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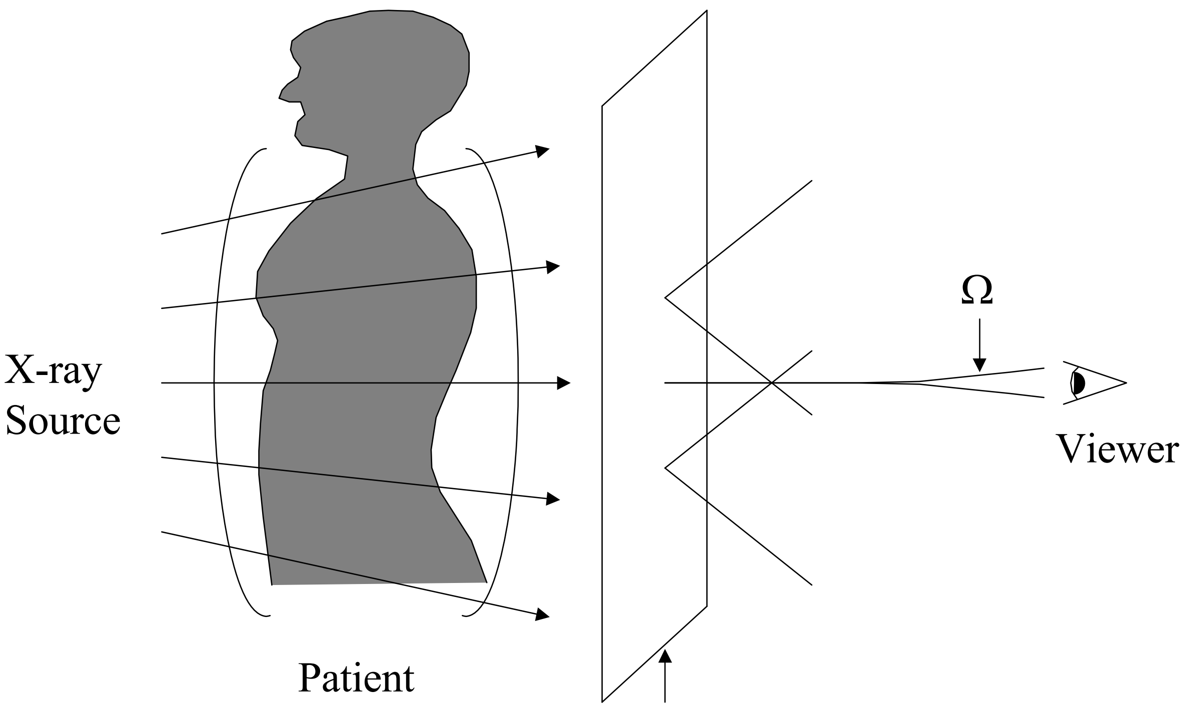
Handout #4
Fluoroscopy/ Digital Fluoroscopy

4.1 Real-time Imaging

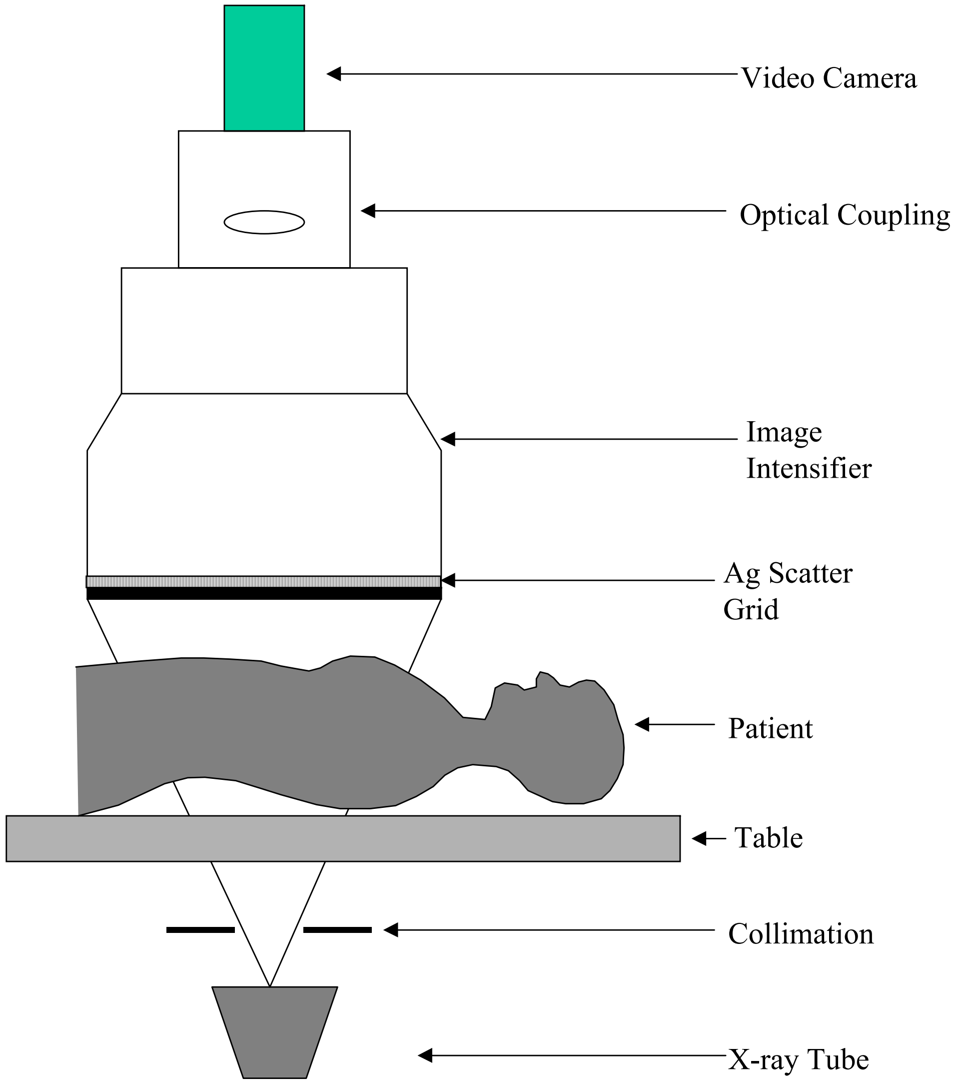
❖ Conventional fluoroscopy

Conventional Fluoroscopy



❖ Modern fluoroscopy: image intensifier-Television system (II-TV and II-CCD)

