X-ray Instrumentation

BME 4401 Medical Imaging

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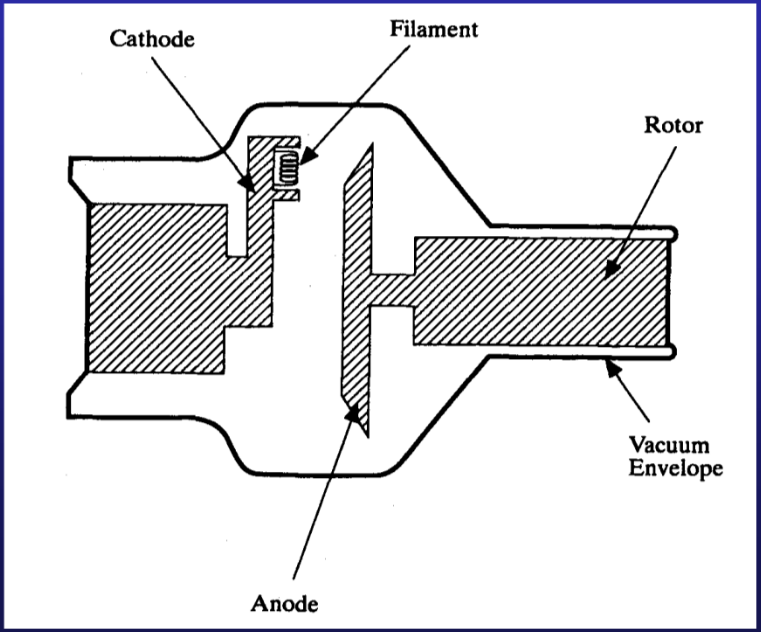
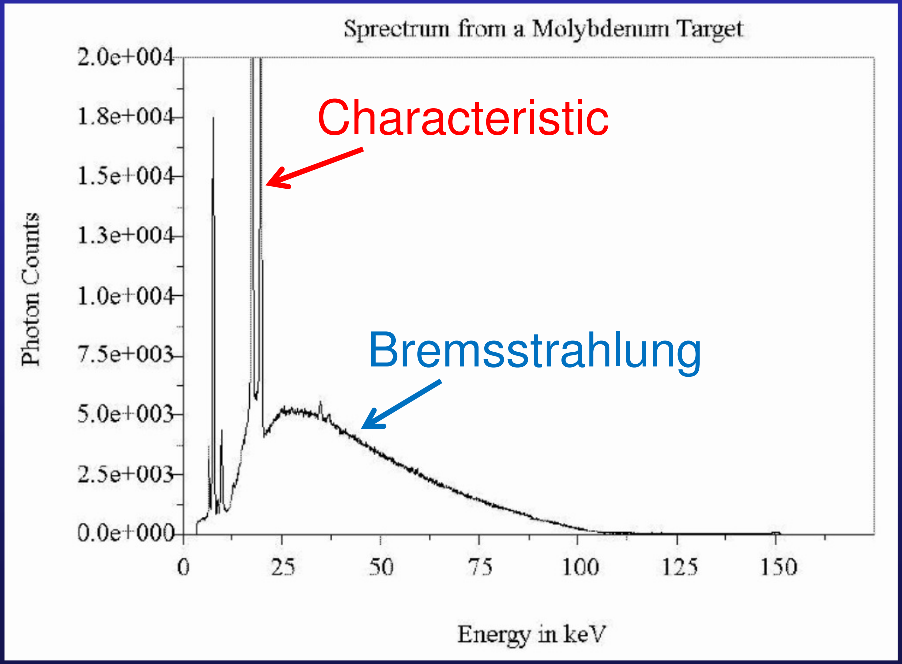
X-ray Production

- A metal filament mounted in the cathode is heated by a current causing electrons to be released.
- Requires enough heat that the thermal energy of the electrons overcomes the binding energy to the metal.



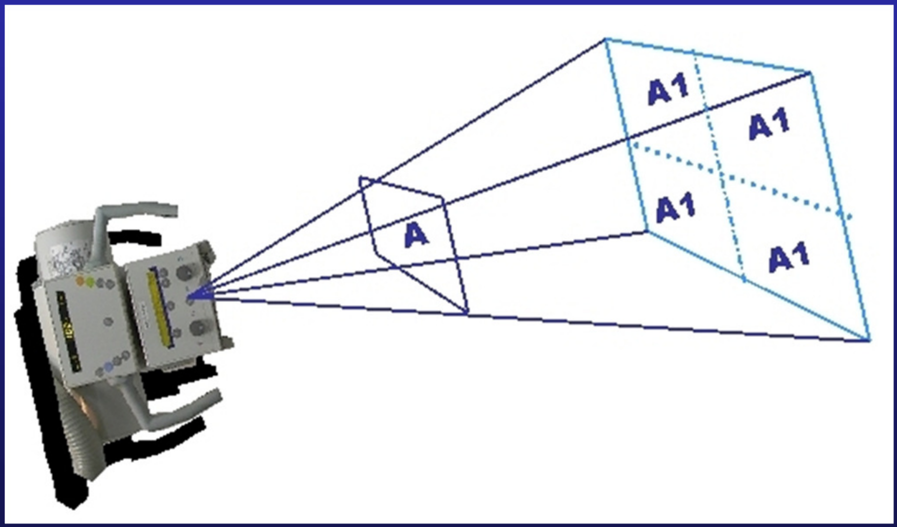
X-ray Production

- Voltage difference supplied by a generator is applied which causes electrons to accelerate from cathode to anode.
- <u>2 types of x-rays released</u>



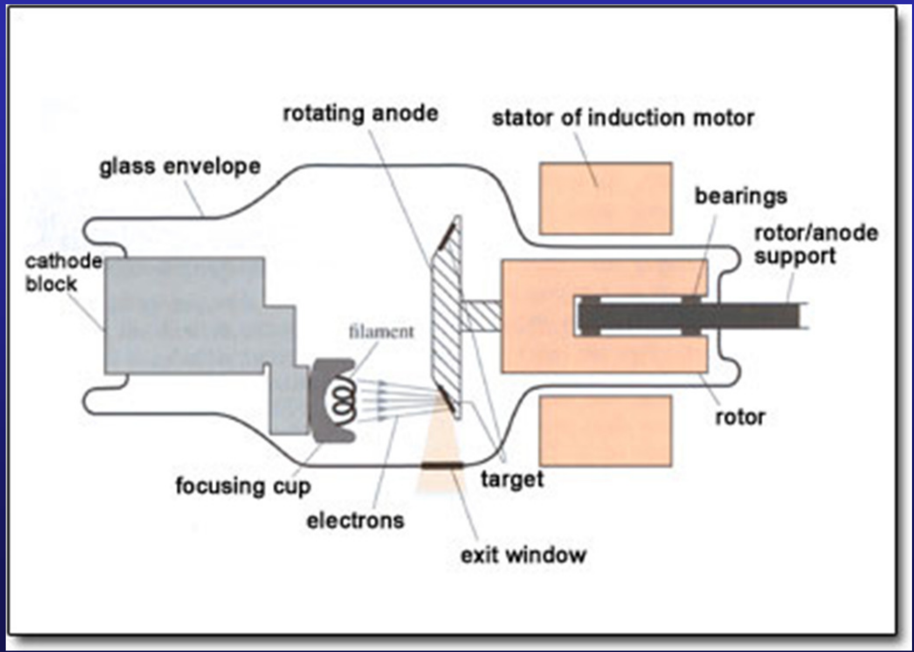
Medical X-ray Optimization

- Materials in an x-ray tube are chosen to produce x-rays with desired energies.
- *Low energy x-rays are undesirable and filtered out before passing to the patient.*
- X-rays should be produced from a point source to reduce blurring.



