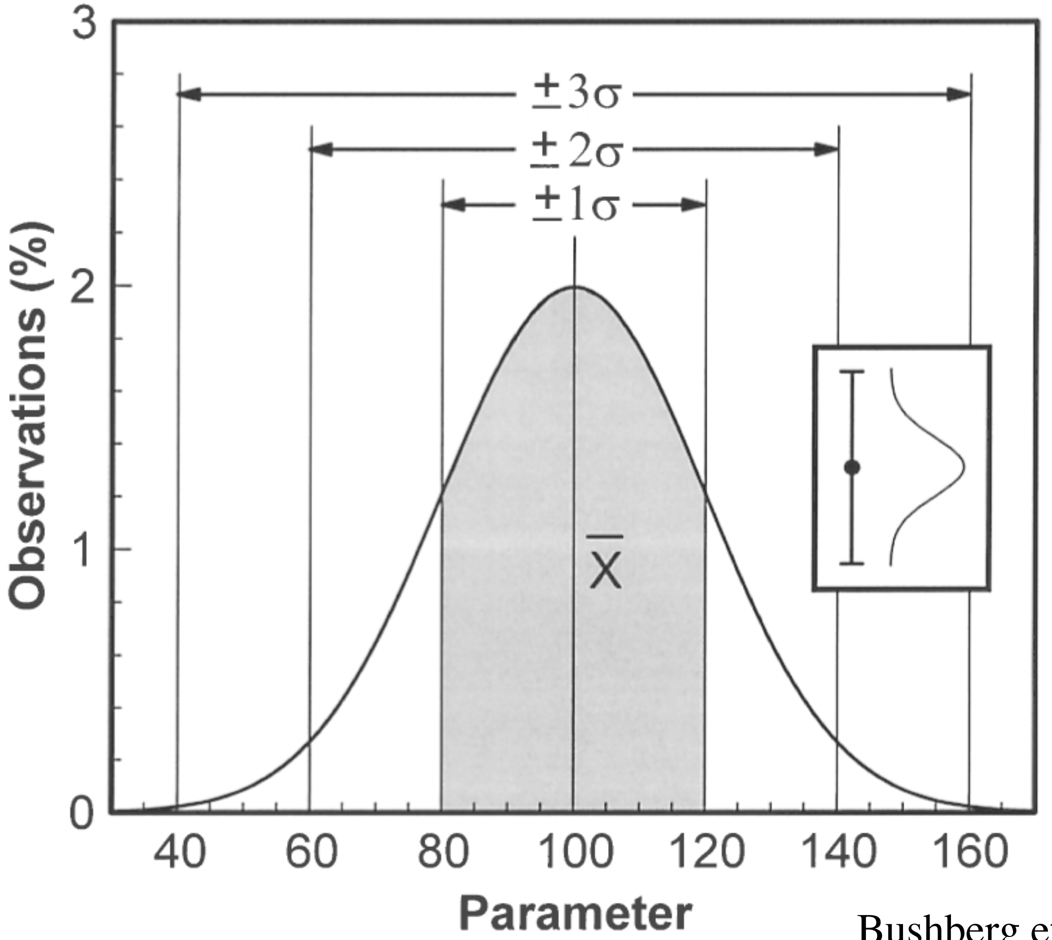




3rd grade heights   6th grade heights

Bushberg et al 2001

Gaussian Distribution



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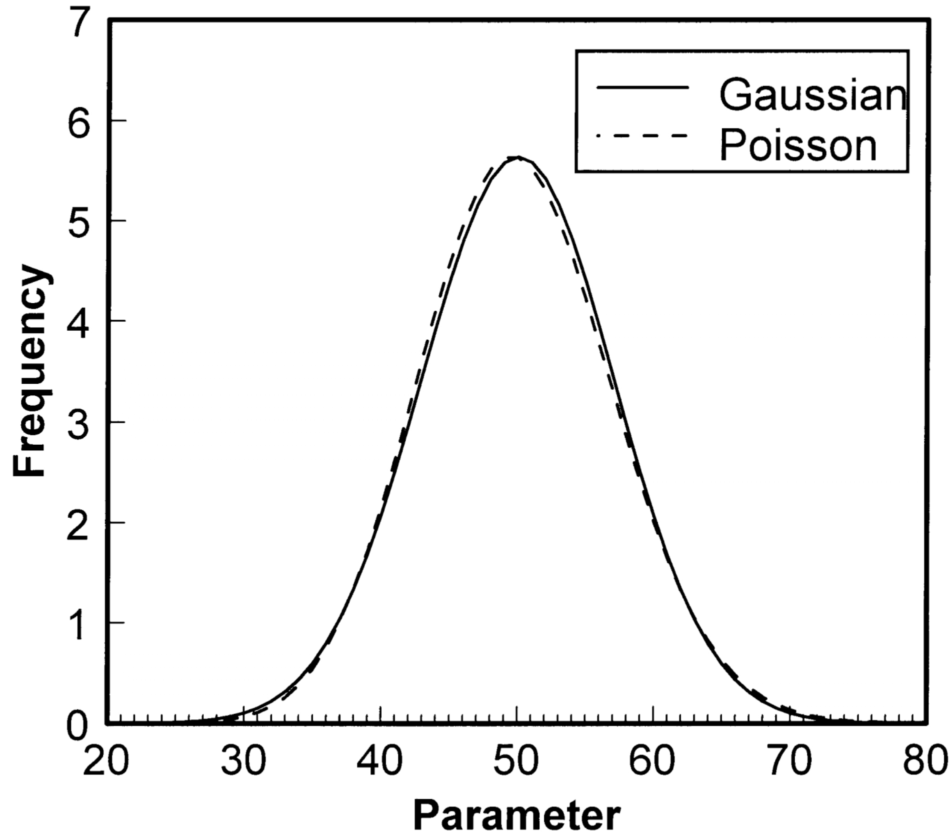
1, 2, and 3 standard deviation intervals correspond to 68%, 95%, and 99% of the observations



Bushberg et al 2001

Poisson Distribution describes x - ray counting statistics.

Gaussian distribution is good approximation to Poisson when $\sigma = \sqrt{\overline{X}}$