Henry Ford Health System

RADIOLOGY RESEARCH

Softcopy Display:

Technology, Performance & Quality

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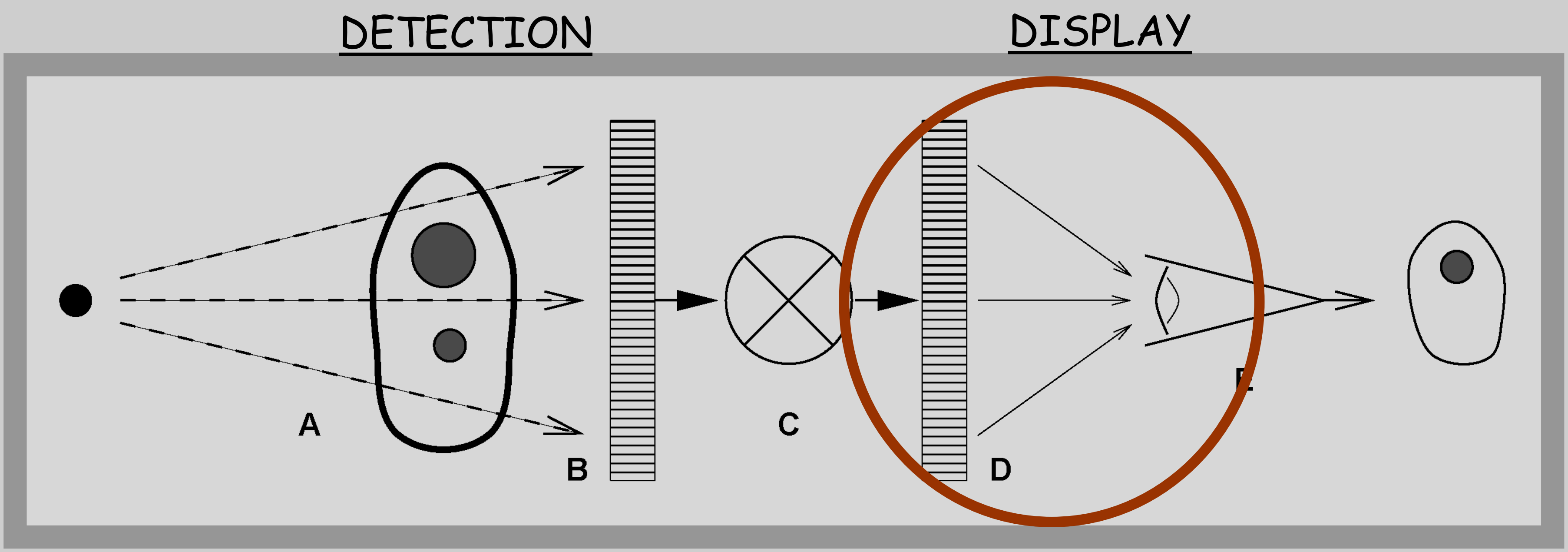
Henry Ford Health System

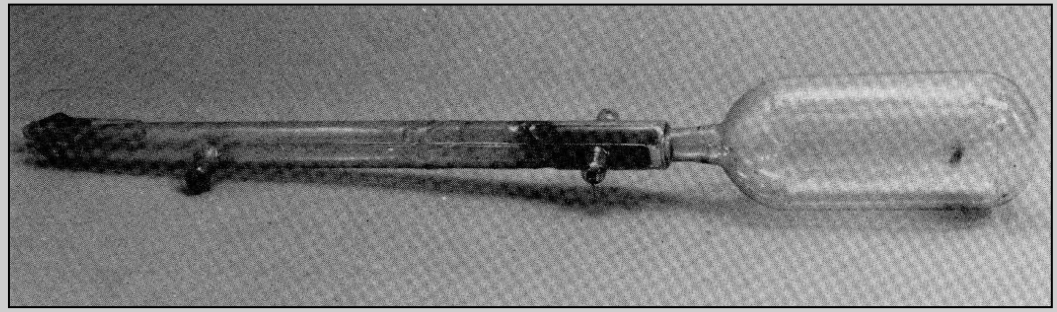
Subject contrast (A) recorded by the detector (B) is transformed (C) to display values and sent to a display device (D) for presentation to the human visual system (E) and interpretation.



The device used for image presentation must effectively transfer spatial and contrast information to the human observer.

History

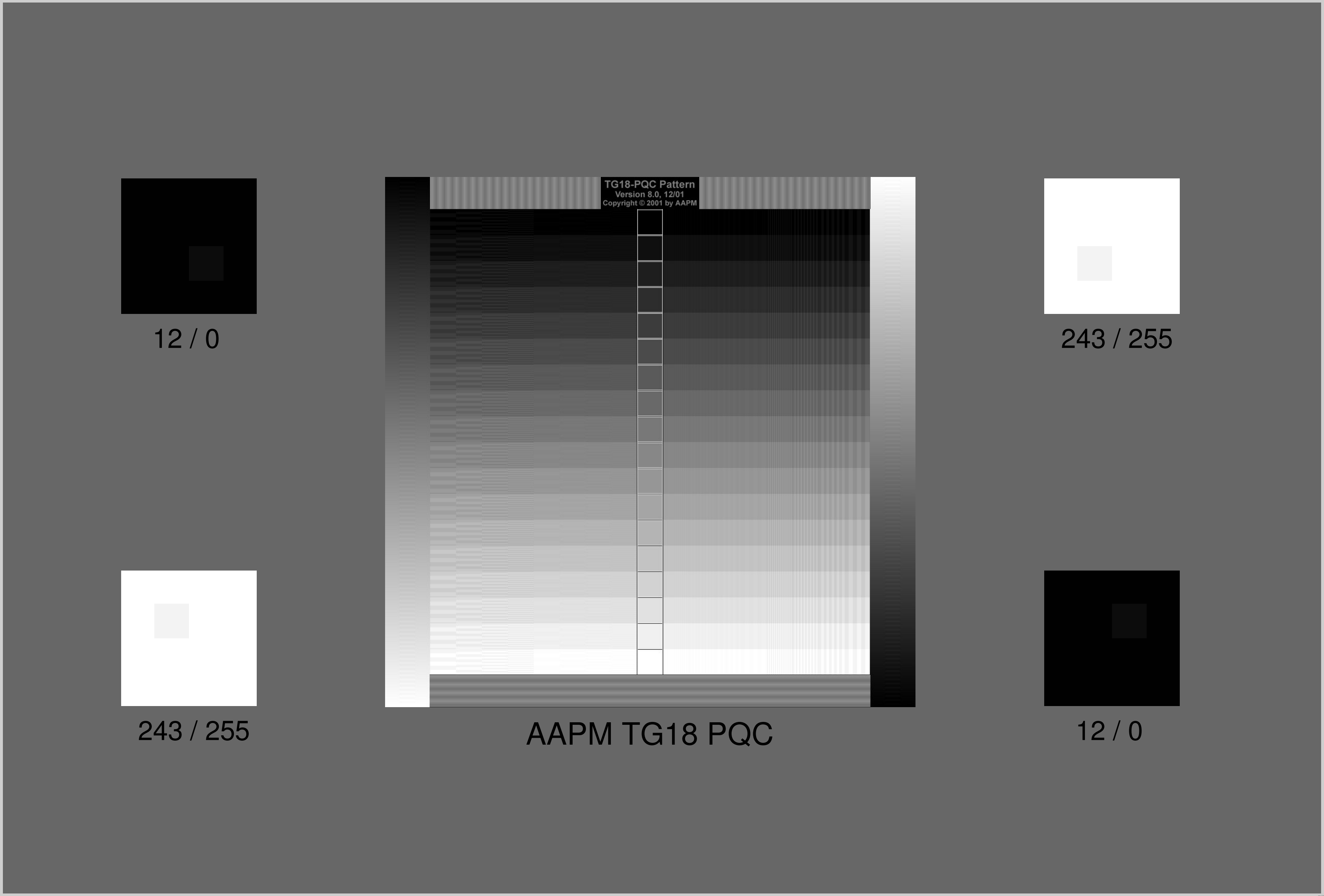
The CRT and the X-ray tube share common origins



• 1890, Crookes.	CRT for electron shadowing of metallic objects,
• 1895, Roentgen	An electron vacuum tube used to produce x-rays.
• 1897, Braun	First tube with all of the elements of the CRT - source, focus, deflection, screen, housing.
• 1904, Wehnelt	Oxide-coated hot cathode.
• 1921, Johnson	First commercial CRT, Western Electric 224-A.
• 1930	Commercial development (50K units).
• 1938,	14-in. CRT introduced by Du Mont.
• 1944	Production of 2 million units per year
• 1950	RCA's shadow mask demonstrated for color.

- **Illuminance:**
  - Quantity of visible light striking a surface per second.
  - Lux - SI unit of lumens/meter² (lm/m^2).
- **Luminance:**
  - Visible light emitted from a surface into a solid angle.
  - Nit - SI unit of lumens/steradian/meter² (cd/m^2).
- **Useful relationships:**
  - multiply footlamberts by 3.43 to get cd/m^2.
  - 1 lux striking an ideal diffuse reflector (white surface) will produce $1/\pi$ cd/m^2.

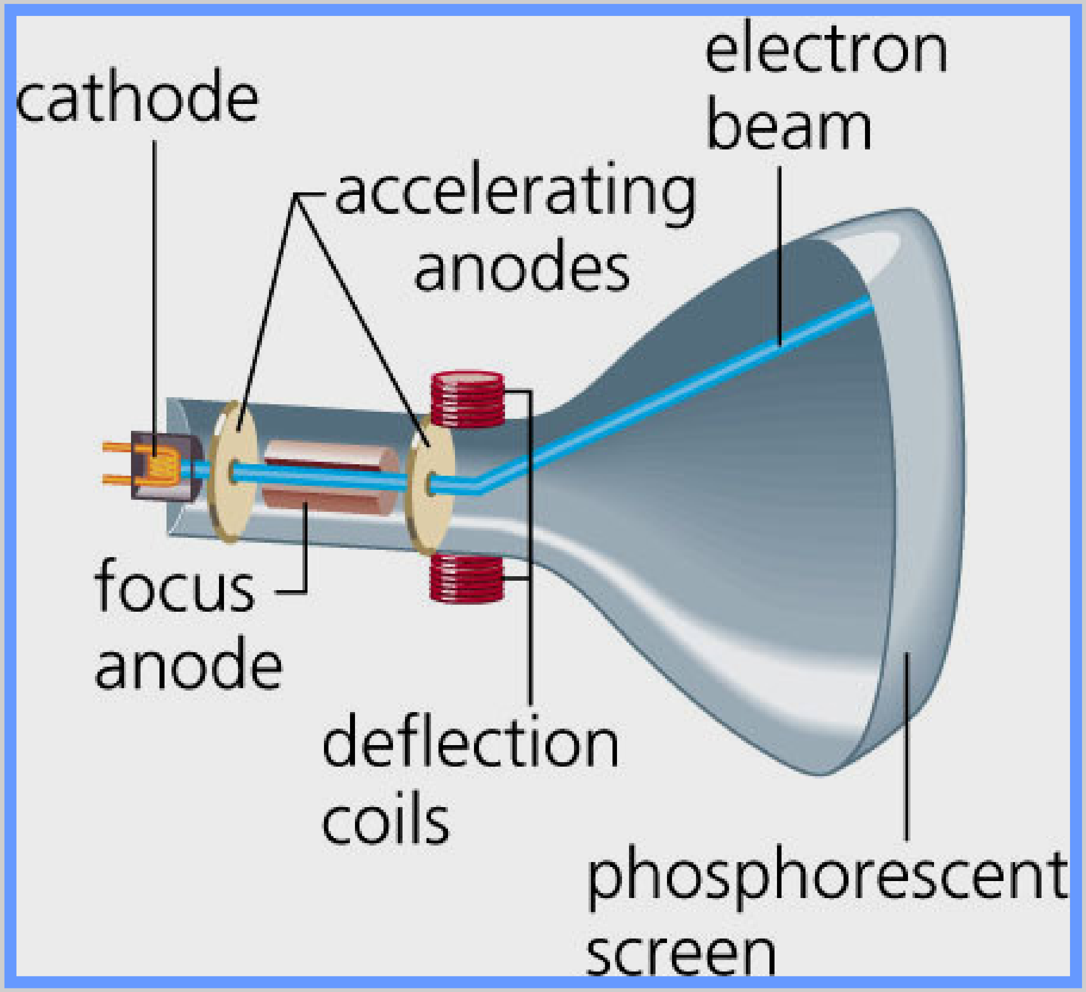
Projection Test Pattern



Cathode Ray Tube (CRT) Technology

CRT

An electron gun emits an energetic electron beam that strikes a phosphor screen in a small spot.



- Magnetic deflection coils steer the beam in a raster scan.
- Cathodoluminescent phosphor converts electron energy into light.
- The beam current is modulated to cause varying brightness.

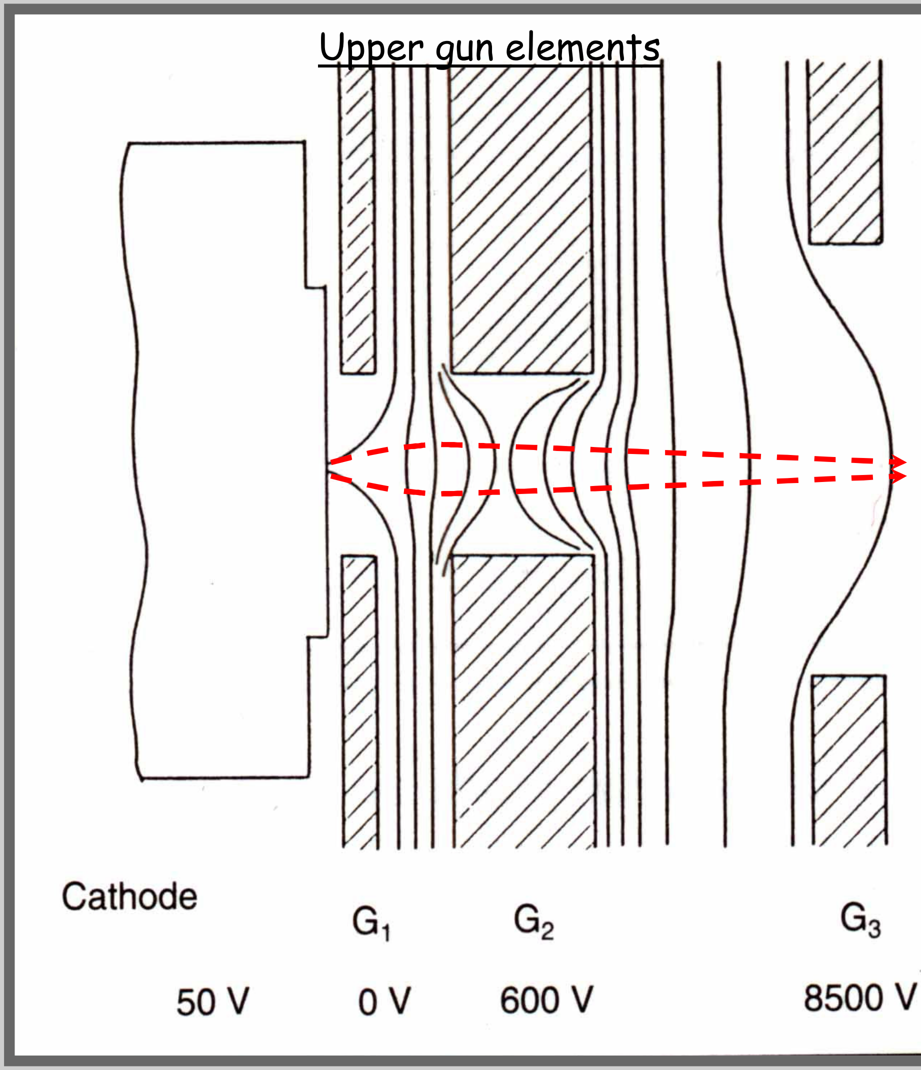
Three design characteristics significantly contrain the image quality that can be presented with a CRT system.

- The need to focus a high current in a small spot limits resolution.
- The thick faceplate induces glare and causes reflections.
- The emissive phosphor material acts as a strong diffuse reflector.

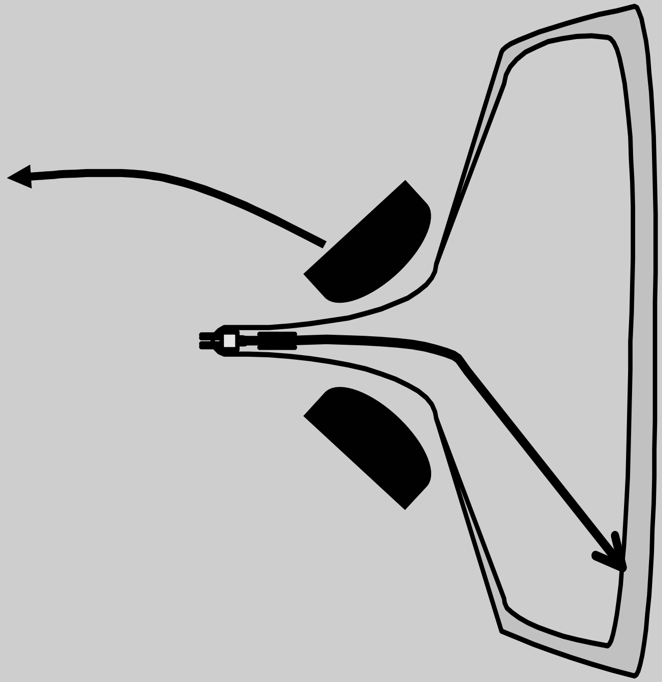
Electrostatic lens (Einzel type) accelerates and focuses the electron beam.

Cathode - G1 potential defines the emissive are on the cathode surface

- G1 , G2, G3 potentials establish a potential field which focuses the electron beam
- G4 …. Potentials provide final beam focus and acceleration



- Electron beam deflection
  - magnetic field causes beam deflection.
  - Electron beam moves in a raster pattern
  - special high performance yoke designs

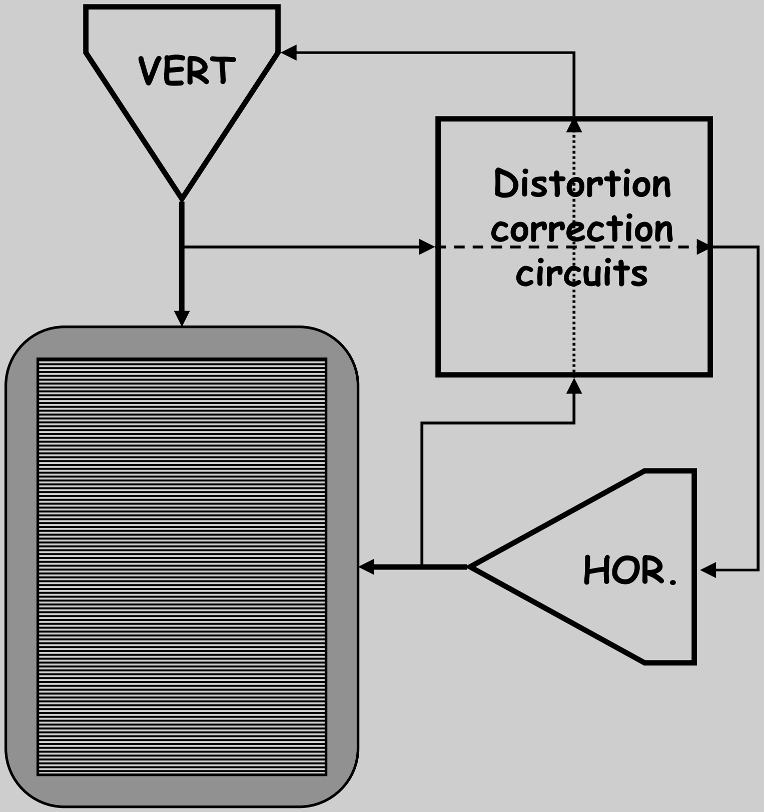


Deflection electronics Bandwidth

Horizontal and vertical deflection amplifiers control the position of the e beam for 1 or 2 frames of an image.

The signal amplifier must have sufficient bandwidth to detail all pixels in the image (Nyquist freq.) and produce sharp graphics:

80 Hz	Image	Graphics
2 Mp, 1fr	80	320 MHz
2 Mp, 2fr	40	160
5 Mp, 1fr	200	400
5 Mp, 2 fr	100	200



Resolution

Beam Spot Size 300 x 400 mm field overlap at 50%		
Pixels	array size	mm
1Mp	0.9k x 1.1k	.35
2Mp	1.2k x 1.6k	.25
5Mp	2.0k x 2.7k	.15

Beam Spot Size 270 x 330 mm field overlap at 50%		
Pixels	array size	mm
1Mp	0.9k x 1.1k	.30
2Mp	1.3k x 1.6k	.21
5Mp	2.1k x 2.5k	.13

Electron spot size:

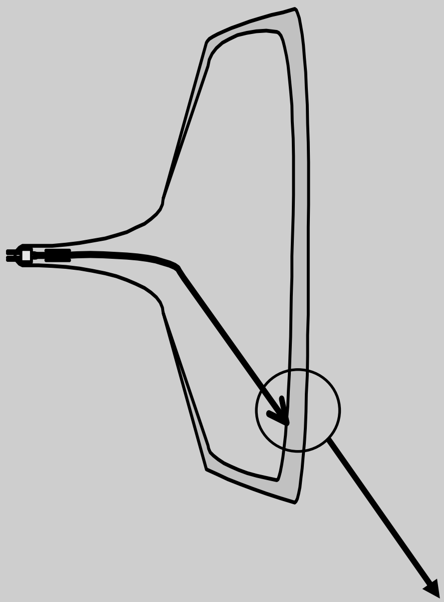
- Typically defined as the 50% beam width
- The 5% width should be about 2X the 50%

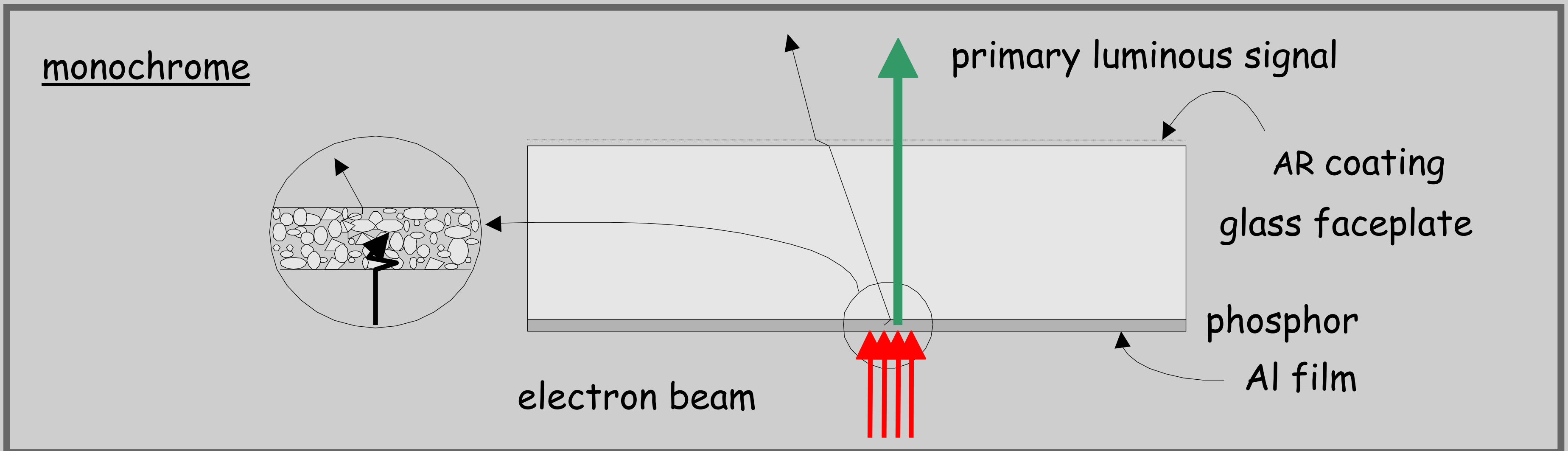
Dynamic focus

- Beam focus is adjusted using deflection information.
- Edge width should not be more than 10% of the center width.

Emissive Structure Elements:

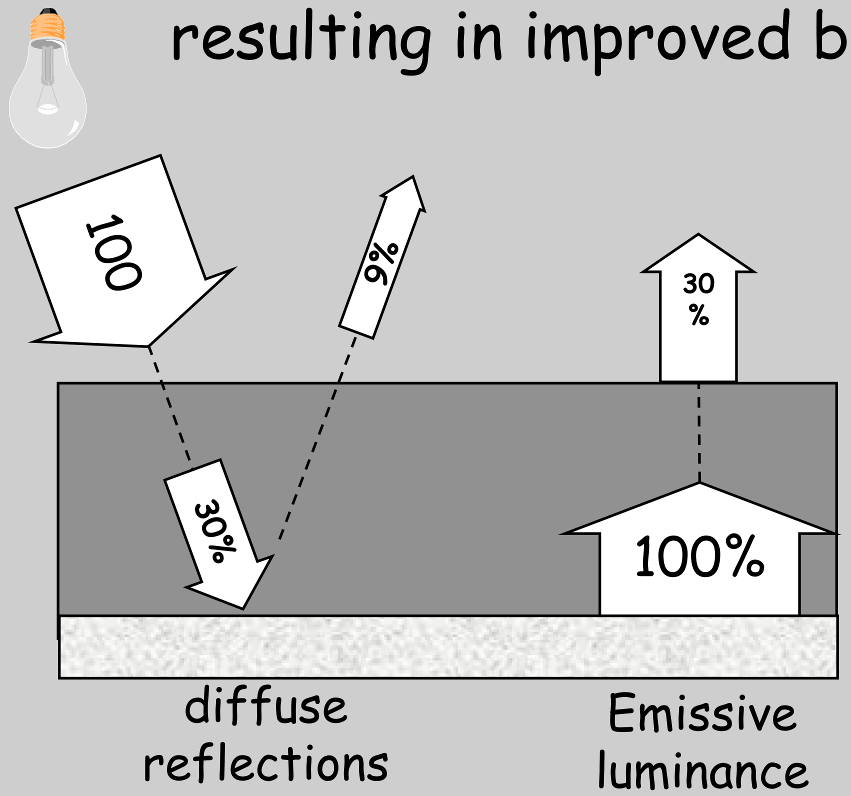
- conductive Al coating
- cathodoluminescent phosphor
- black matrix (color only)
- Glass faceplate
- AR coating





Faceplate absorption

- Transmission through the faceplate of medical monitors is typically 0.2-0.5 to reduce reflections from ambient lights.
- Assuming a transmission of 0.3, diffuse reflections are reduced by at least 0.09 resulting in improved black levels.



