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College on Medical Physics. Digital Imaging Science and Technology to Enhance Healthcare in the Developing Countries

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X-ray Fluoroscopy Imaging Systems

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X-RAY FLUOROSCOPY IMAGING SYSTEMS

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OBJECTIVES

- Fluoroscopic patient dose
- Image Intensifier construction
- Input window
- Accelerating and focusing electrodes
- Output window
- Conversion factor
- II characteristics
- TV camera tubes
- Modulation Transfer function
- DSA
- Digital fluoroscopy
- Unsharp masking
- Roadmapping
- Flat panel fluo parameters

Fluoroscopy delivers very high patient dose. This can be illustrated with an example:

The electrical energy imparted to the anode during an exposure is

$$A = C_1 . U_a . I_a . T$$

The X-ray tube anode efficiency is

$$E = C_2 . Z. U_a$$

From the two equations follows that the energy produced in a single exposure will be

$$X = C . A . E = C . Z . (U_a)^2 . I_a . T = (C. Z) . kV^2 . mAs$$

Radiography of the lumbar spine (with parameters 80 kV, 30 mAs):

X = k. 80.80.30 = k. 192,000

Fluoroscopy - 3 minutes Barium meal (with parameters 80 kV, 1mA)

X = k. 80.80.1.3.60 = k. 1,152,000

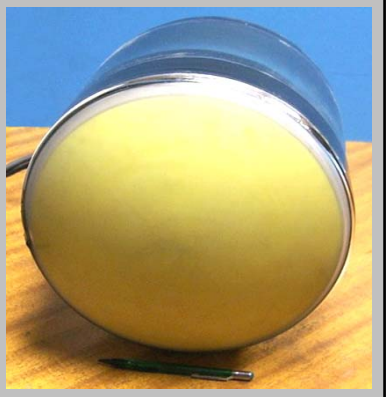
In this example fluoroscopy delivers approx. 6 times more X-ray energy (dose)

Luminescence:

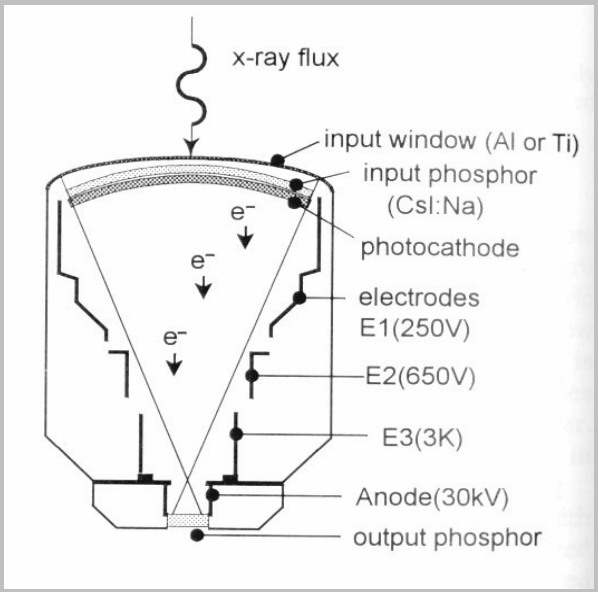
Fluorescence - emitting narrow light spectrum (very short afterglow ~nsec) - PM detectors; II input screens (CsI:Tl)

Phosphorescence - emitting broad light spectrum (light continues after radiation) - monitor screens, II output screens (ZnCdS:Ag)

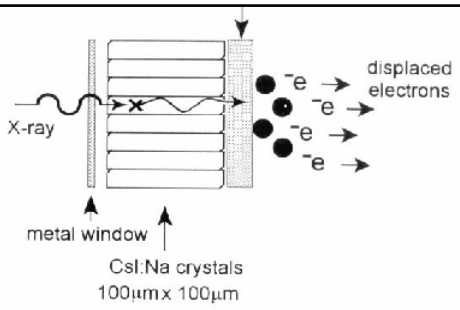
The old fluoroscopic screens are no longer used due to high dose and low resolution