Medical X-ray Optimization

- To avoid blurring, electrons are focused to strike a small spot of the anode.
- However, size of focus spot is limited since too much power in a small area will melt the anode material.
- Limit is improved by use of a <u>rotating anode</u> with an <u>angular surface</u>, and using multiple focal spots.



X-ray Generator

- Supplies the voltages and currents in an x-ray tube.
- Controls cathode-anode voltage which determines:
  - the number of x-rays produced
  - the energy of the x-rays
- Number of x-rays produced is also determined by varying the amount of current from cathode to anode by controlling the length of time the current flows.

X-ray Generator

- 2 major parameters to describe x-ray exposure:
  - peak kilovolts (from anode to cathode)
  - milliampere-seconds
    (current * exposure time)
- Parameters are manually set by an operator based on estimates of the anatomy.

Image Detection: Screen Film

- Radiographic x-ray image is detected using light-sensitive negative film combined with x-ray sensitive screens.
- The film is enclosed in a light-tight cassette in contact with a screen which absorbs the x-rays with high efficiency.



Image Detection: Screen Film

- The x-ray energy is converted to visible light which exposes a negative image on the film.
- Important properties in x-ray film performance:
  - contrast
  - latitude
  - resolution

Image Detection: Screen Film

- Important parameters in x-ray screen performance:
  - quantum detection efficiency
  - speed
- High-speed screen/film system reduces patient dose, but gives a “noisier” image due to small number of x-rays detected.

Image Detection: Fluoroscopy

- Fluoroscopy is a study of moving body structures - similar to an x-ray "movie."
- Fluoroscopic images are used to monitor procedures such as placement of catheters in blood vessels during angiography.
- Much lower x-ray levels are used continuously to produce many images.

Image Detection: Fluoroscopy

- Fluoroscopy uses x-ray image intensifiers in conjunction with television cameras.
- Intensifier detects the x-ray image and converts it to a small, bright image of visible light.
- Visible image is transferred by lenses to a television camera for display on a monitor.

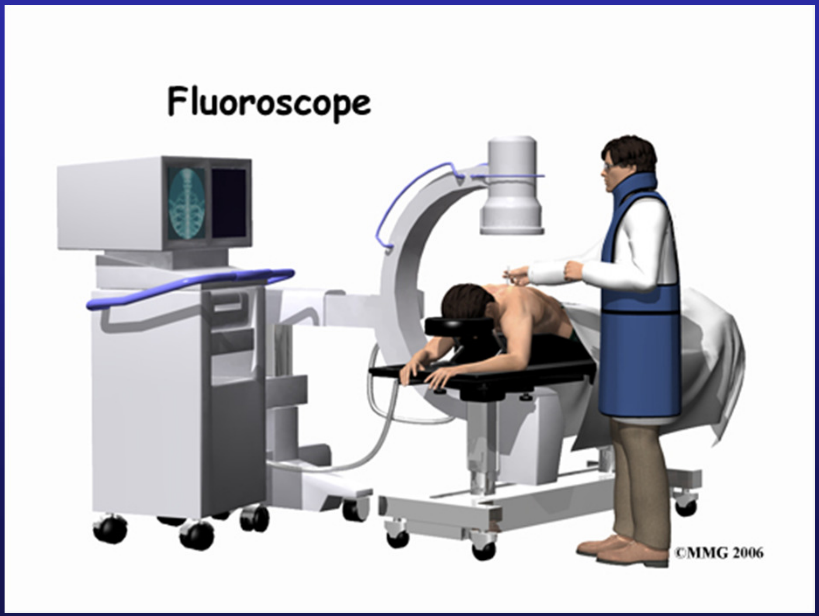


Image Detection: Fluoroscopy

- X-ray image intensifier.
- X-rays enter through a low absorption window and strike an input phosphor (CsI) where they are converted to light.
- A photoemitter absorbs the light and emits low energy electrons spread in various directions.

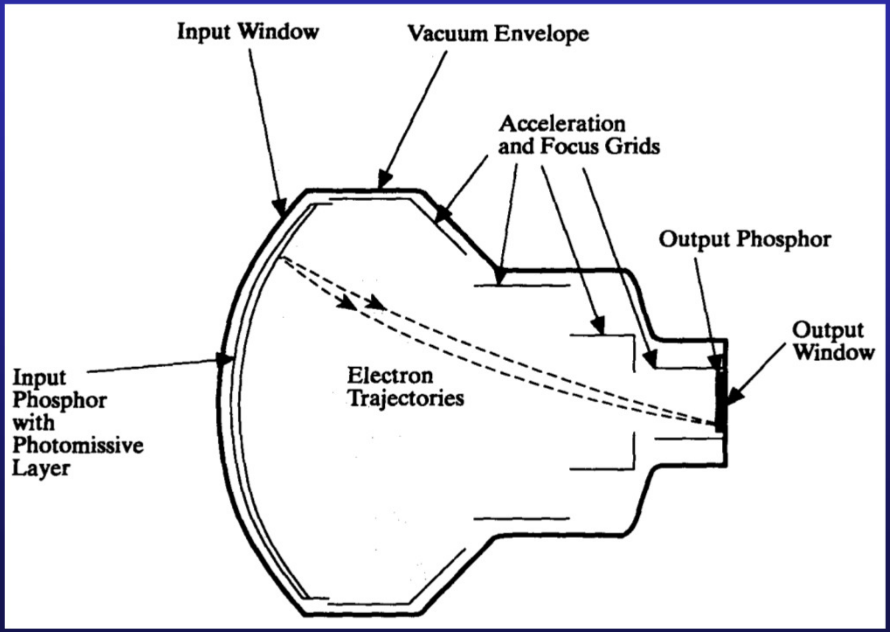


Image Detection: Fluoroscopy

- Photo-electrons are accelerated and steered by a set of grids that have high voltages applied.
- Grid voltages add energy to the electrons to brighten the output image.
- Grid voltages and shapes are selected to minimize distortion and focus electrons back to a point at the output.

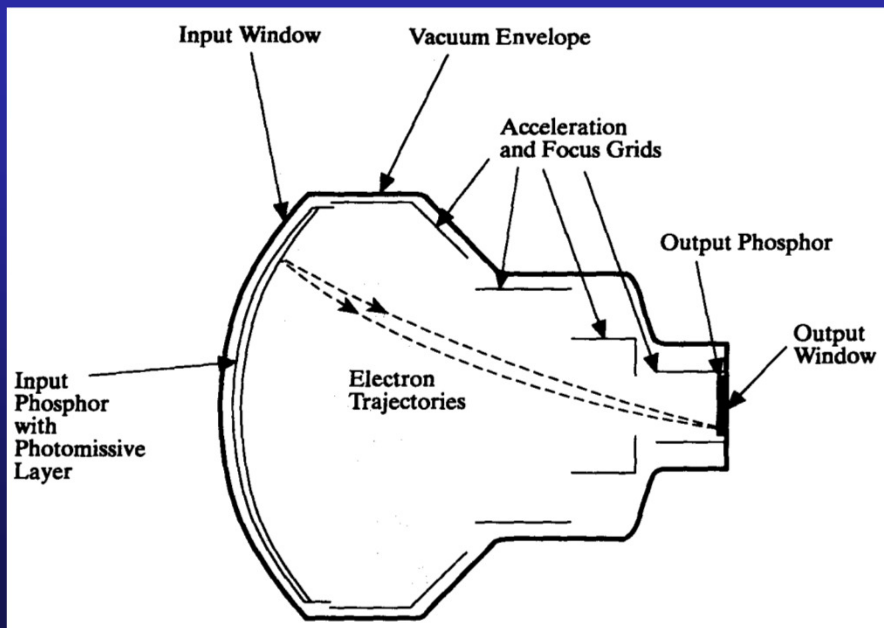


Image Detection: Fluoroscopy

- Performance parameters for x-ray image intensifiers:
  - quantum detection efficiency (60-70% for 59-keV x-rays)
  - control of high and low frequency MTF
- The amount of intensification depends on brightness and size of the output image for a given x-ray input.
  - <u>Gain</u>: intensification relative to a standard x-ray ray screen
  - <u>Conversion efficiency</u>: light output per radiation input
- Image intensifier output can be viewed directly or with a television monitor for more flexibility.