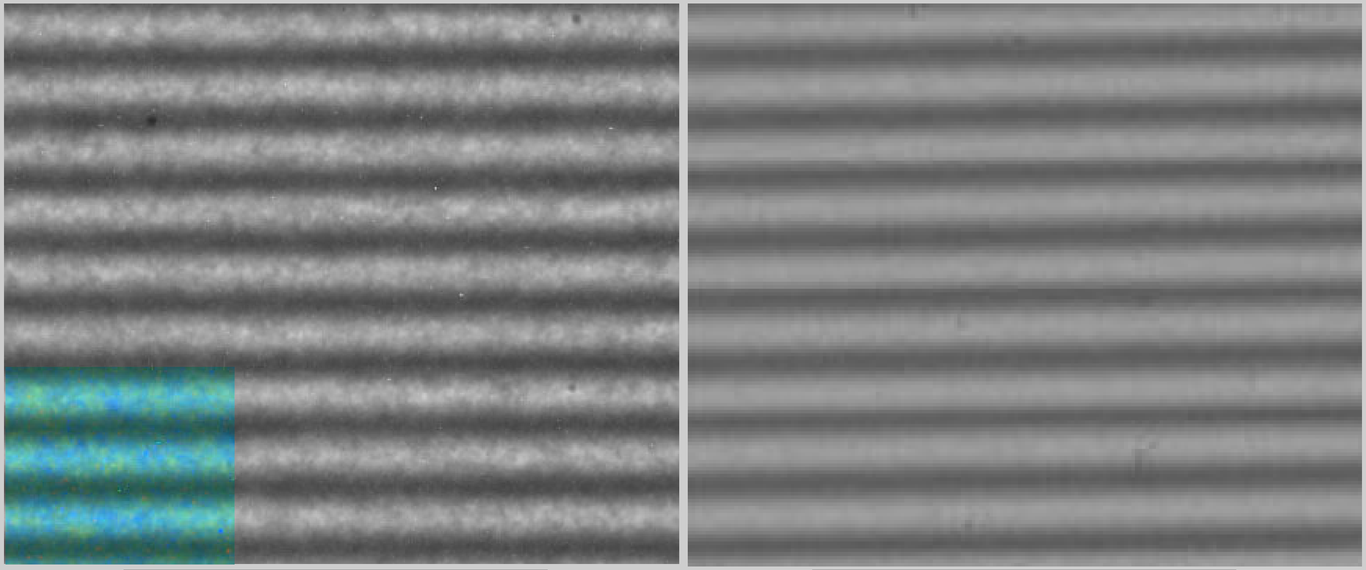
- The display brightness only diminishes by 0.3.
- Absorption also reduce veiling glare by dampening the scattering within the faceplate.

Phosphor granularity and brightness

- P104 phosphors have high luminous efficiency (lm/watt)

  but are made from a mixture of phosphors of different color which causes a granular appearance
- P45 is a single component phosphor with improved granularity but with reduced lm/watt (~65% of P104).

P104



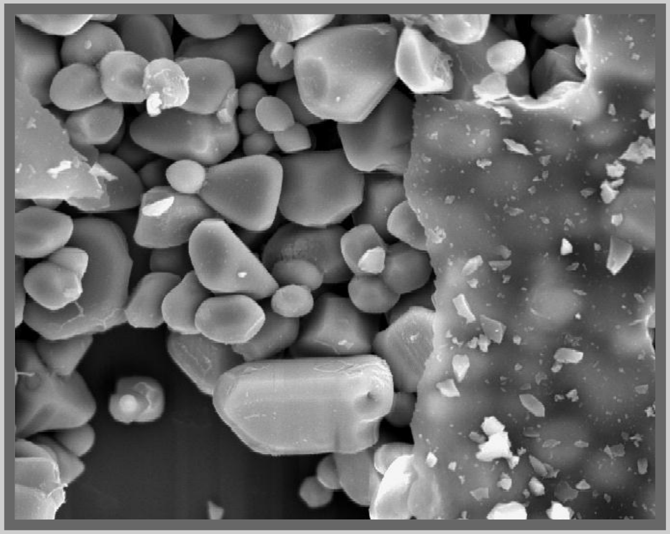
P45

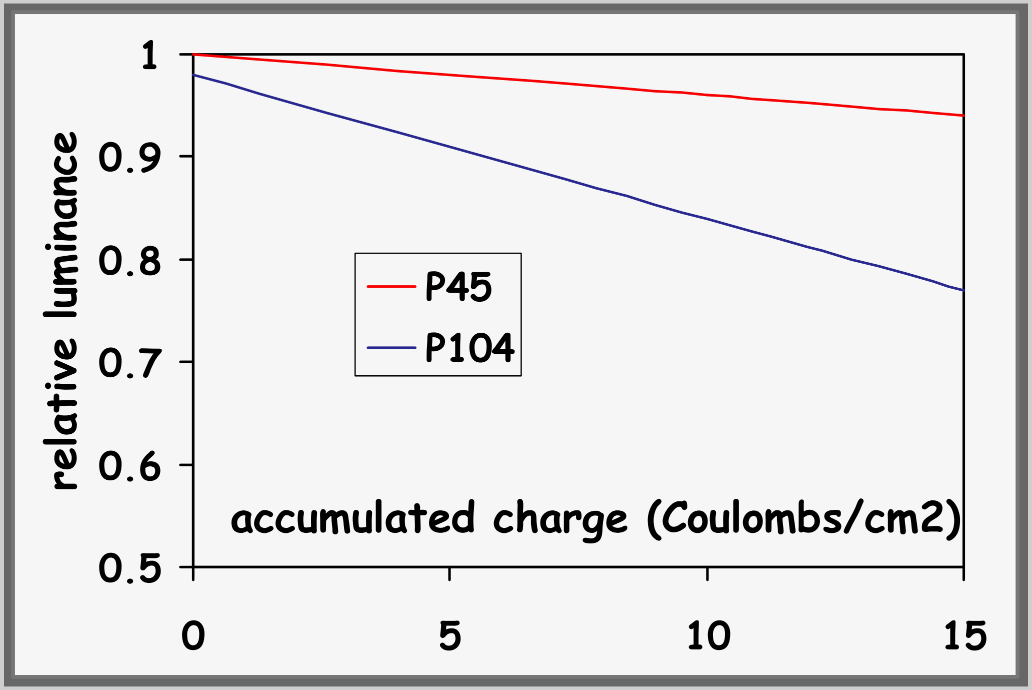
•Monochr. P104 screen
•mixture of color grains
•noisy appearance

•Monochr. P45 screen
•single white grain
•uniform appearance.

Beam current & Phosphor aging

- Phosphor grains will degrade due to material changes in regions of high current density.
- A decrease in brightness occurs with age and needs to be corrected over the useful life of the system



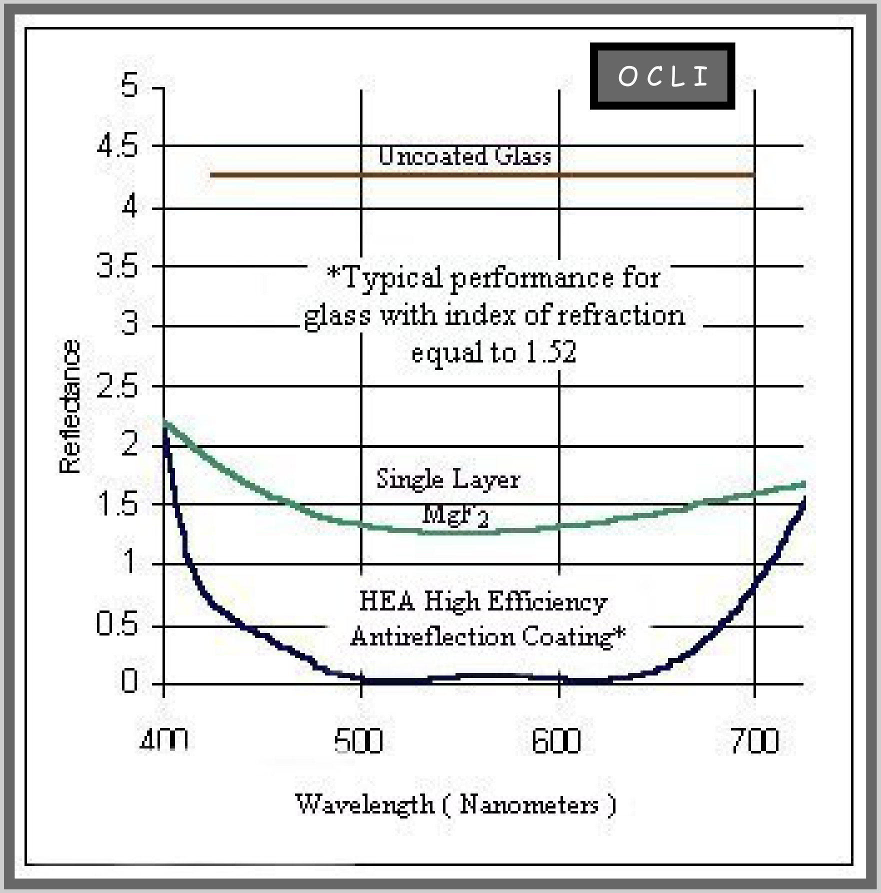


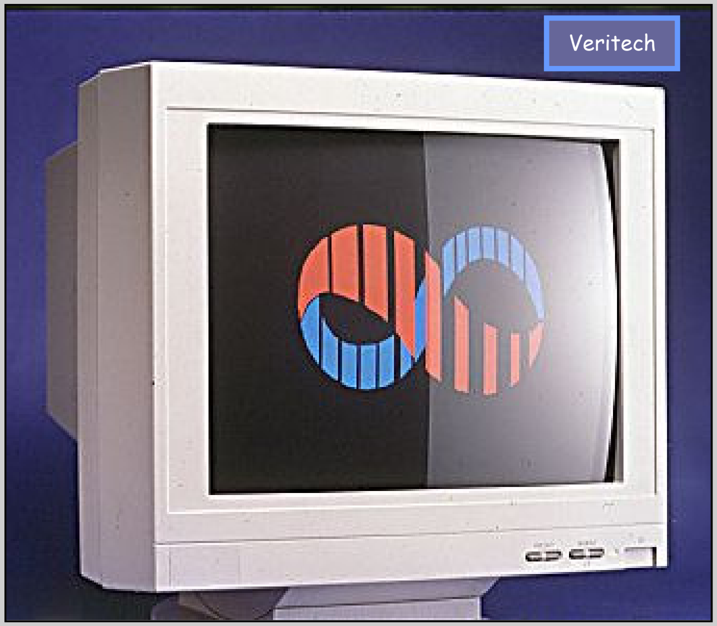
Brightness…….	300 cd/m2	
Phosphor……….	P104	P45
microA/cm2:	.166	.255
hrs/Coul/cm2:	1673	1089
Beam mA	.2	.3
Beam kW	5	7.5

Data from CEC
1200 cm2, 25 kV

Surface treatments

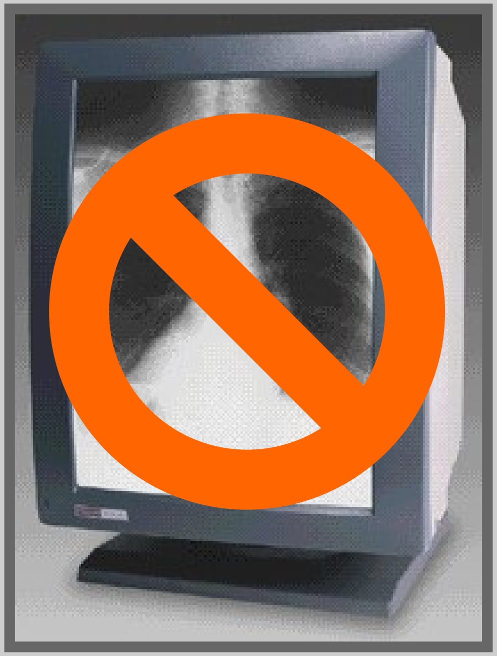
A thin film surface coating provides conduction to reduce static charge and dust collection, abrasion resistance, and anti reflective (AR) properties,





Coatings generally have many thin film layers and are often laminated as an added glass thickness to the display surface.

- viewable area of about 30 x 40 cm
- pixel arrays up to 2K x 2.5K
- Landscape and portrait format.


Significant Problems of the Medical CRT

- Electron Beam focus produces a blurry spot that limits resolution. The spot size is prone to drift and is difficult to maintain over the full field of view.
- A thick faceplate is required to sustain high forces on the surface of the vacuum blub. This causes optical scattering leading to glare.
- The nature of the phospor needs a white material conducive to light emission. This in turn causes excess reflection of ambient light.
- The analog nature of the signal circuits is prone to drift and requires frequent recalibration to maintain proper grayscale.
- The large size and weight of the vacuum blub leads to a total weight of 80 to 120 lb and a bulky size.

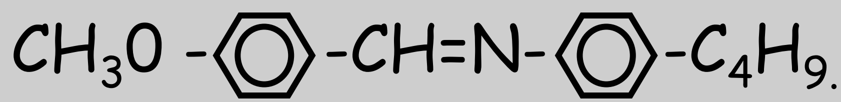
Liquid Crystal Display (LCD) Technology

Intermediate state of matter:

crystal --------------$\xrightarrow{T}$> liquid -------------$\xrightarrow{T}$> vapor.

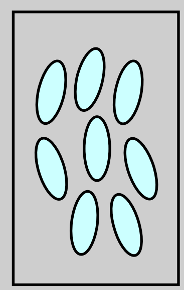
(liquid crystal).

- De-localized charge in long organic molecules defines anisotropy:



- Molecules are arranged loosely along main axis (or director).
- The spatial configuration of the directors is determined by elasticity and deformation constant.

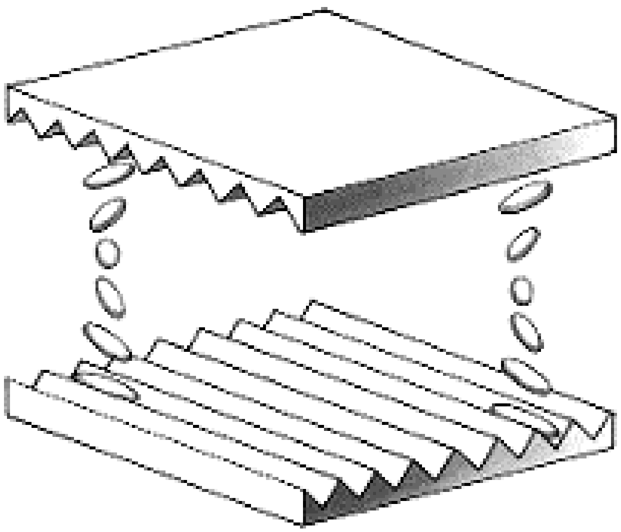
Natural state of liquid crystal molecules

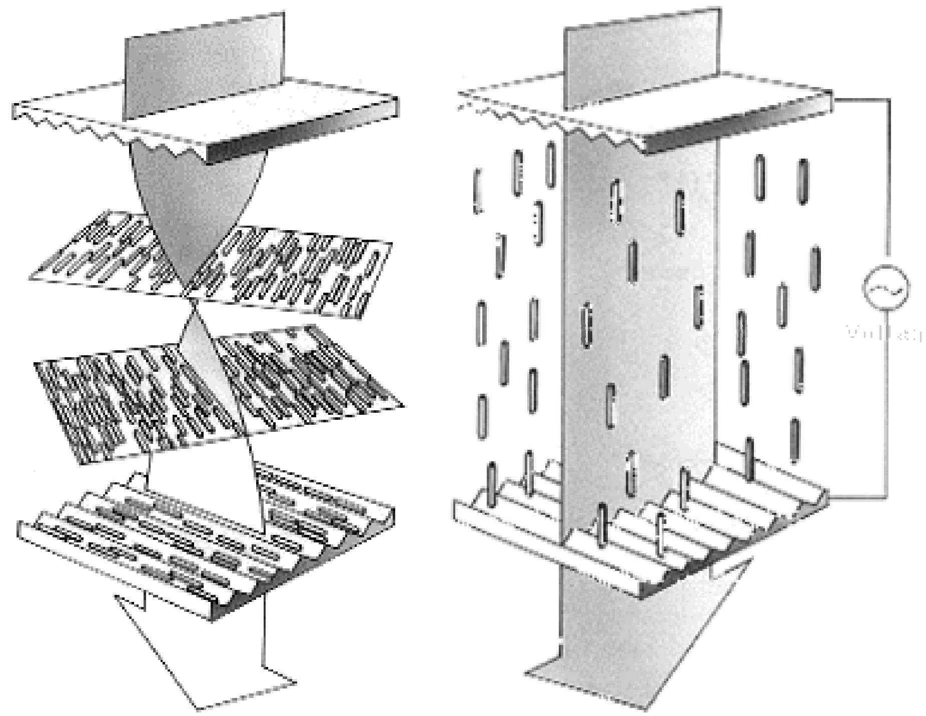


Electro-optical Effect

Twisted Nematic (TN) LC cell

When LC molecules contact a grooved surface, they align parallel to the grooves.



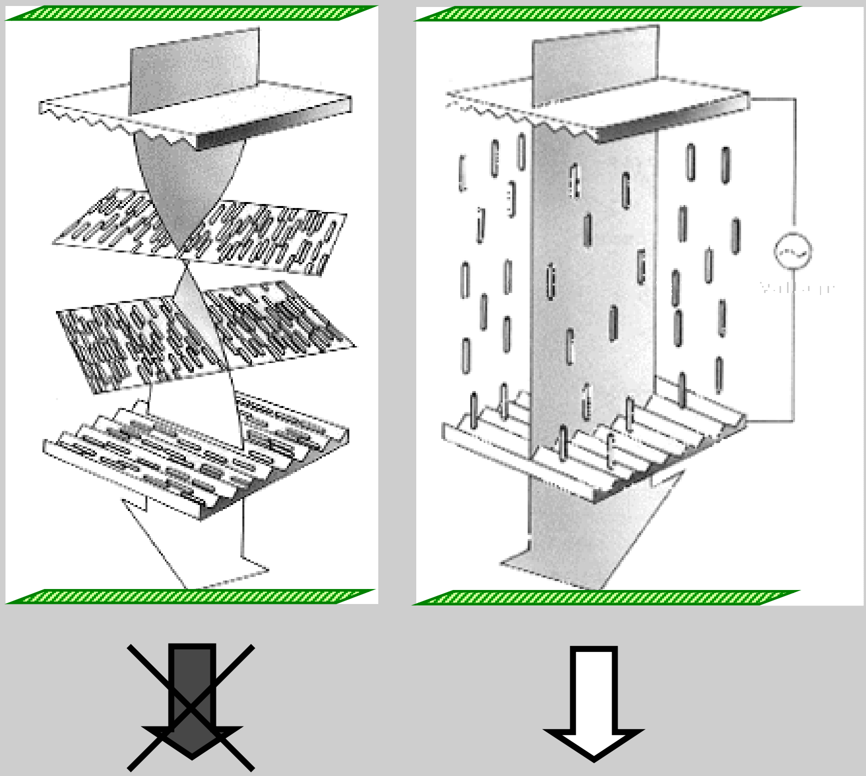


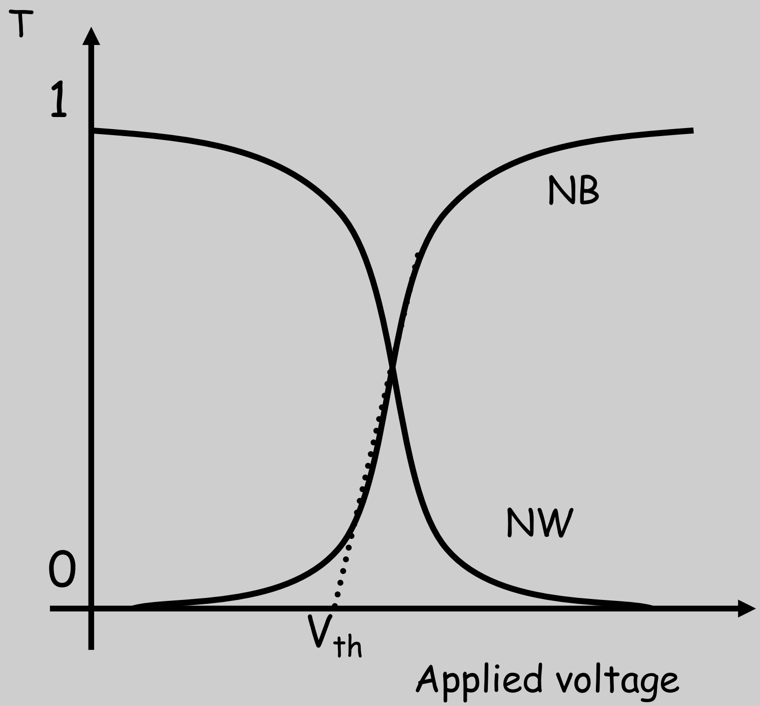
Adapted from Sharp Co. brochure

The director is altered by external electric field. When the director is twisted, light polarization also twists.

Light Modulation With Polarizer

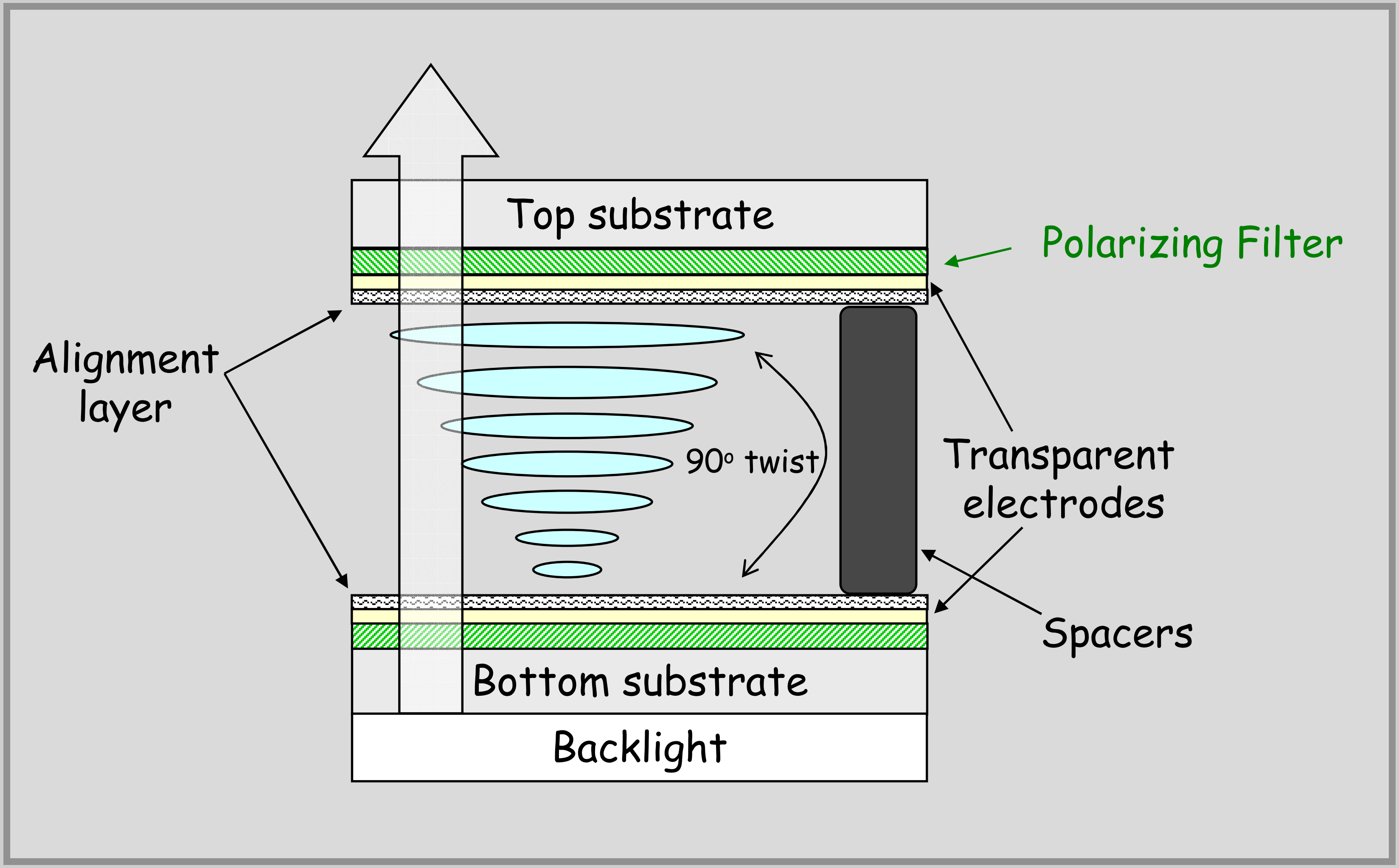
With polarizer filters, the LC electro-optical effect defines light transmission as a function of applied cell voltage.



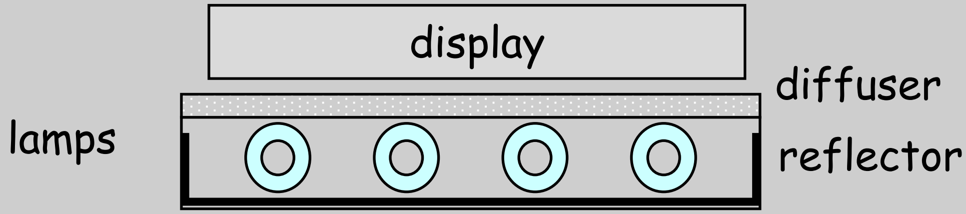


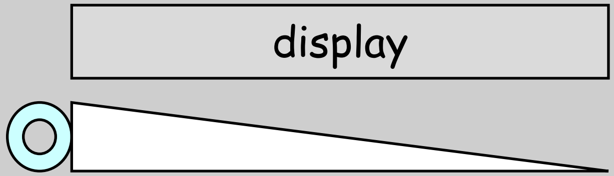
For normally black (NB with aligned polarizers), there is no transmission when voltage is applied.