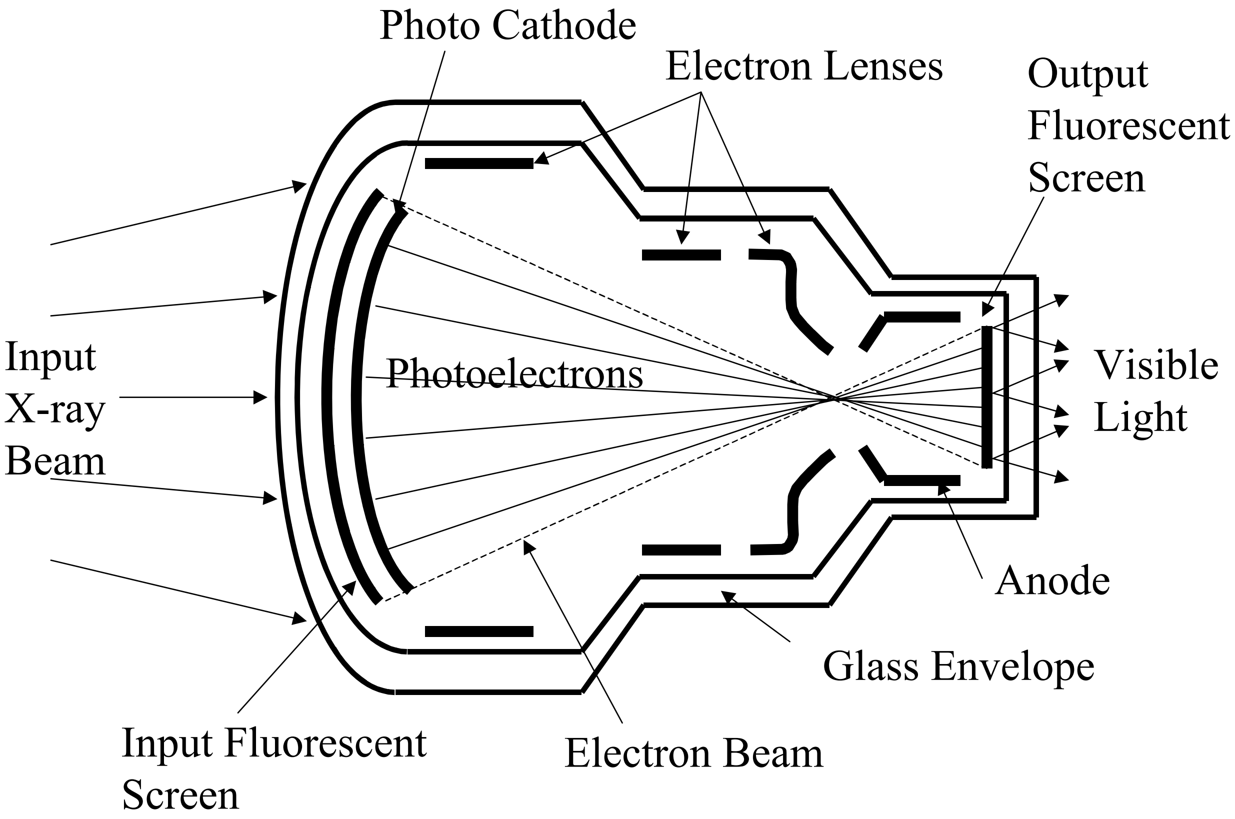
Modern Fluoroscopy



4.2 Image Intensifier Based Fluoroscopy Systems

❖ Modern fluoroscopic systems use image intensifiers coupled to digital video system or digital detectors as image receptors.

❖ A diagram of a modern image intensifiers is shown in the following figure.



4.3 Image Intensifier

(1) Basic principle of an image intensifier

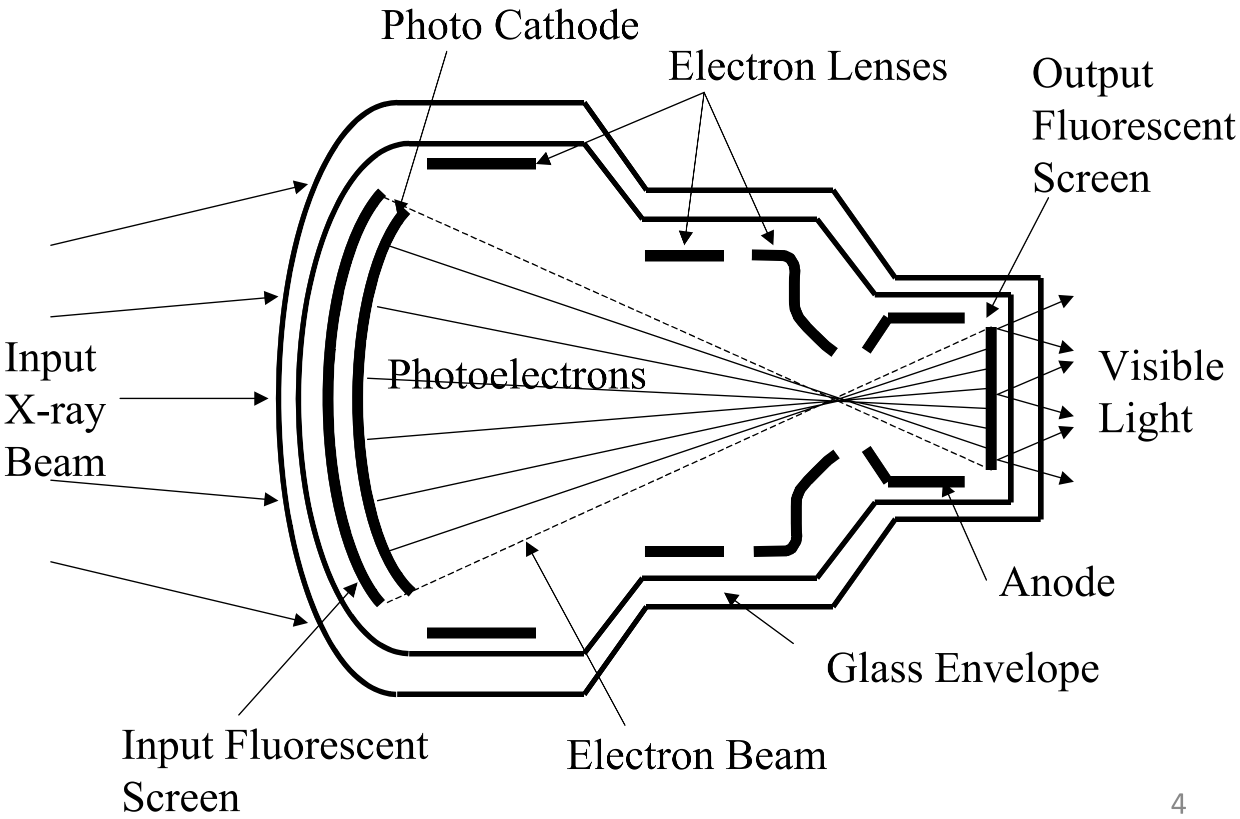
(a) A vacuum bottle;

(b) An input fluorescent screen that converts x-ray photons to a light photons; and a photo cathode that receives the light photons and emit electrons;

(c) Electron lens that focus the electrons from the cathode to the output screen

(d) The anode that accelerate electrons emitted from the cathode toward the output screen

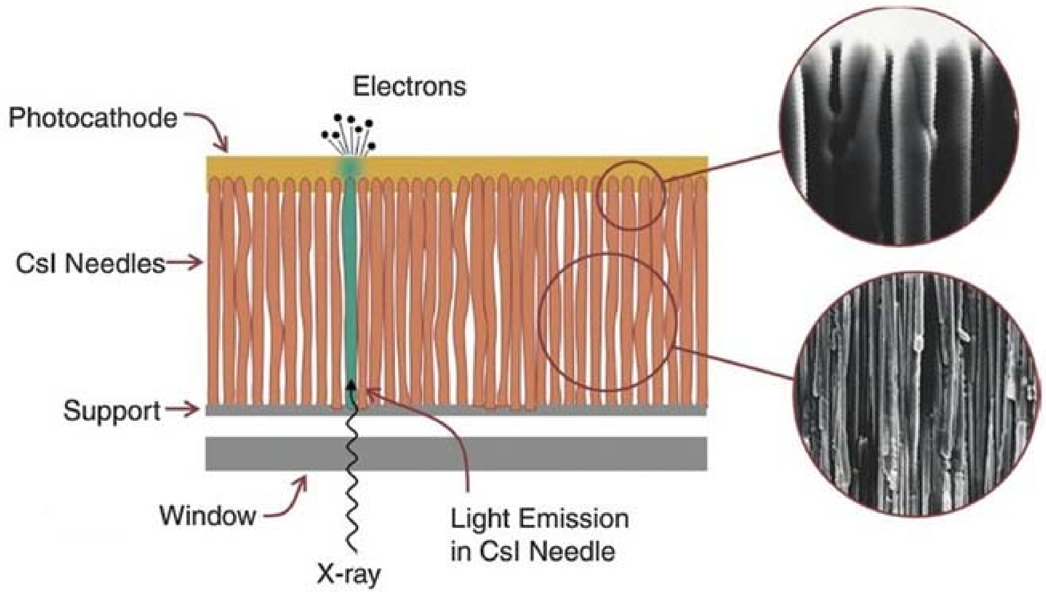
(e) The output phosphor that converts the electrons to visible light.



