Flouroscopy

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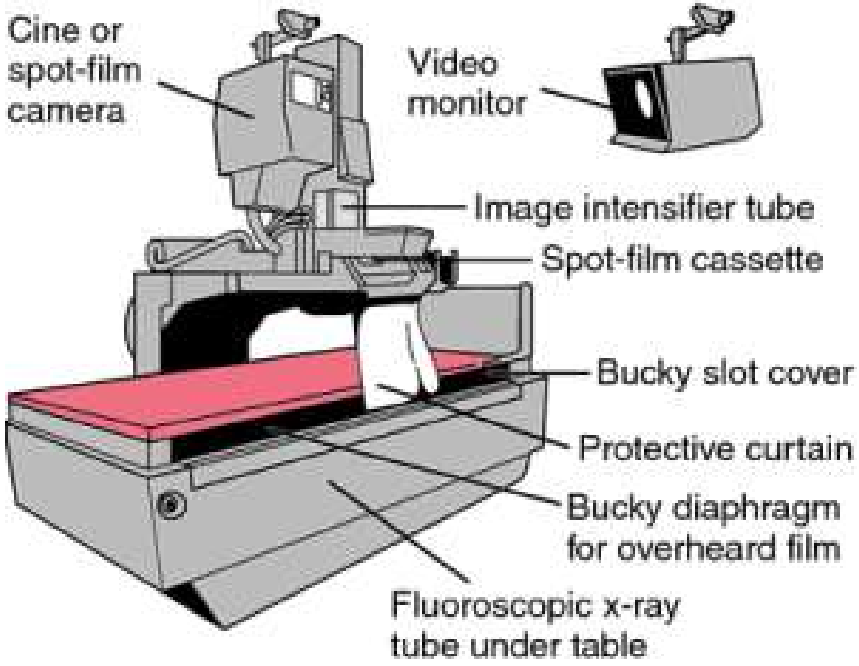

Cine or
spot-film
camera
Video
monitor
Image intensifier tube
Spot-film cassette
Bucky slot cover
Protective curtain
Bucky diaphragm
for overheard film
Fluoroscopic x-ray
tube under table

FLUOROSCOPY - BASICS OF FLUOROSCOPIC IMAGING SYSTEM

- Fluoroscopy is a real-time imaging technique using X-rays to detect internal motion.
- Initially requiring a dark room and dim images, then evolved with

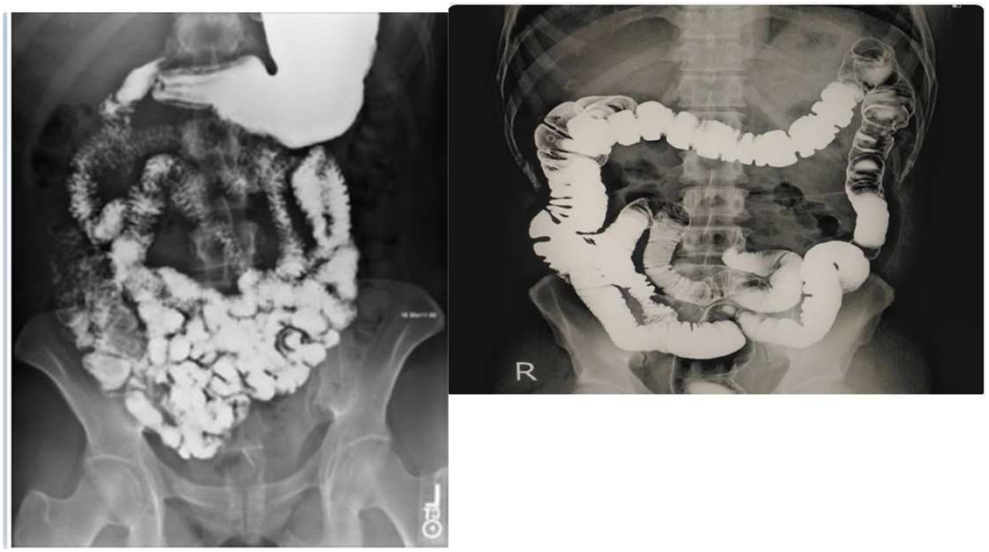
❑ image intensifiers (IIs)

❑ Flat panel detectors (FPDs), eliminating the need for a dark room and reducing radiation exposure.

- While advanced imaging techniques have largely replaced it, fluoroscopy still holds diagnostic value with judicious use due to potential radiation accumulation.

Procedures

- Detecting real-time body fluid movement in studies like barium, IV pyelography, cystourethrography, and hysterosalpingography.
- Placement of devices and catheters, such as central lines, Freka's tube, nephrostomy, and biliary drainage.
- Assessing leak sites in postoperative cases, and perforations.
- Therapeutic reduction of intussusception in children.

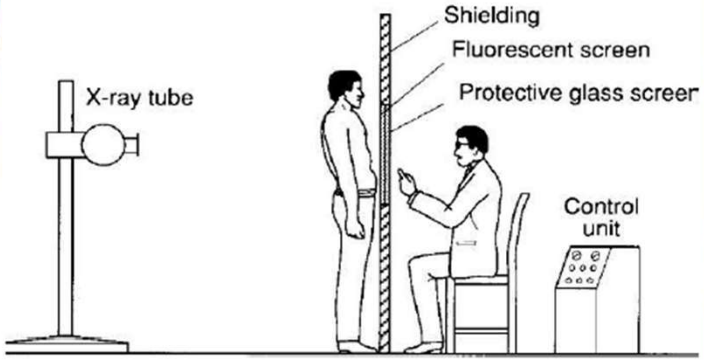


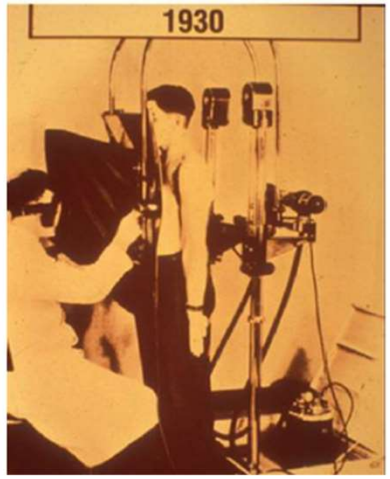
Fluoroscopy Development

- The initial fluorescent material used in the screen was barium platinocyanide, followed by cadmium tungstate and later zinc–cadmium sulfide.
- The technician/radiologist would place himself in front of the patient.
- X-ray tube would be behind the patient and screen would be between the patient and the technician.
- Lead covering was provided over the screen to reduce radiation exposure to the technician.
- Low light levels: 10-30 minute dark adaptation required by wearing red goggles

Early ages:

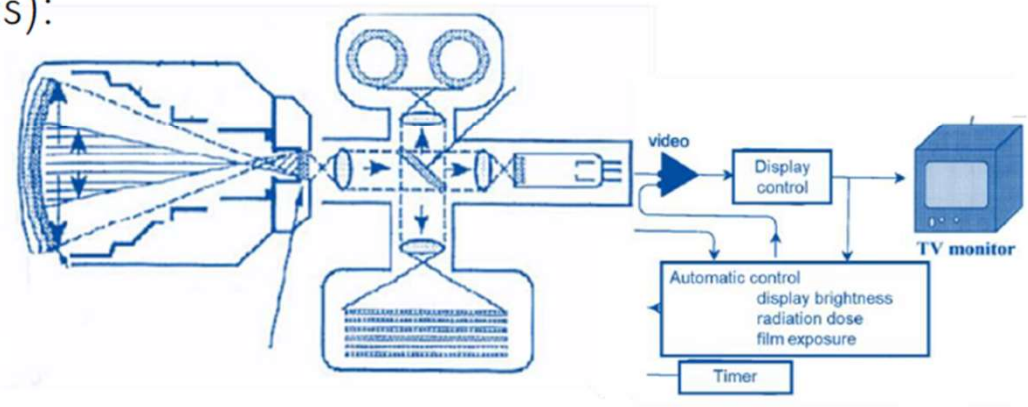
- Direct fluoroscopy screens
- Dark adaptation of radiologists 'eyes
- High radiation exposure to radiologists





1950-s to 2000-s

- X-ray image intensifier (II)
  - ZnCdS phosphor
  - CsI phosphor (**mid 1970-s**)
- TV camera:
  - Analog (orthicon or vidicon camera tubes)
  - Digital CCD TV camera (**1980-s**)
  - TV monitor
- Image recording (through tandem optics):
  - Film-screen
  - Spot cameras (cut or roll films)
  - Cine cameras
- Automatic control circuit
  - Automatic Brightness Control (ABC)
  - Automatic Dose Rate Control (ADRC)



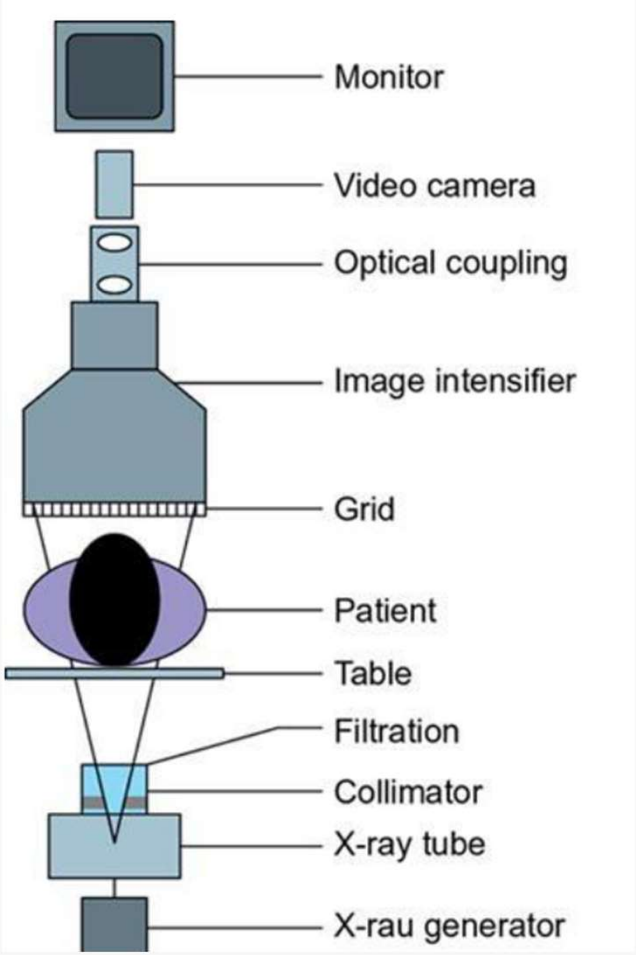
Intensifying Screens

- Developed in 1953
- improved image brightness and contrast resolution, eliminating the need for a dark room.
- They used optical mirrors to view images
- They had a narrow viewing angle, required frequent technician movement, and allowed only one viewer at a time without image storage.