Elements of a TN LC Cell



Brightness by Backlight

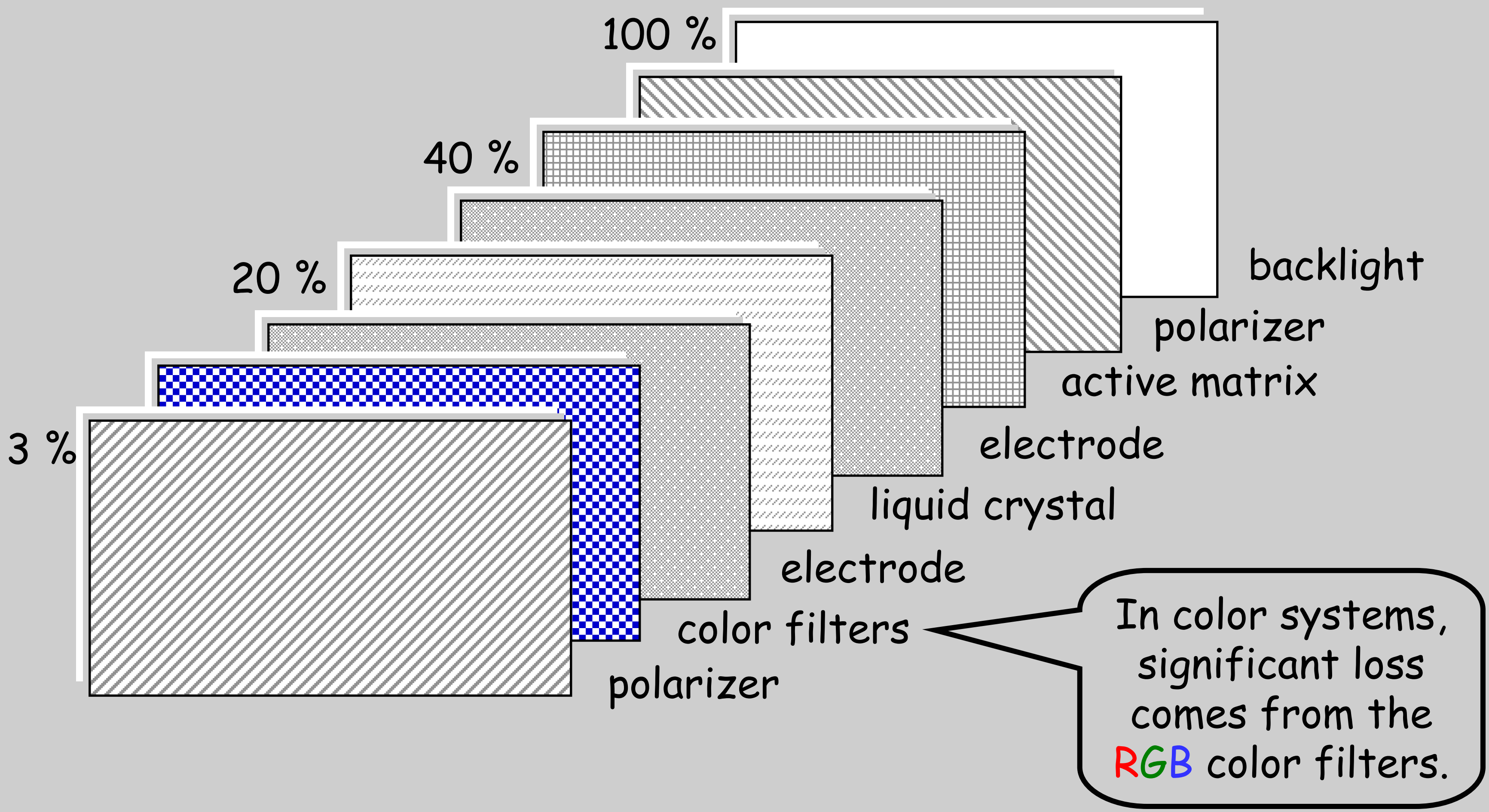




Backlight:

- Multiple-phosphor lamps, reflector, diffuser.
- Compact, high efficiency and long life.
- Behind panel (brighter) or on edge (better uniformity and thickness).
- HCFT (hot cathode fluorescent tube): brighter, 10,000 h life.
- CCFT (cold cathode fluorescent tube): 20,000 h life.

Power efficiency and brightness are related to optical performance of several layers.

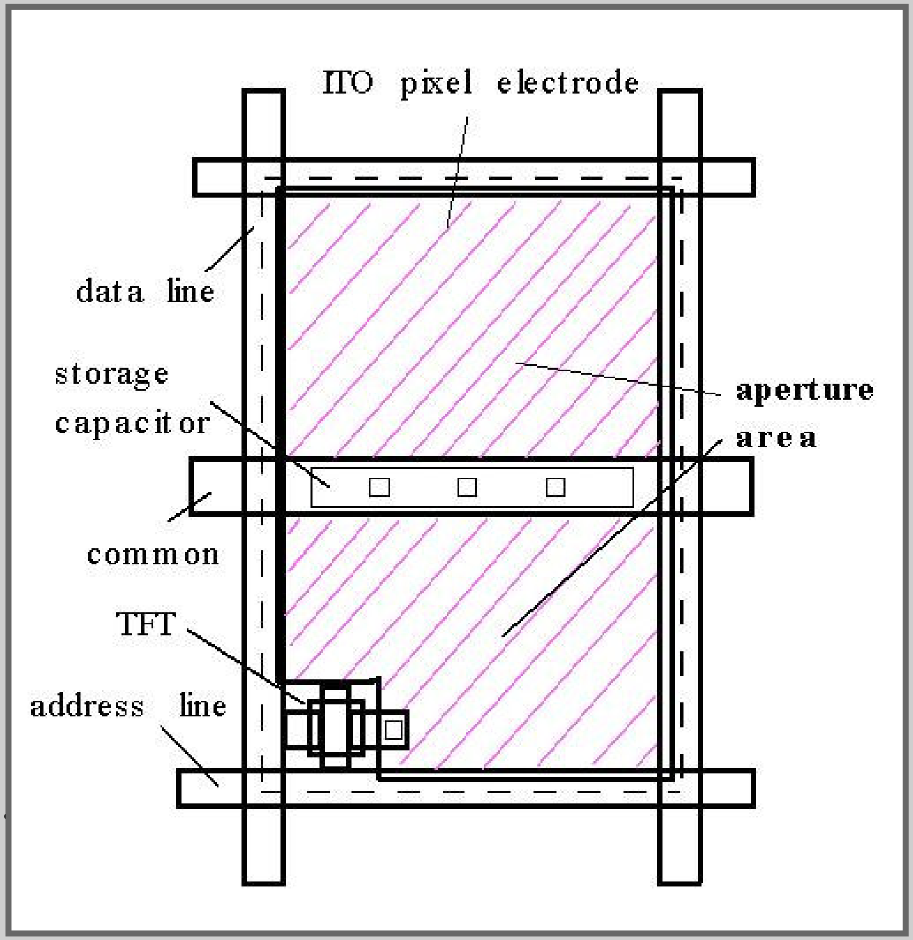


Active Matrix Design

All pixels in a row are changed in sequence.

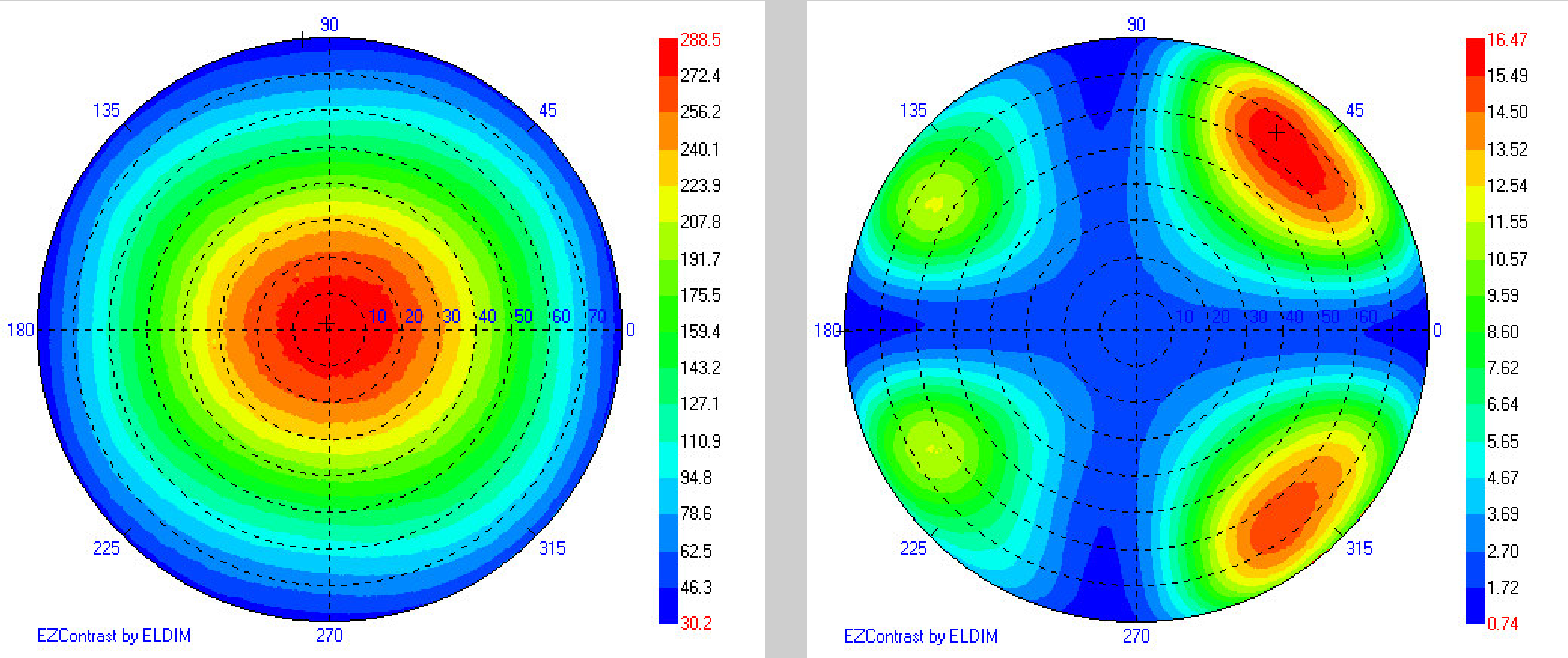
No flicker even at modest refresh rates.

- a-Si TFTs:
  - good switching performance.
  - low leakage in OFF state.
- Aperture ratio:
  - Typically 50%
  - 80% increased luminance (Sharp)
- Challenges:
  - low resistance scan lines (lag).
  - photo-conductivity.



Luminance Changes With Viewing Angle

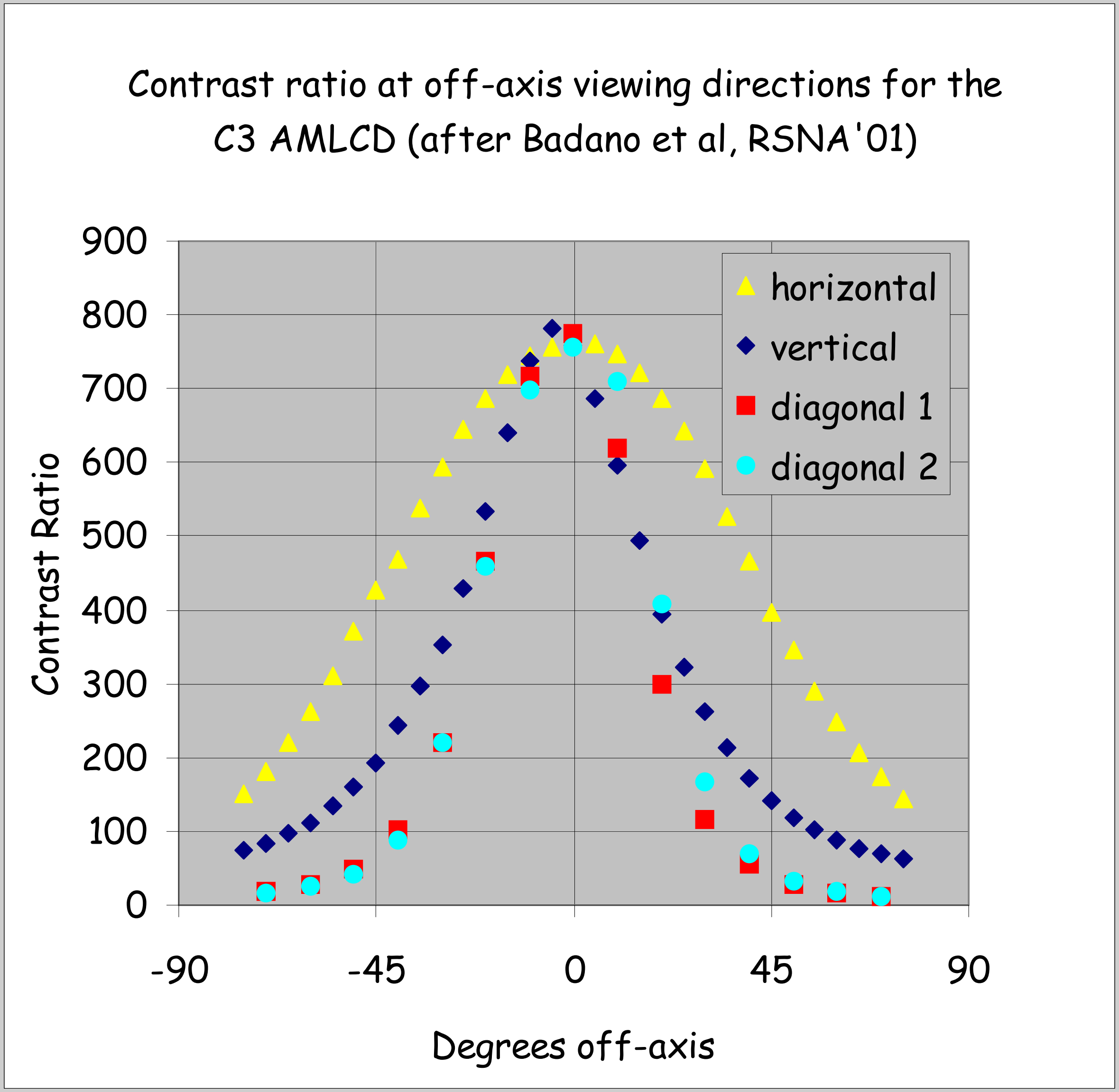
- CRTs have quasi-Lambertian emission that provides uniform luminance and contrast in all viewing directions.
- LCDs do not. This results in asymmetric contrast degradation and grayscale inversion.



Polar plot of luminance of uniform images at G=15 (right) and G=220 (left) (data taken at Army Research Laboratory, MD, with ELDIM EZ Contrast with the C3 from DOME). Data Badano *et al*, RSNA'01.

Off axis contrast ratio

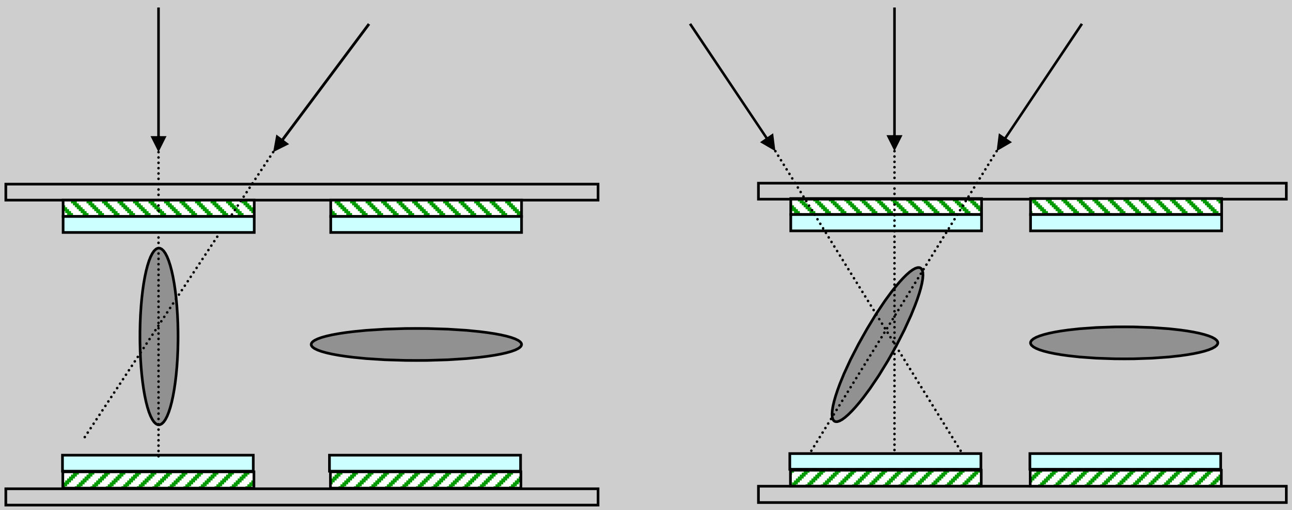
- The ratio of the maximum luminance to the minimum luminance is known as the contrast ratio
- Contrast ratio is measured in the absence of ambient light.
- For LCD systems, the contrast ratio can be severely degraded in relation to viewing angle



Solutions to TN Viewing Angle Problem

Due to the high anisotropy of light modulation:

- The effective cell gap (ON/OFF state) changes.
- The effective LC orientation differs for intermediate gray-level.

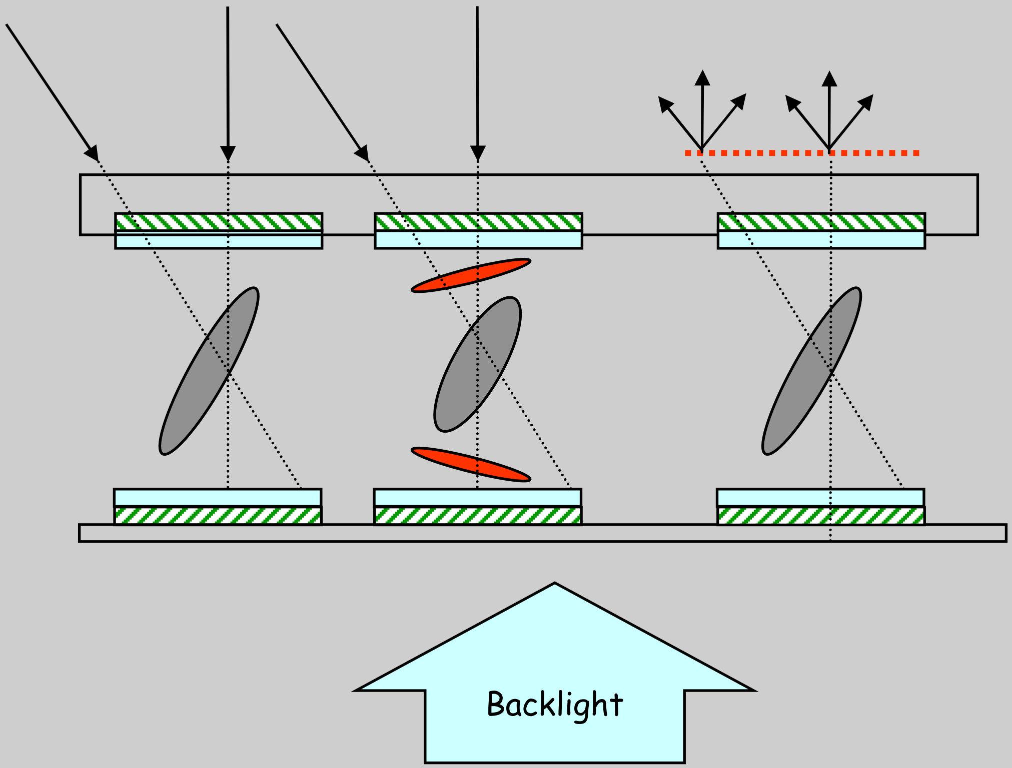


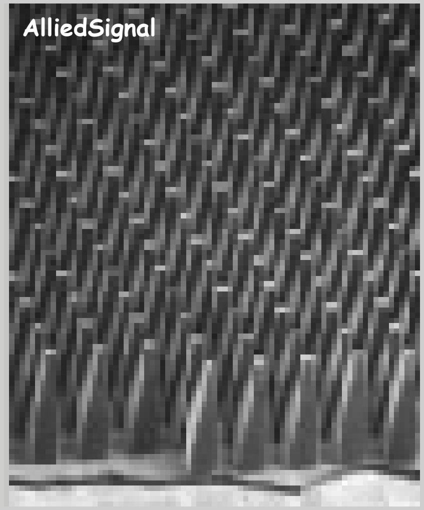
Solutions:

- Compensation foils
- Multiple sub-pixel domains (m)
- In-plane switching (IPS, mIPS)
- vertical alignment (VA, mVA)

TN + Compensation foils

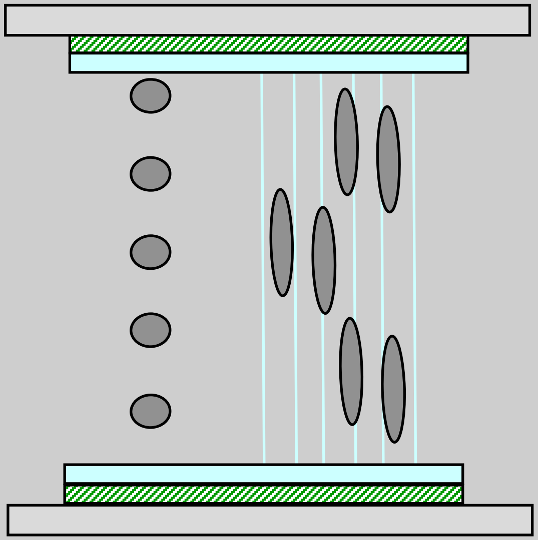
- Compensate phase variations occuring in different directions.
- 1 or 2 films in symmetrical configuration.
- Compensation foils using UV-polymerized LC layer.
- Micro-optic foils increase viewing angle but introduce artifacts



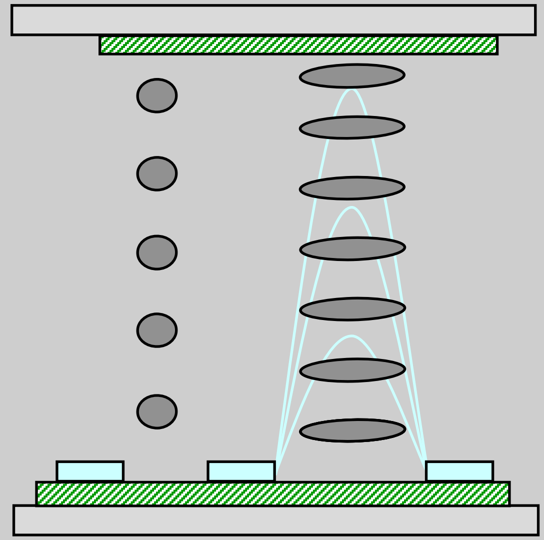


<u>Inexpensive but very low contrast (poor black) and a slow response time</u>

In Plane Switching (IPS)



TN cell
OFF (W) ON (B)



IPS cell
OFF (B) ON (W)

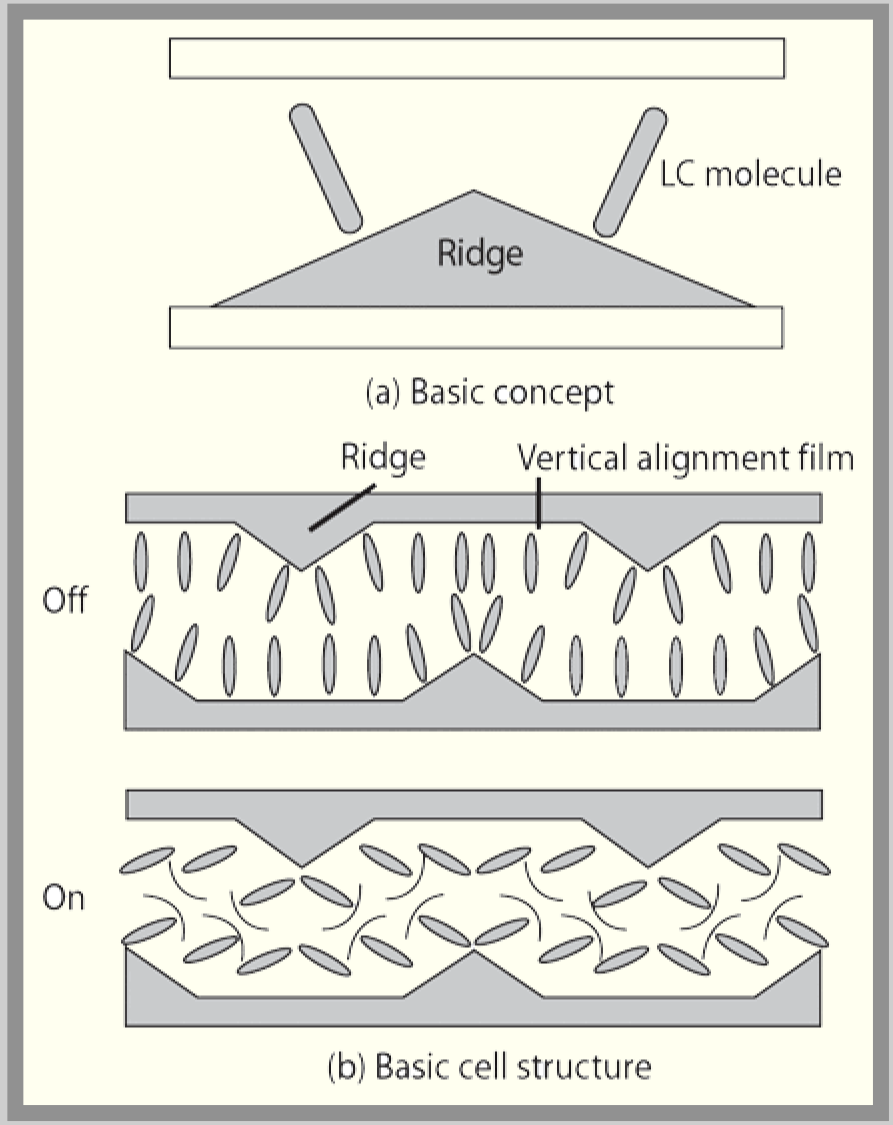
For in-plane switching (IPS) designs, the rubbing directions are the same on the top and bottom of the cell. When an electric field is applied, the directors remain in plane producing improved viewing angle response.

Advantage: High contrast (excellent black).