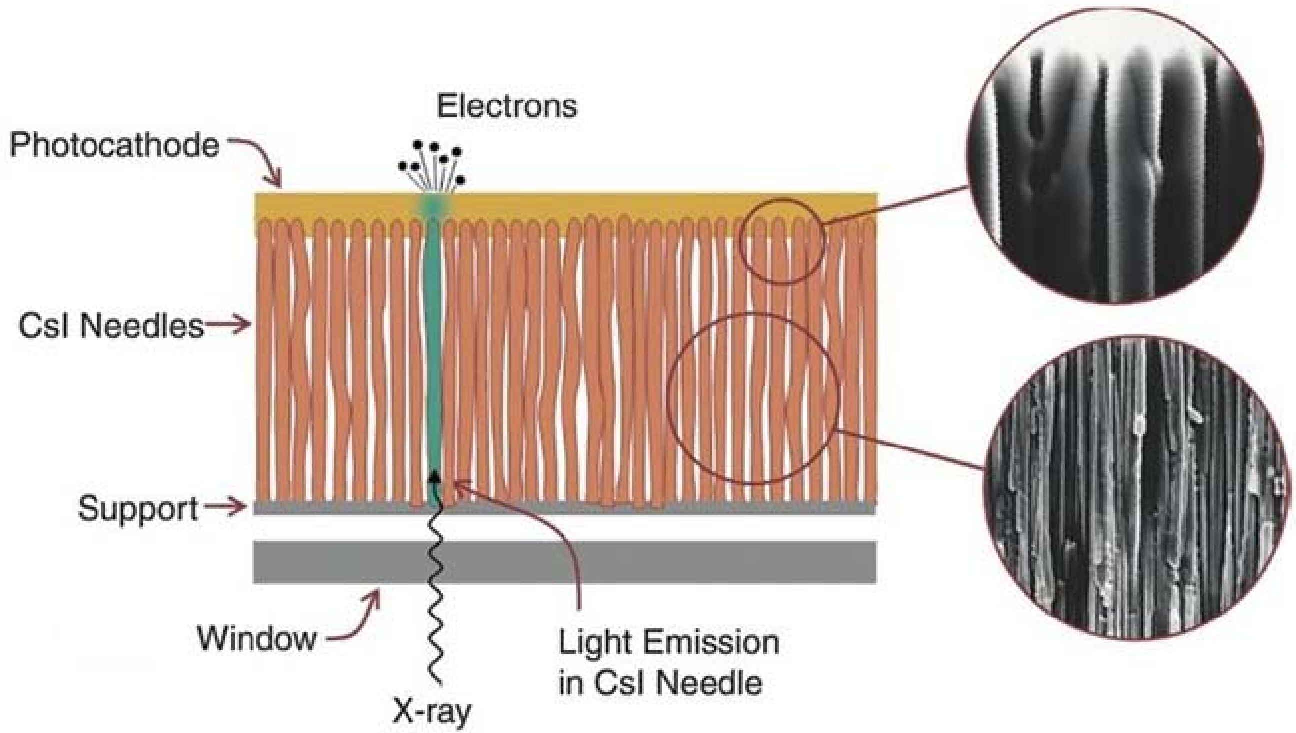
(2) Input screen

The input screen of image intensifiers consist of four different layers, as shown in following figure.

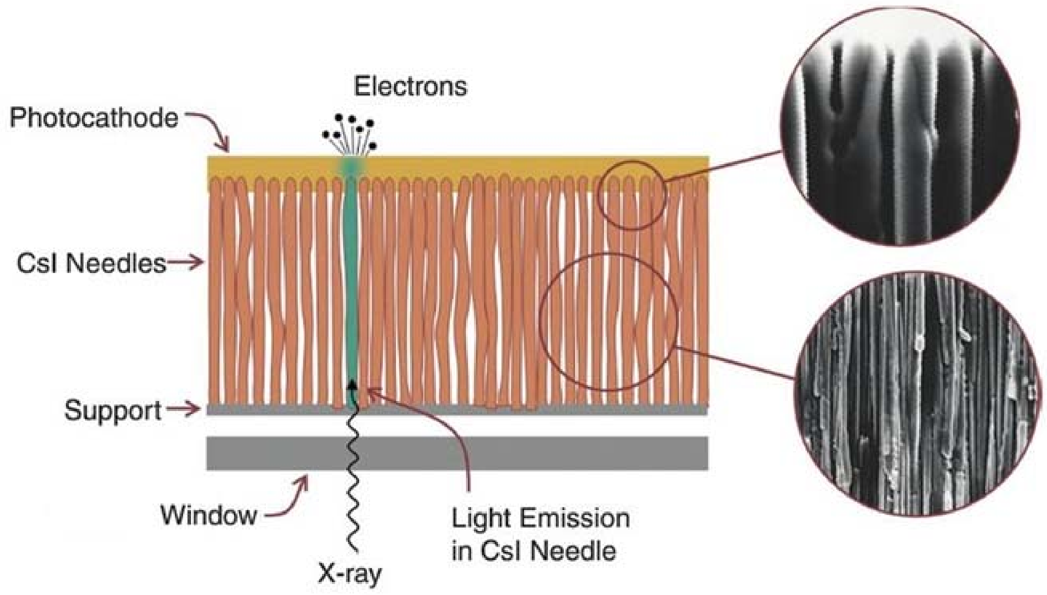
- ❖ The first layer is a thin (typically 1 mm) aluminum window that is part of the vacuum containment vessel. The window keeps the air out of the image intensifiers, and its curvature is designed to withstand the force of the air pressing against it.



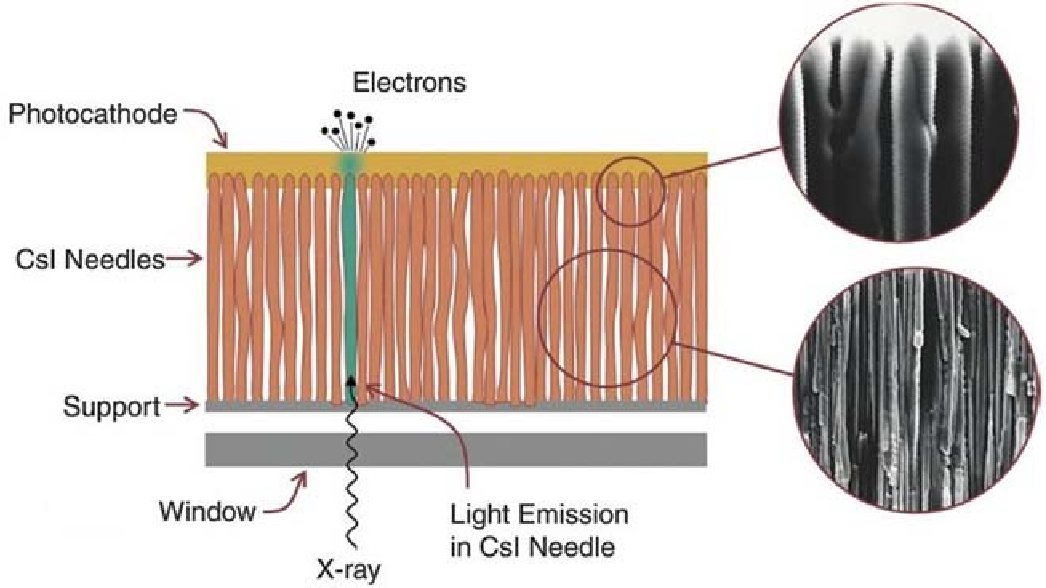
- The second layer is the support layer, which supports the input phosphor and photocathode layers. The support, commonly 0.5 mm of aluminum, is the first component in the electronic lens system, and its curvature is designed for accurate electron focusing.