- evacuated glass envelope
- vacuum tube

Advancements in fluoroscopy

- Large screens
- Video cameras and video recorder
- Digital screens instead of optic couplers
- Replacement of IIs with FPDs



X-ray generator

❑The X-ray generator here is similar to radiography but with added features:

- low continuous tube current with 30 frames/second image acquisition
- rapid pulse exposure in short pulses of 3-10msec at 30 frames/second,
- automated brightness control adjusting Kvp and mAs for consistent image brightness.
- Pulse fluoroscopy reduces radiation, improves temporal resolution, and minimizes motion blur.

X-ray Tube

- Similar to radiography, electrical energy is converted into an X-ray beam. Electrons from a heated cathode move towards a positively charged anode, producing X-rays when they strike the anode at the focal spot.
- The focal spot can be 1–1.2 mm or 0.3–0.6 mm, with the smaller size offering sharper images. ,
- The anode is angled at 7–20 degrees to reduce the focal point size.
- A vacuum and metal shielding are used in the X-ray tube.
- Fluoroscopic X-ray tubes must produce continuous and pulsed X-rays, requiring a grid-controlled tube for pulsed fluoroscopy to reduce radiation dose.
- Efficient heat dissipation is crucial, achieved with high-speed anodes, coolers, and water or oil exchangers.

Filter

- X-ray tube exit ports and collimators use aluminium or copper filters to attenuate low-energy X-rays, reducing patient radiation dose without affecting image formation.
- The half value layer (HVL), typically 2.3 to 3 mm Al at 80 kVp for fluoroscopy, measures X-ray penetration.
- Some systems allow operators to choose high or low-dose modes, while others adjust automatically based on beam attenuation and image brightness.

Collimator

- This is essential to reduce the radiation exposure to the patient, scatter radiation and glare from the edges.
- It makes the images sharper.
- It can have shape varying from round to rectangle depending on shape of image receptor and shutters the X-ray beam to the size of field of view (FOV).
- The collimators are just larger than the field of view.
- They adjust depending on source to image distance (SID) so as to prevent any radiation outside the FOV.

Table

- Carbon alloys provide high strength and minimal radiation absorption, ensuring the patient's safety and image quality.
- Foam pads can be used for patient comfort without increasing radiation dose.
- Can be moved in different angles

Table rotates in a wide range to meet the needs of different body positions.

Table horizontally moving, reduce movement of patients.

The spot film device move longitudinally in a wide range, cover whole body parts' examinations.

Item	Parameters
Table horizontal movement	±110mm
Table body rotation	+90°~-25°
Radiography device travel	>720mm

Grid

- Grids reduce scatter radiation to the image receptor, increasing contrast resolution but also radiation dose.
- The grid ratio for fluoroscopy is 6:1 to 10:1.
- Removing the grid can reduce the radiation dose by about 50%.

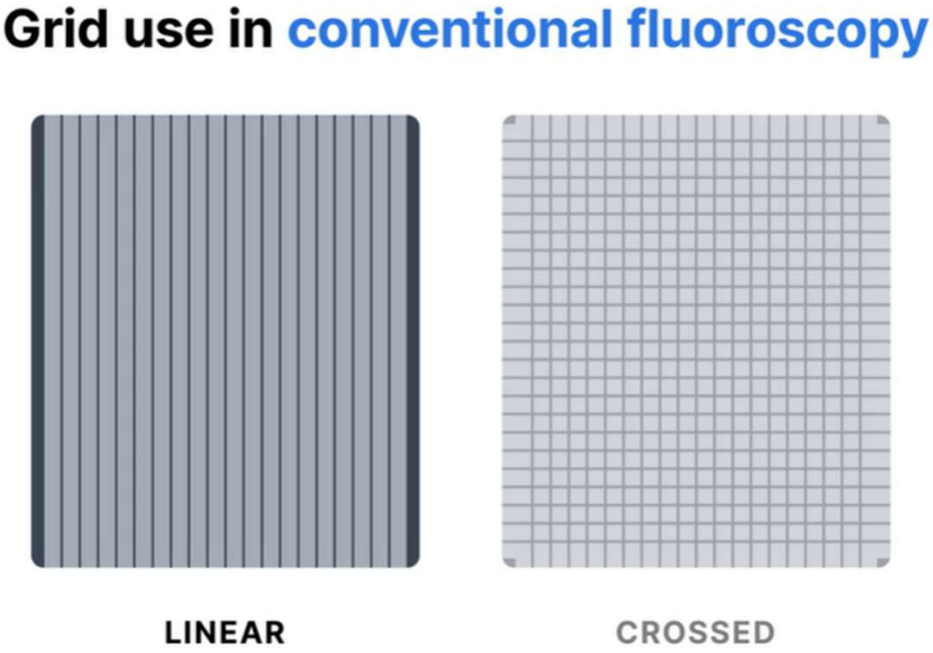
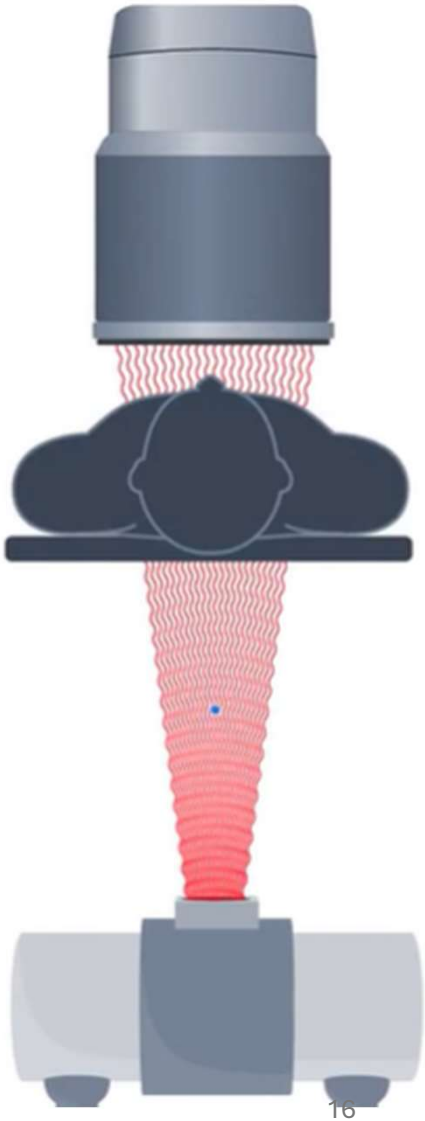


Image Intensifiers



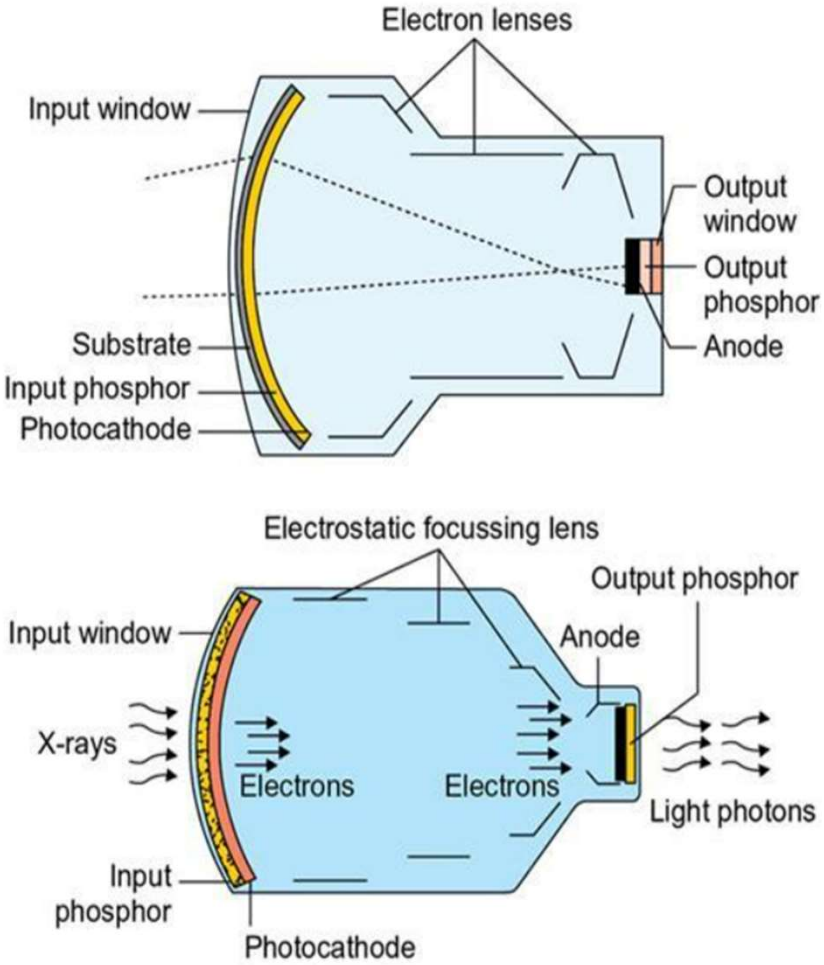
Intensifier

➢Input window:

- (Made up of metal or glass): It is convex in shape and made up of aluminium or titanium.
- X-rays pass through this to the substrate.
- The size of input windows can vary from 10 to 40 cm depending on the area of the body part to be imaged.