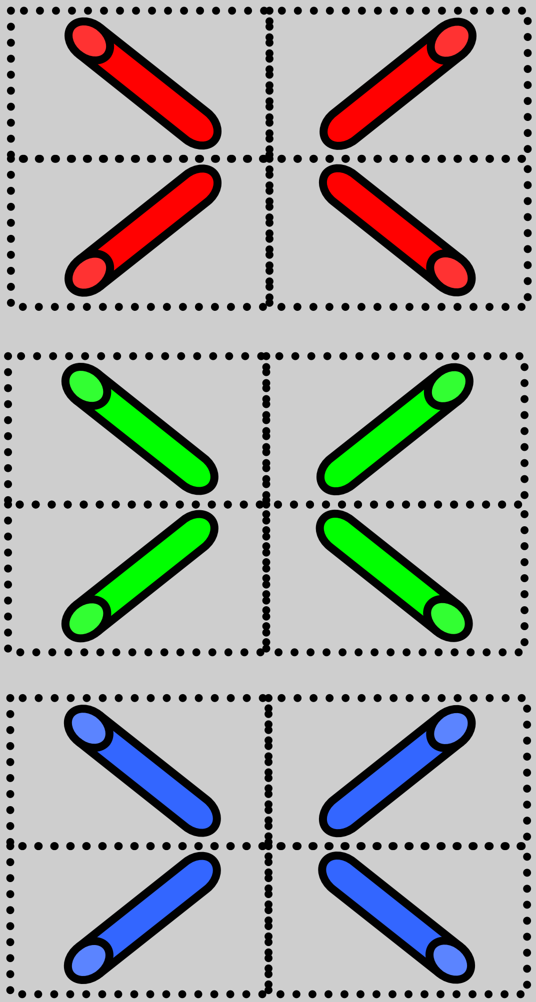
Disadvantages: low aperture ratio -> reduced brightness.
Relatively high power
slow response time.

Vertically Aligned LCD

- LC alignment is from a protrusion producing directors that are perpendicular to the display surface. No rubbing processes are employed.
- The sub pixel is divided into several regions in which the crystals are free to move, independently of their neighbors, in opposite directions (mVA).
- Wide horizontal and vertical viewing angle.
- Excellent low luminance response (deep black).
- Switching times are ~1/2 that of IPS designs producing improved cine display.



Multi-domain Cells

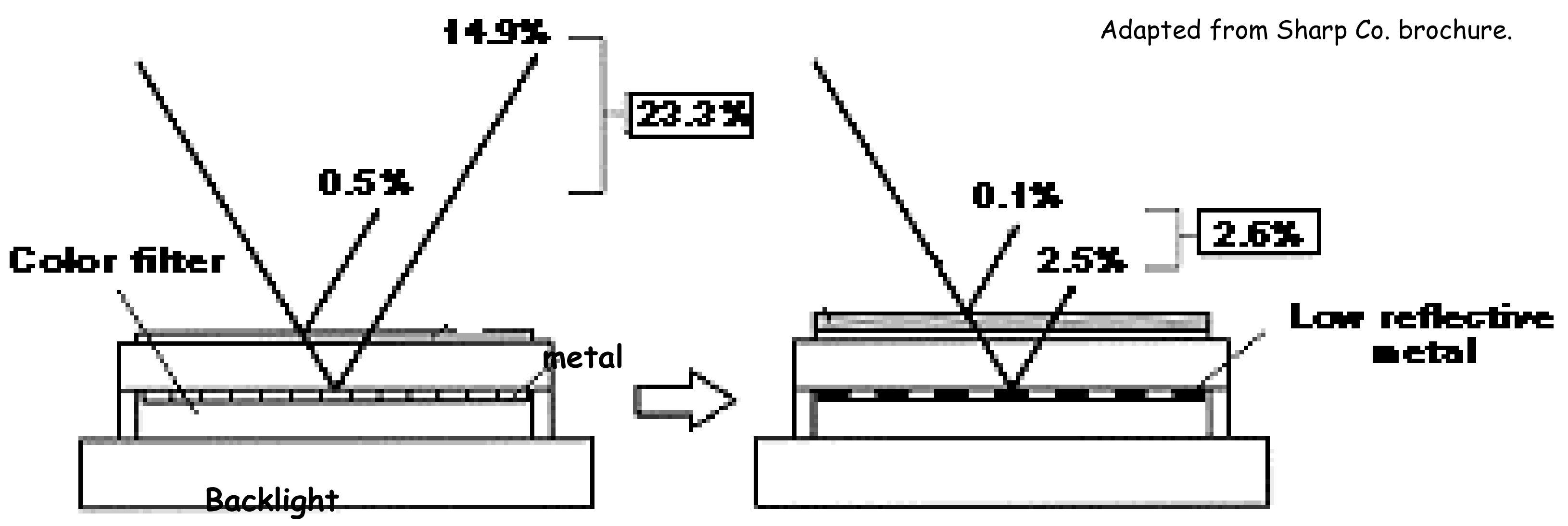


Emission angles can be distributed by using multiple domains with different orientations for each of the sub-pixels structures.

- 2- and 4-domain designs have been demonstrated, 8-domain designs simulated.
- The domain areas are defined with different alignments using
    - Sequence of differential rubbing treatments and photolithographic steps.
    - Patterned alignments with differential UV light exposure.
- Challenges:
    - domain stability (polymer stabilization)
    - more fabrication steps and cost

Low Reflectance Panels

- Anti-reflection (AR) coating on the front cover.
- Use of low-reflection materials:
  - spacers of absorbing material, instead of glass balls (IBM).
  - Low-reflectivity metal electrodes (Sharp)
- For avionics applications, index matching of layers for maximum light absorption (US patent 05579139) by.
  - Diffuse reflection coefficient R_d = 0.005 nit/lux , 3-5 times lower than medical imaging CRT with AR coating.



Adapted from Sharp Co. brochure.

Macro Recording of LCD pixel structure

Leitz 24mm Summar

Ernst Leitz, Wetzlar (Germany)

Max aperture f2.0

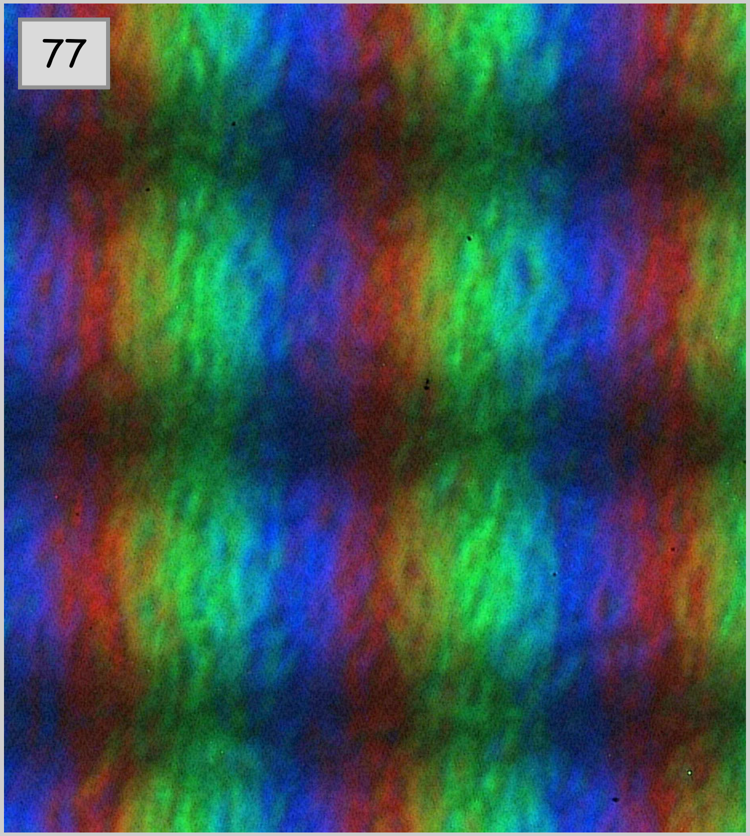
Nikon PV4 bellows

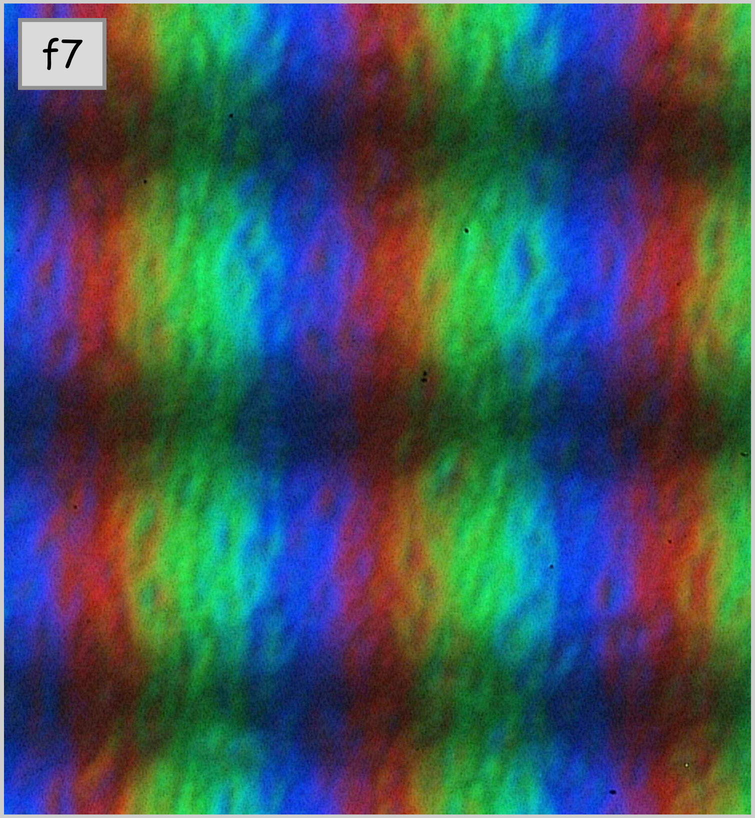
Fuji S1 digital camera at ASA 1600

TN + Film

Macro photographs recorded with varying luminance.

Contrast/Brightness adjusted for similar appearance.



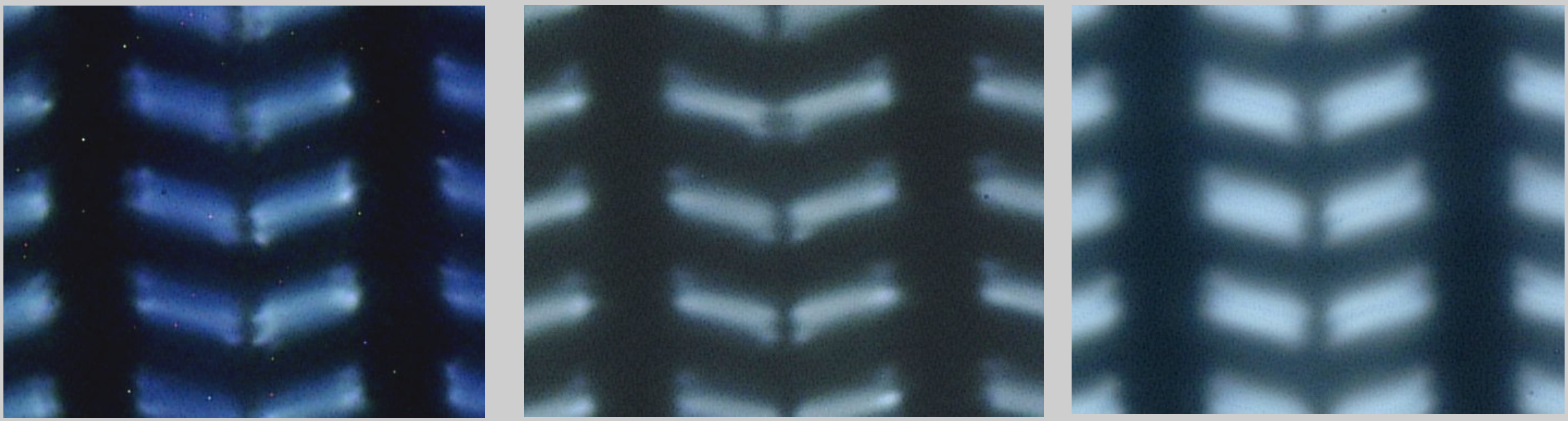


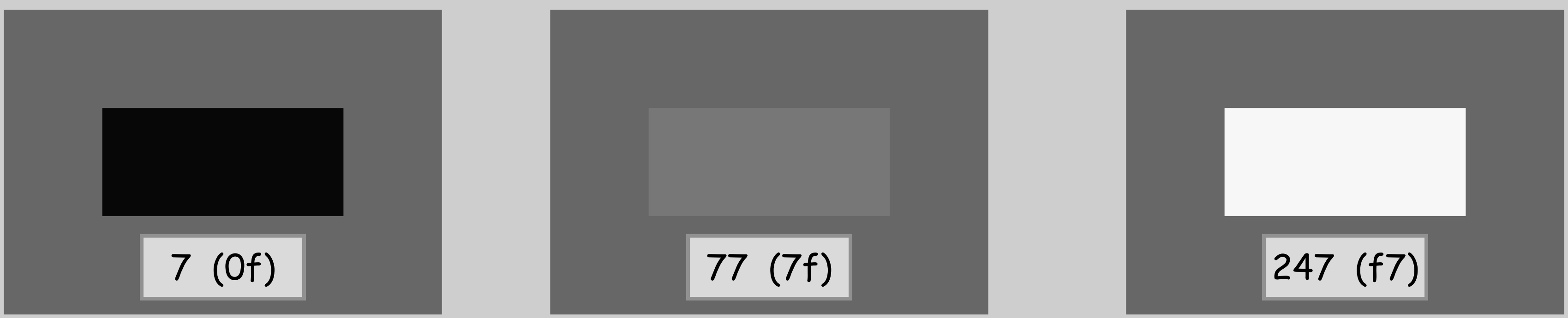
NDS Nova (IBM panel) - 3MP

IPS – dual domain

Macro photographs recorded with varying luminance.

Contrast/Brightness adjusted for similar appearance.

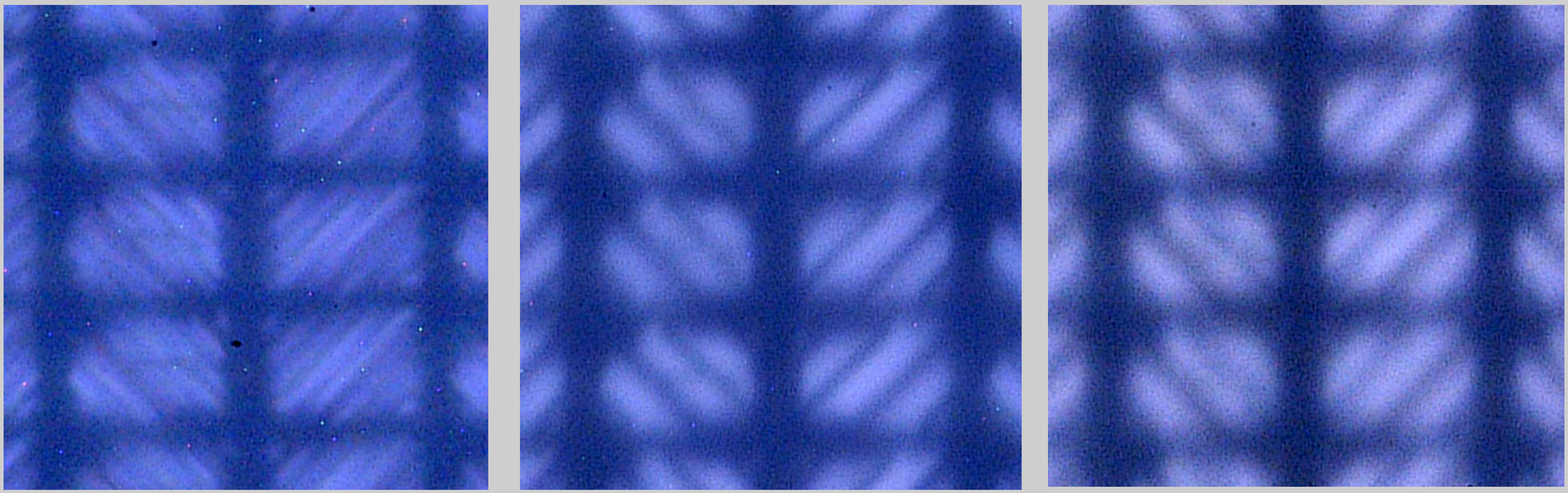


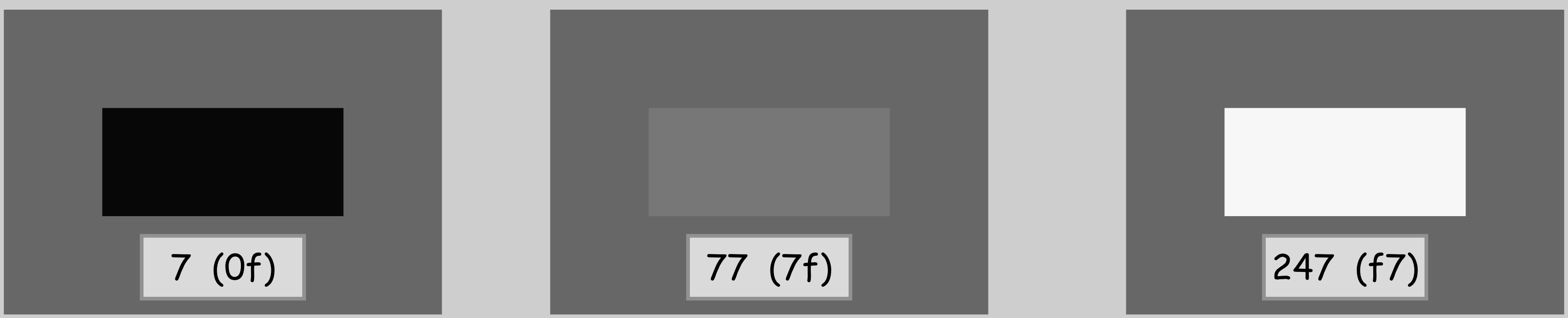


VA – dual domain

Macro photographs recorded with varying luminance.

Contrast/Brightness adjusted for similar appearance.

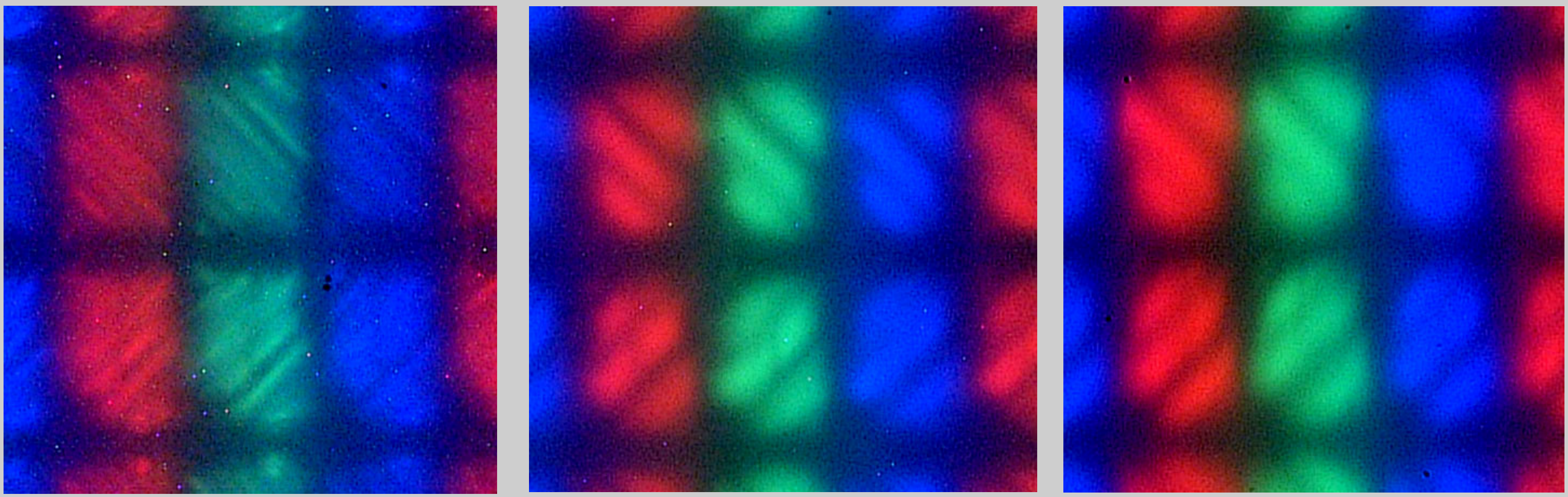


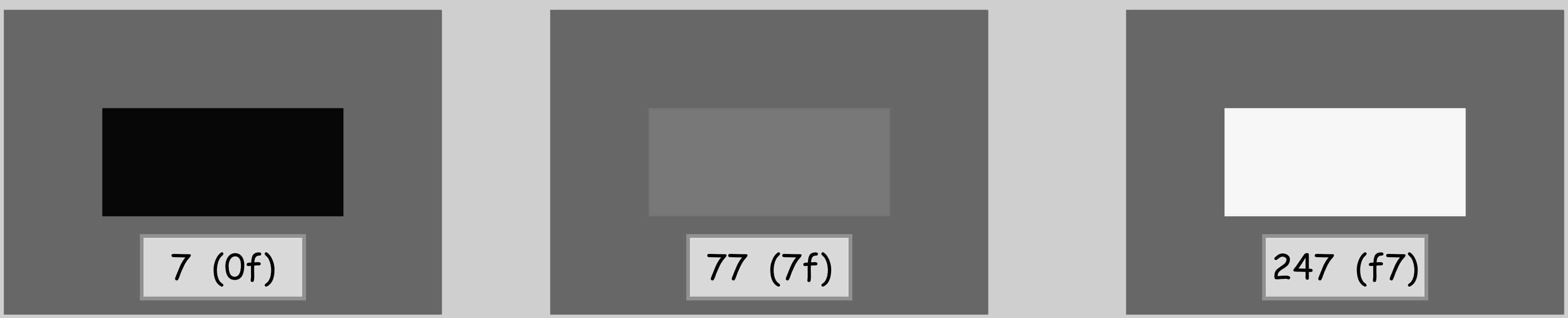


VA – dual domain

Macro photographs recorded with varying luminance.

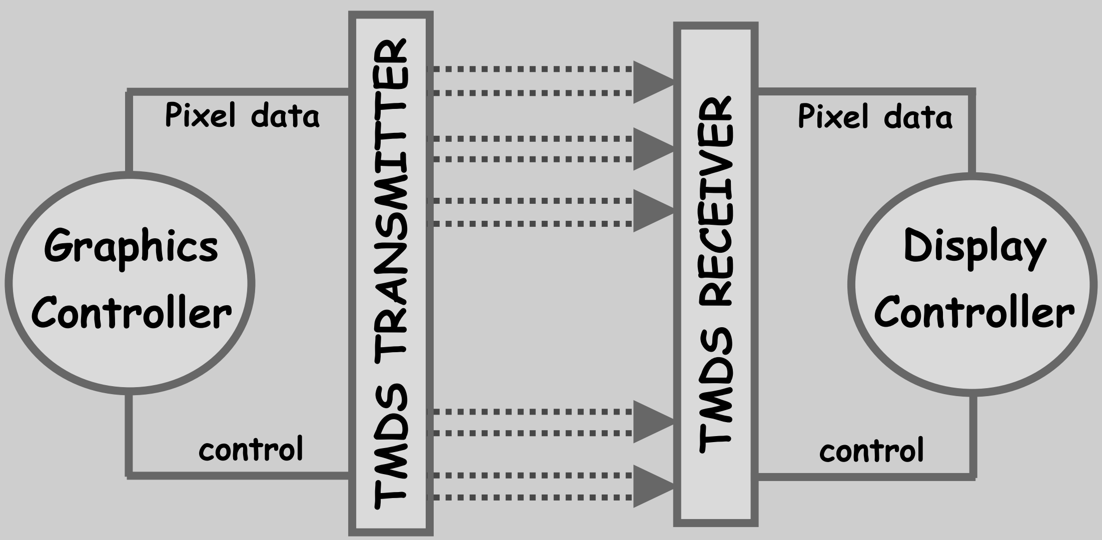
Contrast/Brightness adjusted for similar appearance.





Digital Display Controllers

- Intel, Compaq, Fujitsu, HP, IBM, NEC, and Silicon Image organized a Digital Display Working Group to define digital connectivity specifications (www.ddwg.org). The DVI 1.0 specifications was published 2 April 1999.
- Silicon Image's PanelLink technology for Transition Minimized Differential Signaling (TMDS) provides the technical basis for the working groups proposed interface specification. (www.siimage.com).



- Standardized connector
- Single link mode:
  - 165 Mpixels/sec
  - 2Mp @ 82 Hz
- Dual link mode:
  - 330 Mpixels/sec
  - 4Mp @ 82 Hz

LCD vs CRT summary

- High performance monochrome medical display suitable for diagnosis can be achieved with either CRT or LCD technology.
- The attractive environmental and service characteristics of the LCD make it more favorable overall.

	LCD	CRT
• Grayscale	★★★★☆	★★★☆☆
• Resolution.	★★★★☆	★★☆☆☆
• Display Noise.	★★★☆☆	★★★☆☆
• Environmental	★★★★★	★★☆☆☆
• Cost	★★☆☆☆	★★☆☆☆
• Service	★★★★☆	★☆☆☆☆
OVERALL	22 ★	13 ★

The HFHS choice

- 100% LCD for all ePACS operations.
- All CRT systems have been removed.
  - 5mp portrait mono CRTs
  - 2 mp portrait mono CRTs
  - .5 mp color CRTs from Radiology & clinic floors
- All LCD systems have DICOM grayscale calibration.