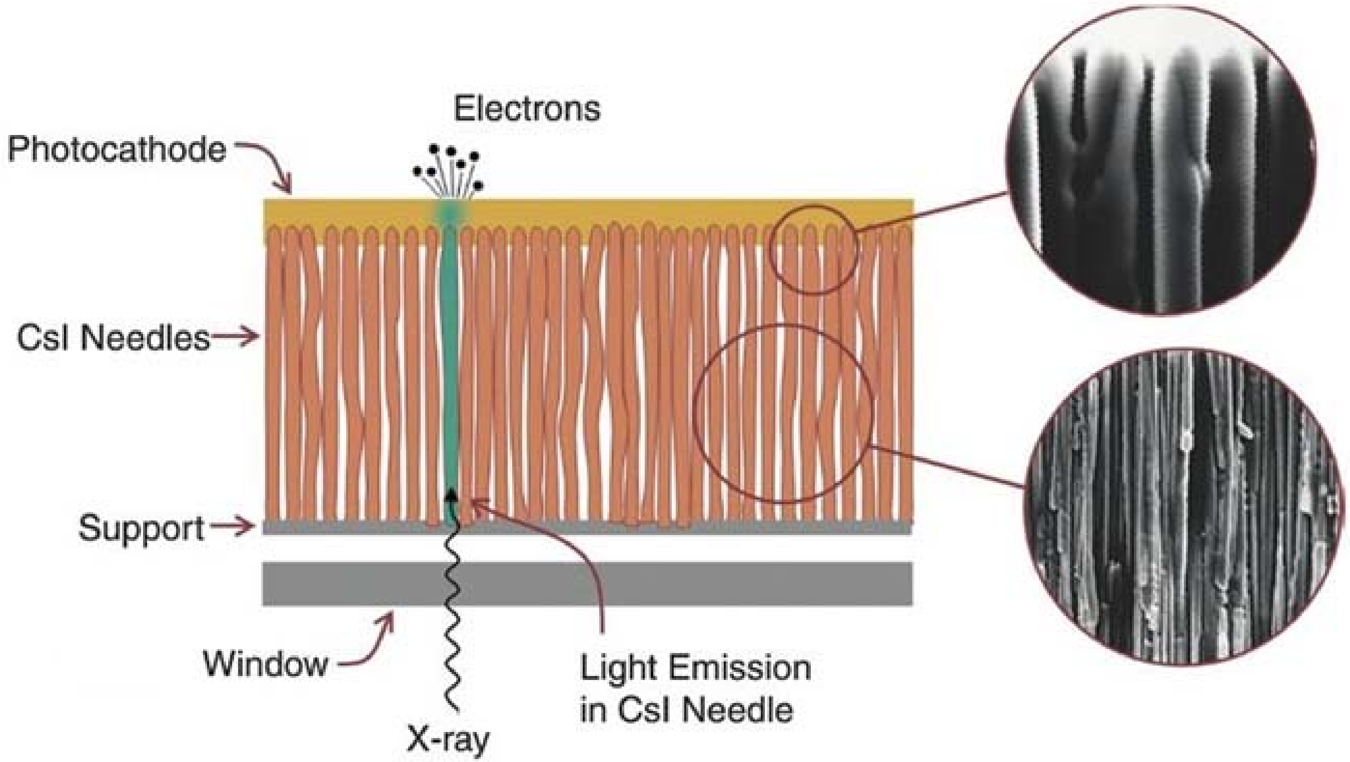
- After passing through the Al input window and substrate, x-rays strike the input phosphor, whose function is to absorb the x-rays and convert their energy into visible light.
- The input phosphor must be thick enough to absorb a large fraction of the incident x-rays, but thin enough to not significantly degrade the spatial resolution of the image by the lateral dispersion of light through the phosphor.
- Virtually all modern image intensifiers use cesium iodide (CsI) for the input phosphor. With proper deposition techniques, CsI can be made to form in long, columnar crystals.



- The long, thin columns of CsI function as light pipes, channeling the visible light emitted within them toward the photocathode with less lateral spreading than an amorphous phosphor.
- As a result, the CsI input phosphor can be quite thick and still produce high resolution.
- The CsI crystals have a trace amount of sodium, causing it to emit **blue light**.



❖ The fourth layer of the input screen is the photocathode, which is a thin layer of antimony and alkali metals (such as Sb_2S_3) that emits electrons when struck by visible light.



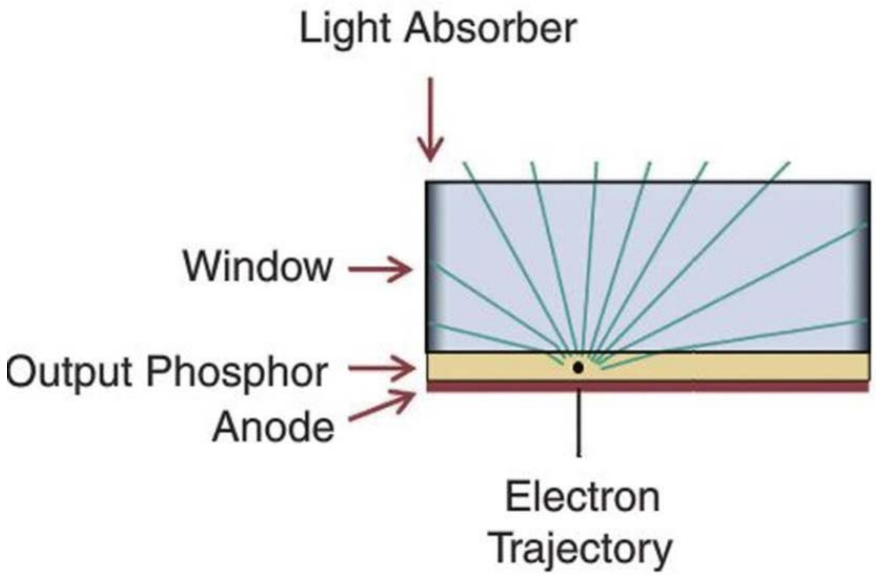
(3) Electron optics

- ❖ X-rays are converted into light which then ejects electrons from the input screen into the evacuated volume of the image intensifiers .
- ❖ The electrons are accelerated by a large electric field created by a high voltage between the anode and the cathode.
- ❖ Focusing the electrons is accomplished by the several electrodes in the electron optics chain. The kinetic energy of each electron is dramatically increased by acceleration due to the voltage difference between the cathode and anode, resulting in ***electronic gain***.
- ❖ The spatial pattern of electrons released at the photocathode is maintained at the output phosphor, albeit minified.

- The electrons are released from the photocathode with very little kinetic energy, but under the influence of the 25,000 to 35,000V electric field, they are accelerated and arrive at the anode with high velocity and considerable kinetic energy.
- The intermediate electrodes shape the electric field, focusing the electrons properly onto the output layer, where the energetic electrons strike the output phosphor and cause **visible light** to be emitted.

(4) The output phosphor

- The output phosphor is made of zinc cadmium sulfide doped with silver (ZnCdS: Ag), which has a **green (~530 nm) emission spectrum.**
- The anode is a very thin (0.2 μm) coating of aluminum on the vacuum side of the output phosphor, which is electrically conductive to carry away the electrons once they deposit their kinetic energy in the phosphor.
- Each electron (with high kinetic energy) causes the emission of a large number of **light photons** from the output phosphor.



4.4 Overall “Brightness” Gain

- The overall “brightness” gain is the product of the electronic and minification gains of the image intensifiers.

The overall “brightness” gain =(**electronic gain**)×(**minification gain**)

The following example explains the **overall “brightness” gain**.

Example:

The diameter of the input screen of an image intensifier tube is 23cm, and the diameter of the output screen is 2.5 cm. Assume a 50keV x-ray photon is absorbed by the input screen and 20% of the absorbed photon energy is re-emitted from the input screen in the form of 5000 visible light photons. These together may cause the ejection of a total of about 150 electrons from the adjacent photocathode. Each such electron acquires enough kinetic energy on the way to the anode, and produces 2000 or so visible light photons at the output screen.

What is the overall "brightness" gain of the image intensifier tube?