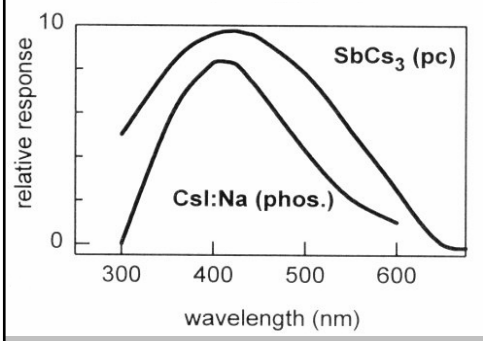


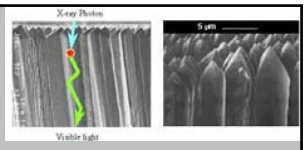
Basic Components of an Image Intensifier



- Input window (Ti or Al) 95% transmission
- Input screen: CsI (new) or ZnS (old) phosphor
- Photocathode (a layer of $CsSb_3$)
- Accelerating electrodes zoom (e.g. 30/23/15 cm)
- Output screen (2.5 cm)
- II housing (mu-metal)
- Output coupling to the TV camera





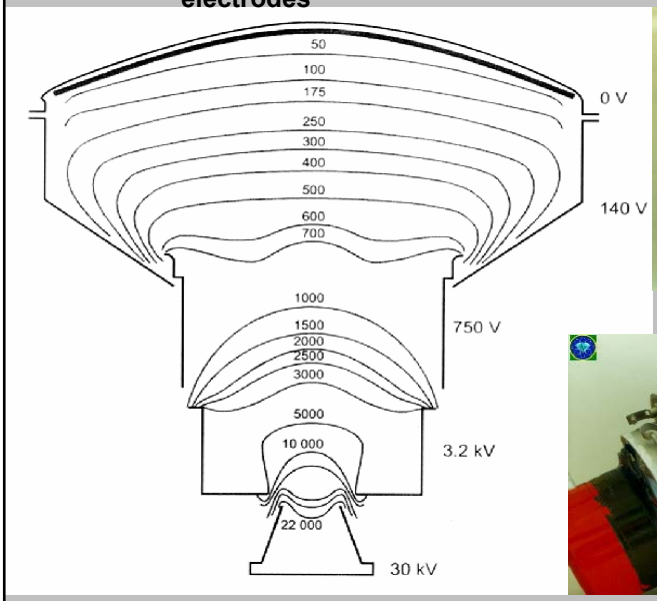


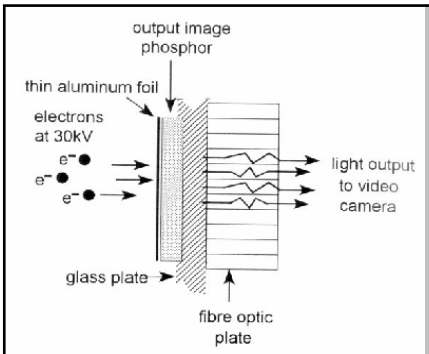
II Input screen:

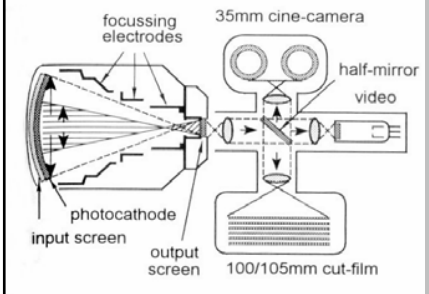
Columnar crystals of CsI which reduces dispertion (collimation); absorbs approx. 60% of X-rays

Photocathode applied directly to CsI both light spectrum match very well

II Accelerating electrodes







II Output screen:

Phosphor (ZnCdS:Ag) on glass base

The accelerated e^- produce multiple light photons; thin Al foil prevent return of light (veiling glare)

Coupling: fibre optic or tandem optic

Conversion factor ~100-1000 ($cd.m^{-2}/\mu Gy.s^{-1}$) = (output phosphor light / input screen dose rate)

Total gain (out. light photons /inp. X photons)