➢Substrate.

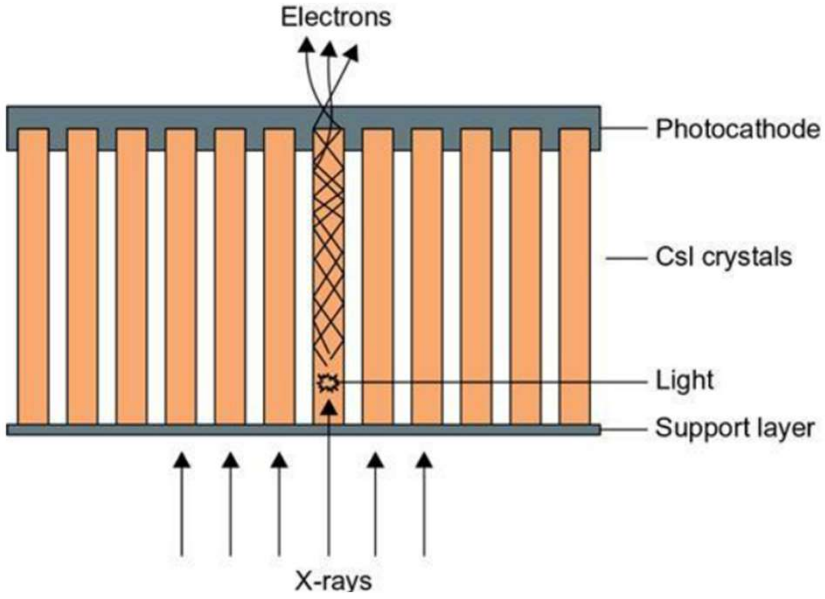
- Made up of aluminium.



Components of image intensifier.

Input Phosphor

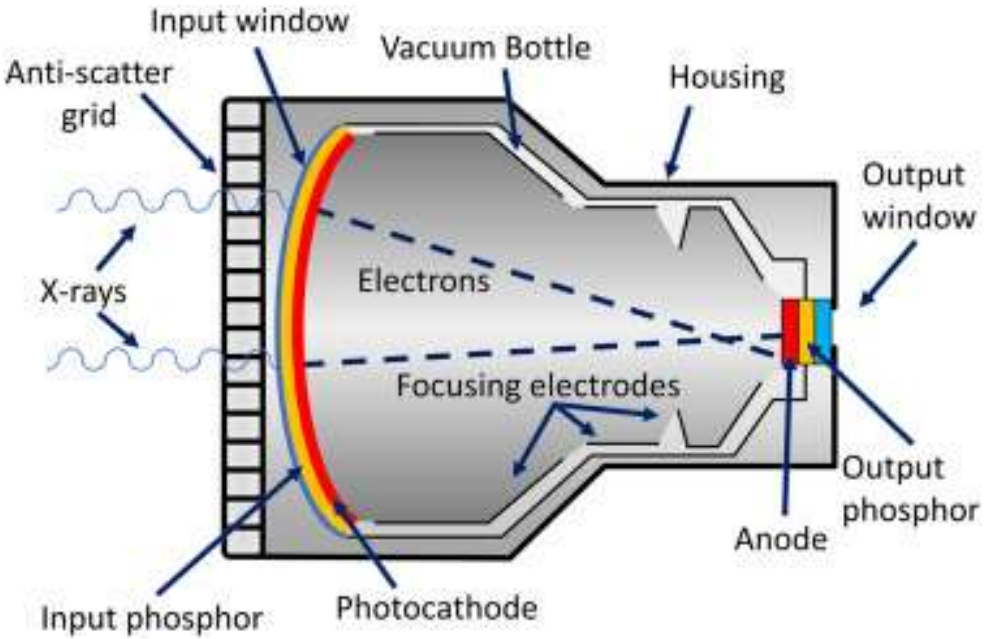
- Phosphor (made up of sodium-activated caesium iodide)
- These are needle-shaped crystals with fiber-optic characteristics.
- The layer of CsI: Na is ~400–500 µm thick and is laid over aluminium substrate.
- It converts X-rays into light photons which have very high X-ray absorption capacity to the tune of 70%–80%.
- Each X-ray can produce up to 300 light photons in blue spectrum.



Input Phosphor

Photocathod

- It is made up of a thin layer of antimony caesium alloy which absorbs fluorescent light emitted from input phosphor, matching to the blue spectrum.
- It absorbs light photons to emit electrons in II.
- One X-ray photon can release up to 200 electrons at 60 KeV.
- Multialkali photocathodes containing sodium, potassium and caesium are much more effective than single-alkali photocathodes, as they emit thrice the number of photoelectrons.

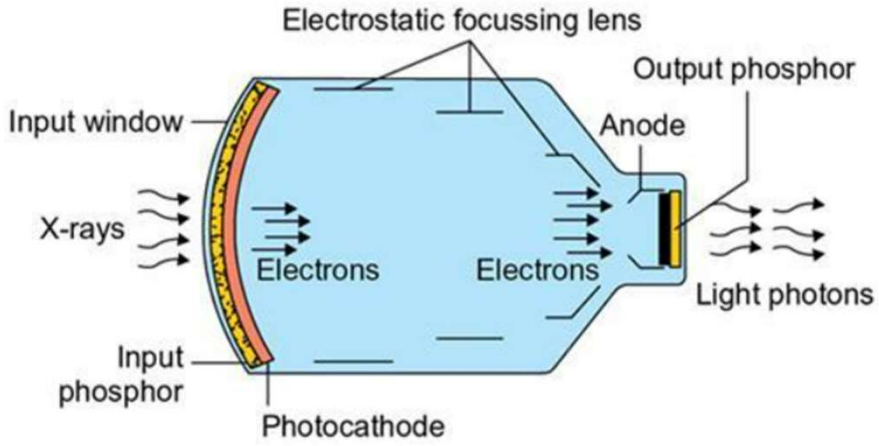


Electron lens

- Electron lens which steers, focuses, and accelerates electrons from cathode to anode.
  - inverts & reverses image
    - Side-side
    - Top=bottom
    - Black-white

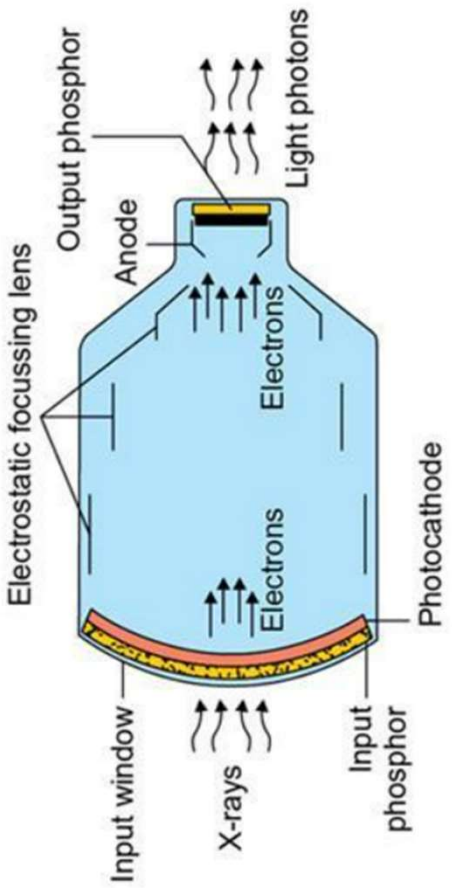
Anode

- Anode and three electrodes which create negative potential of about 25 kV to accelerate and focus the electrons towards the anode and output screen



output layer

- The output layer has a phosphor coating that converts the electron beam into visible light photons.
- The output beam is 1/10th the diameter of the input screen, minifying the image and inverting it upside down.
- The inner surface of the output window is coated with silver-activated zinc cadmium sulphide (ZnCdS:Ag) crystals, and a thin layer of aluminium
- The output screen is about 25–35 mm in diameter and a few micrometers thick.
- Overall, brightness gain is 5000–20,000 due to the rapid acceleration of electrons and the reduced width of the output beam.
- ~ 50 fold increase in # light photons over input phosphor



Brightness Gain

- Brightness gain is defined as the ratio of output screen brightness to input screen.
- It can vary from 5000 to 3000.
- G(brightness) = G(minification gain) × G(flux gain)
- Minification gain is the increase in the brightness of the image due to demagnification:

$$G(\text{minifaction gain}) = \left\{ \frac{\text{Diameter of input screen}}{\text{diameter of output screen}} \right\}^2$$