Image Detection: Fluoroscopy

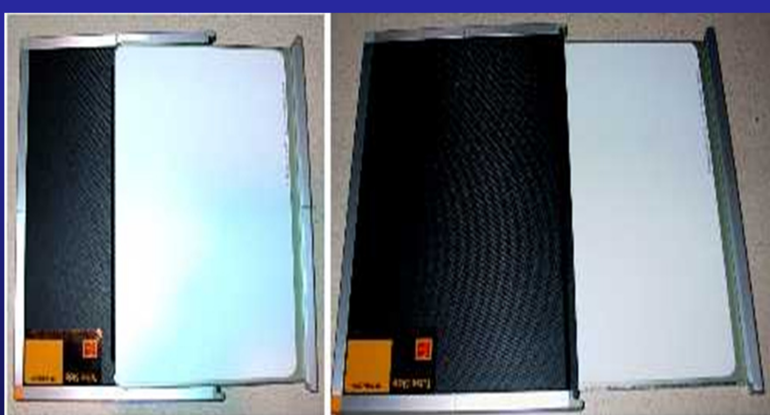
- In fluoroscopy, the same detected dose is used for all studies to keep the image noise approximately constant.
- Image brightness in a central part of the image intensifier's output is monitored with:
  - photomultiplier tube that samples it directly
  - analyzing signal levels in the television
- Federal regulations limit the maximum patient dose leading to darker images; compensated by automatic gain control for constant brightness.

Image Detection: Digital Systems

- Image processing for better displayed images, use of lower doses, and digital storage.
- Better image quality due to fewer processing steps, lack of distortion, or improved uniformity.
- Digital systems can be used for both radiography and fluoroscopy.

Image Detection: Digital Systems

- 3 ways medical x-ray images are digitized:
  - voltage output from an image intensifier / TV system
  - photostimulable phosphors
  - active-matrix thin-film-transistor technology



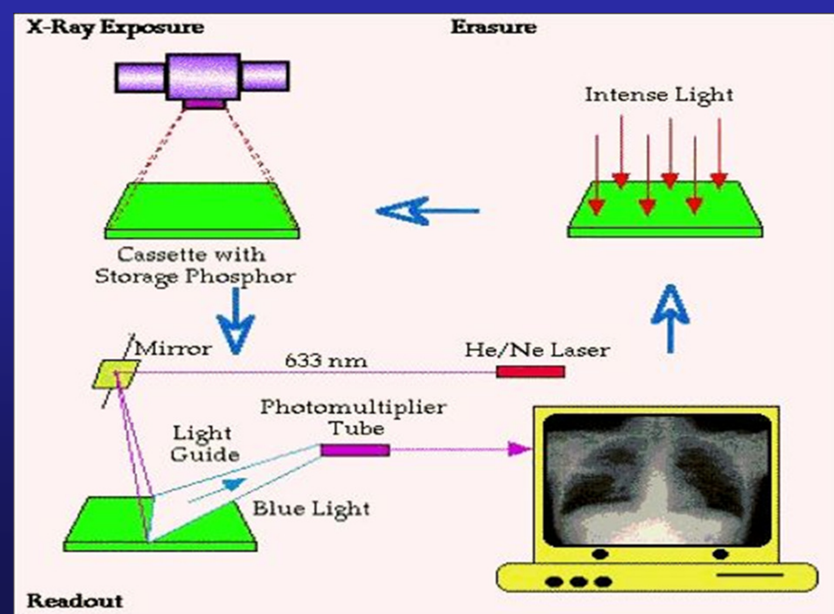


Image Detection: Digital Systems

- Photostimulable phosphors
- X-rays strike an enclosed sheet of phosphor that stores the x-ray energy.
- Phosphor scanned in a read-out unit by a small light beam of proper wavelength.
- As a point on the surface is read, the stored energy is emitted as visible light, which is then detected, amplified and digitized.

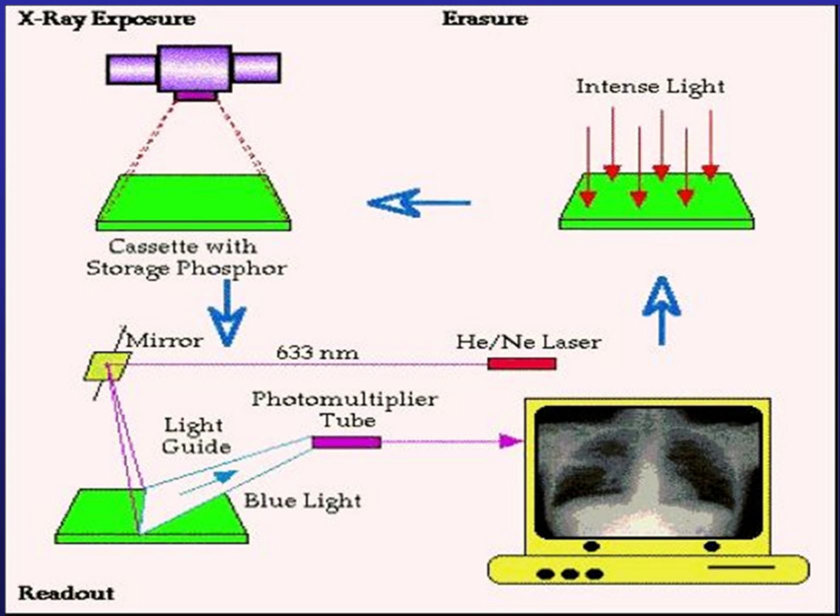


Image Detection: Digital Systems

- Active-matrix thin-film transistor technology
- An array of small sensors each having an electrode for storing charge proportional to its x-ray signal.