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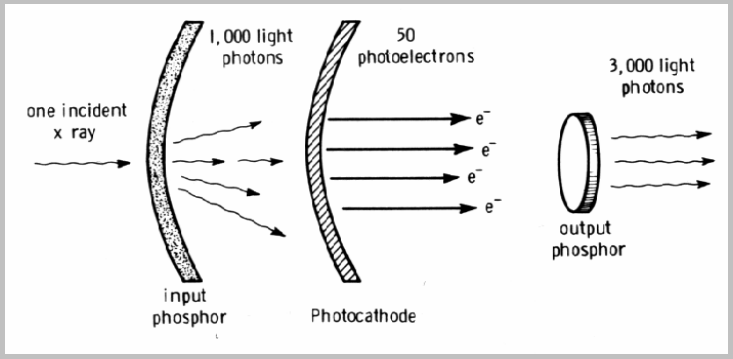
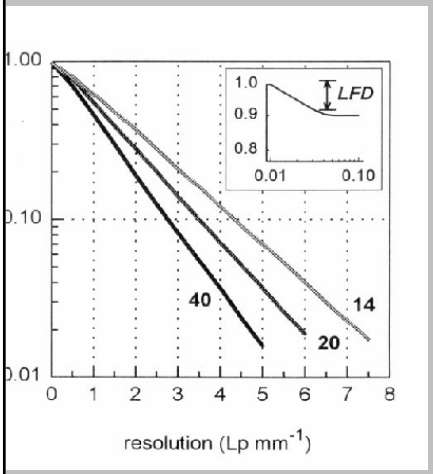
1 X-ray photon >> 1000 light photons (input screen) >>

>>50 photo e^- >> 3000 light photons (output screen)

in the case above the total gain is 3000



MTF of II depending on zoom (magnification)



Some II Characteristics:

Minification gain -D_m-inp./output diam.

$(D_{inp} / D_{out})^2$

Flux gain - F_x (approx. 30-60):

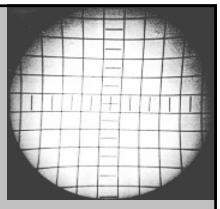
Out.scr. light photons / inp. ligh photons to photocath.

Brightness gain - G_B

$G_B = D_m \times F_x$

***** Zooming increases the resolution, but requires higher dose rate !!

Contrast Ratio



-X-ray scatter at input window, input phosphor

-Light scatter within phosphor, not-absorbed light by phosphor

-Back scatter from output phosphor (to photocathode), at output window

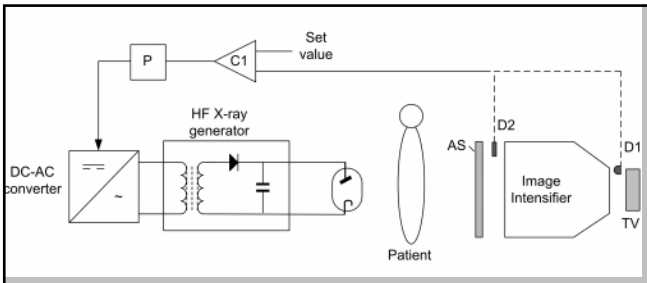
L_c – light intensity at centre of image (pure white)

Cont. Ratio (C_v)= L_c/L_d *: ideally max/0 ; in reality approx. 30/1*

L_d - light intensity at centre of image (cover with Pb)

II field size	40 cm (16")	32 cm (12.5")	20 cm (8")	15 cm (6")
Resolution (Lp/mm)	4.0	4.2	5.5	6.0
Contr. ratio	20:1	25:1	30:1	35:1
Convers. Factor (cd/m / mR/s)	166	100	60	50
Distortion (pincushion %)	9	4.5	1.4	1
Dose (relative)	0.25	0.5	0.75	1

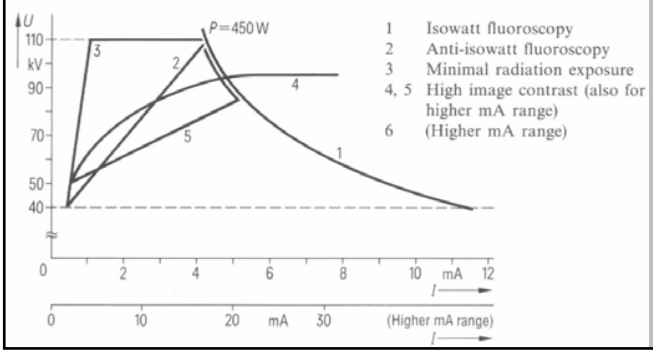
Table from: D.Dowsett, P.Kenny, E.Johnston



Automatic Brightness Control System (ABS)

- produces images with constant brightness by keeping constant entrance dose rate to the II

The feedback C1 have two options - taking signal from D1 (dosimeter) or D2 (photometer).