Flux gain

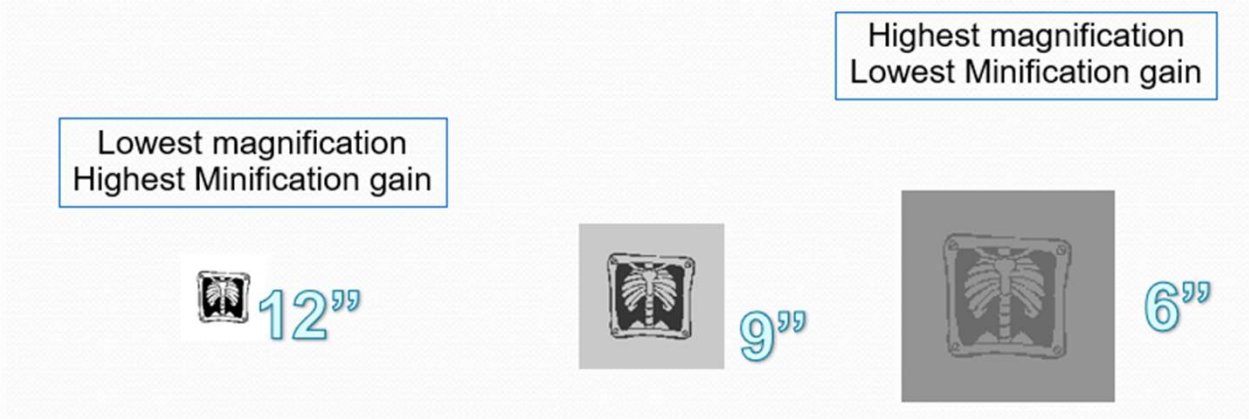
- Flux gain is gain due to difference in voltage at two ends.
- The higher the difference, the greater the flux gain.
- The images can be magnified with II by focussing a small part onto the larger output image screen.
- Flux gain = No. of light photons at the output screen number of photons at the input screen

$$\text{Flux gain} = \frac{\text{No. of light photons at output screen}}{\text{number of photons at input screen}}$$

- These days, brightness gain is replaced by II conversion factor (Gx) due to difficulty in measuring the brightness of input screen.
- Gx = Luminance of output screen (candela / m 2) dose rate of II input (microgray / sec)

$$Gx = \frac{\text{Luminance of output screen } (\text{candela}/\text{m}^2)}{\text{dose rate of II input } (\text{microgray}/\text{sec})}$$

- The conversion factor can vary from 50 to 300.
- The higher the conversion factor, the more efficient the II.



- image brighter because output screen smaller than input screen
- Minification Gain changes with magnification mode (9”, 6”, etc)
- Minification Gain changes by about 2X for each mag mode
  - typically 81 for 9” mode (output phosphor about 1” diam)
  - 36 for 6” mode
  - 16 for 4” mode

Properties of image intensifier

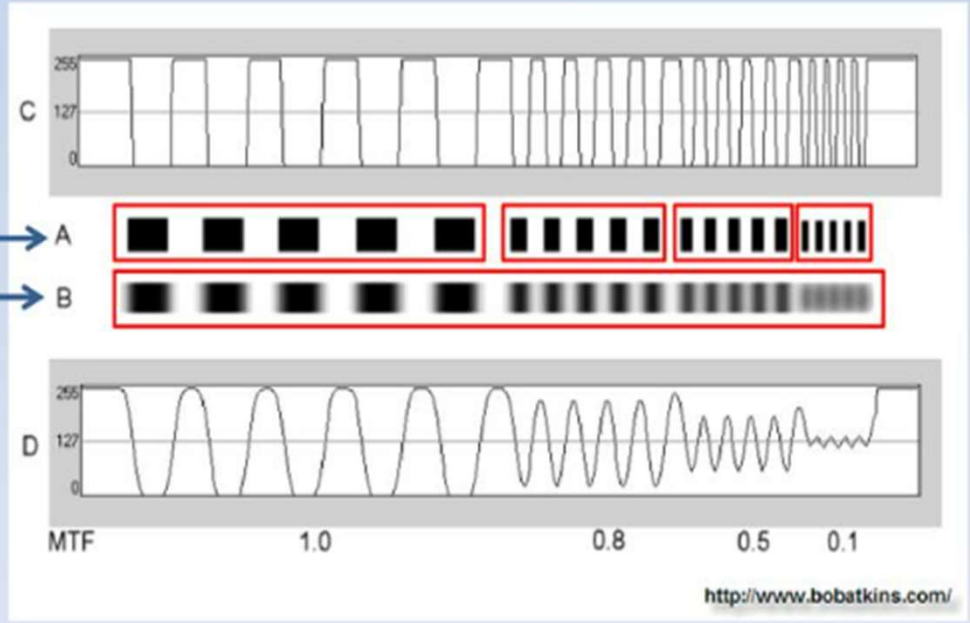
- **Spatial resolution.**
- It is the ability to resolve fine details.
- Due to convexity of the input screen of II, spatial resolution is greater at the centre than at the periphery of the input screen.
- It is around 4 lines/mm at 25 cm mode for CsI II.

- **Contrast resolution.**
- It is the brightness of the image at the periphery to that at the centre of output screen.
- It is generally in the range of 20:1 and can vary from 10:1 to 30:1
- Image tube contrast degrades over time depends on
  - collimation
  - tube properties

Resolution

Modular Transfer Function (MTF)

"A" is a set of patterns of dark and light bars.
There are 4 sets of bars at increasingly smaller spacing.



"B" is an "image" of what those bars might look like when imaged by a lens. The edges of the dark and light regions will be blurred. The closer the spacing, the more blurred they become.

Resolution

Ability to resolve recorded detail will vary depending on geometrical factors:
(same as static radiography)

Minification Gain	Electrostatic Focal Point	Input and output screen diameter
Viewing System Resolution (monitor resolution)	OID	Phosphor crystal size and thickness

Geometrical factors are of a different nature than in static radiography

Resolution Capabilities

Zinc-cadmium input phosphor intensifier tubes

1-2 lp/mm

Cesium iodide (CsI) input phosphor image intensifiers

4 lp/mm

Optical mirror systems that permit "indirect" viewing of the fluoro output screen

3 lp/mm

Magnification or multi-field image intensifiers

6 lp/mm

(in mag mode)

- **Noise.**
- Image noise is high in II due to low mAs.
- To reduce the noise, mAs have to be increased, which will proportionately lead to rise in radiation dose.
- CsI input phosphor due to its inherent high DQE produces little noise with good quality images.

Artefacts

✓Image lag

- It is the persistence of emission of light from the screen even when the radiation beam has been switched off.

✓Vignetting

- It is the reduction in brightness at the periphery of the image than the centre due to which image formed at the centre is sharper.

✓Veiling glare

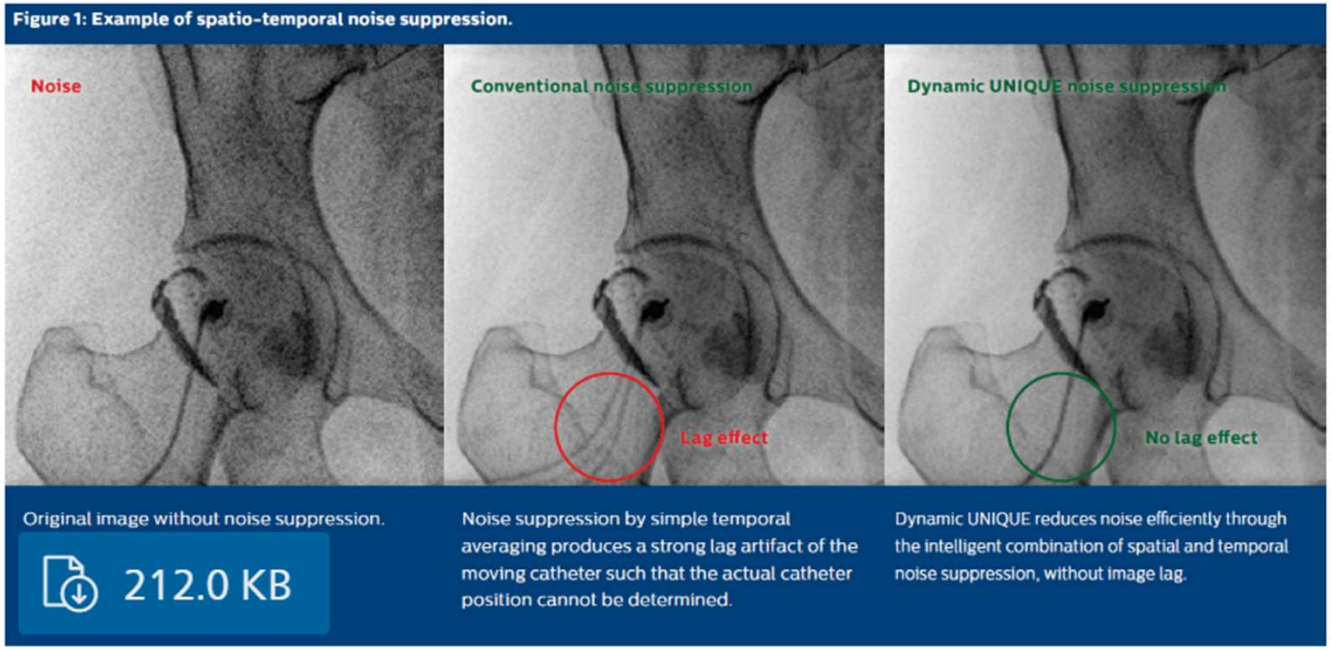
- It is produced due to scattering of light in the II.

✓S distortion

- This results due to the presence of electromagnetic field near the II.

✓Pincushion distortion

- This occurs with the rectangular grid due to curved nature of the input screen within II.



- Lag: Degrades the temporal resolution of the dynamic image.
- Older image intensifier tubes had phosphors with lag times on the order of 30-40 msec
- Current image intensifier tubes have lag times of approximately 1 msec
- lag in modern fluoroscopic systems is more likely caused by the closed-circuit television system than the image intensifier.

Lag

- Effect of camera lag. Angiogram of a rapidly moving coronary artery shows a trailing "ghost" due to excessive camera lag (the direction of travel is from right to left).