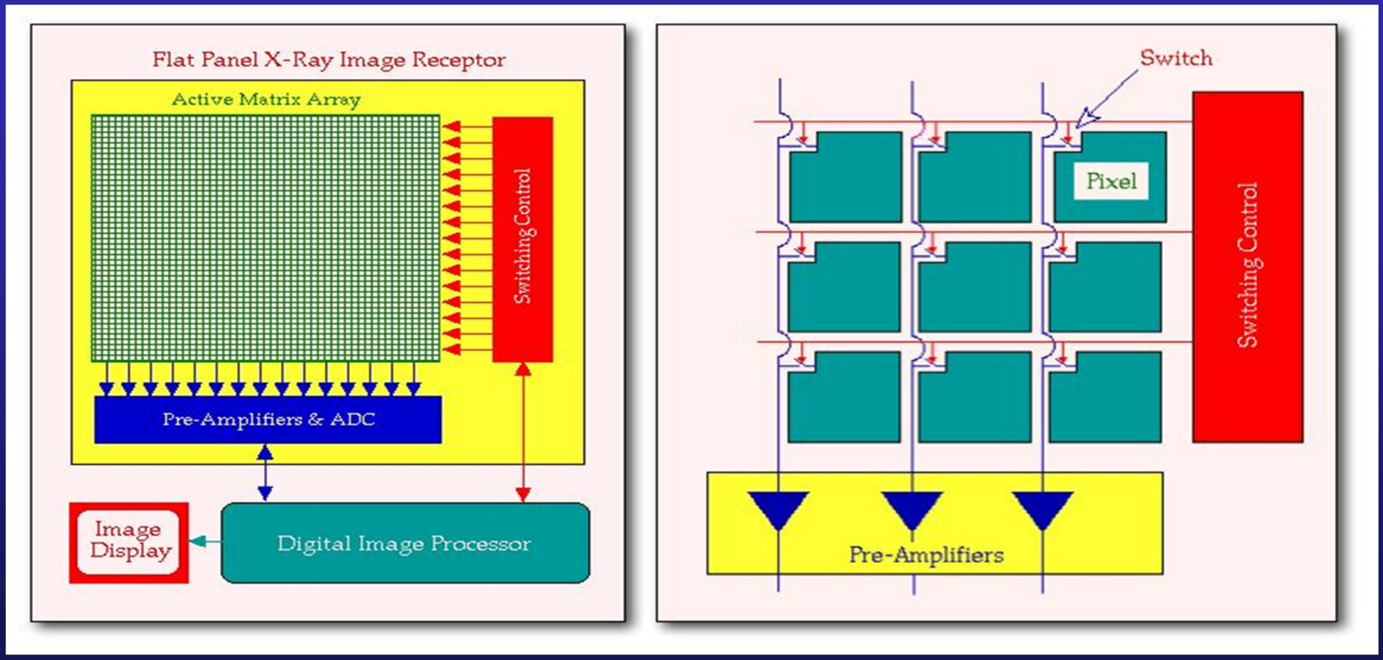


Image Detection: Digital Systems

- Each electrode is coupled to a transistor.
- Either isolates it during acquisition, or couples it to digitization circuitry during readout.

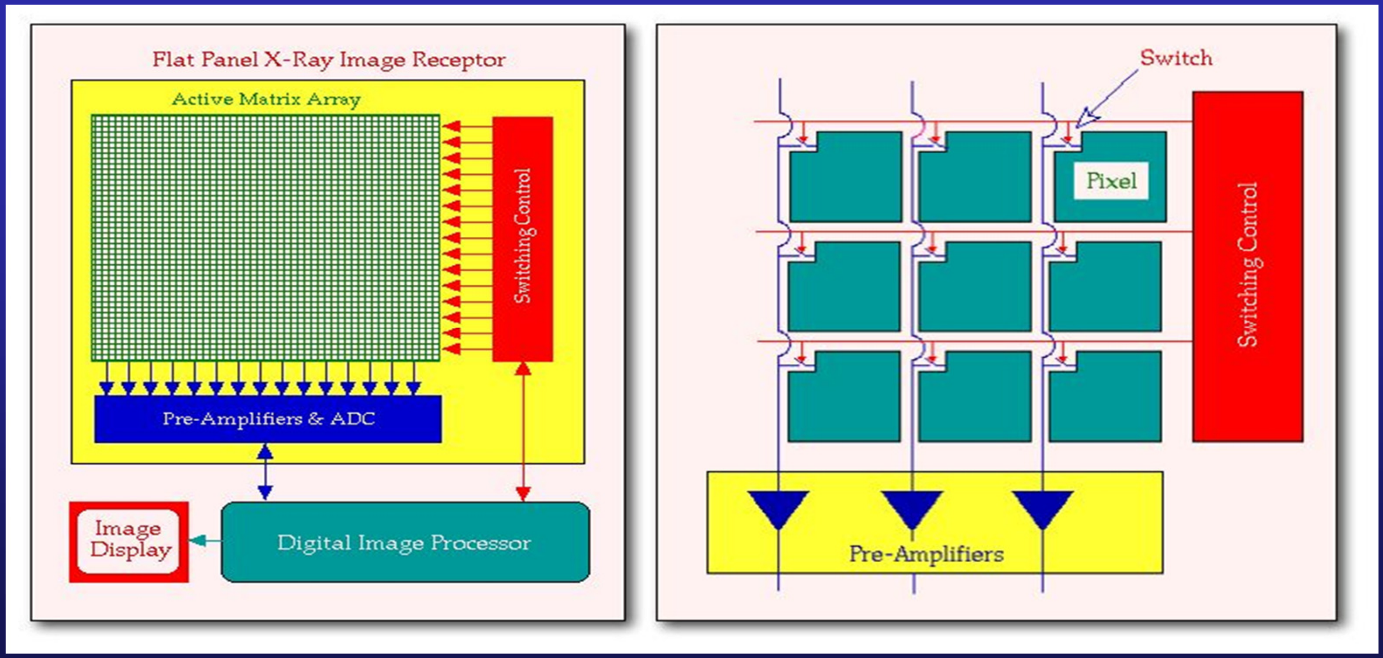
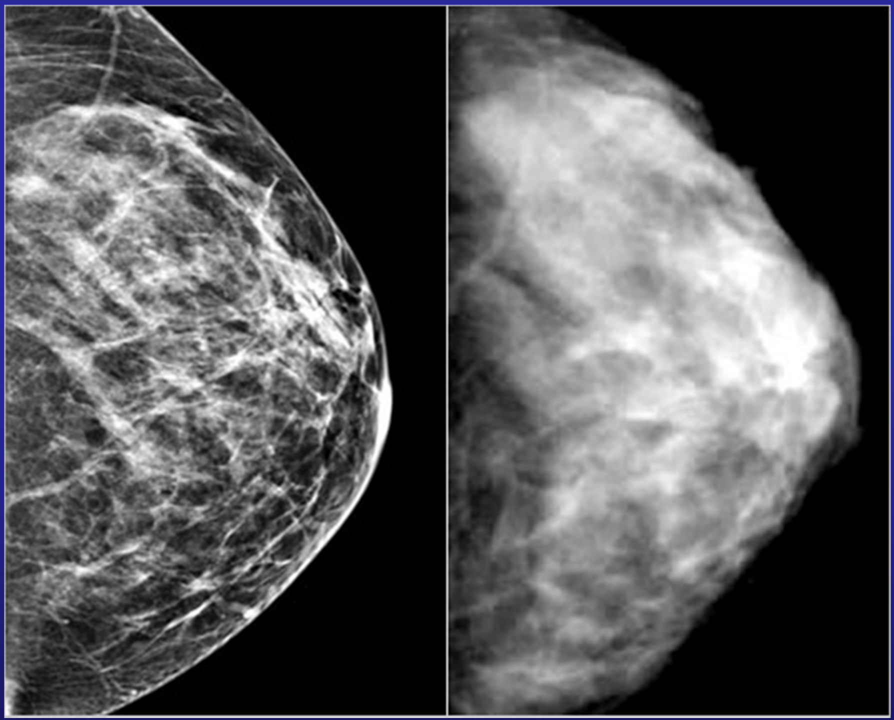


Image Detection: Digital Systems

Comparison of digital and screen-film x-ray images

Example: X-ray Mammography



Digital Image **Screen-film Image**

X-ray Mammography

- X-ray mammography involves x-ray imaging of the breast for the detection and diagnosis of breast cancer.