Solution:

(a) The minification gain of the tube:

The diameter of the input screen: $d_i = 23cm$

The diameter of the output screen: $d_o = 2.5cm$

$$\text{Minification gain} = (d_i/d_o)^2 = (23\text{ cm} / 2.5\text{cm})^2 = 84.64$$

(b) The electronic gain:

For each X-ray photon absorbed by the input screen,

\# of light photons from input screen is : 5000 photons

\# of light photons from output screen is: 150(electrons)×2000 (photons/electron)

=150 × 2000= 300,000 photons

The electronic gain = 300,000 photons / 5000 photons

= 60

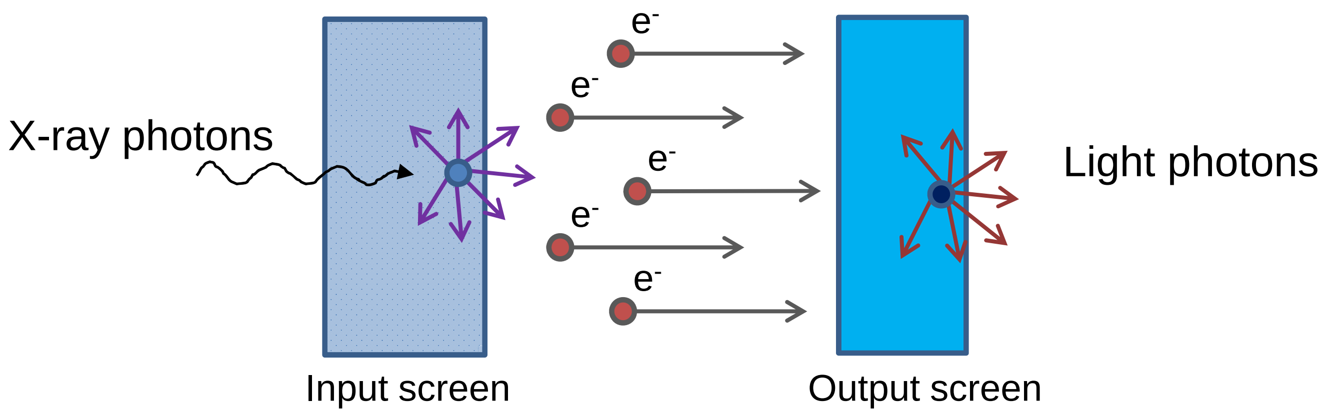
(c) The overall "brightness" gain of the image intensifier tube:

= (electronic gain)×(minification gain)

= 84.64 × 60

= 5078.4

More discussion about "brightness" gain



The **"brightness" gain** is the ratio of the image brightness on output screen of an image intensifier to the brightness on the input phosphor.

Brightness:

- In general, **brightness** can be understood as an attribute of visual perception of a target that appears to radiate a given amount of light.

Fluence:

- The number of photons or particles passing through a unit cross-sectional area is referred to as the ***fluence*** (phontons/m^2)

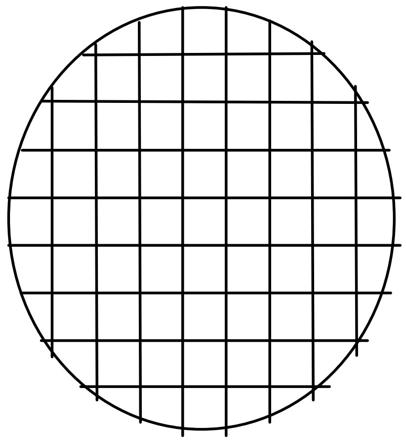
4.5 Other Characteristics of the Image Intensifier

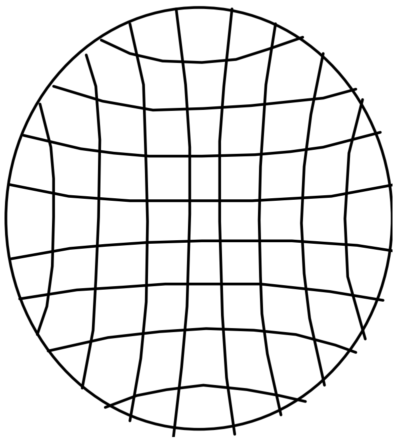
Typical image intensifier parameters

Input Diameter (FOV)	14 in. (36 cm)	9 in. (23cm)	6 in. (15 cm)
Output diameter	1 in. (2.5 cm)	1 in. (2.5 cm)	1 in. (2.5 cm)
Spatial Resolution	3.6 lp/mm	4.2 lp/mm	5.0 lp/mm

Other limitations:

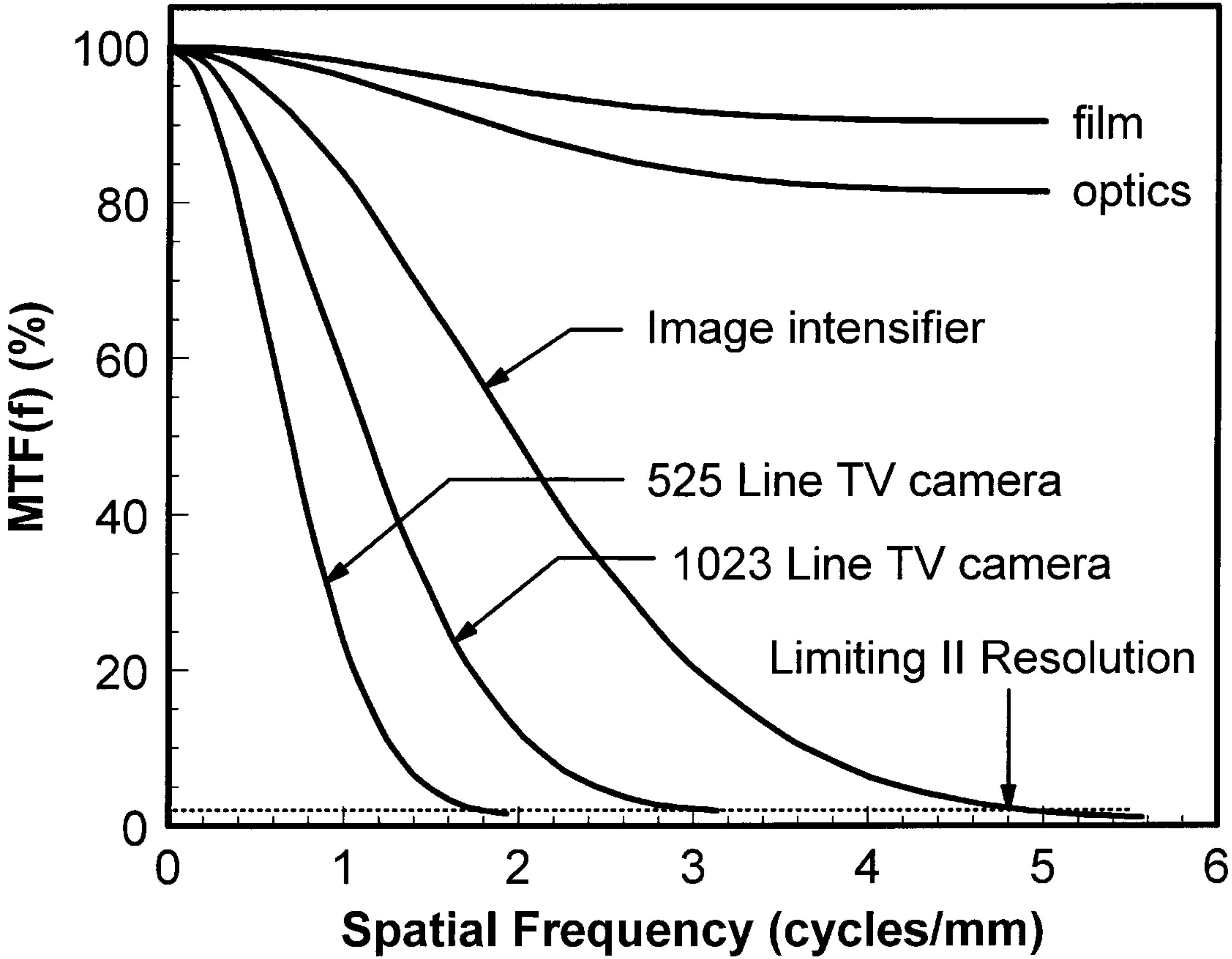
- Contrast degradation –
  - Veiling glare (light scatter in the output window)
- Vignitting
- Lag
  - (About 1 ms)
- Distortions:
  - Pincushion (result of projecting the image with a curved input phosphor to the flat output phosphor)
  - S distortion (caused by earth's magnetic field)