HFHS diagnostic module

40 diagnostic workspace modules

- 80 3mp monochrome lcd
- 40 1mp color lcd

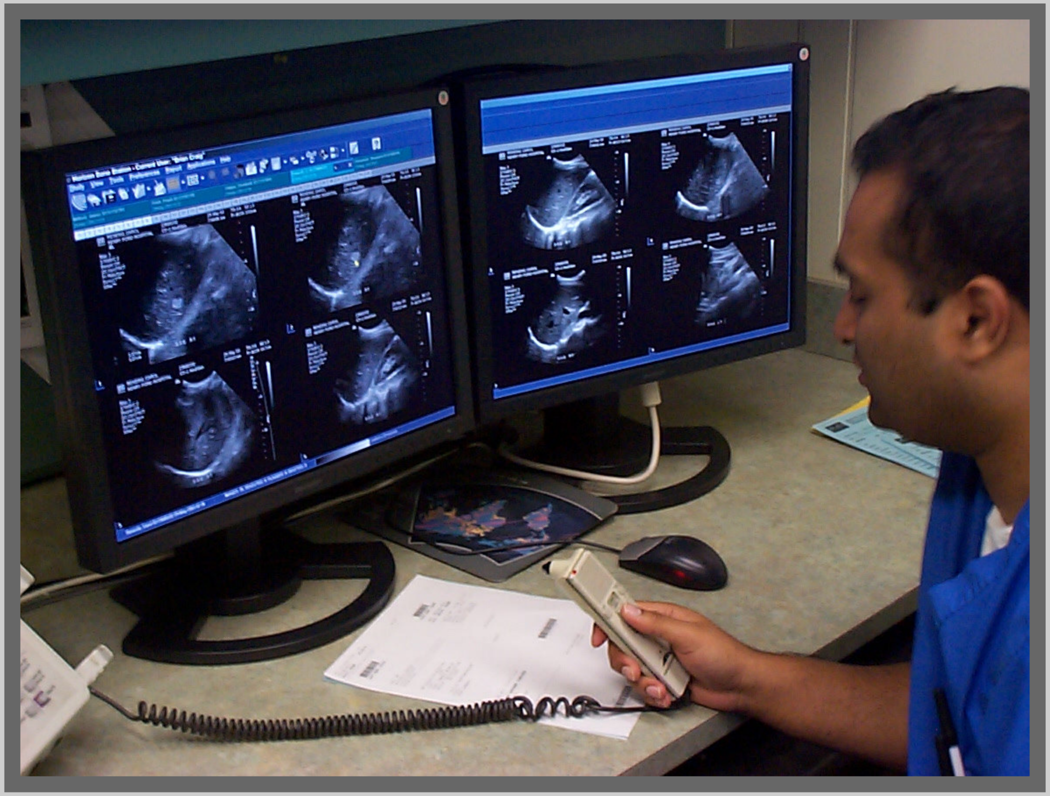
Radiology Conference Room

radiology resident interprets a case with guidance from staff

40" LCD Monitors with DICOM calibrated grayscale and matched luminance range provide appearance equivalent to reading stations

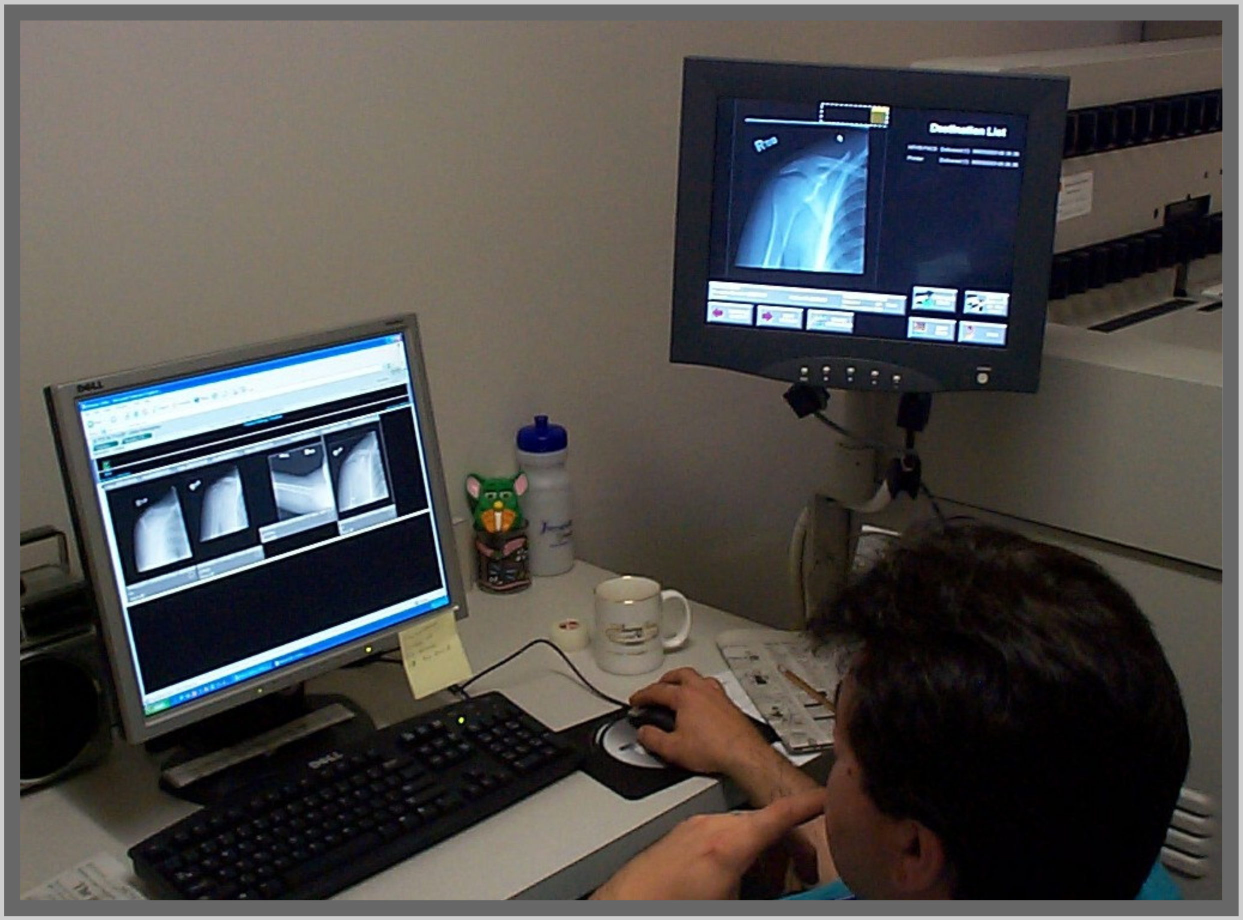
12 ultrasound workspace modules

- 24 2mp color lcd



Radiology Technologist workstation

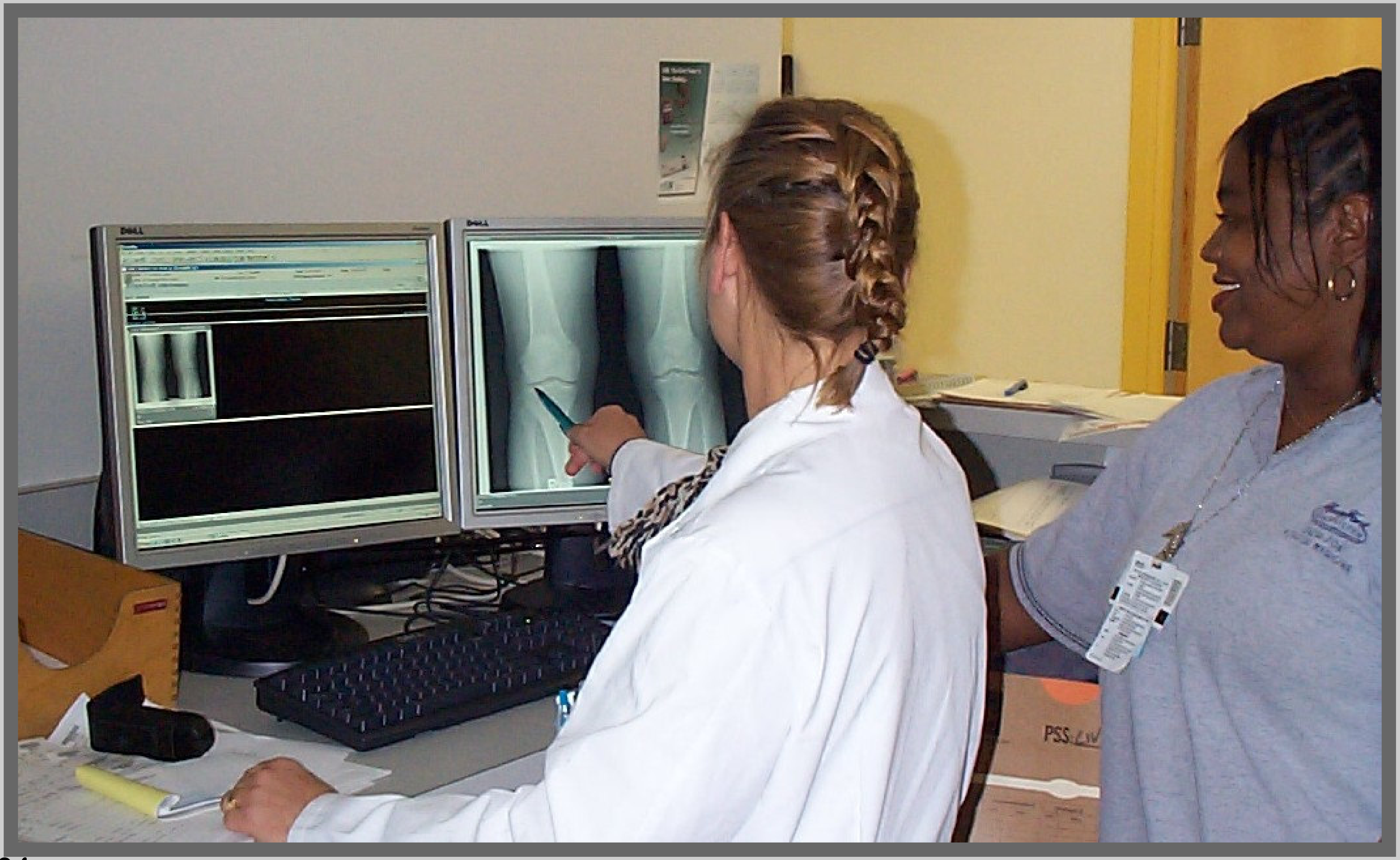
- 85 1mp color lcd



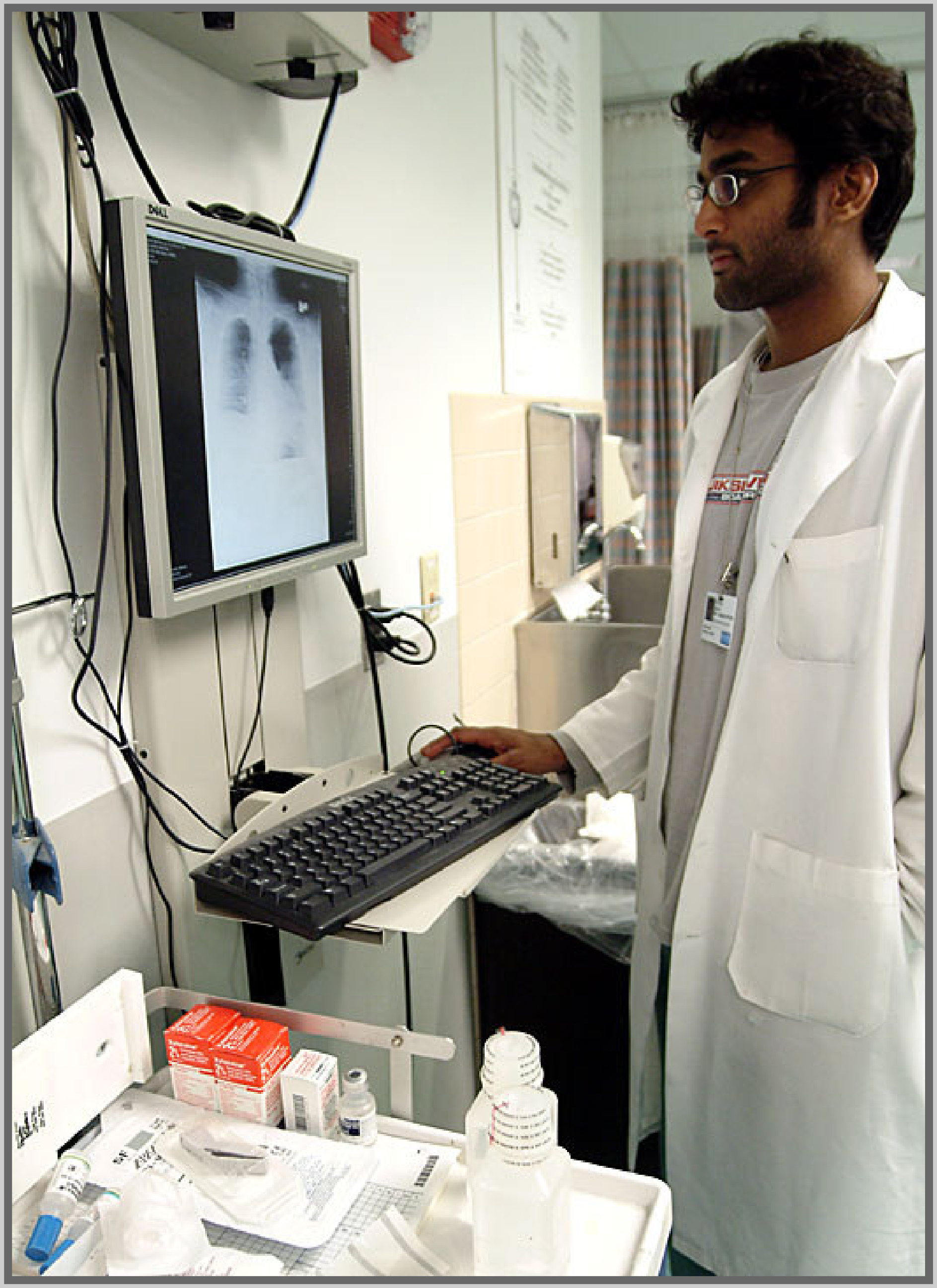
- New Angio / Fluoro systems are now all sold with LCD displays for in room use.
- Older fluoro systems remain a problem

Clinic workstations

- 530 single 1mp color lcd stations
- 20 dual 1mp color lcd stations
- 10 stations with 1mp color lcd + 2mp mono lcd



Specialized wall mounts with an overhead computer shelf in areas where space was limited



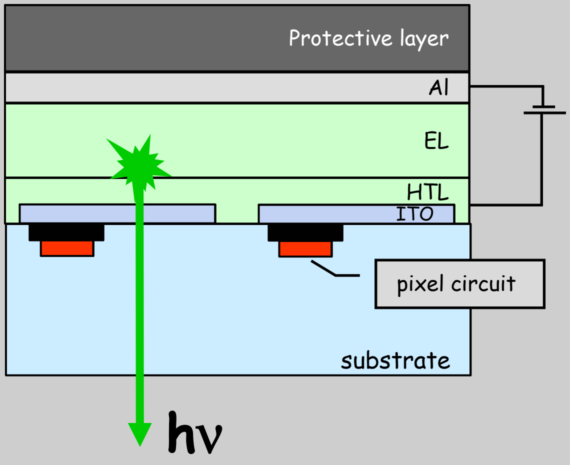
Main Campus ER

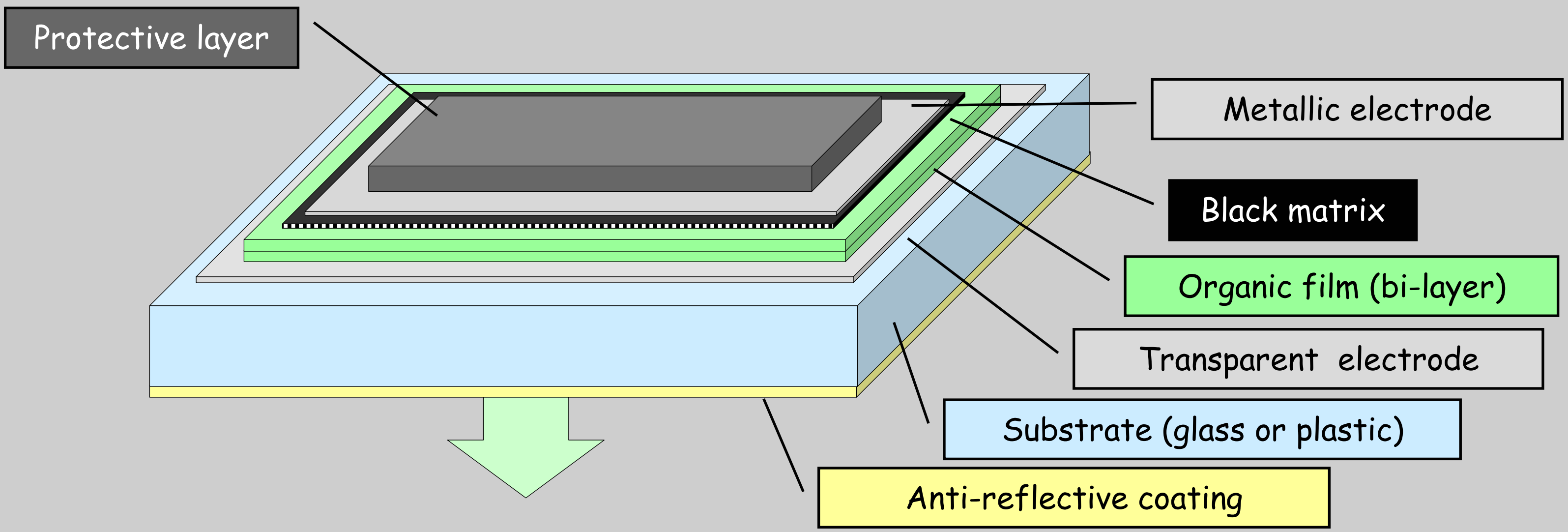
A few comments on OLEDs

Organic Light Emitting Devices

OLED Device structure

- Organic thin-films are deposited onto a substrate coated with a conductive transparent electrode usually Indium Tin Oxide (ITO).
- One or two organic material thin films are deposited, a hole-transporting layer (HTL) of ~ 17 nm, and an emissive layer (EL) of ~ 200 nm.





OLED recent history

- 1960s
  - first EL observation from organic semiconductors
- 1987
  - first efficient EL observation from small molecule thin films.
- 1990
  - first EL observation from conjugated organic polymers from poly(p-phenylene vinylene) (PPV) single layer OLED.
- 1993
  - introduction of the double layer OLED structure improved light emission intensity and external quantum efficiency.

OLED potential

- Simple fabrication process ⇒ low cost
- Light weight, flat and thin ⇒ portable
- High resolution (50 μm)
- Emissive device ⇒ wide viewing angle
- High brightness, and contrast
- Fast response time ⇒ video rate
- Low drive voltage ⇒ low power
- High luminance efficiency ⇒ low power

Products in development

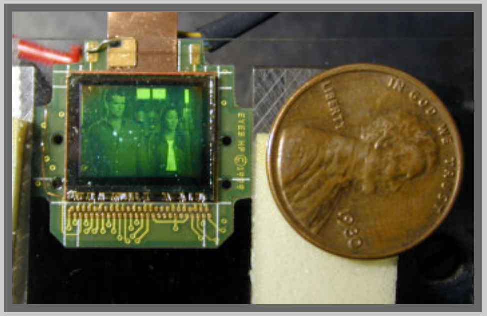
Small size products for portable electronics

Companies with active OLED development programs:

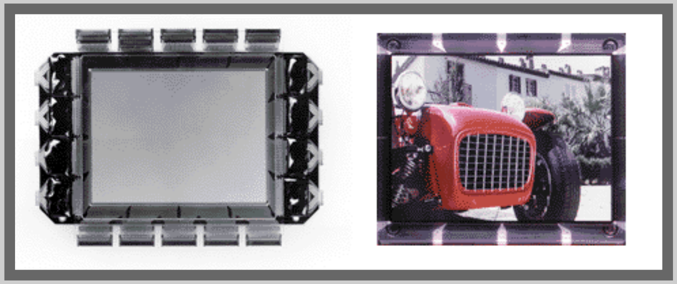
- e-Magin
- Hewlett-Packard
- Philips
- Pioneer
- Seiko-Epson

Philips

AM OLED on LT poly-Si TFT



CDT



Pioneer

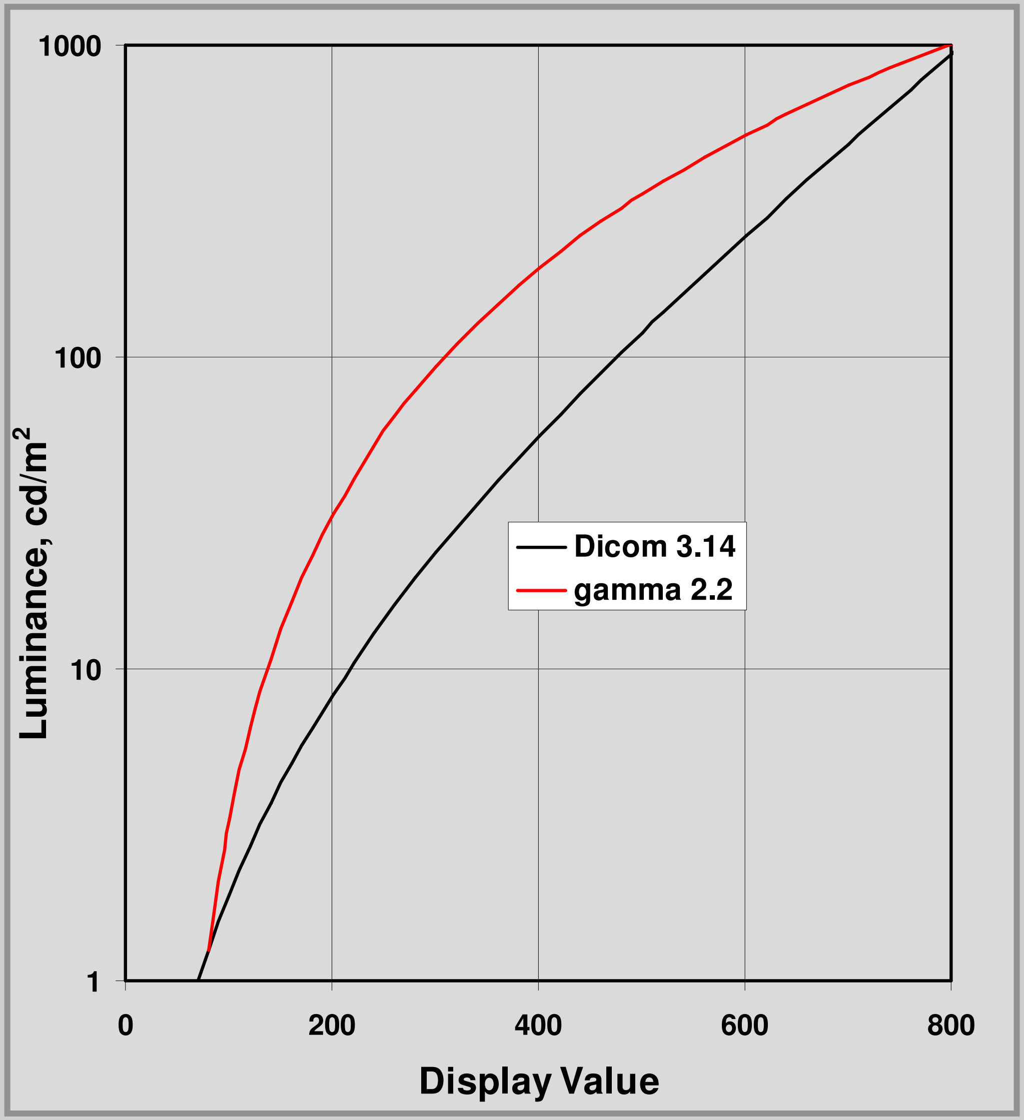
Grayscale calibration

For

Digital Monitors

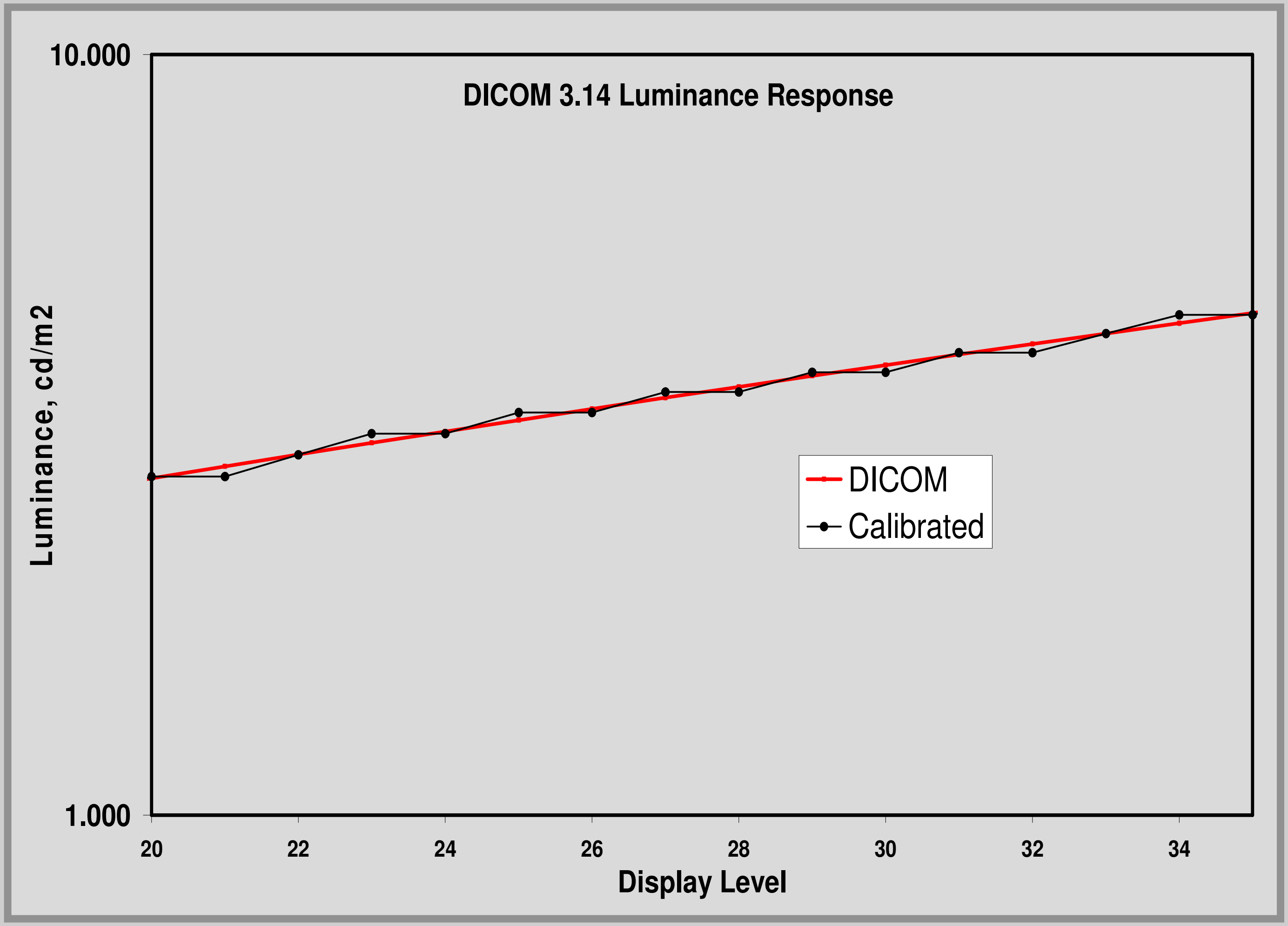
Standardized luminance response

- The intrinsic luminance response of a CRT monitor follows a power law relationship with voltage with a gamma of about 2.2.
- Luminance response is calibrated with a display controller that adjusts the relationship between display value and voltage.



Calibrated CRT Controllers

The Digital to Analogue Converter (DAC) in a CRT display controller determines the ability to control the shape of the luminance versus display value curve. Conventional controllers with 8 bit DACs have limited control over the slope (dL/L).