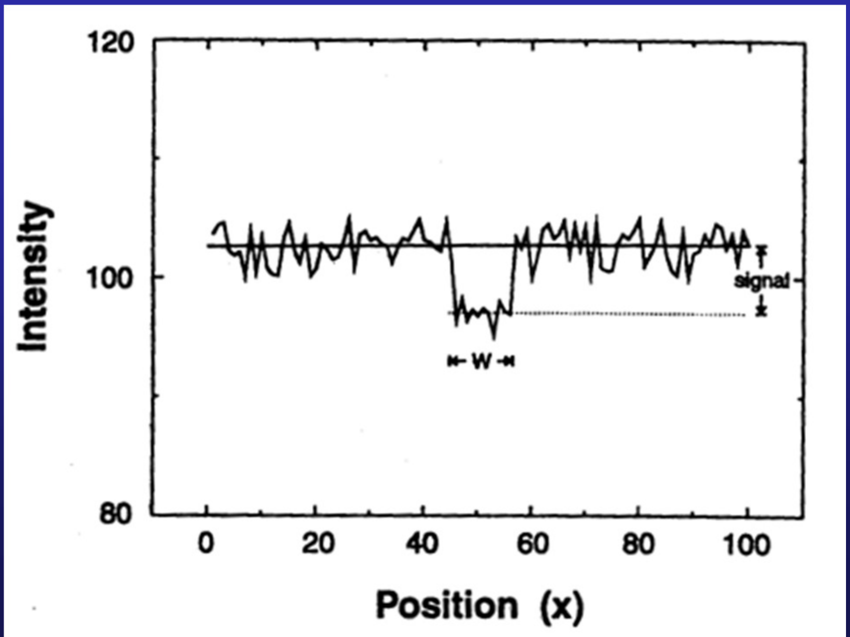
- 2 types of mammogram:
  - Screening
  - Diagnostic

X-ray Mammography

- The mammogram is an x-ray shadowgram formed when x-rays irradiate the breast from a point source.
- The transmitted x-rays are recorded by an image receptor as a magnified projection.
- The signal is a result of differential attenuation of x-rays as they pass though the structures of the breast.

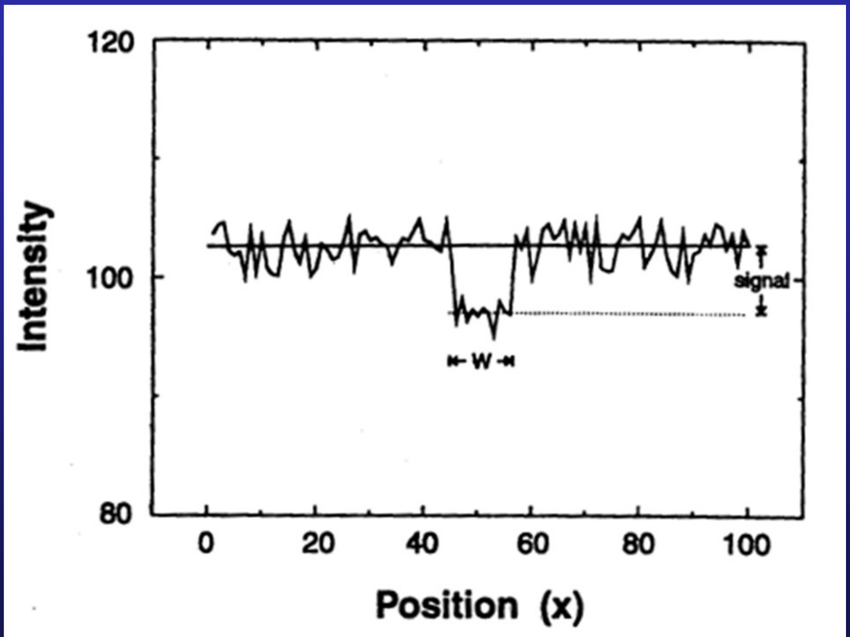
X-ray Mammography

- One-dimensional profile of x-ray transmission through a simplified computer model of the breast.
- Region of reduced transmission corresponding to a structure of interest (e.g. tumor, calcification).
- The imaging system must have sufficient *spatial resolution* to delineate edges of fine structures (~50 µM).

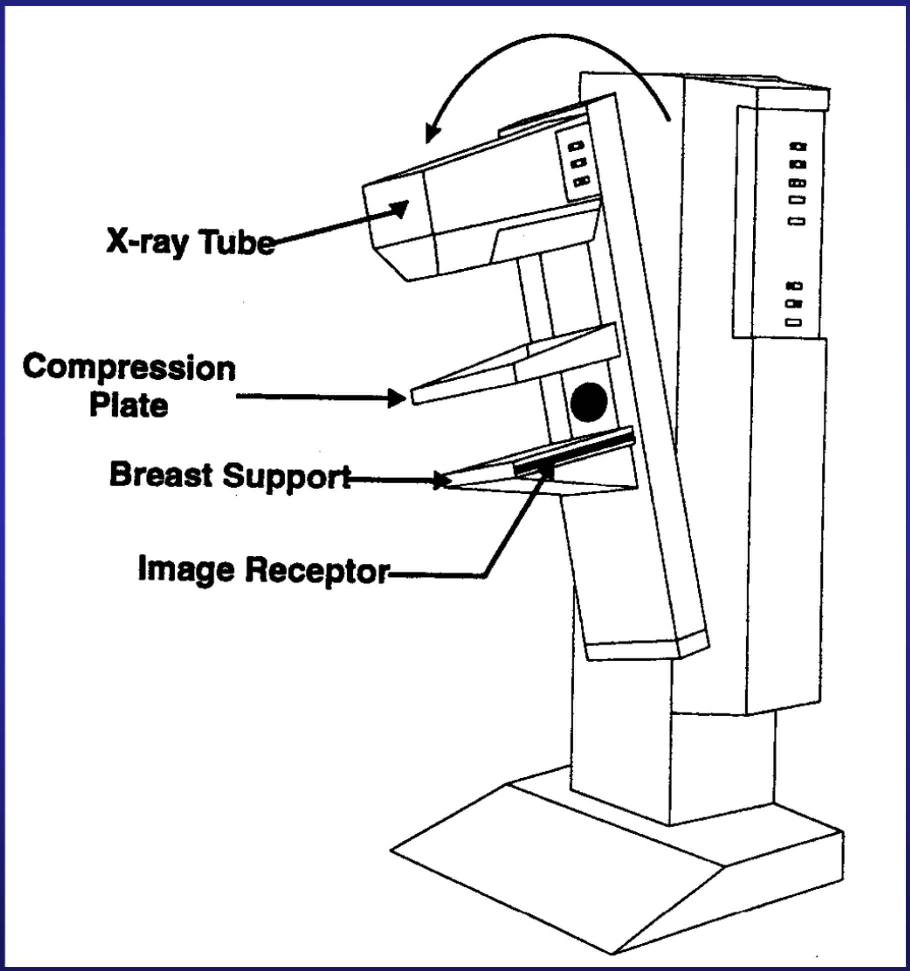


X-ray Mammography

- Variation in x-ray attenuation among tissue structures gives *contrast*.
- Subtle contrast can be hidden by random fluctuation (noise) in the profile.
- Since x-ray ionization can cause breast cancer at high doses, the lowest radiation dose compatible with excellent image quality must be used.