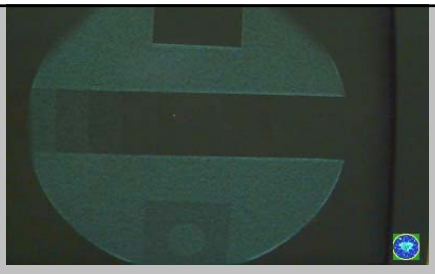
*** II entr. dose rate is approx. 1 μGy/sec and should not exceeds 2 μGy/sec.**

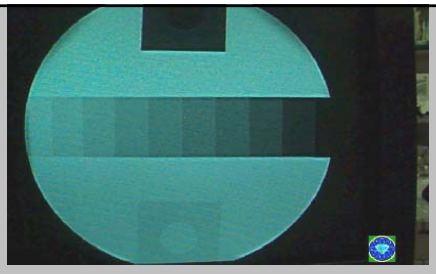
*** The maximal patient entrance skin dose should not exceed 0.01 Gy/min).**

- different types and characteristic curves of changing the kV/mA

Graph from: E Krestel (SIEMENS)

60 kV

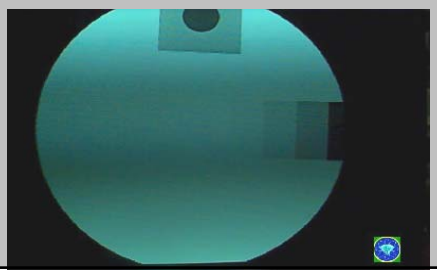


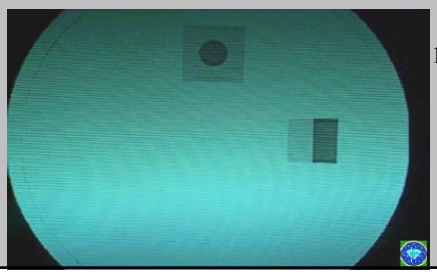


70 kV

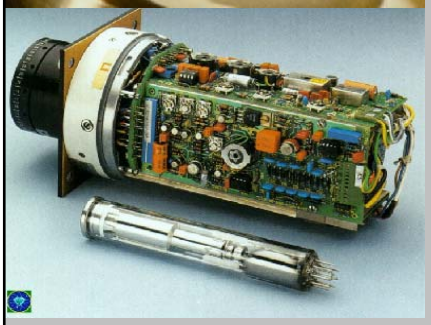
II contrast with different kV (constant mA)

90 kV





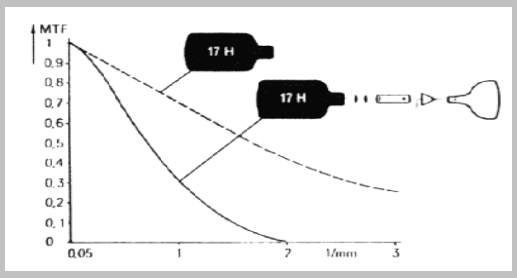
100 kV

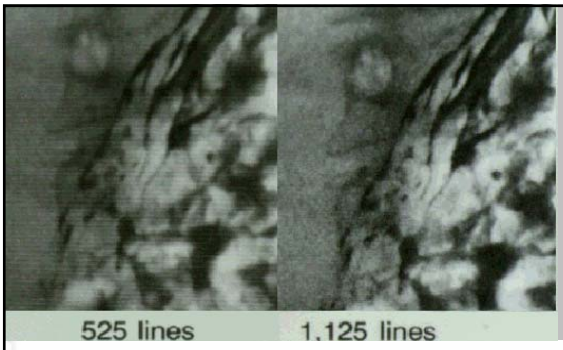


TV camera types:

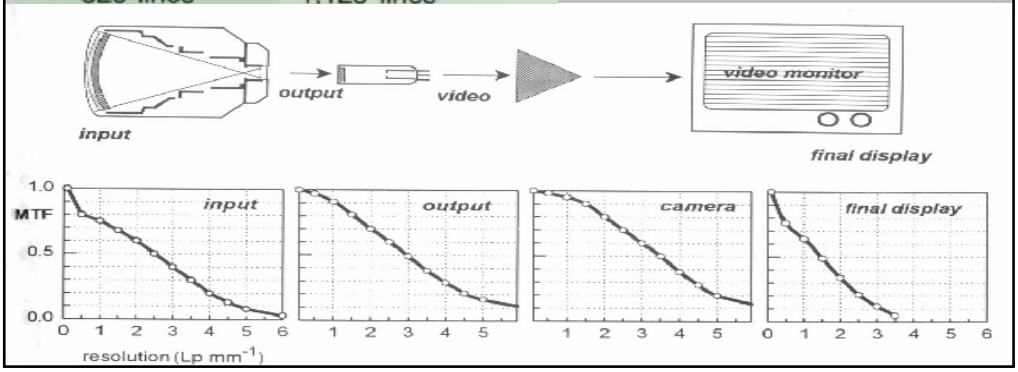
Vidicon - gamma 0.7; slow response, some contrast loss (light integration), high dark current, but low noise - suitable for organs

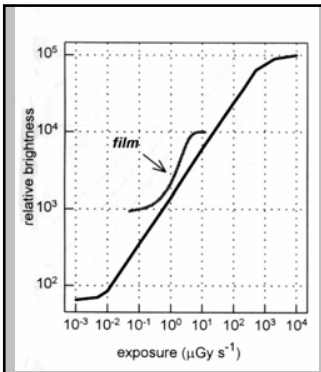
Plumbicon - gamma 1; quick response, small dark current, but high noise - suitable for cardiac examinations

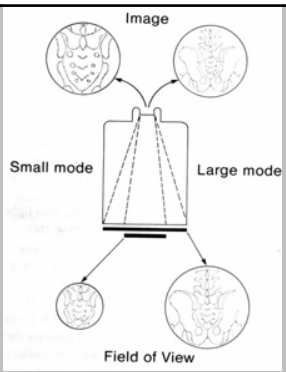


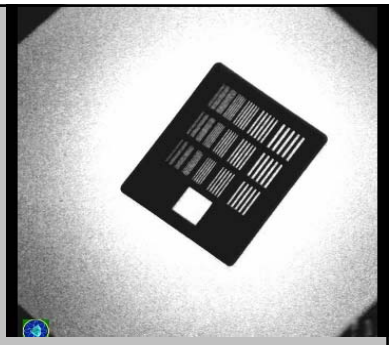


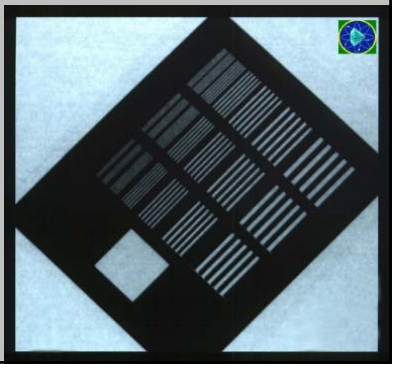
Overall II-TV system MTF = MTF_1 x MTF_2 x …x MTF_n