Display controllers intended for medical applications use 10 and 12 bit DACs

LCD gray scale calibration

- Computer display are commonly understood to have 256 gray values for which R=G=B.
- For color displays, a luminance response following the DICOM standard can be obtained by selecting 256 nearly gray colors from a palette of 1786 RGB.
- For monochrome LCD panels, 256 gray values can be selected from a palette of 766.

1786 color sequence

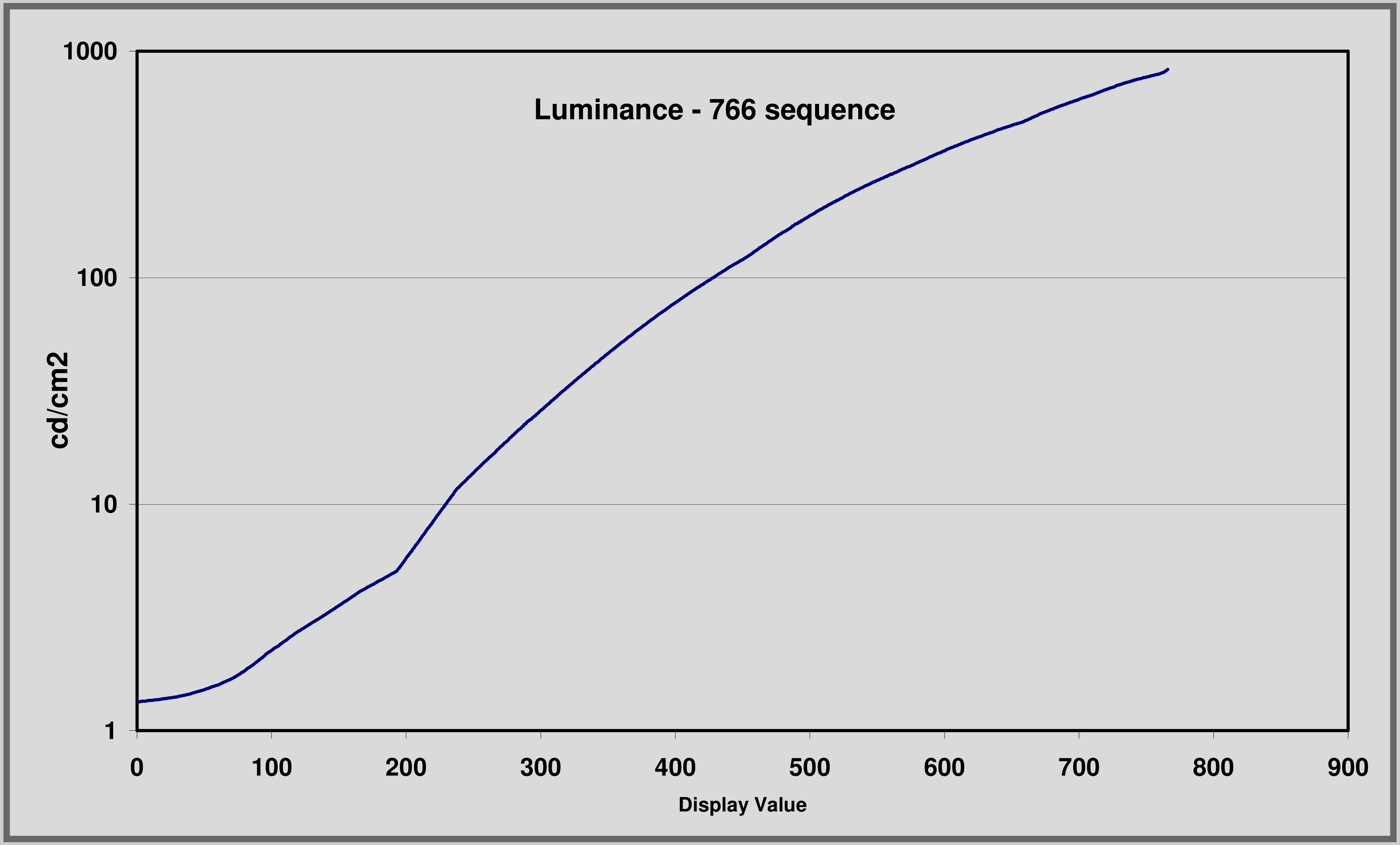
Step	R	G	B
1	0	0	0
2	0	0	1
3	1	0	0
4	1	0	1
5	0	1	0
6	0	1	1
7	1	1	0

766 monochrome sequence

Step	'R'	'G'	'B'
1	0	0	0
2	1	0	0
3	0	1	1

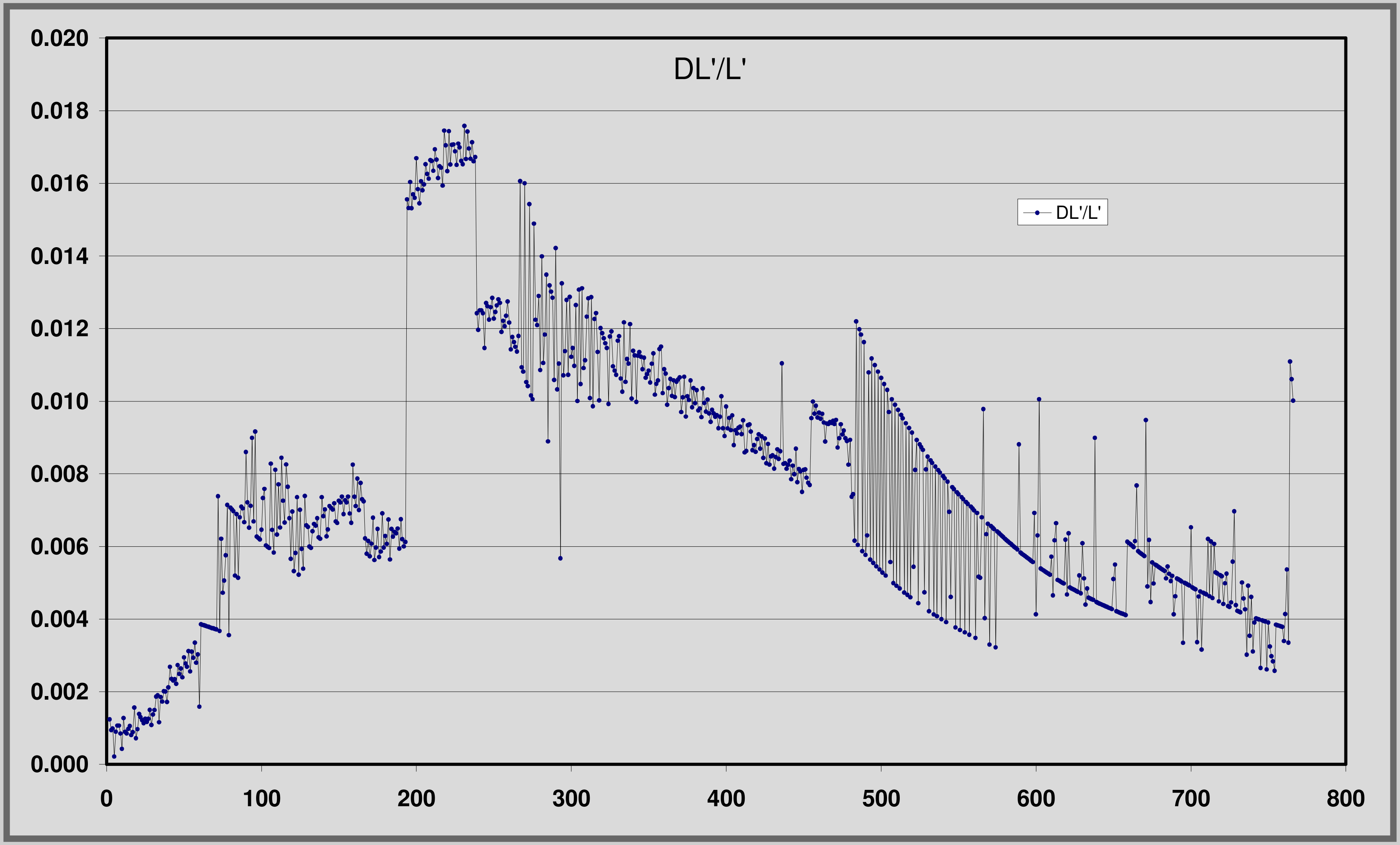
LCD uncalibrated luminance response

The uncalibrated luminance response of an LCD panel typically has an irregular shape.



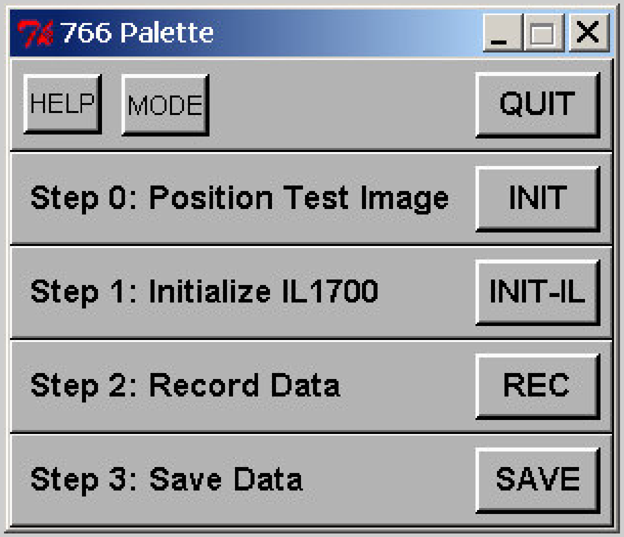
dL/L for 766 palette sequence

The relative light change between sequential palette entries varies discontinuously.

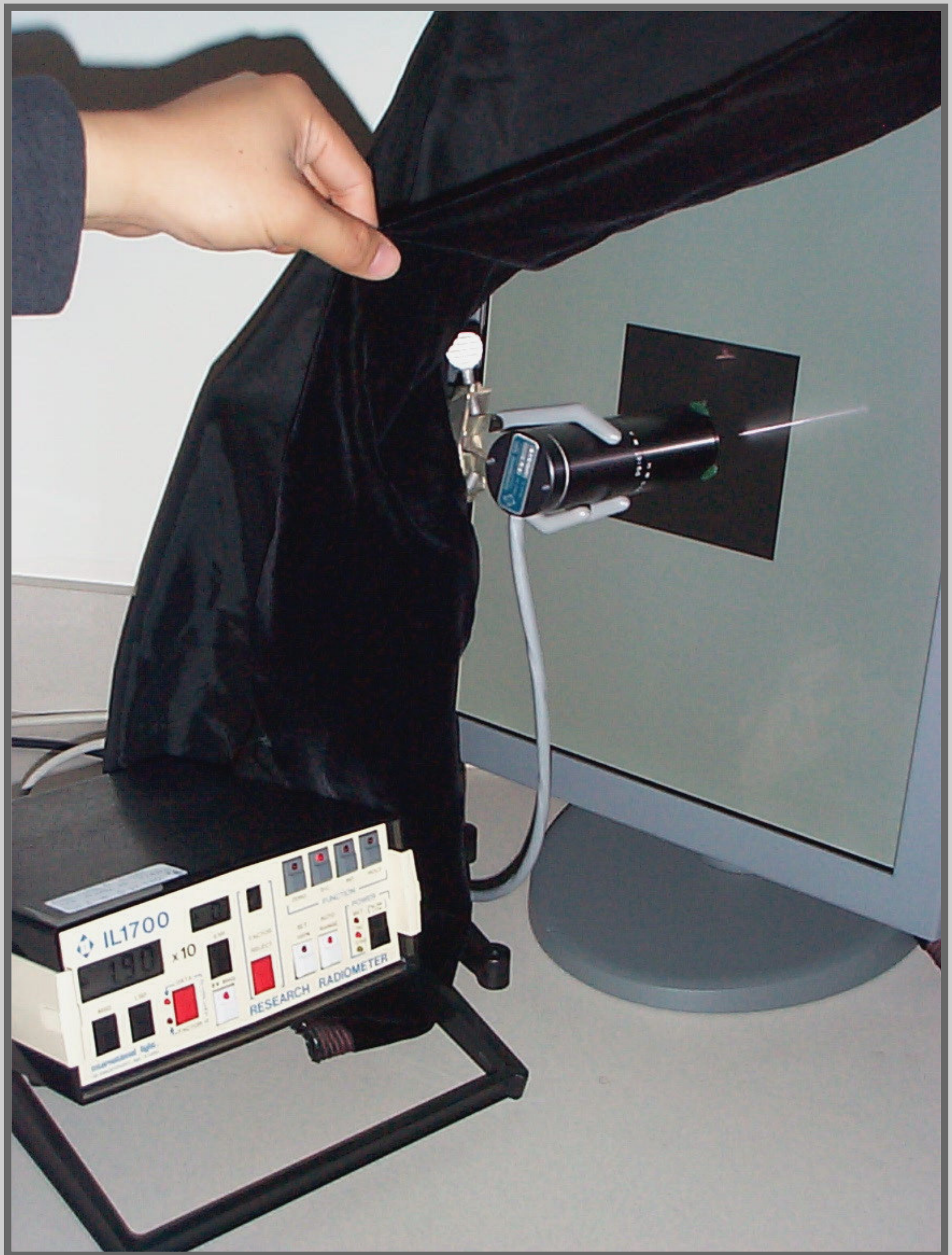


Luminance measurements

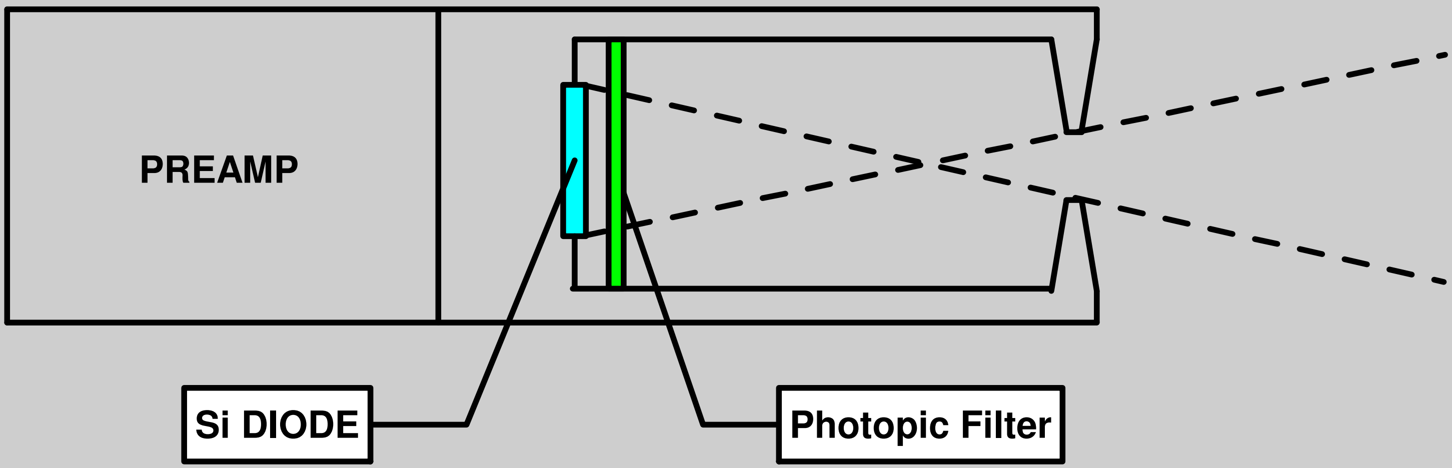
Calibration requires precise measurement of luminance for all gray values in the palette.



4 min for 256
12 min for 766
30 min for 1786



- International Light Radiometer with high sensitivity Si photodiode.
- Collimated aperture to restrict the angular response to emissions normal to the surface.

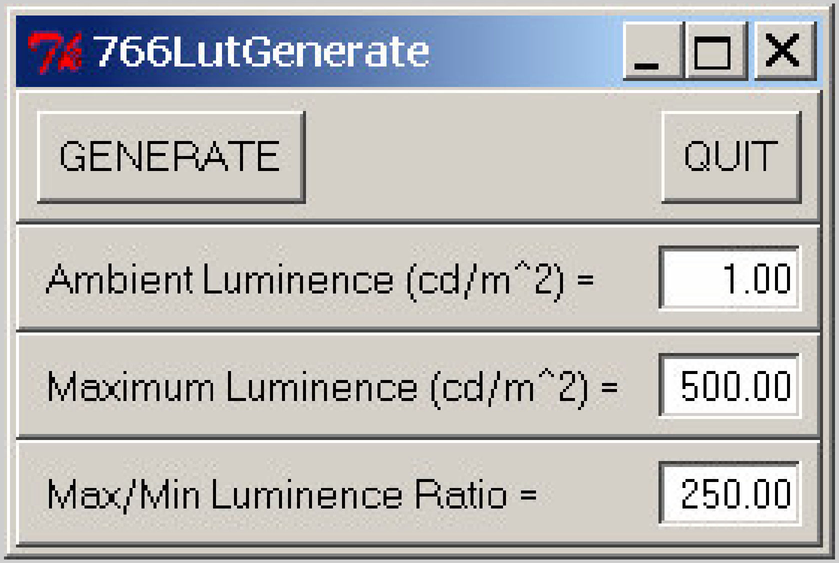


Calibration LUT

- Define the exact luminance for 256 luminance values that follow the DICOM 3.14 standard between a designated Lmin and Lmax.
- Adjust for ambient luminance by subtracting a nominal value for Lamb.
- From the measured palette, select those entries that most closely match the desired values.

LutGenerate

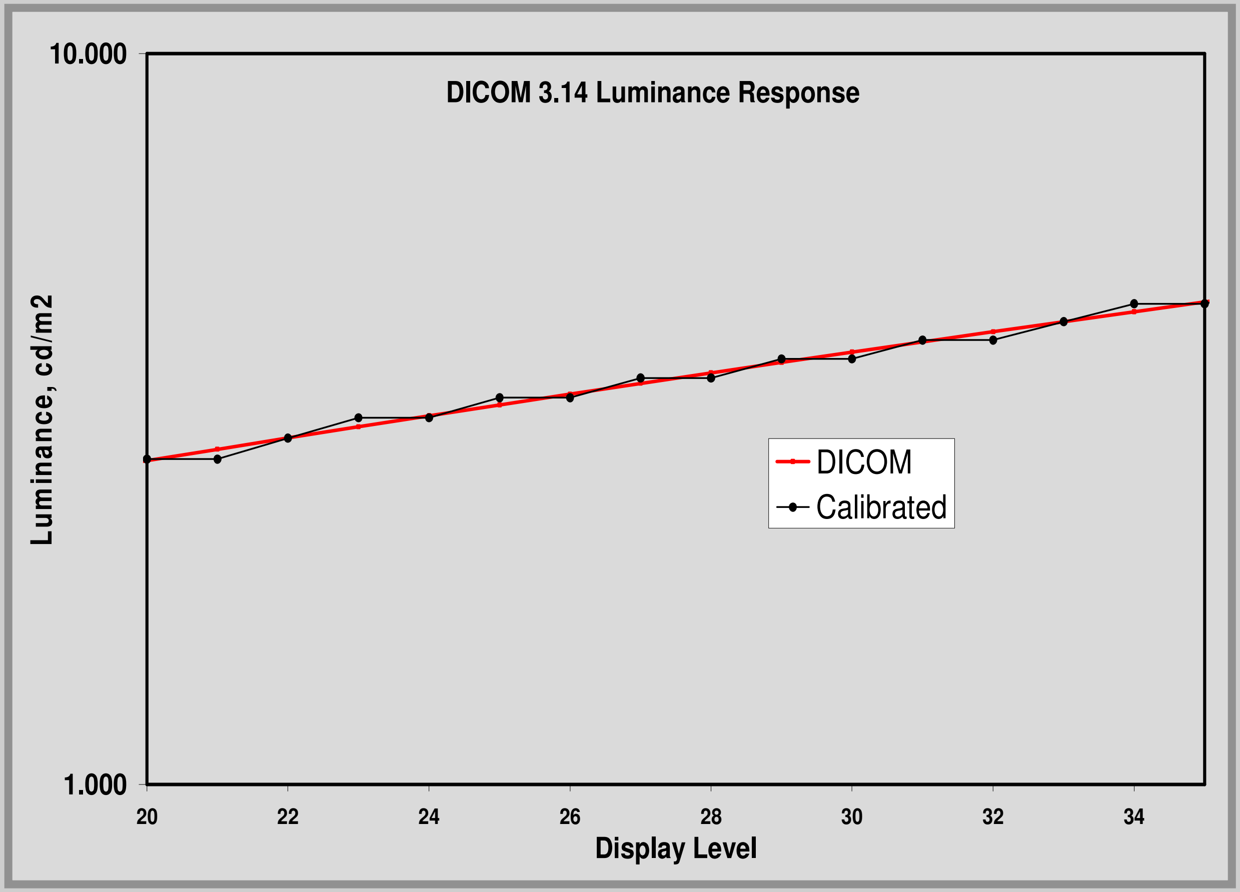
Measured palette data is converted to a calibration LUT in a format that can be automatically installed for controller with standard drivers.



Calibrated response evaluation - AAPM

"Assessment of Display Performance for Medical Imaging Systems"

"… The measured contrast associated with the luminance difference between each sequential gray level available from the display controller, dLp/Lp, should be compared to the expected contrast per JND associated with the DICOM GSDF."

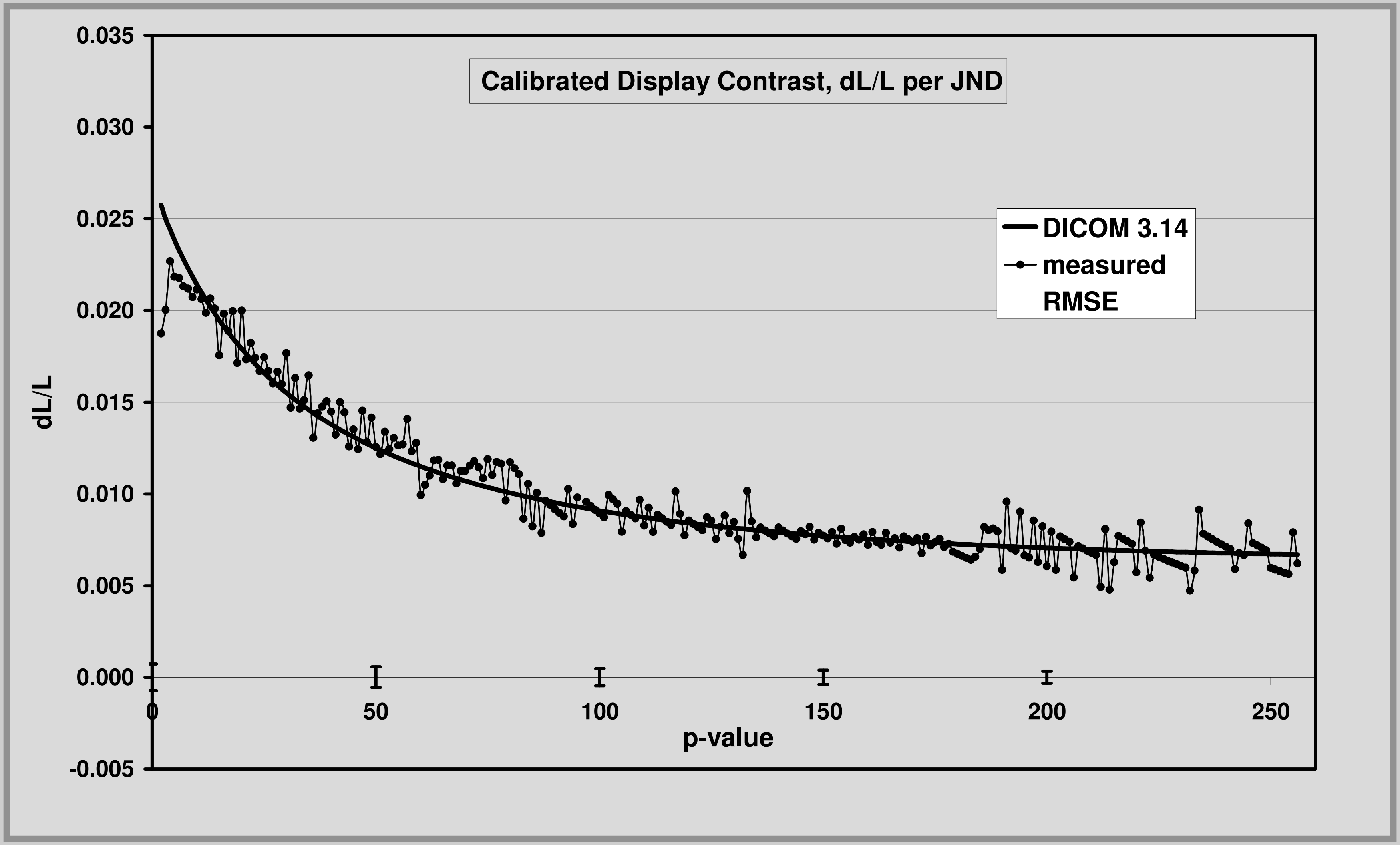


"The contrast noise can then be described by the maximum deviation and the root mean squared error of the observed JNDs per luminance interval values. …"

Dome 3Mp – Calibrated – LR 600

Max. L' =	513.1	ΔJND =	645.0453407
Min. L' =	0.844	JND/ΔL =	2.529589571
L_amb =	0.10	L'max/L'min=	608

JNDs/p	2.53
avg ΔJND	0.00
st. dev:	0.30 , 12%
Max |ΔJND|:	2.53



Calibration recommendations

- LCD gray calibrations should be done using measurements of the luminence for all possible states of the palette being used.
- Precise measurements of luminance can be easily made using rapid automated methods.
- Calibration LUTs should be delivered by the supplier or obtained when monitors are received.
- A wide range of devices can be calibrated using the methods described.