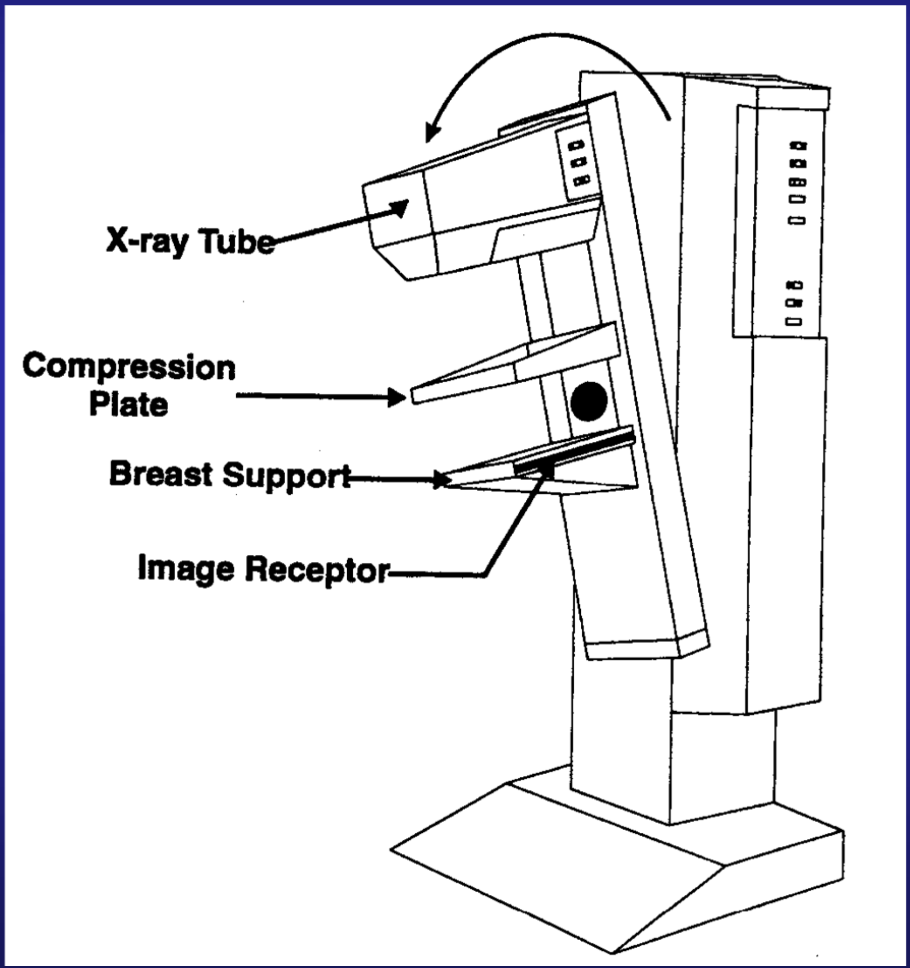


Mammography Instrumentation



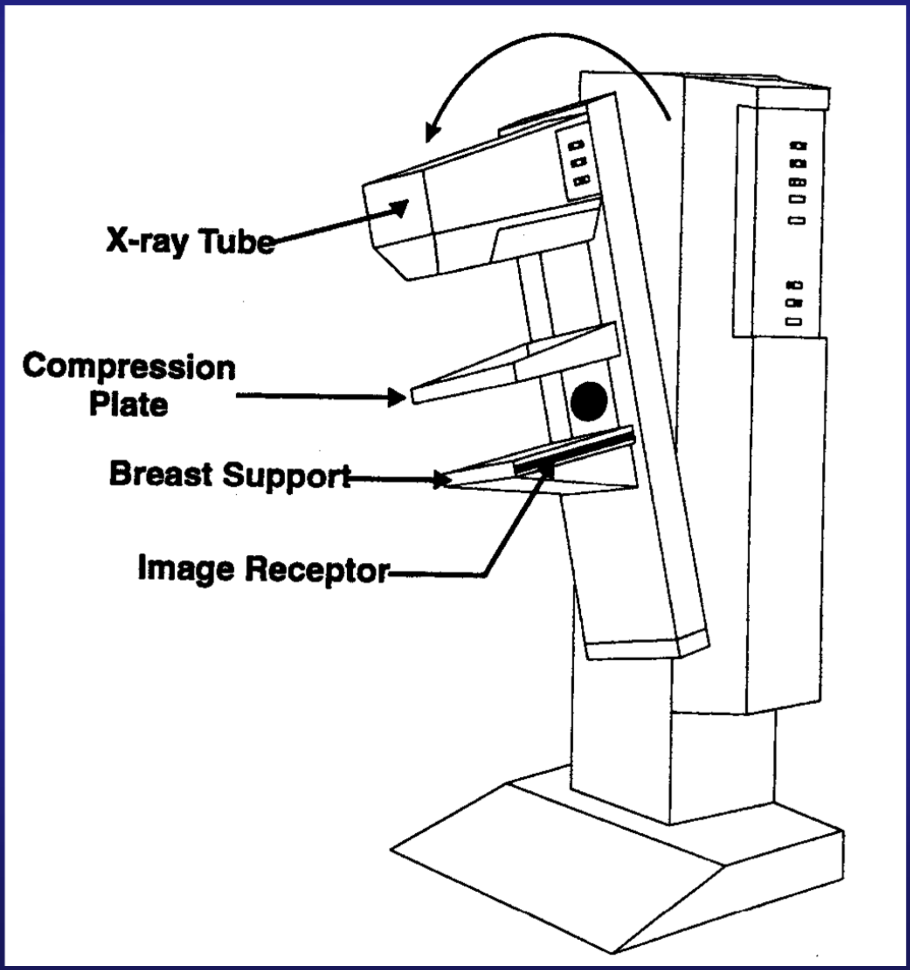
- Mammography unit consists of an x-ray tube and an image receptor mounted on opposite sides of a mechanical assembly or gantry
- Breast must be imaged from different aspects and patients of different height must be accommodated.

Mammography Instrumentation



- Assembly can be adjusted in a vertical axis and rotated about a horizontal axis.
- Radiation passes through a metallic spectral-shaping filter, beam-defining aperture, and compression plate.

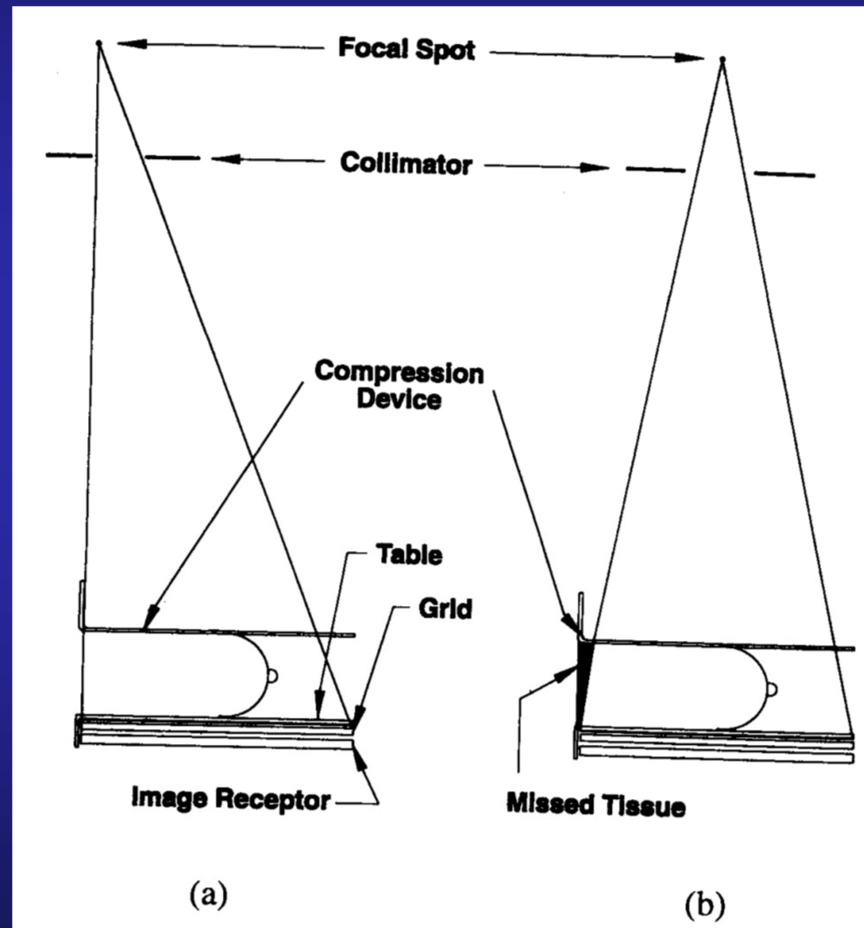
Mammography Instrumentation



- Transmitted rays are incident on an anti-scatter “grid” and then strike the image receptor.
- Non-interacting x-rays impinge on a sensor used to activate the automatic exposure control mechanism.