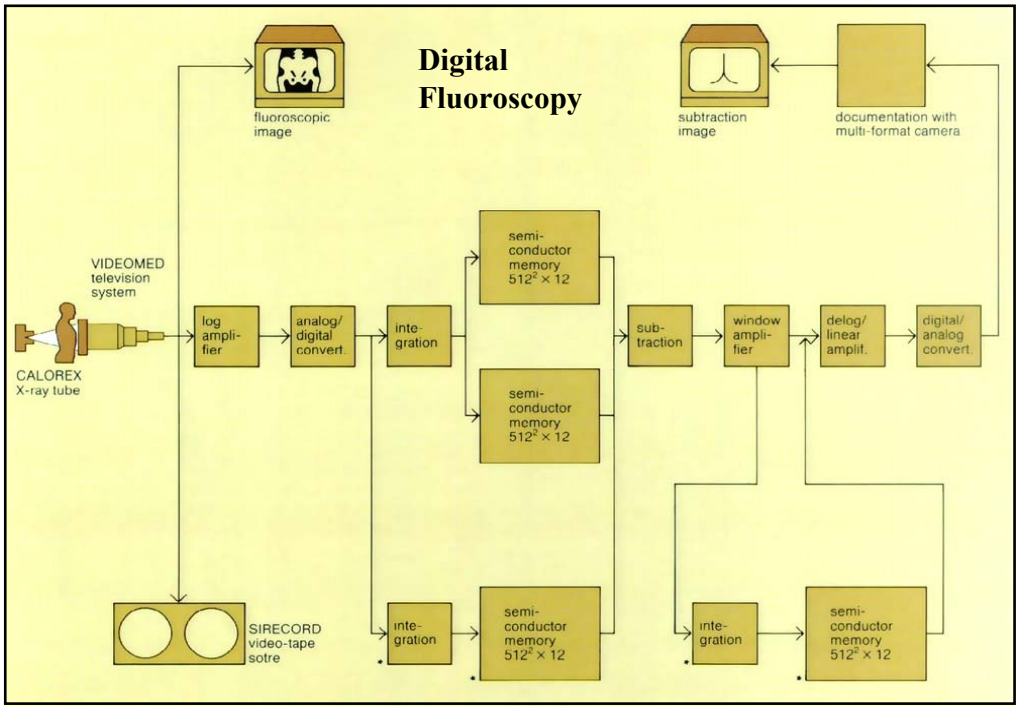


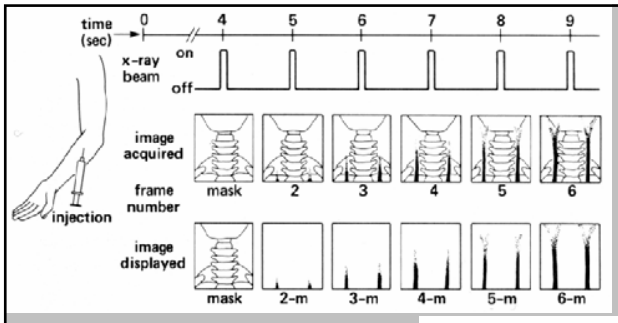
Dynamic range of II

-much larger than this of radiographic film (output luminance per dose unit)

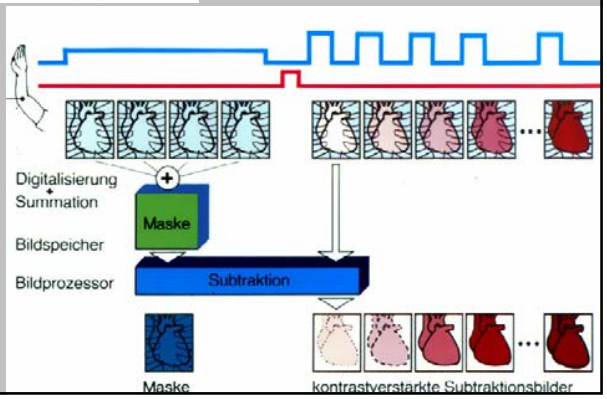
Resolution and Magnification of II

- electronic zoom up to 4 times (lp/mm)