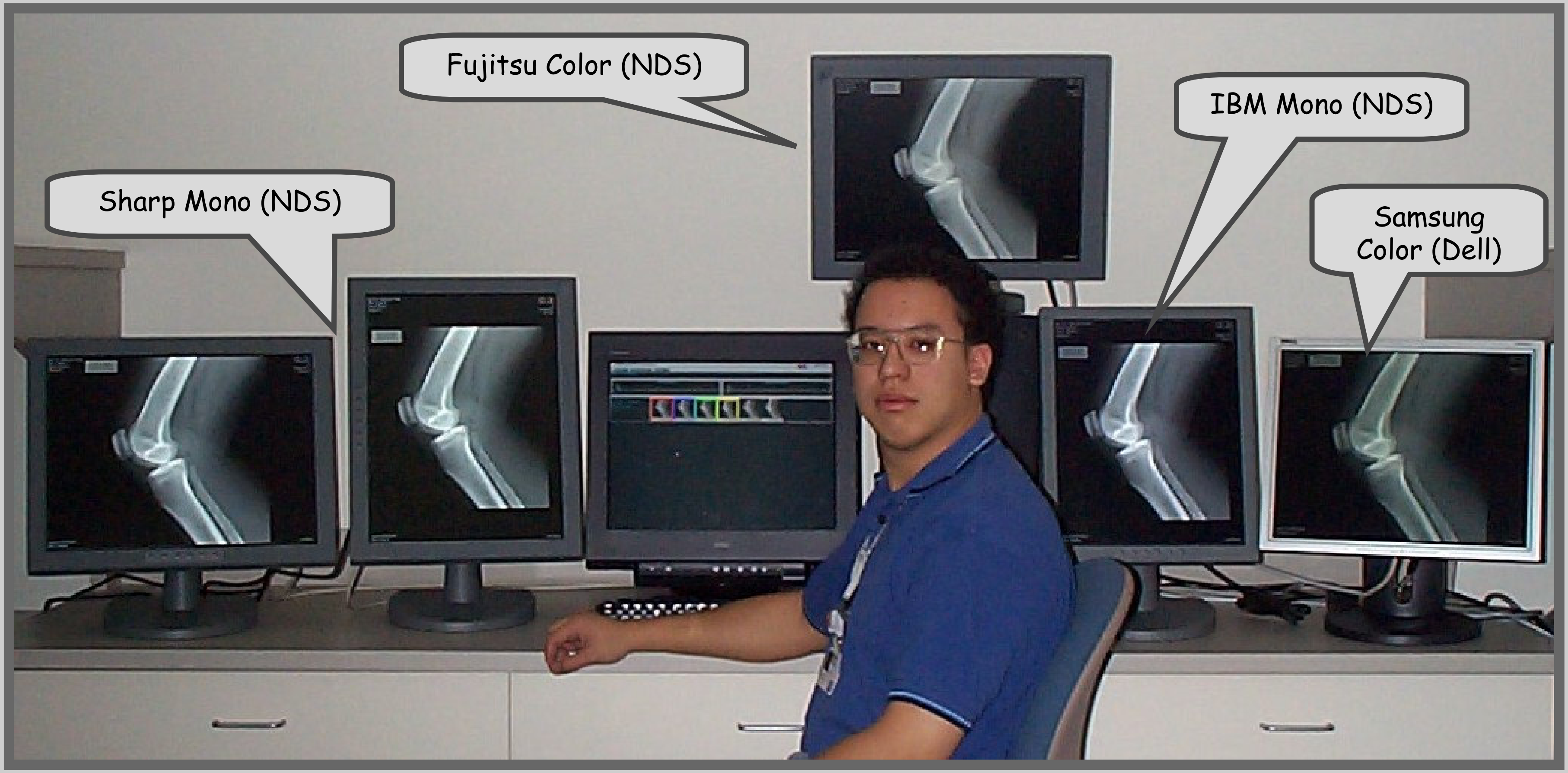
Requirements

For

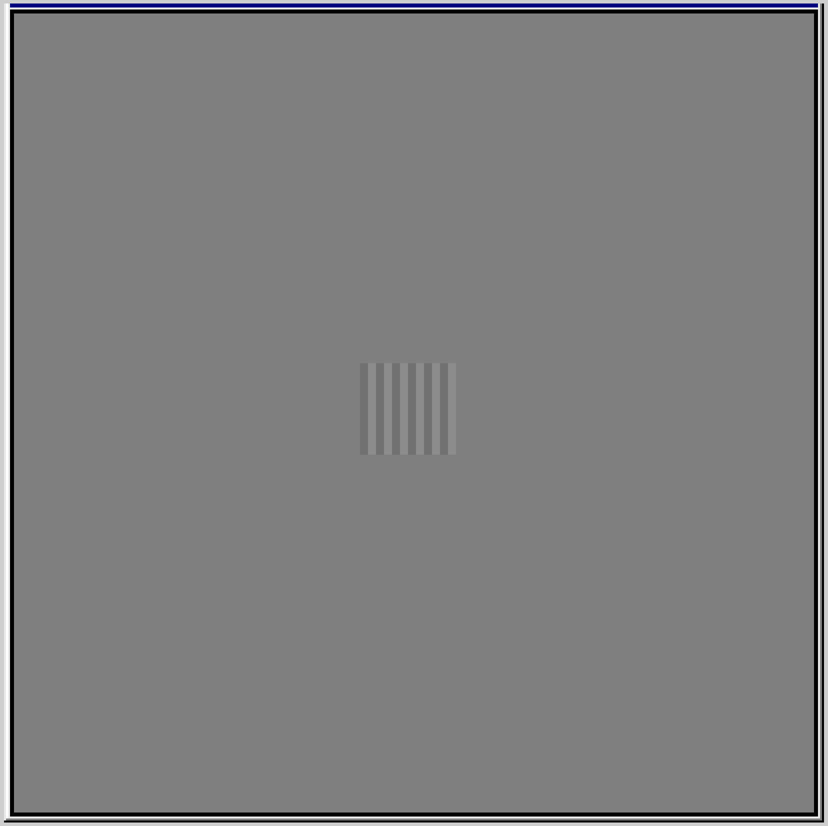
Equivalent Appearance

2 requirements for equivalent contrast appearance!

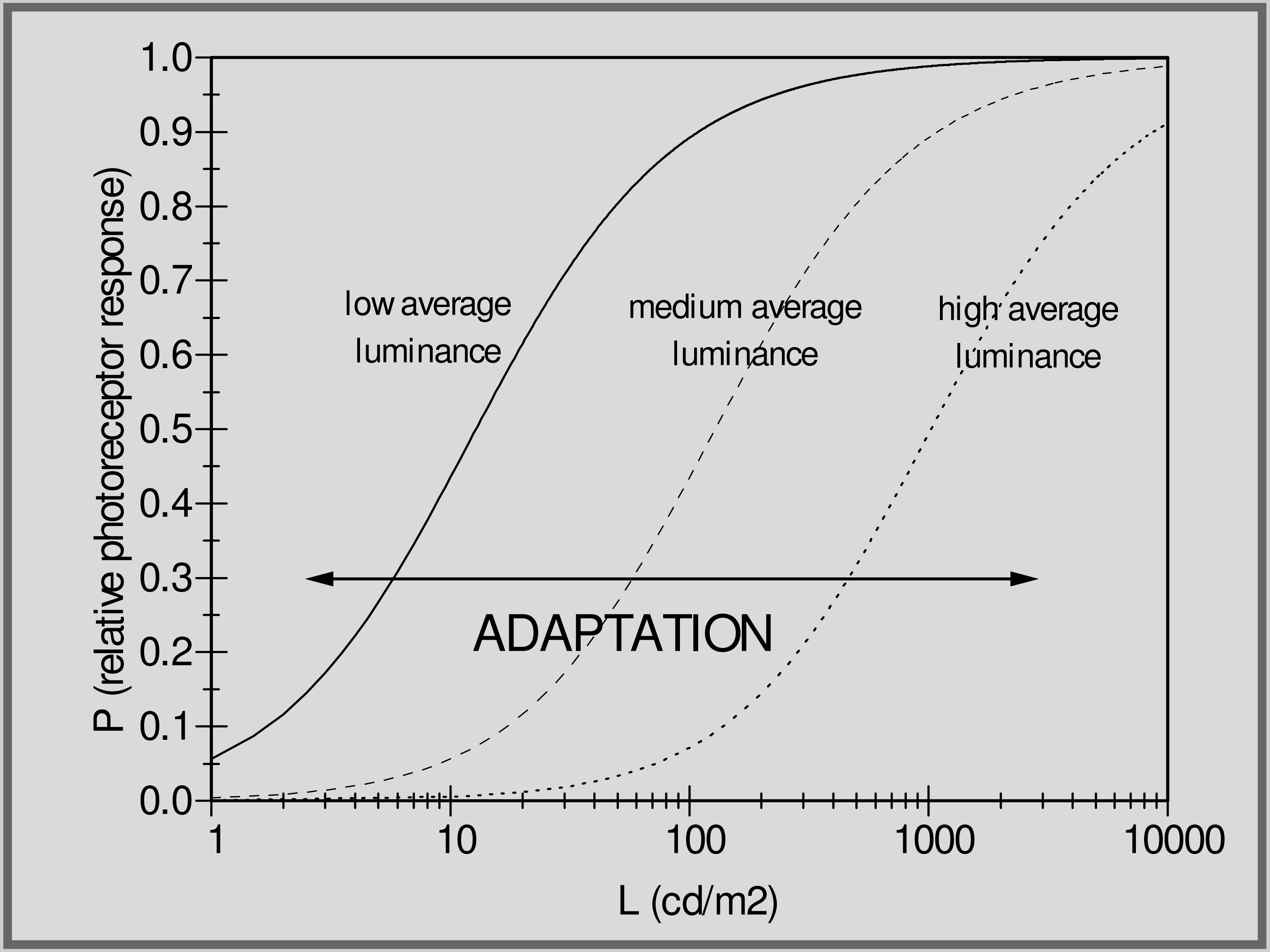
- The same luminance response (DICOM GSDF)
- Equal luminance ratio (Lmax/Lmin)



Contrast sensitivity varies with adaptation to the average luminance of a relatively large field.

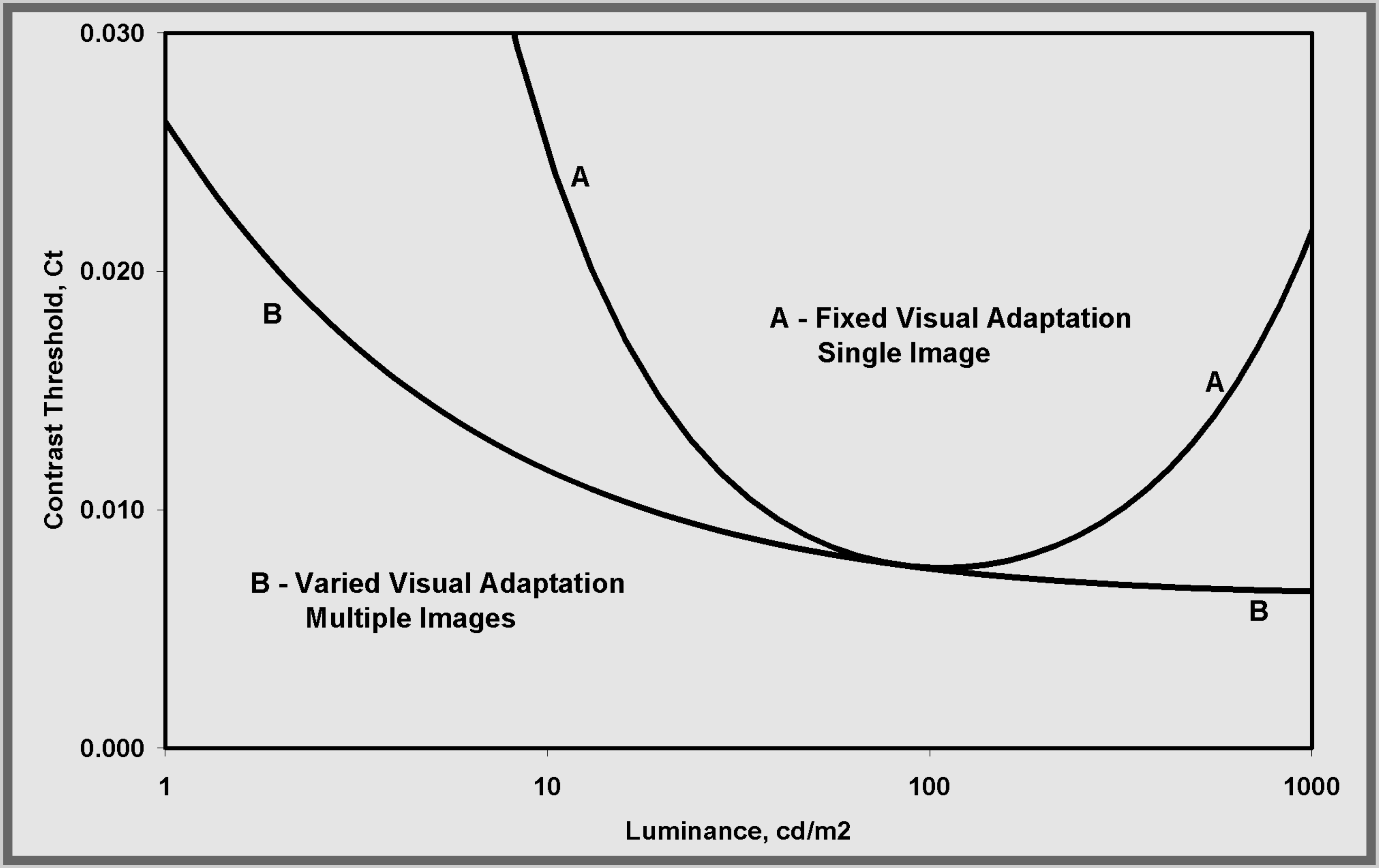


Luminance response of photo-receptors in the eye



Flynn, Radiographics 1999

Fixed versus variable adaptation

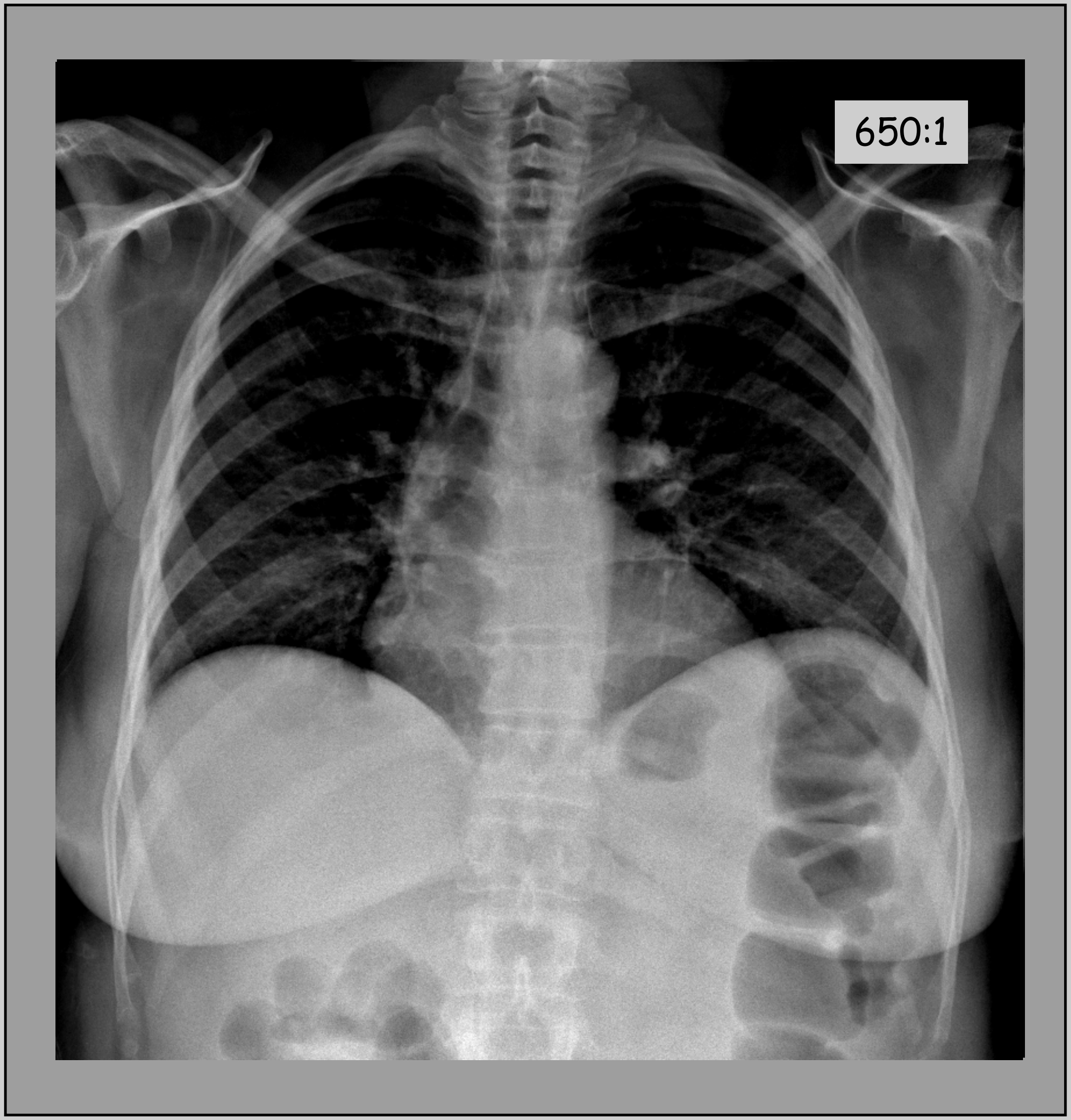


Contrast threshold for varied visual adaptation (A, Flynn 1999b) and fixed (B) visual adaptation: The contrast threshold, $\Delta L/L$, for a just noticeable difference (JND) depends on whether the observer has fixed (B) or varied (A) adaptation to the light and dark regions of an overall scene.

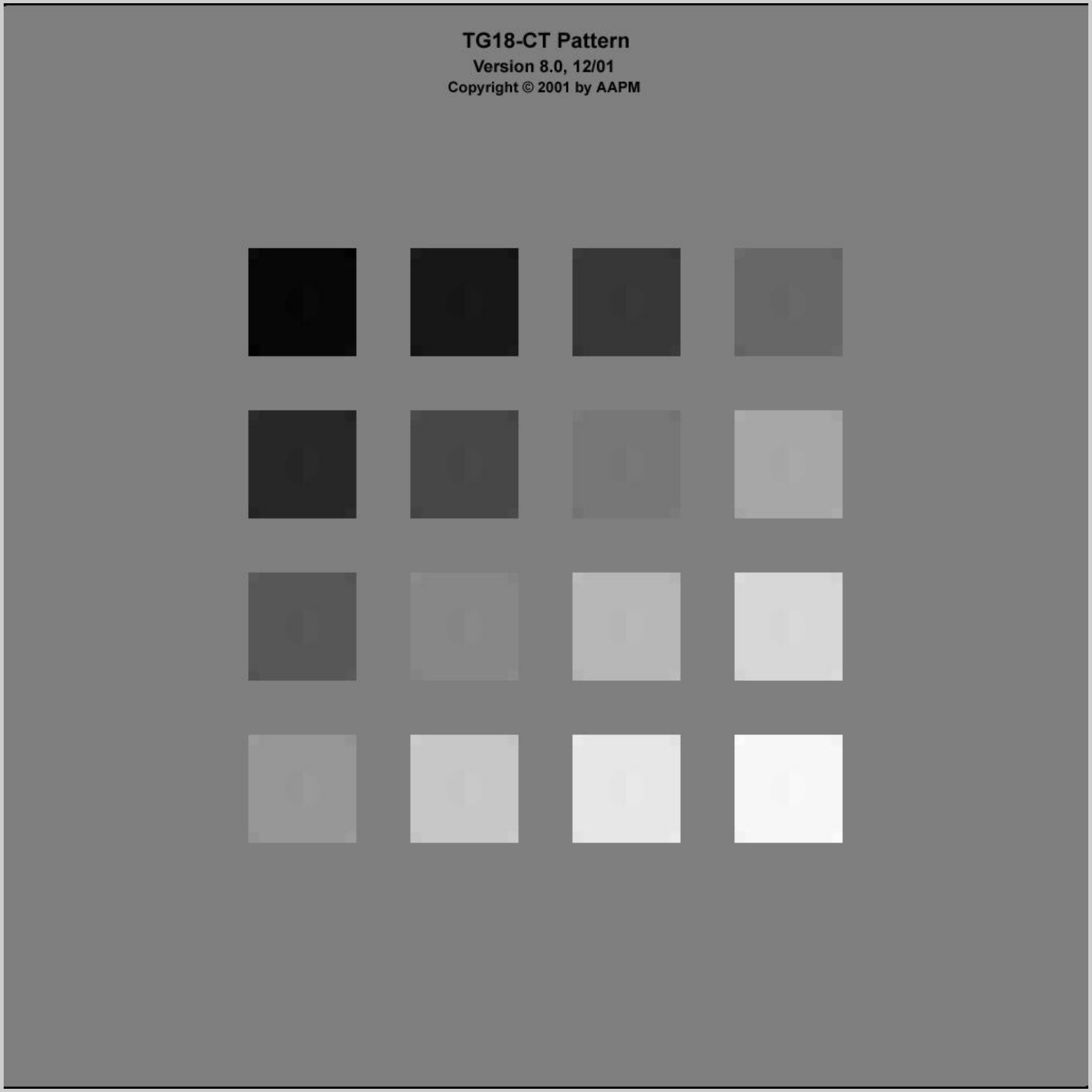
Effect of Lmax/Lmin

250:1 → .1 to 2.50 FD
350:1 → .1 to 2.65 FD
650:1 → .1 to 2.90 FD

- Medical images should be displayed using a luminance ratio of 250-350.
- Images should be processing and WW/WL set with the expection that they will be displayed using a specific luminance ratio.
- Display at a different luminance ratio cause improper appearance.



TG18-CT



AAPM visual test pattern for the assessment of contrast transfer

Setting Luminance Ratio for LCDs

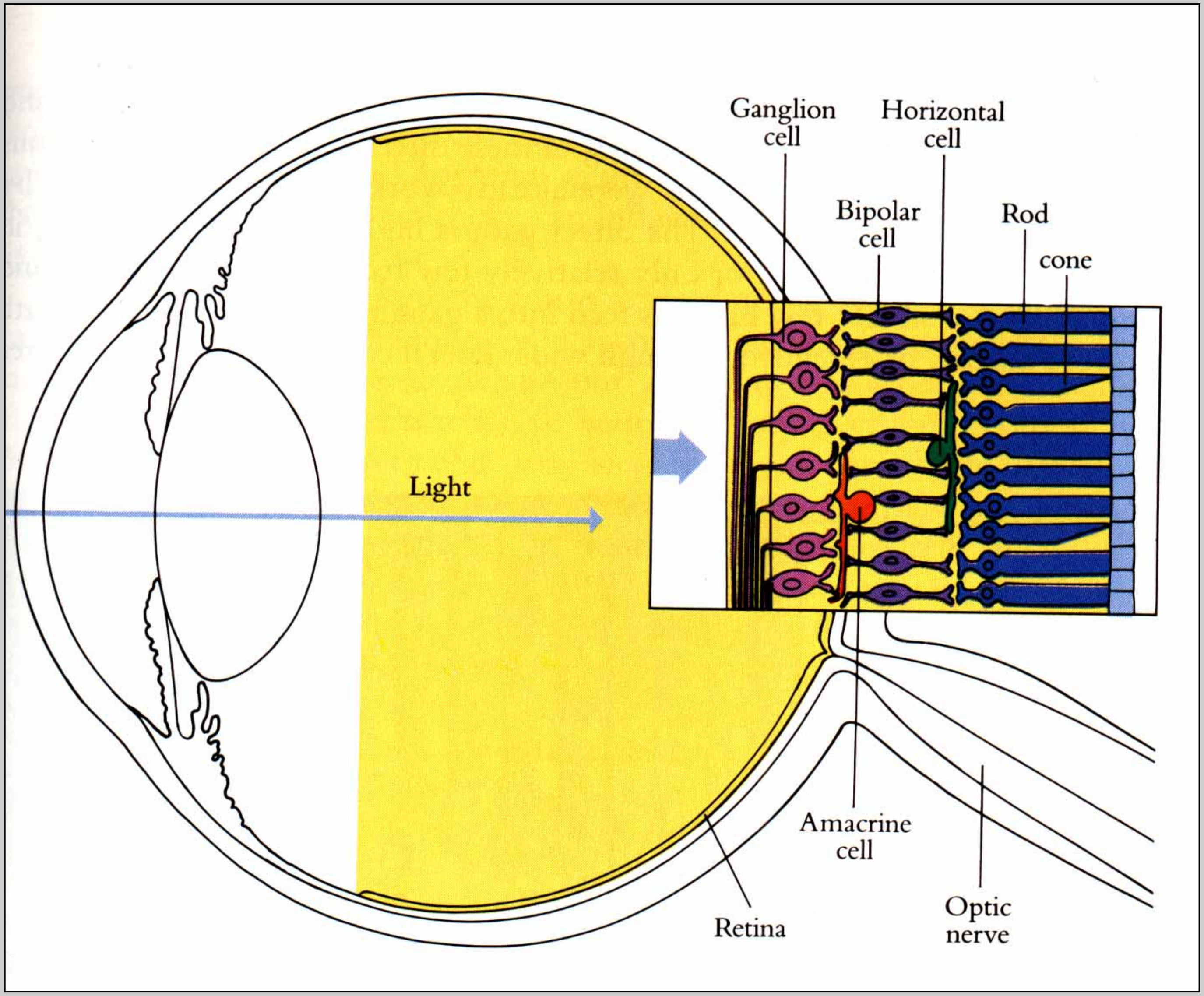
- Previously, CRT monitors could be set to a desired luminance ratio by adjusting the contrast and brightness controls. This was often done using the SMPTE test pattern. Monitors were set such that the low contrast object in the dark and bright regions were both visible. This results in a luminance ratio of about 250.
- However, for LCD systems there is no simple control to adjust Lmin and set the desired luminance ratio. This must be specified when the calibration table is generated for the monitor. New monitors have provisions to store alternative look up tables internally to allow the desired calibrated luminance ratio to be set from menu selections.