Size Distortion

Size distortion is caused by the same factors that affect static radiography magnification: OID

- Multifield image intensifiers that produce magnification by changing the electrostatic focal point do not significantly affect actual size distortion
- Some size distortion is always present in the minified image
- Size distortion becomes more visible in a magnified image

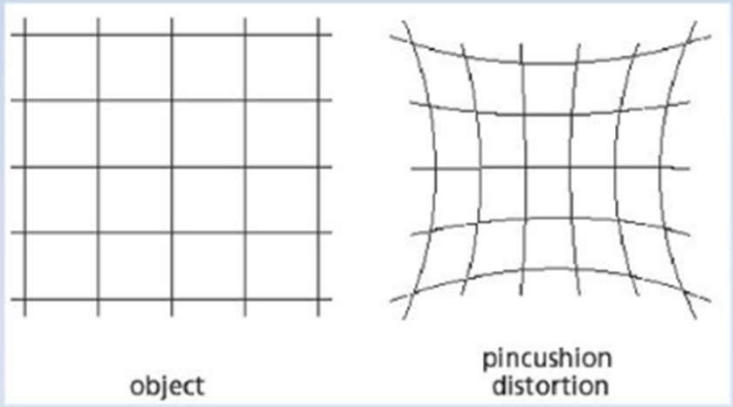
Shape Distortion

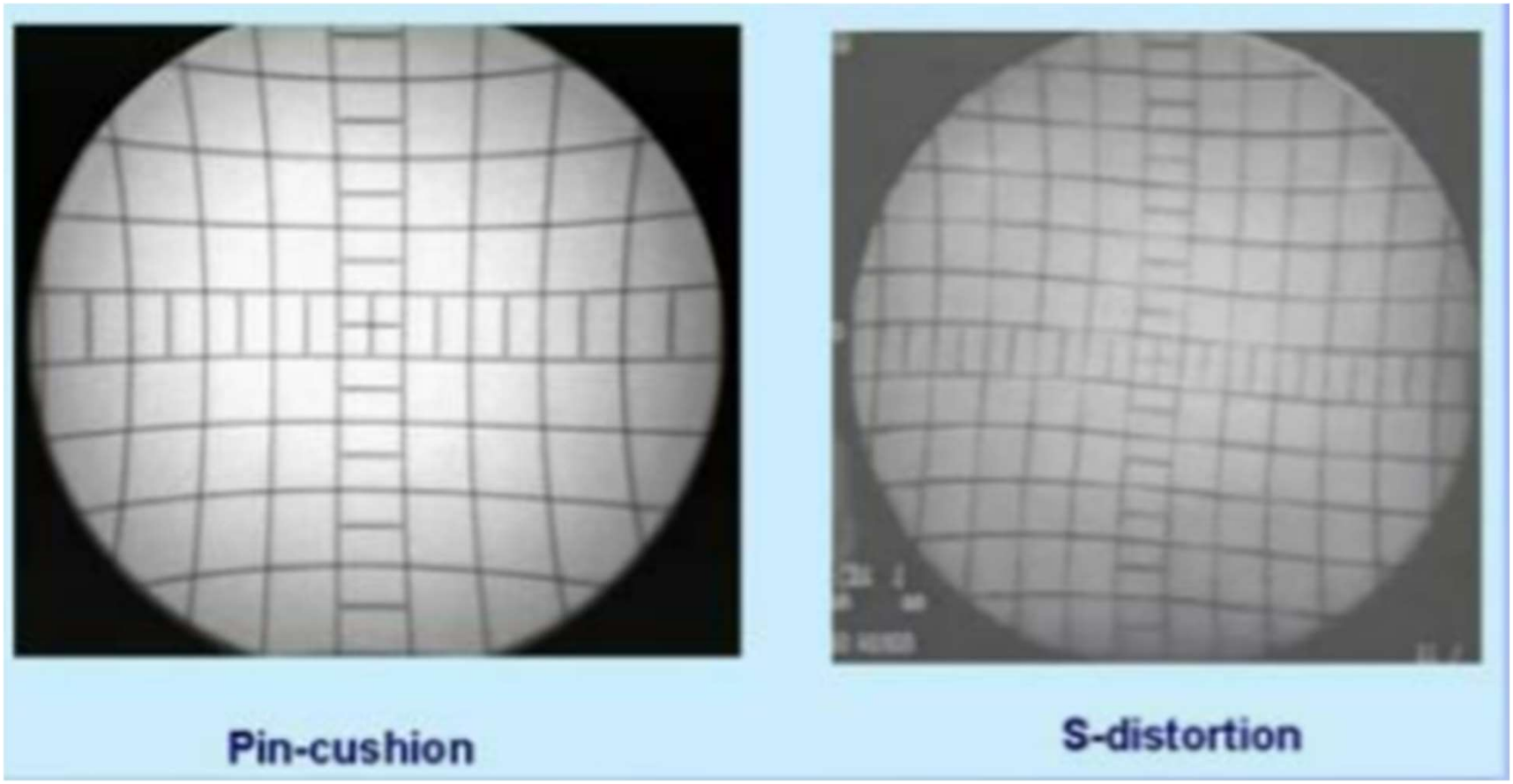
Is significant when distorting 8-10% of the image area

Shape distortion (pincushion) is primarily caused by shape of image intensification tube

Inherent edge distortion at output screen even with concave input screen

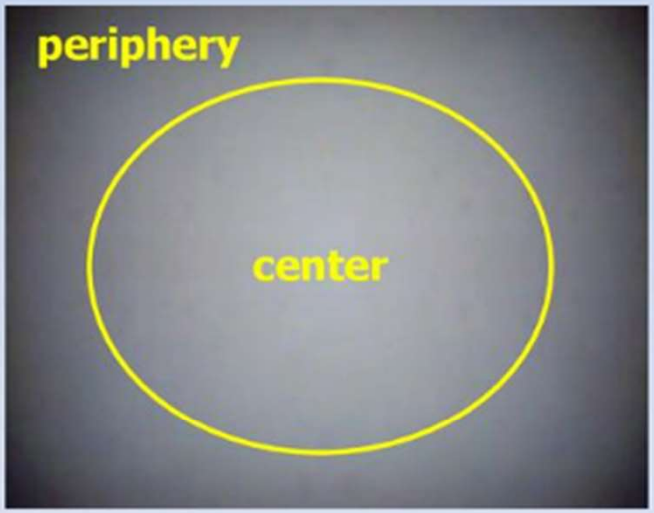
- Electron stream focusing not uniform across entire field of image intensifier
- Electrons at outer edges of image flare outward as they are electrostatically focused
  - Due to repulsion of like charges
- Partially due to divergence of primary x-ray beam




Pin-cushion
S-distortion

Vignetting

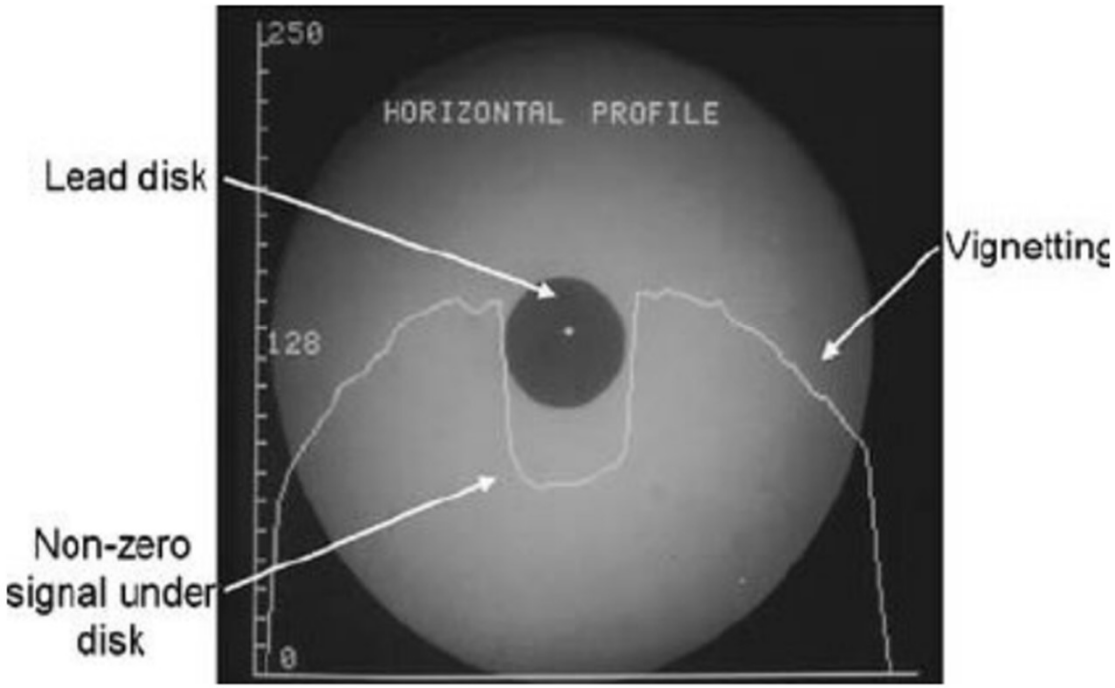
- Center of output screen brighter than periphery due to unequal magnification of the electron stream causing unequal illumination at output phosphor
- In center of image:
  - Resolution is better
  - Distortion is minimized
  - Contrast is improved



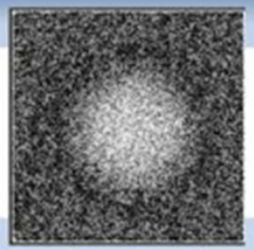
The contrast ratio is a good measure of determining the veiling glare of an image intensifier.