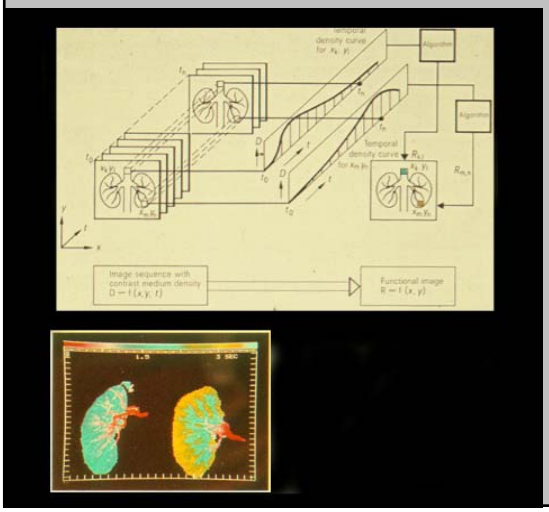


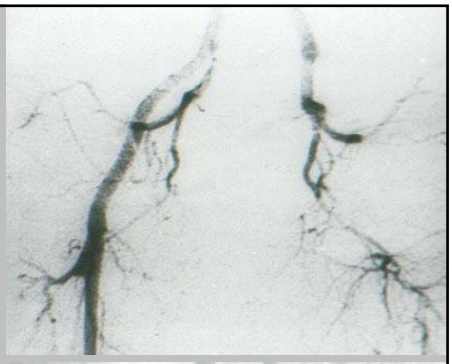
Digital subtraction and unsharp masking

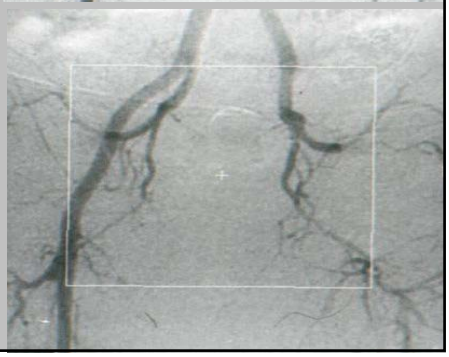


Mathematical operation in DSA:
Functional imaging; Logarithmic &
Square Root Subtraction, etc.

Functional Imaging







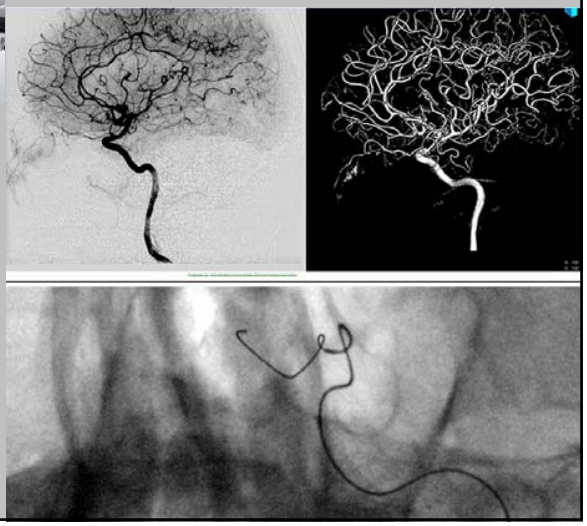
Digital Fluoroscopy

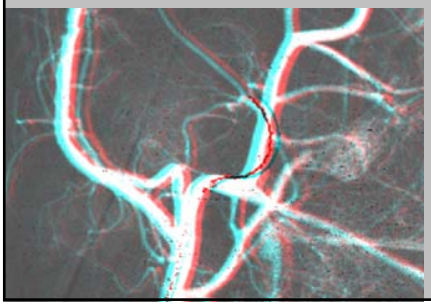
Recent types II+ADC or FP detector

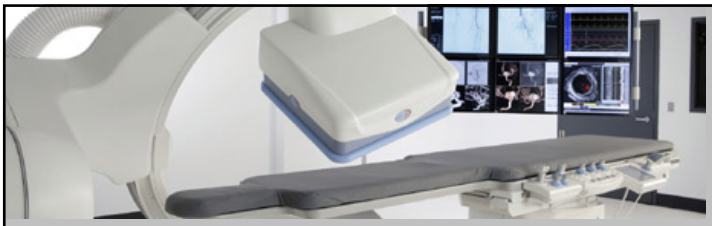
- Dose saving pulse fluoroscopy (with last image hold)
- DSA and Roadmap
- Digital Cine
- X-ray Fluoroscopy + integrated Ultrasound imaging
- Cost 3x the normal fluoroscopic cost

Digital fluoroscopy roadmapping (biplane):

2D image, 3D reconstruction, guide wire and stereo guiding







Some parameters of contemporary Digital Fluoroscopic systems (CsI)

15 pulses per sec with 10msec pulse duration = 150msec X-ray time (15% from continuous fluoroscopy dose)

Resolution 1024x1024 matrix at 200mm view field = pixel 0.2mm =2.5 lp/mm (new FP fields 400mm and 2048 x 2048 matrix)

Contrast 1024 grey levels (10 bits)

Dynamic capture (digital cine) up to 30 fr./sec