4.6 Image Intensifier-Video System

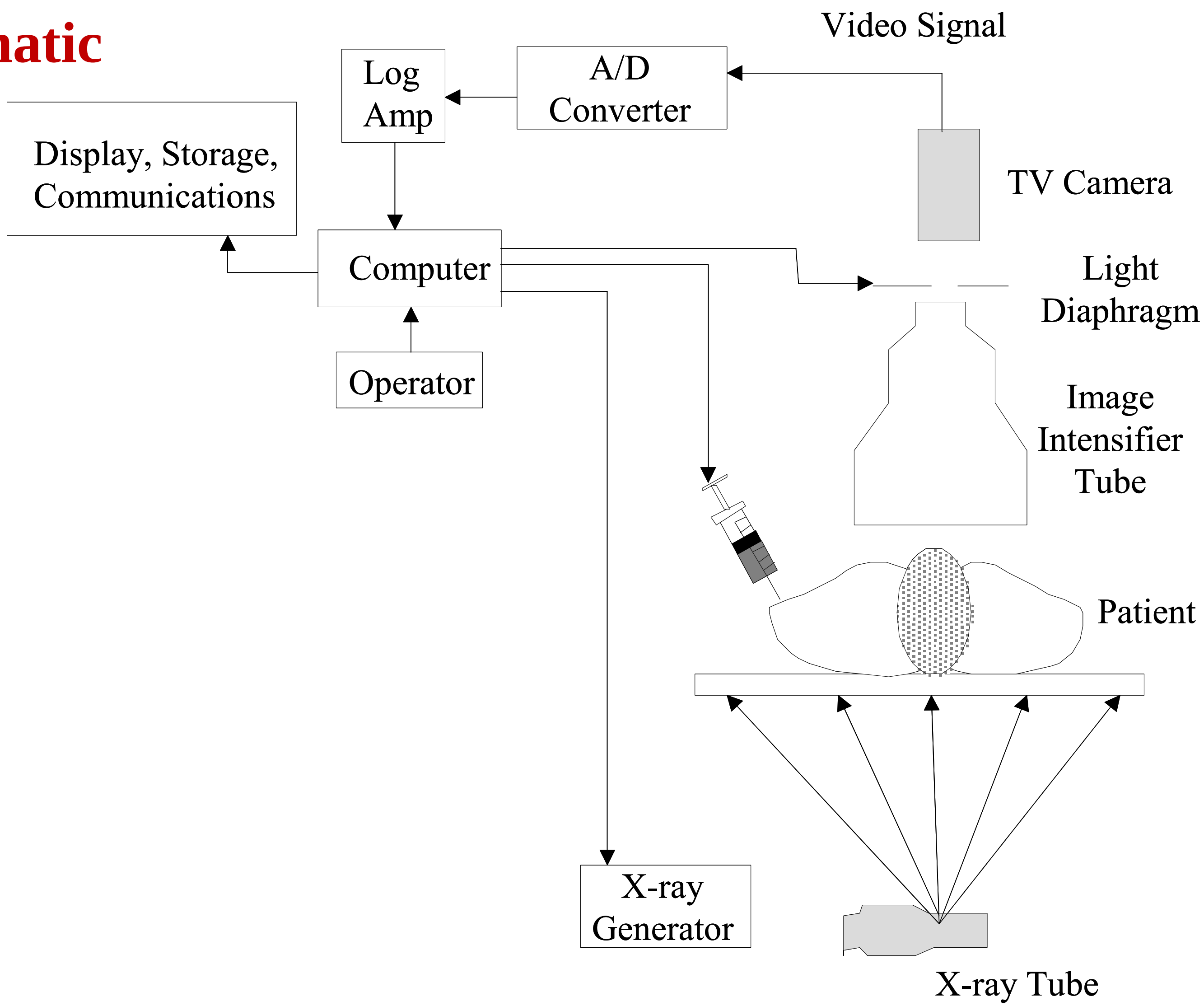
- ❖ The real-time fluoroscopic images can be viewed directly from the output of the image intensifier (through some mirrors/lenses) by the radiologists.
- ❖ Modern fluoroscopy systems use a TV system for viewing the output of the image intensifier.
  - A TV camera can view the output of the image intensifier through a set of lenses and thereby transform the optical image into an electronic video signal.
  - The electronic video signal generated by a TV camera and fed into a TV monitor can, at the same time, be recorded on video tape.
- ❖ The spatial resolution of a fluoroscopic system with a TV link is limited primarily by the TV raster pattern.



MTF(f) (%)
100
80
60
40
20
0
0
1
2
3
4
5
6
Spatial Frequency (cycles/mm)
film
optics
Image intensifier
525 Line TV camera
1023 Line TV camera
Limiting II Resolution

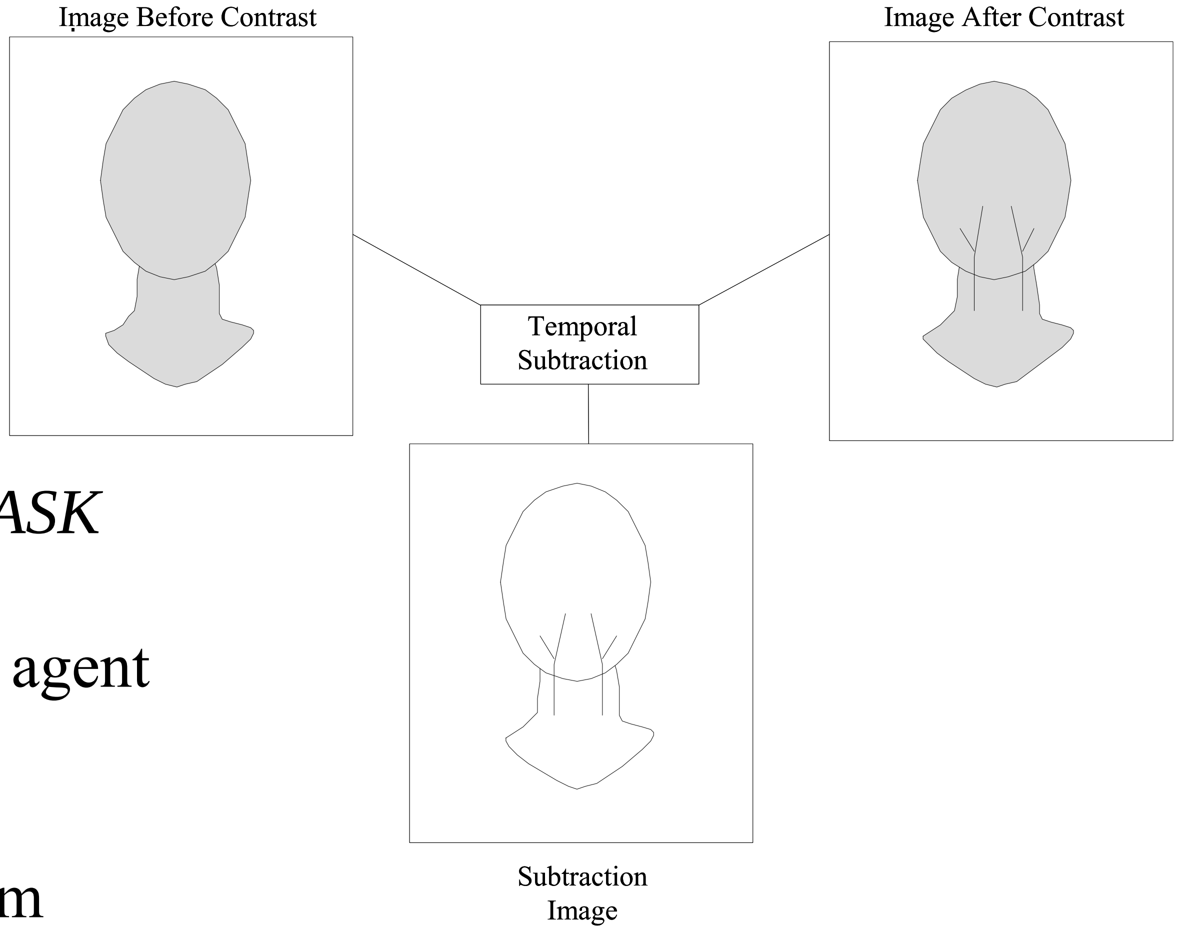
4.7 Digital Fluoroscopy and Digital Subtraction Angiography (DSA)

❖ Schematic



❖ Digital subtraction angiography

(a) Acquire a digital *MASK* image before the injection of contrast agent into a vein or artery
(b) Inject contrast agent
(c) Acquire an angiogram image after the injection
(d) Image subtruction (Log subtruction)



- Digital logarithmic converter or log amplifier

Before contrast agent:

$$N_{mask} = N_0 e^{-\mu_b x_b}$$

μ_b: Linear attenuation coefficient of the object

x_b : Thickness of the object

After contrast agent

$$N_{angio} = N_0 e^{-\mu_b x_b - \mu_a x_a}$$

μ_a: Linear attenuation coefficient of contrast agent

x_a :Thickness of vessel that the contrast agent is in.