- Ideally, the signal would be at zero, while in the figure a value of about 60 occurs (**Veiling glare**)

- **Vignetting** is also illustrated; it is the fall-off of light intensity at the periphery of the image relative to the center, caused by light scatter loss at the edge of the image



Quantum Mottle, Quantum Noise, Scintillation



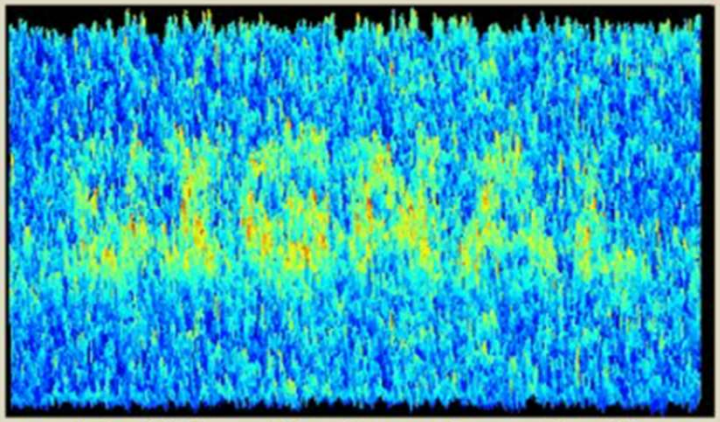
Blotchy or grainy appearance caused by insufficient radiation to create a uniform image

- Static radiography: mA and time as mAs controls quantity of photons creating density on image receptor
- Fluoroscopy: factor of time limited by length of time human eye can accumulate or integrate enough visible light photons from the fluoro imaging chain to be perceived
    - This time period is 0.2 seconds
    - Fluoro mA must be high enough to avoid excessive mottle as perceived by the observer

Quantum Mottle, Quantum Noise, Scintillation

Inherently present in any electronic video system as 'video noise' or 'electronic noise'

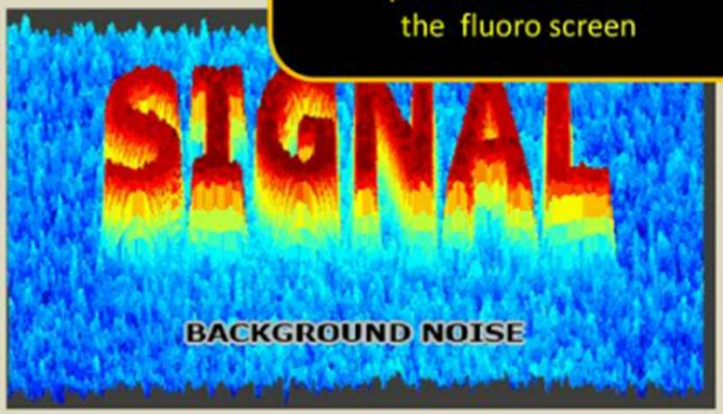
mA too low causes "excessive" quantum mottle / scintillation



A low SNR would produce an image where the "signal" and noise are more comparable and thus harder to discern from one another

mA increased signa

Creates a special problem as fluoro units are operated with the minimum mA (dose) possible to activate the fluoro screen



The image above has a sufficiently high SNR to clearly separate the image information from background noise

Quantum Mottle, Quantum Noise, Scintillation

Factors affecting quantum mottle include:

Initial Radiation Output	Viewing system (direct, monitor, film, etc.)
Total Brightness Gain	Conversion efficiency of input screen
Beam attenuation by subject matter	Distance of observer from viewing sytem (inverse square law of light)

Solutions

Increasing efficiency of any of these will reduce quantum mottle

↑ Efficiency

↓ Quantum Mottle

Common solution is to increase fluoro tube mA

(Results in an increased patient dose rate)

FPD

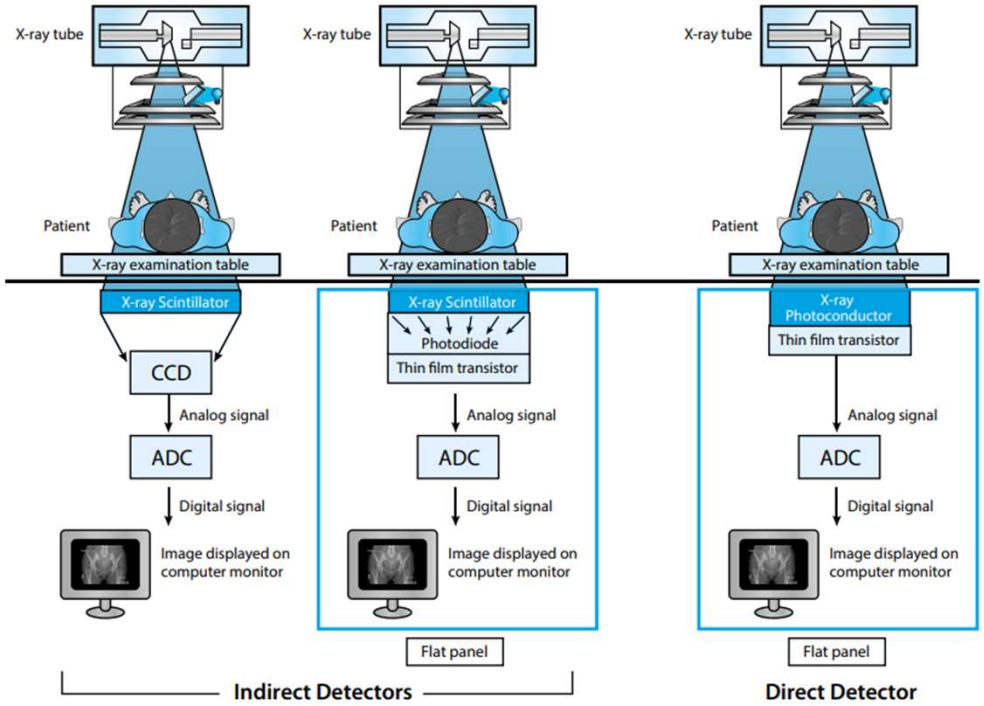
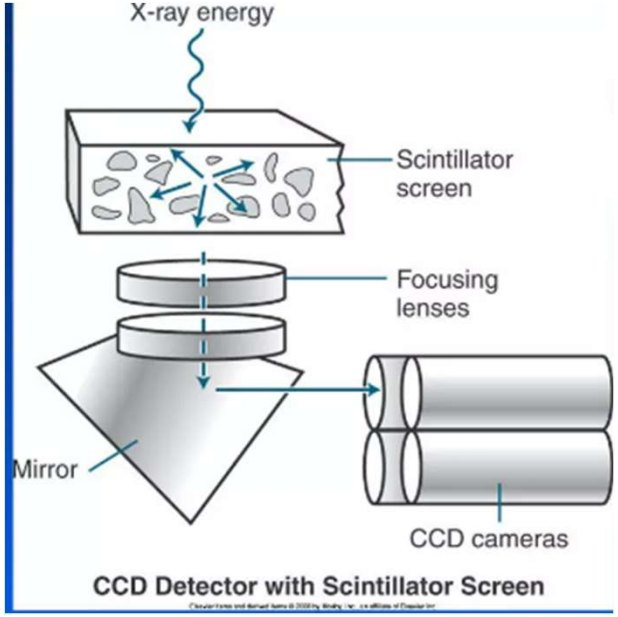
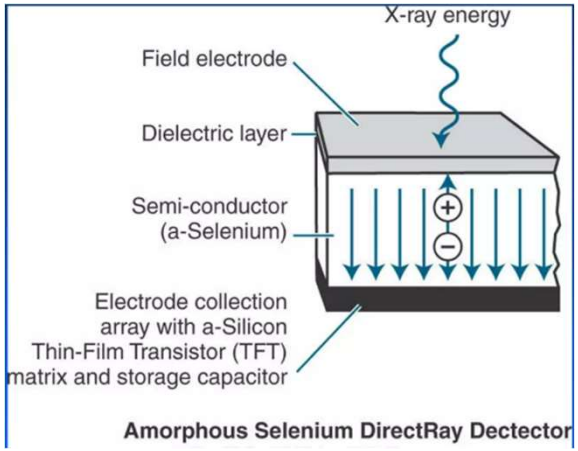


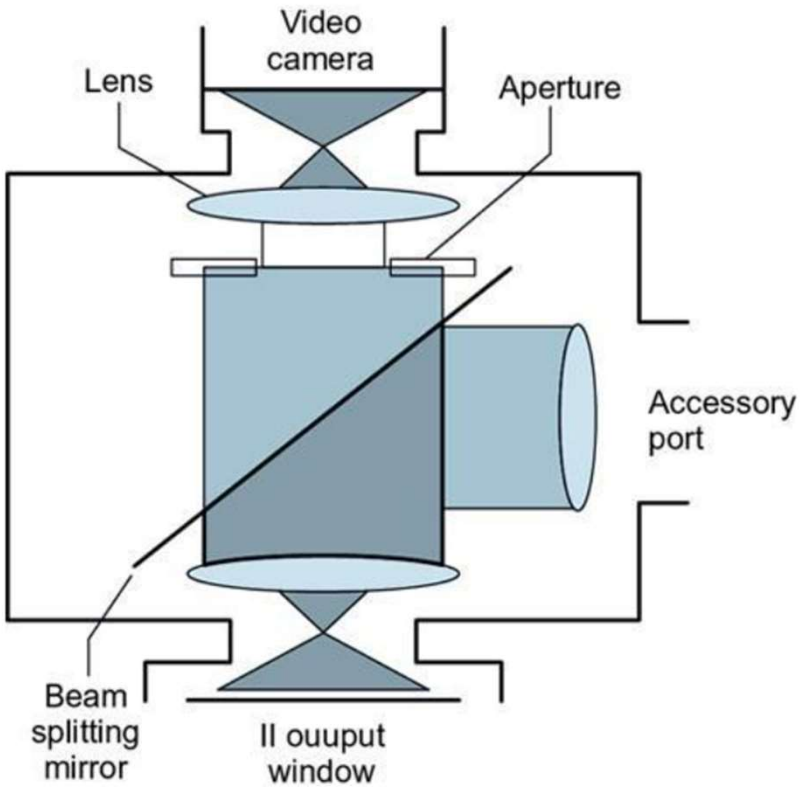
Figure 3. *Indirect radiography systems and direct digital radiography systems appear similar in the physical state but differ in how x-rays are captured and processed. Systems using indirect detectors go through a 2-step process requiring a scintillator before creating the signal needed for image display. Systems with direct detectors convert x-ray photons directly into an electrical charge using a photoconductor. Abbreviations: CCD, charge coupled device; ADC, analog-to-digital converter. © ASRT 2016.*