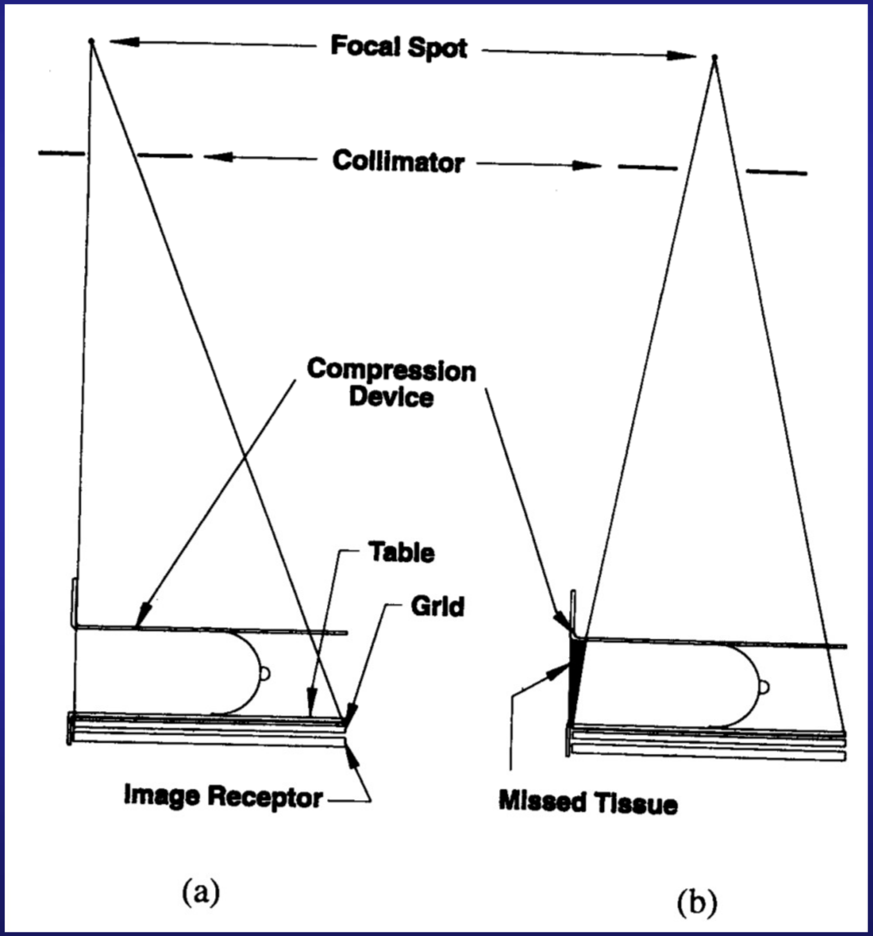
Mammography Instrumentation

- Most general radiography equipment is designed such that the image field is centered below the x-ray source.
- In mammography, the system's geometry is arranged with the x-ray source off center such that a vertical line grazes the chest wall of the patient.



Mammography Instrumentation

- The line intersects orthogonally with the edge of the image receptor closest to the patient.
- A centered beam would cause some tissue to be missed.



Instrumentation: X-ray Source

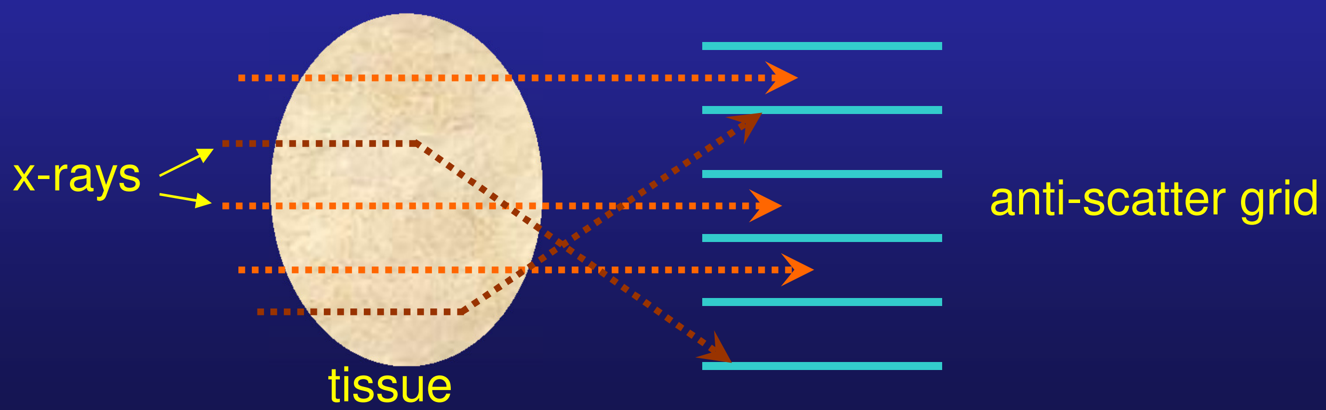
- Magnification of a smaller tissue region of interest is accomplished by elevating the tissue above the image receptor which:
  - reduces the source-object distance (SOD)
  - increases the object-image receptor distance (OID)
- This improves the signal-to-noise ratio of the image.
- A spectrum of x-ray energies must be defined that gives a reasonable compromise between radiation dose and image contrast (about 18-23 keV)

Instrumentation: Compression Device

- Compression causes the tissue to spread out, minimizing superposition from different planes and improving visibility of structures.
- Decreases the ratio of scattered to directly transmitted radiation reaching the image receptor.
- Reduces geometric unsharpness by decreasing the distance from any plane in the tissue to the image receptor.
- Lower attenuation, allowing decreased radiation dose.

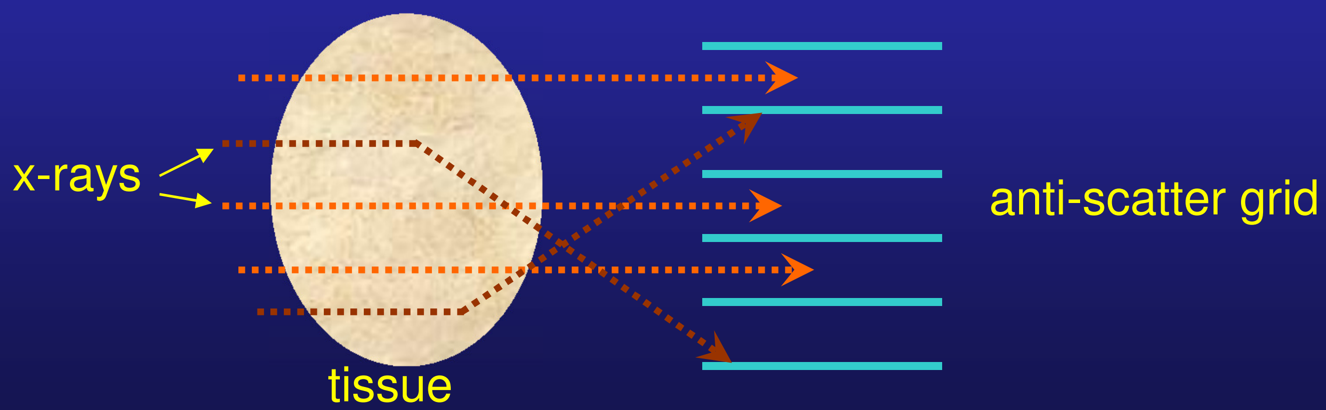
Instrumentation: Anti-Scatter Grid

- Lower x-ray energies are used for mammography than for other radiological examinations.
- Probability of photoelectric and Compton scattering of x-rays within the breast is high.
- Scattered radiation recorded by the image receptor can create haze on the image and reduce contrast.