Linear subtraction:

$$S_{linear} = N_{mask} - N_{angio} = N_0 e^{-\mu_b x_b}(1 - e^{-\mu_a x_a})$$

If $\mu_a x_a << 1$, we have :

$$e^{-\mu_a x_a} = 1 + (-\mu_a x_a) + \frac{1}{2!}(-\mu_a x_a)^2 + \frac{1}{3!}(-\mu_a x_a)^3 + \ldots = 1 - \mu_a x_a \quad where \quad \mu_a x_a << 1$$

$$1 - e^{-\mu_a x_a} = 1 - (1 - \mu_a x_a) = \mu_a x_a$$

Therefore:

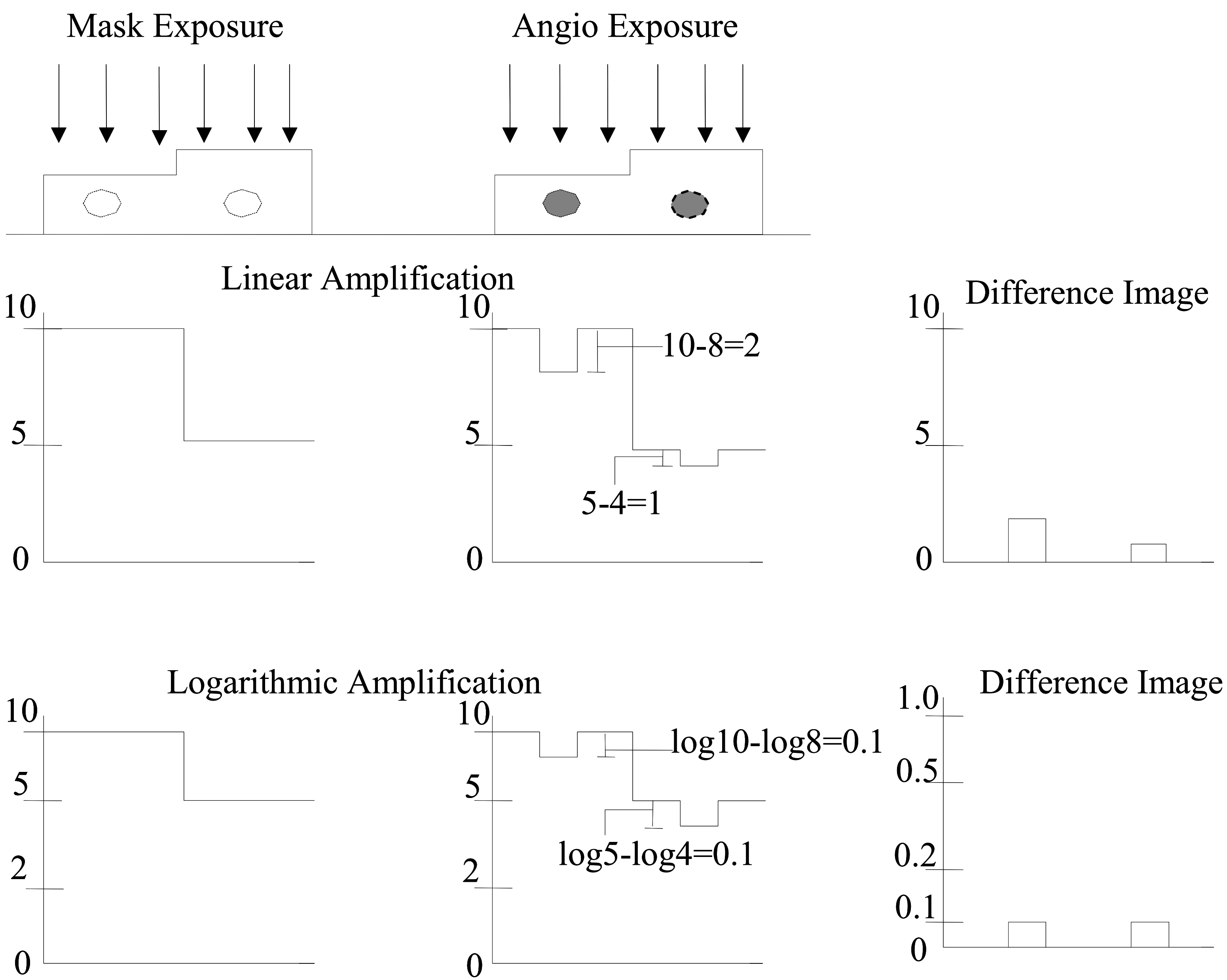
$$S_{linear} = [\mu_a x_a] N_0 e^{-\mu_b x_b}$$

Logarithmic subtraction:

$$S_{\log} = \ln(N_{mask}) - \ln(N_{angio}) = \ln(N_0 e^{-\mu_b x_b}) - \ln(N_0 e^{-\mu_b x_b - \mu_a x_a})$$

$$= \ln N_0 + \ln e^{-\mu_b x_b} - \ln N_0 - \ln e^{-\mu_b x_b - \mu_a x_a}$$

$$= [-\mu_b x_b] - [-\mu_b x_b - \mu_a x_a] = \mu_a x_a$$


Mask Exposure
Angio Exposure
Linear Amplification
10
5
0
10
5
0
10-8=2
5-4=1
Difference Image
10
5
0
Logarithmic Amplification
10
5
2
0
10
5
2
0
log10-log8=0.1
log5-log4=0.1
Difference Image
1.0
0.5
0.2
0.1
0