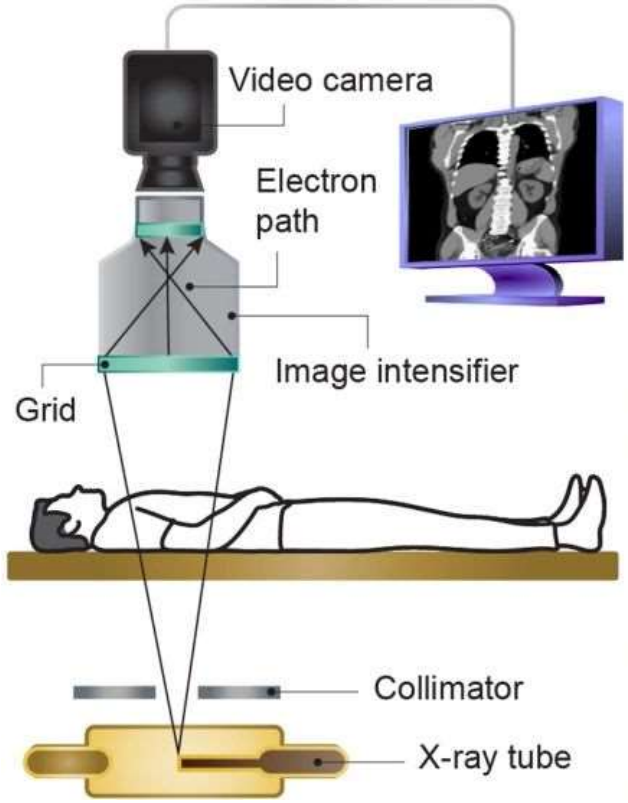
Optic coupling devices

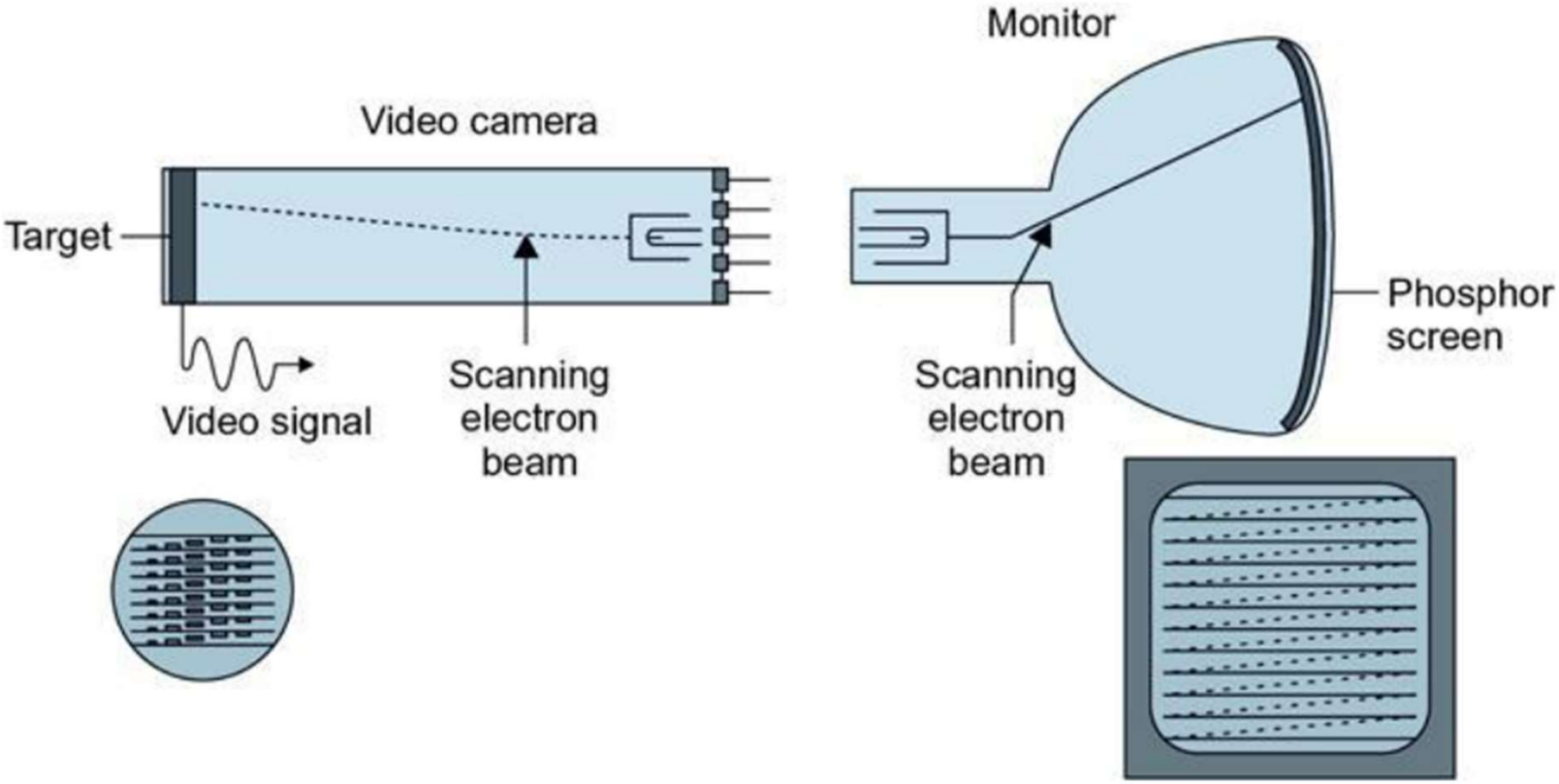
- A beam-splitting mirror directs 10% of the light photons to the recording video camera
- 90% to the photospot film camera.
- Another small mirror between the collimating lens and beam-splitting mirror directs part of the beam to an automatic exposure control sensor, controlling radiation exposure and noise.



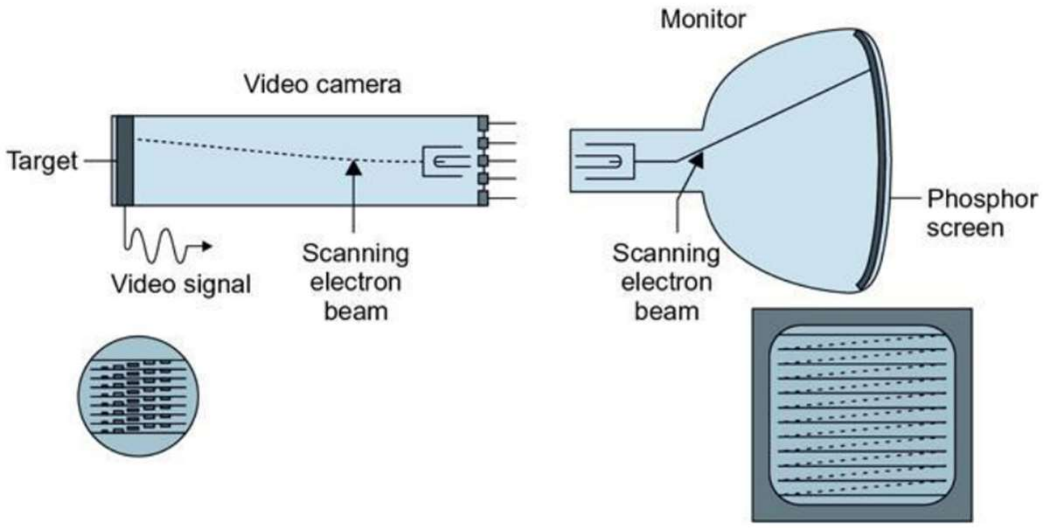
Television monitor and image recording systems

- Modern fluoroscopic units are connected to television monitors, allowing multiple viewers.
- They are linked to recording systems for storage and postprocessing.
- A video camera converts the light image into a voltage signal, and a monitor displays this image .
- These components are connected via coaxial cable.