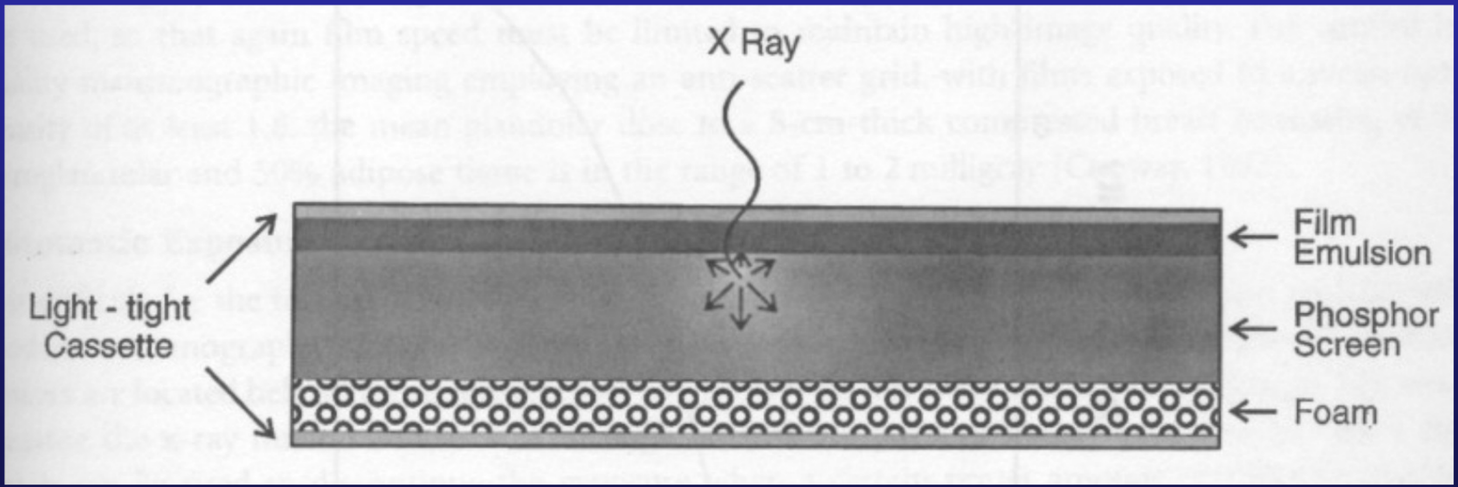
Instrumentation: Anti-Scatter Grid

- Anti-scatter grids are designed to allow passage of x-rays in a direct path while rejecting those that have been scattered.
- With no anti-scatter device, 37-50% of the total radiation incident on the image receptor would have experienced Compton-scattering.



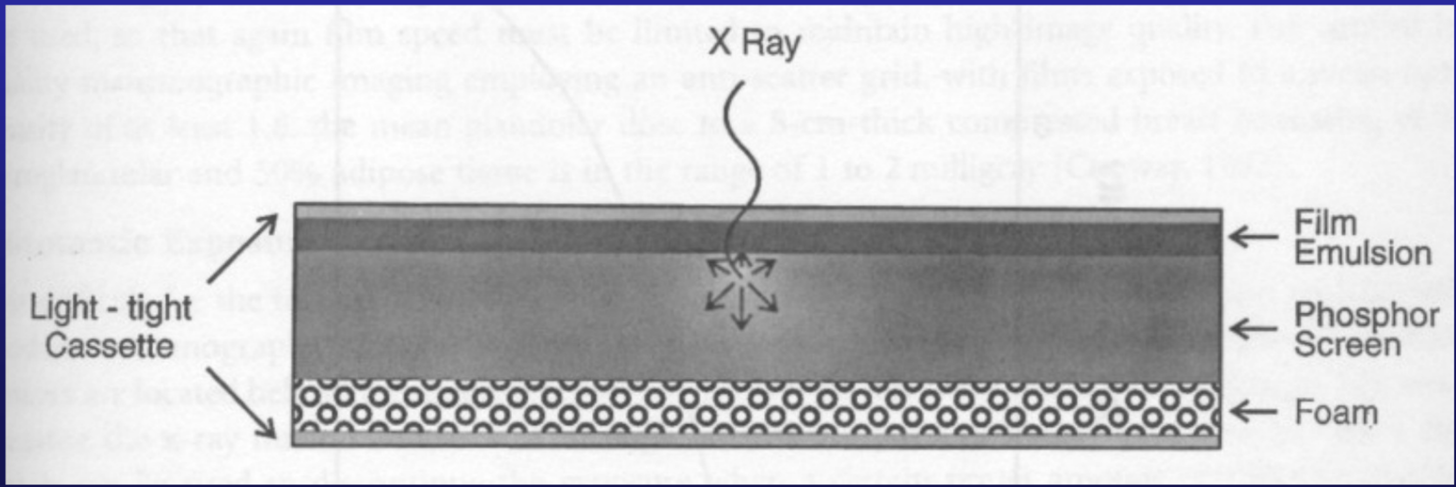
Instrumentation: Image Receptor

- High resolution fluorescent screens have been used to convert the x-ray pattern into an optical image.
- These screens are used in conjunction with single-coated radiographic film.
- X-rays are absorbed exponentially by phosphor crystals producing light in an isotropic distribution.



Instrumentation: Image Receptor

- These screens are used in conjunction with single-coated radiographic film.
- Due to short distance, only light quanta traveling longer distance can spread laterally and degrade the spatial resolution.
- Phosphor screen is treated with a dye to absorb quanta traveling oblique paths giving an sharper image.



Instrumentation: Noise and Dose

- Noise in mammography results from 2 sources:
  - random absorption of x-rays in the detector
  - granularity associated with the screen and film
- The noise in an image is dependent on both the amount of radiation which strikes the imaging surface per unit area, and the quantum efficiency of the imaging system.
- Quantum efficiency is related to the attenuation coefficient of the phosphor material and the thickness of the screen.
- Increasing film sensitivity increases granularity, so film speed must be limited to maintain high image quality.

Quality Control

- Mammography is one of the most technically demanding radiographic procedures.
- In order to obtain optimal results, all components of the system must be operating properly.
- The U.S. Mammography Quality Standards Act stipulates that a quality control program must be in place in all facilities performing mammography.
- A program for tests and methods for performing them are contained in the quality control manuals for mammography published by the American College of Radiology.

Quality Control

TABLE 8.1 Mammographic Quality Control Minimum Test Frequencies

Test	Performed By:	Minimum Frequency
Darkroom cleanliness	Radiologic technologist	Daily
Processor quality control		Daily
Screen cleanliness		Weekly
Viewboxes and viewing conditions		Weekly
Phantom images		Weekly
Visual check list		Monthly
Repeat analysis		Quarterly
Analysis of fixer retention in film		Quarterly
Darkroom fog		Semi-annually
Screen-film contact		Semi-annually
Compression		Semi-annually
Mammographic unit assembly evaluation	Medical physicist	Annually
Collimation assessment		Annually
Focal spot size performance		Annually
kVp Accuracy/reproducibility		Annually
Beam quality assessment (half-value layer)		Annually
Automatic exposure control (AEC) system performance assessment		Annually
Uniformity of screen speed		Annually
Breast entrance exposure and mean glandular dose		Annually
Image quality — phantom evaluation		Annually
Artifact assessment		Annually
Radiation output rate		Annually
Viewbox luminance and room illuminance		Annually
Compression release mechanism		Annually