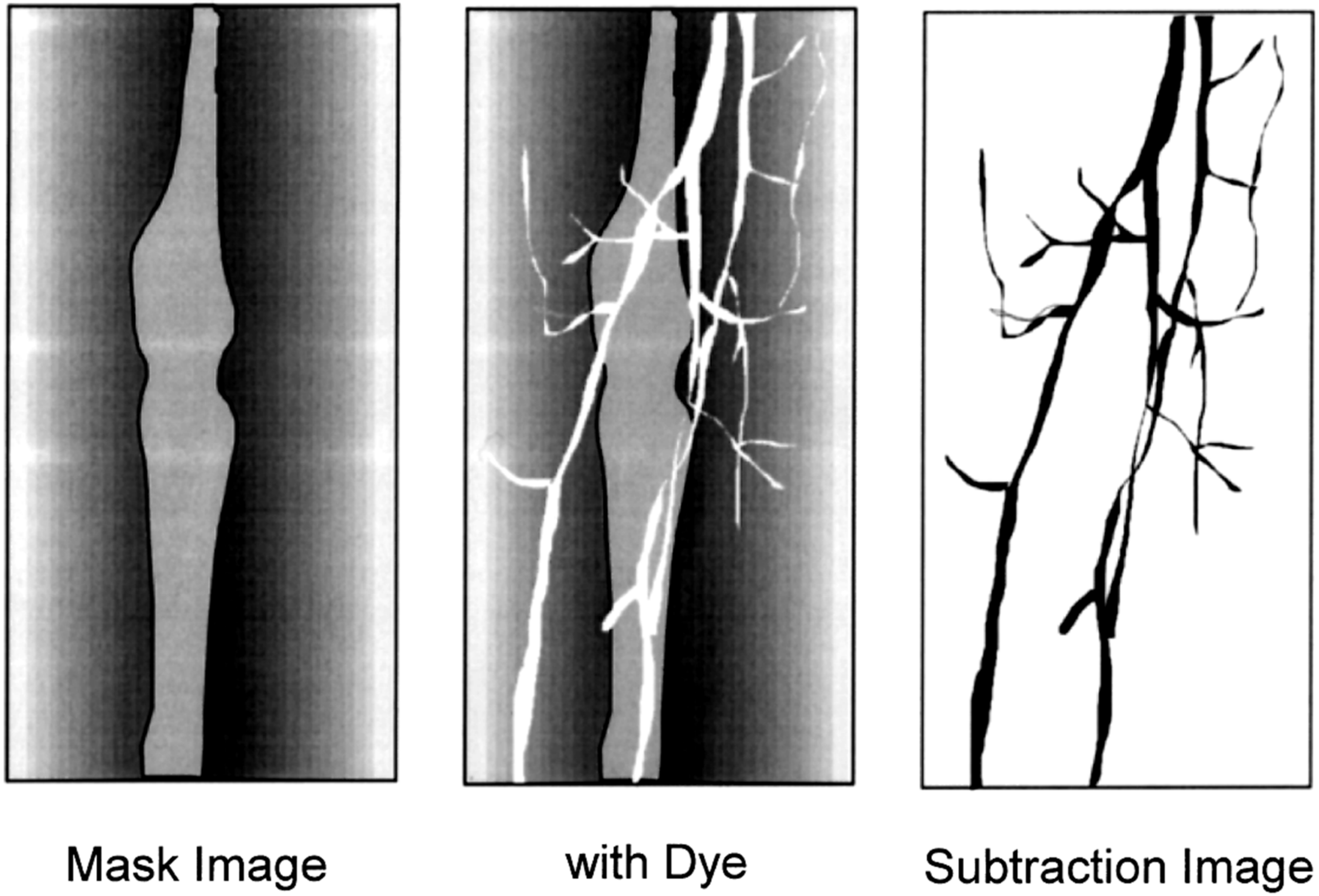


Figure: In digital subtraction angiography (**DSA**), a mask image containing only patient anatomy is acquired before dye injection, and then a series of images are acquired as the iodine bolus passes through the patient's vasculature. Subtraction of the dye images from the mask results in the **DSA** subtraction image, which demonstrates only the vascular anatomy (i.e., the patient's background anatomy is subtracted out).

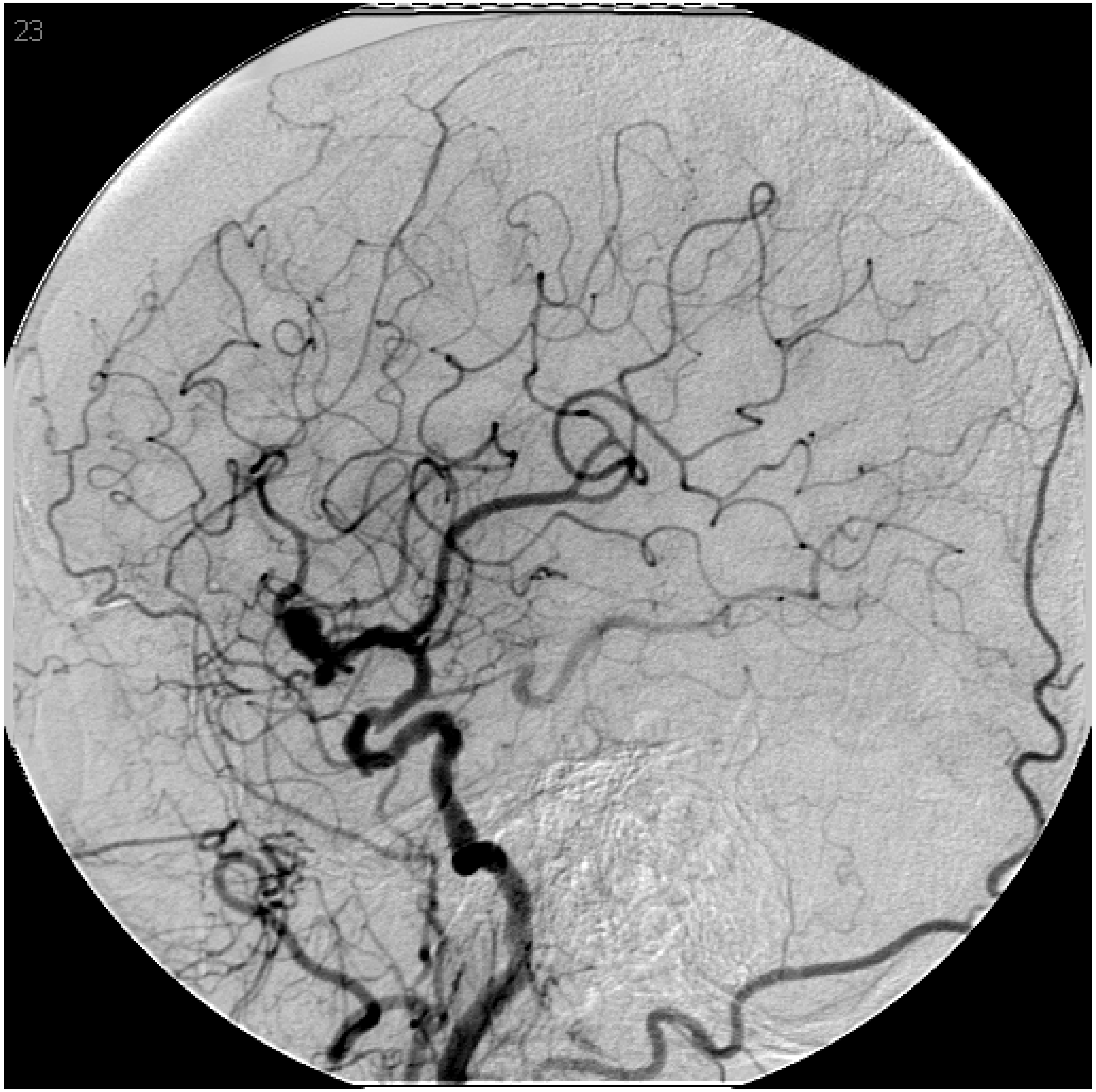


Figure: A sample of digital subtraction angiography (**DSA**)---**DSA**_head image.

Summary

- Image intensifier and real time imaging
- “Brightness” gain
- Image quality considerations
- Subtraction angiography removes the shadows of tissues that do not contain contrast agent

$$S_{\log} = \ln(N_{mask}) - \ln(N_{angio}) = \mu_a x_a$$

Homework #4_A

1. The diameter of the input screen of an image intensifier tube is 17cm, and the diameter of the output screen is 2.5 cm. Assume a 60KeV x-ray photon is absorbed by the input screen and some 20% of the absorbed photon energy is re-emitted from the input screen in the form of 3000 visible light photons. These together may cause the ejection of a total of about 400 electrons from the adjacent photocathode. Each such electron acquires enough kinetic energy on the way to the anode, and produces 1000 or so visible light photons at the output screen.

   (a) What is the minification gain of the tube?

   (b) What is the overall brightness gain of the tube?

2. Why is the surface of the vacuum window of the image intensifiers is designed with curvature?

3. (a) What is the cause of the pincushion distortion of image intensifiers?

(b) What is the cause of the S distortion of image intensifiers?

4. In fluoroscopy, switching image intensifiers from 9 inch to 6 inch field-of-view (FOV) results _______in the spatial resolution and ________in the overall "brightness" gain of system.

   A. an increase,
   B. a decrease,
   C. no change,

5. A DSA procedure was performed for a patient in order to determine the thickness of his/her vessel at a specific location. The pixel value measured from the Mask image was 1000, and the pixel value measured from the Angio image was 900. Assume that the linear attenuation coefficient of the contrast agent used in the procedure was previously determined as 0.5 cm^{-1}. What is the vessel thickness?