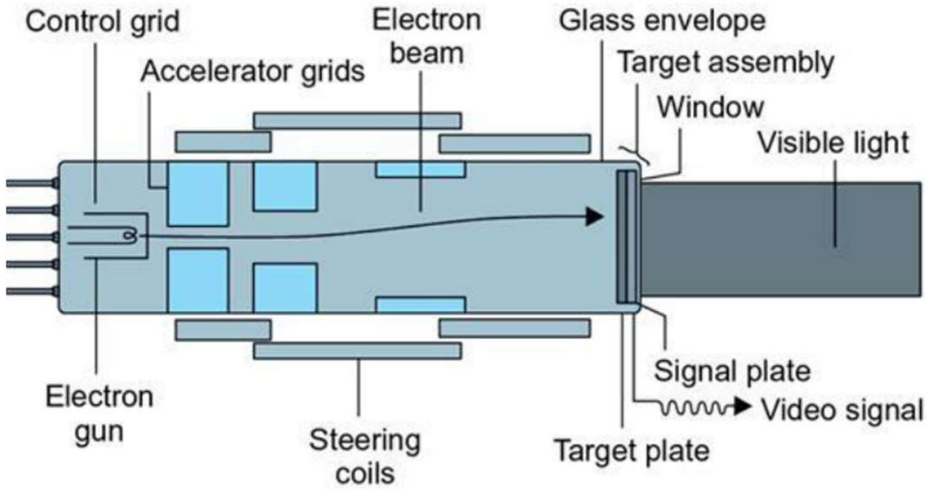



Video camera
Target
Video signal
Scanning
electron
beam
Monitor
Phosphor
screen
Scanning
electron
beam

- Video camera is a thermionic television camera tube, which is cylindrical in shape and has vacuum inside.
- It has two parts: one is the photoconductive target and other is the electron beam.
- Photoconductive target is the one on which optical coupling devices project the photon image from the II output and form a latent image.
- This latent image is scanned by the electron beam forming an electronic signal, which is the image in the form of raster lines.
- This is further converted into an image by the display monitor.
- Examples of television camera tube are vidicon and plumbicon: it is modified version



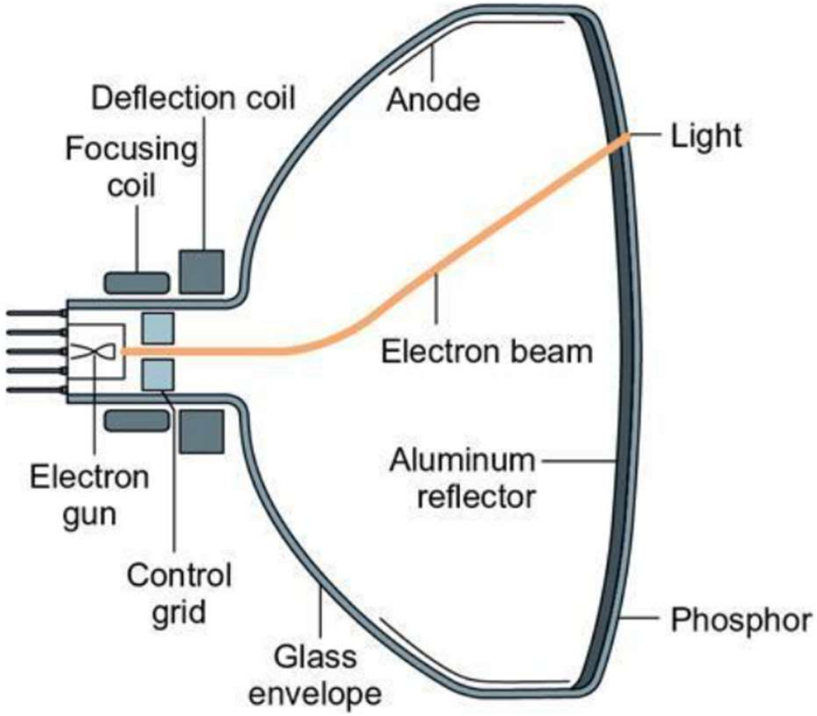
- A classical vidicon consists of a glass envelope maintaining vacuum.
- Inside, there's a cathode with an electron gun and an anode with the target assembly.
- The electron gun emits a constant electron current through thermionic emission and is surrounded by a control grid that accelerates electrons towards the anode.
- The electron beam passes through electrostatic grids and electromagnetic coils, which focus and control its size and position.
- It then reaches the target assembly, composed of a photoconductive target plate, a signal plate, and a window.
- The target plate, made of antimony trisulfide, is swept by the electron beam, and the signal plate conducts the video signal out of the tube to the external video circuit.



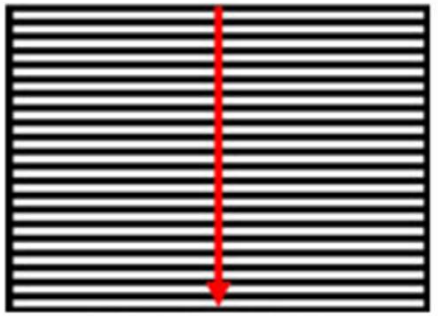
- Conventional cameras are now replaced by smaller, more powerful charge-coupled devices (CCDs).
- These devices convert light images into pixels, which are read as voltage signals.
- A layer of crystalline silicon acts as the sensitive component, which produces electrical charge when illuminated
- CCDs have no image lag, no spatial distortions, a wider dynamic range (3000:1), high SNR, and better contrast resolution, all of which help reduce patient radiation dose.

Video monitor

- A video monitor converts signals into images using a television picture tube, also known as a cathode ray tube.
- It is similar to a video camera tube but larger, with an anode composed of a fluorescent screen and graphite lining.
- The control grid modulates the electron beam intensity, which is then accelerated and focused onto the phosphor screen, creating light bursts.
- The phosphor screen consists of linear crystals with thin aluminium coating, arranged perpendicular to the glass envelope to prevent lateral dispersion.

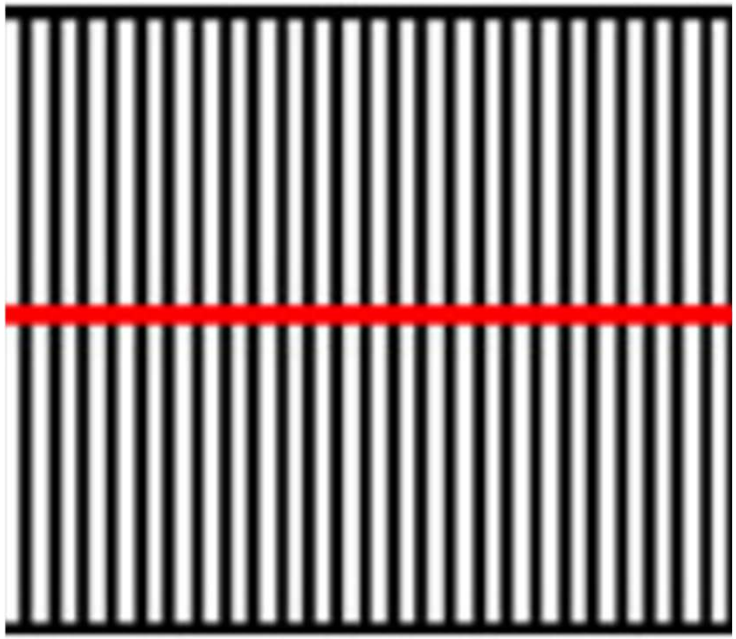


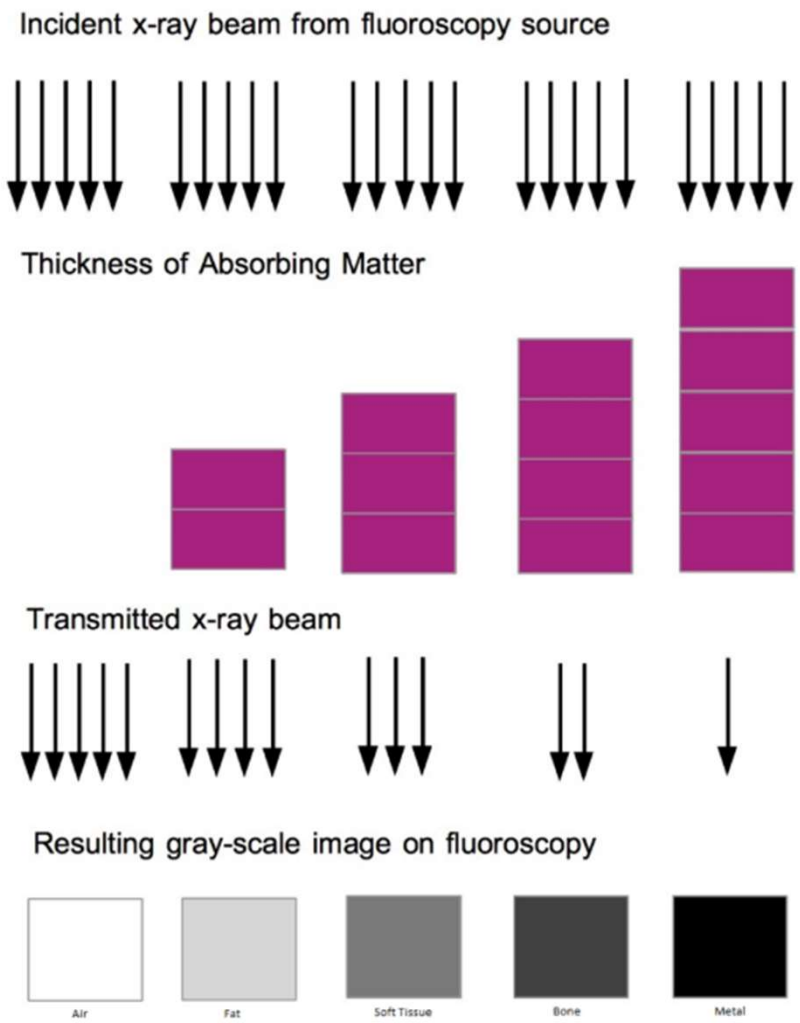
- TV vertical resolution is based on scan lines, with 525 in North America and 490 usable.
- Kell's factor shows about 70% of this is perceived, equating to 343 lines or 172 line pairs.
- For a 9” field, it is 0.75 lp/mm;
- for a 7” field, 1.0 lp/mm;
- and for a 5” field, 1.4 lp/mm.



Vertical Resolution

- The horizontal resolution depends on the speed of video electronics in responding to light intensity changes, influenced by the camera, cable, and monitor.
- It's mainly governed by system bandwidth. Scanning each video line (525 lines at 30 frames/sec) takes 63 ms: 11 ms for horizontal retrace and 52 ms for available scanning.
- To achieve 172 cycles in 52 ms, a bandwidth of 3.3 MHz is required.
- Higher bandwidths are necessary for high-line video systems.




Incident x-ray beam from fluoroscopy source
Thickness of Absorbing Matter
Transmitted x-ray beam
Resulting gray-scale image on fluoroscopy
Air
Fat
Soft Tissue
Bone
Metal