Visual Acuity

And

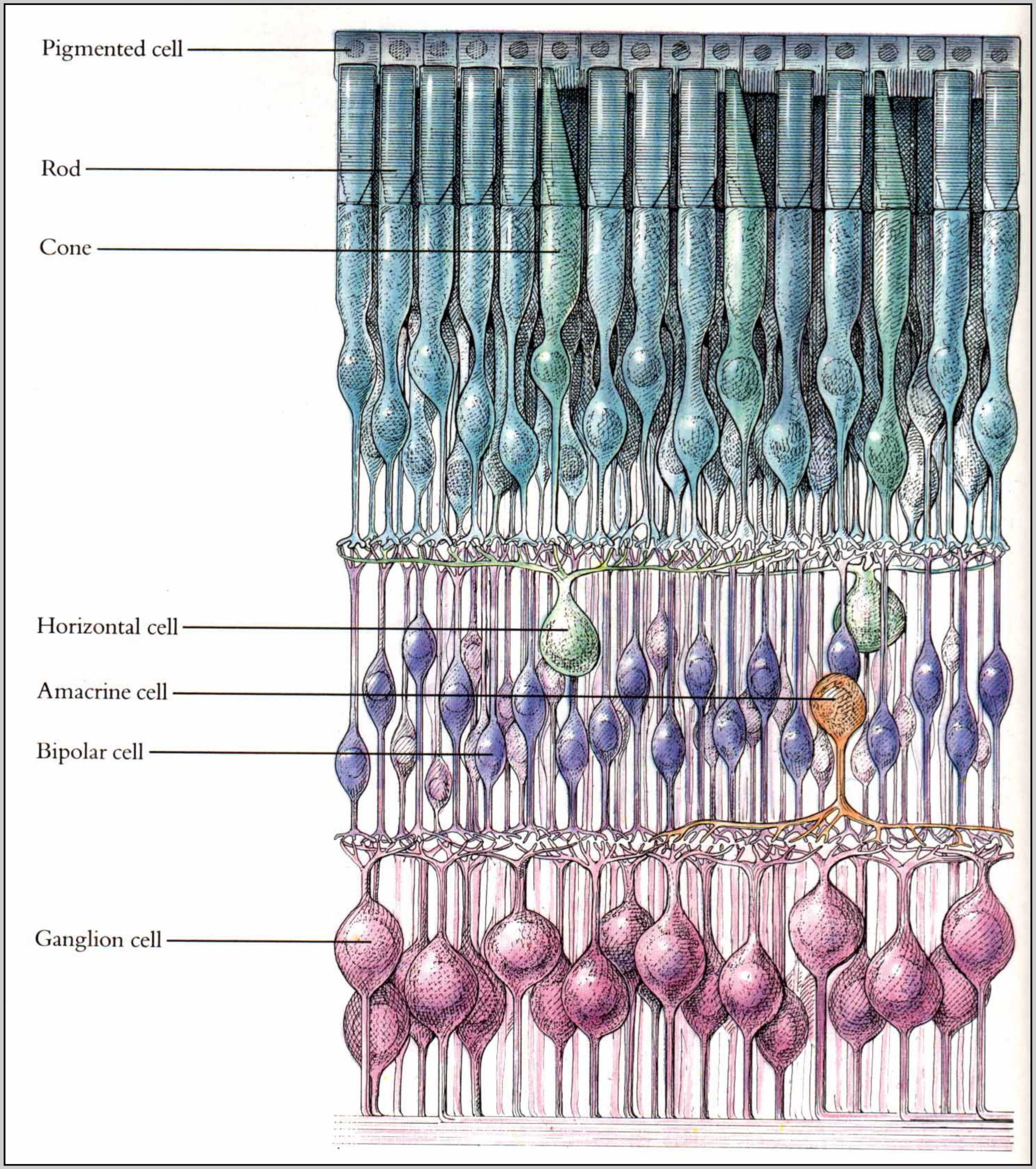
Display Detail

The retina of the human eye contains a network of rods and cones interconnected by neural cells.



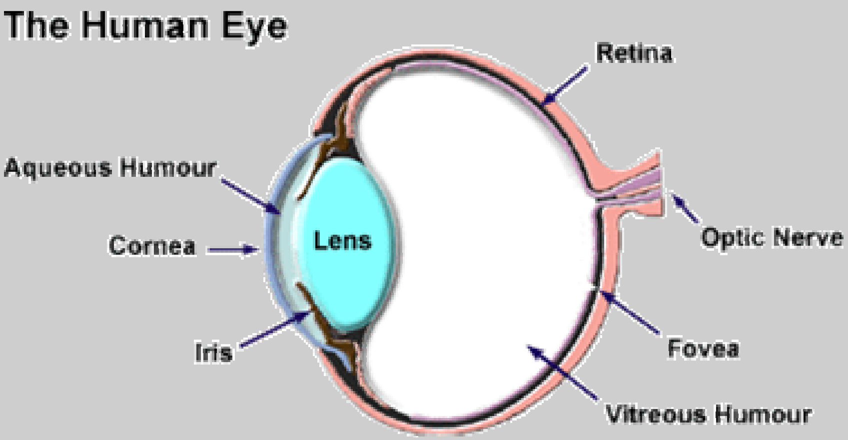
160 million rods
- high sensitivity
- gray response

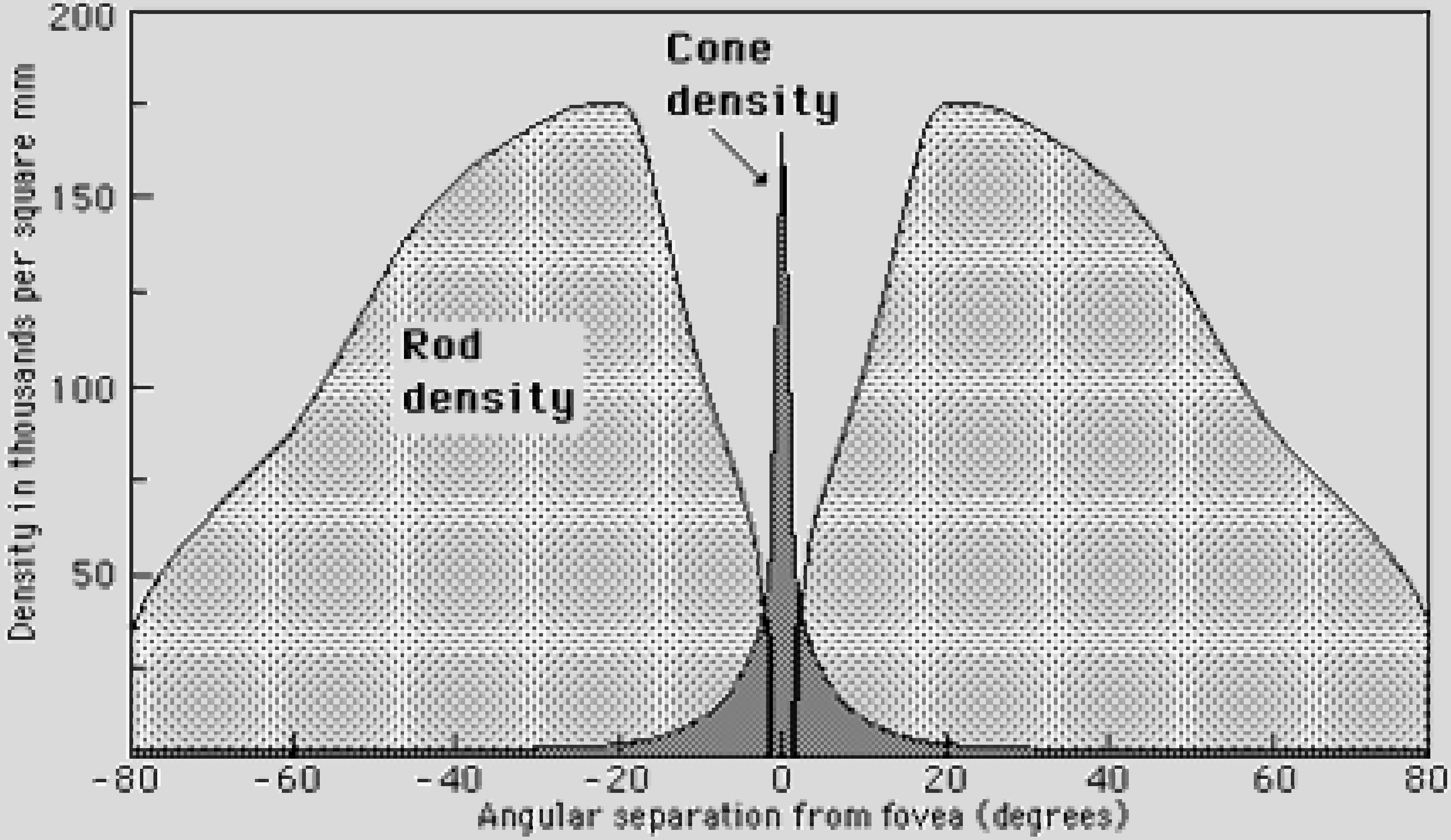
6-7 million cones
- low sensitivity
- color response



HVS: Foveal response

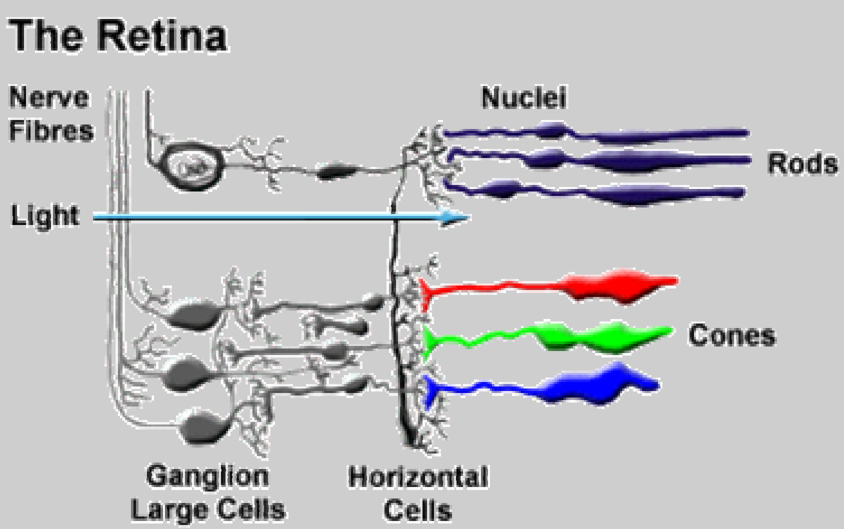
Particularly thin cones (2 μm) are densely packed in the fovea centralis. They provide high detail color response.





HVS: Cone spectral response

- The pigments for three different types of cone receptors have varying spectral response.
- The spectral response was measured in 1965 and are often labeled as beta(blue), gamma (green) and rho(red).



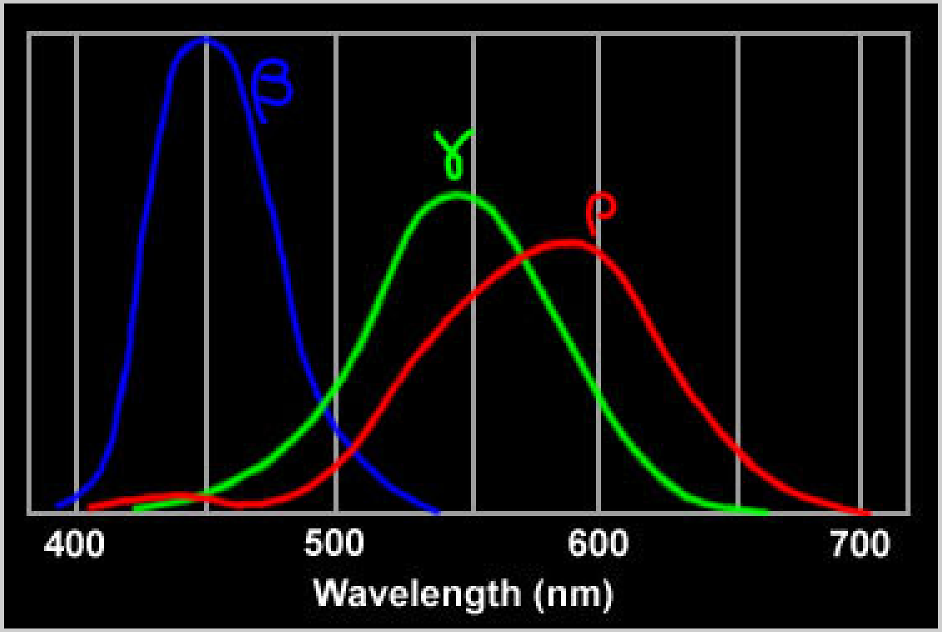
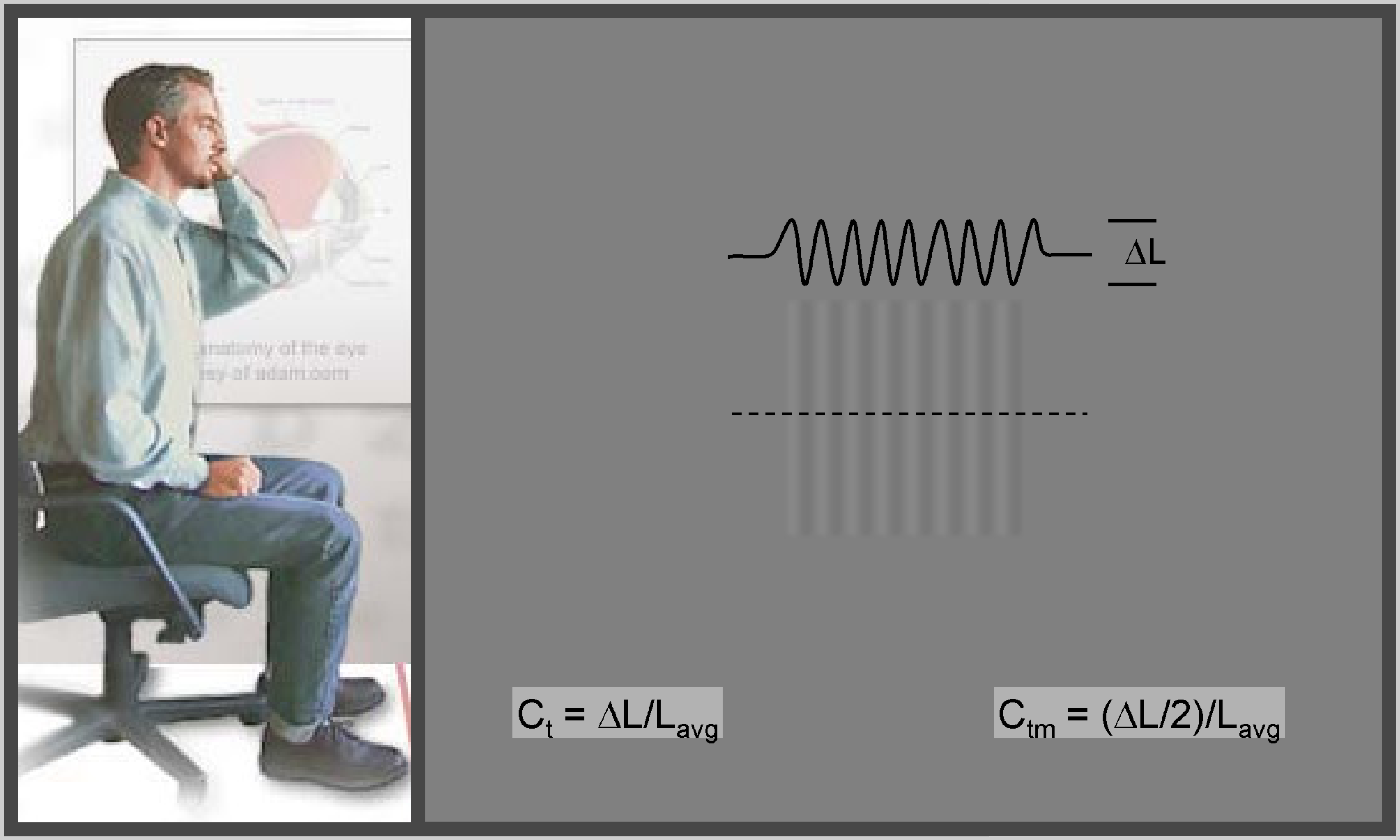


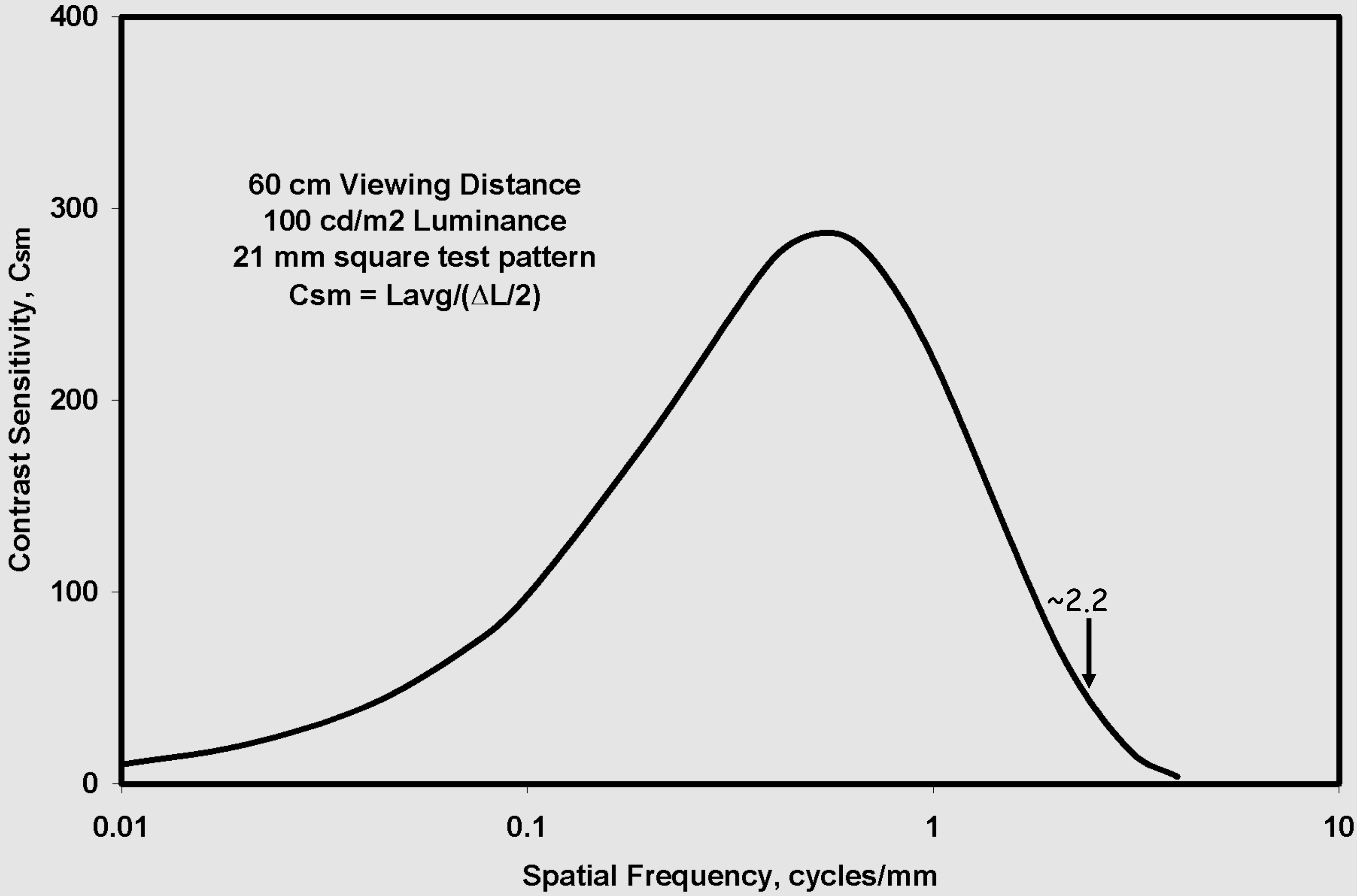
Illustration from Photo.net (Ed Scott)

A variety of test patterns are used to assess visual acuity. Clinical measures are done typically with a Snellen eye chart. Much psychovisual research has been done using sinusoidally modulated test targets.



Contrast Sensitivity as a measure of spatial acuity

Contrast sensitivity is the inverse of contrast threshold: $C_s = 1/C_t$



- The pixel size of a display system that matches the resolving power of the human eye depends on the observation distance and on the display luminance.
- For a square-wave pattern with a contrast of 0.05, the maximum frequency that will be visible and the corresponding pixel size can be determined from contrast sensitivity data.

Luminance (cd/m^2)	100	1000
Close inspection (0.33 m)	4 cycles/mm **0.125 mm/pixel**	5 cycles/mm **0.100 mm/pixel**
Normal viewing (0.66 m)	2 cycles/mm **0.250 mm/pixel**	2.5 cycles/mm **0.200 mm/pixel**

Monitor size and resolution

For digital radiographs with 7.5 million pixels

(.140 mm pixel, 35 x 43 cm, 2.500 x 3000),

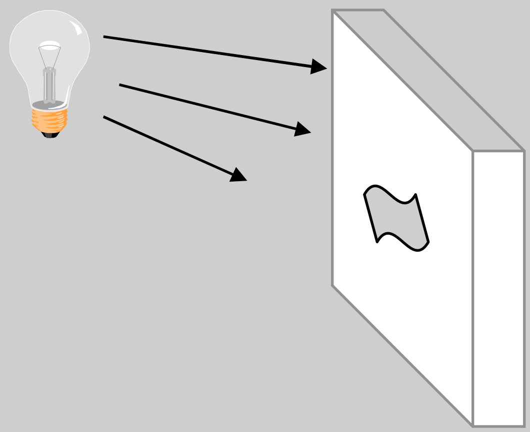
- **3 MP LCD monitors**:
  - 20.8 inch (32 x 42 cm) 3.1 megapixels (.207 mm pixels)
  - 66 cm viewing distance to match visual acuity limits.
  - With detector and display pixels matched (no interpolation)
    - Image presented at 1.5 times true size (no interpolation)
    - 2/3 x 2/3 of the radiographic field visible.
- **9 MP LCD monitors**:
  - 22.2 inch (30 x 38) 9.2 megapixels (.125 mm pixels)
  - 33 cm viewing distance to match visual acuity limits.
  - With detector and display pixels matched (no interpolation)
    - Image presented at .9 times true size (no interpolation)
    - The radiographic field fills 80% of the display field.

Effects of Ambient Light

Degradation by diffuse and specular reflection

- Specular - Light sources should not be visible
- Diffuse - Minimal luminance with monitor off

- White objects:
  - The brightness of a white object illuminated by I lux is .9I/π nit.



- Criteria:
  - The change in luminance caused by the reflection of a white object should be below the visible threshold: ($C_t L_{min}$).

$$R_S\left(\frac{0.9I}{\pi}\right) = C_t L_{\min}$$

- Example:
  - The contrast threshold, Ct, at 4 nit is 0.012. In a room with 100 lux, the specular reflection coefficient, Rs, should be < 0.002.

Max Illumination to Control Reflections

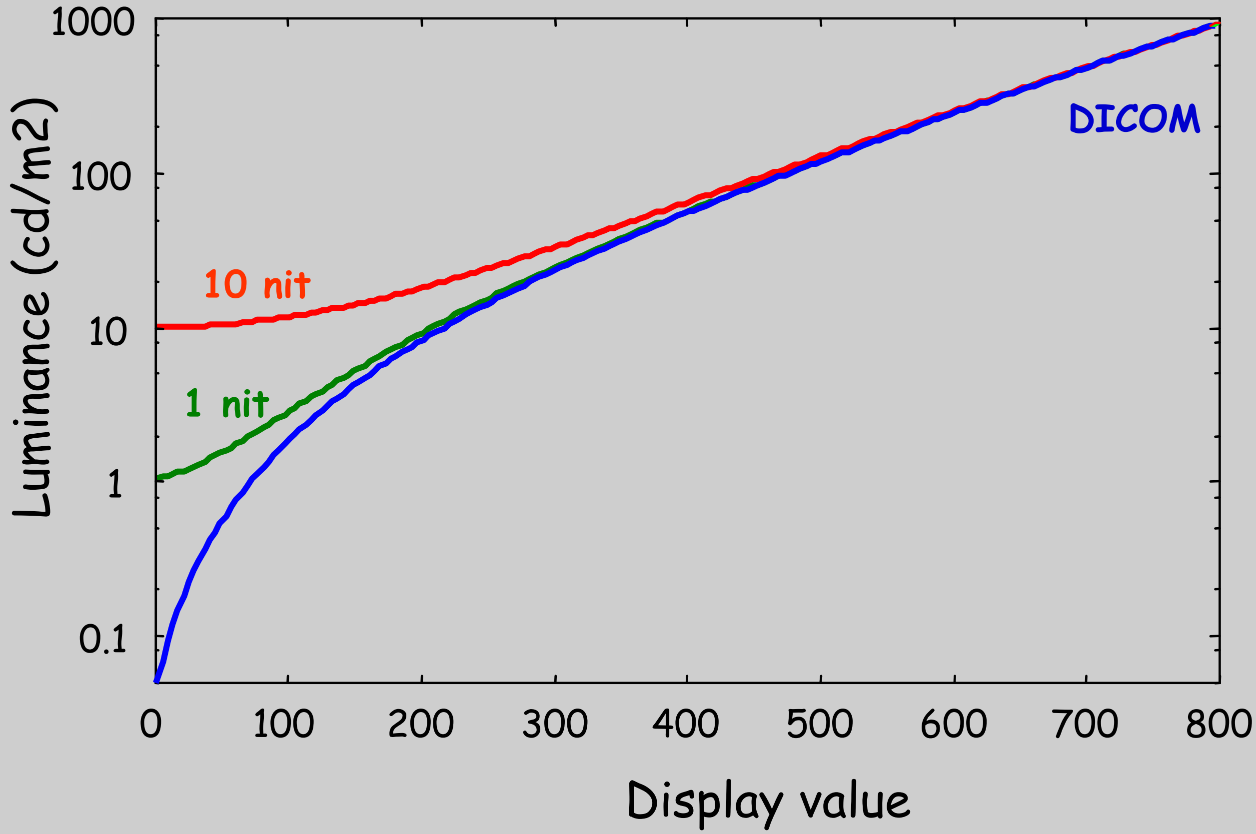
Rs for CRT - .004 to .008
Rs for LCD - ~.002

Ambient illumination (LUX) which maintains specular reflections of white and black objects below the contrast threshold (C_t).

L_{max} - L_{min}	C_t @ Lmin	.002	.004	.008	.020	.040 = R_s	
5000 - 20	.010	349	175	87	35	17	
2500 - 10	.011	192	96	48	19	10	MAX
1000 - 4	.015	105	52	26	10	5	=ROOM
500 - 2	.018	63	31	6	6	3	LUX
250 - 1	.024	42	21	10	4	2	

Operating Rooms……… 300-400 Lux
Emergency Rooms……. 150-300
Staff Offices…………… 50-180
Clinical Viewing Areas…………….. 200-250
Diagnostic Viewing (CT/MR)…… 15 - 60
Diagnostic Viewing (X-ray)……… 2 - 10

Contrast reduction from diffuse added luminance



- **Problem:**
  - The Diffuse reflection of light adds an unstructured constant luminance to the image which reduces contrast in dark regions.
  - The diffuse reflection coefficient describes the added luminance per illuminance, Rd (nit/lux).

$$\Delta L = R_d I$$

- **Criteria:**
  - The relative change in contrast produced by ambient illumination should not be less than .8.

$$\frac{1}{\left(1 + \frac{\Delta L}{L_{\min}}\right)} \geq .8$$

- **Example:**
  - For a display with 400 nit max, 4 nit min in a room with 100 lux, the diffuse reflection coefficient should be < 0.01 nit/lux.

D: Max Illumination to Control Diffuse Artifacts

Rd for CRT - .02 to .03
Rd for LCD - ~.005

Ambient illumination which maintains 80% contrast in dark regions

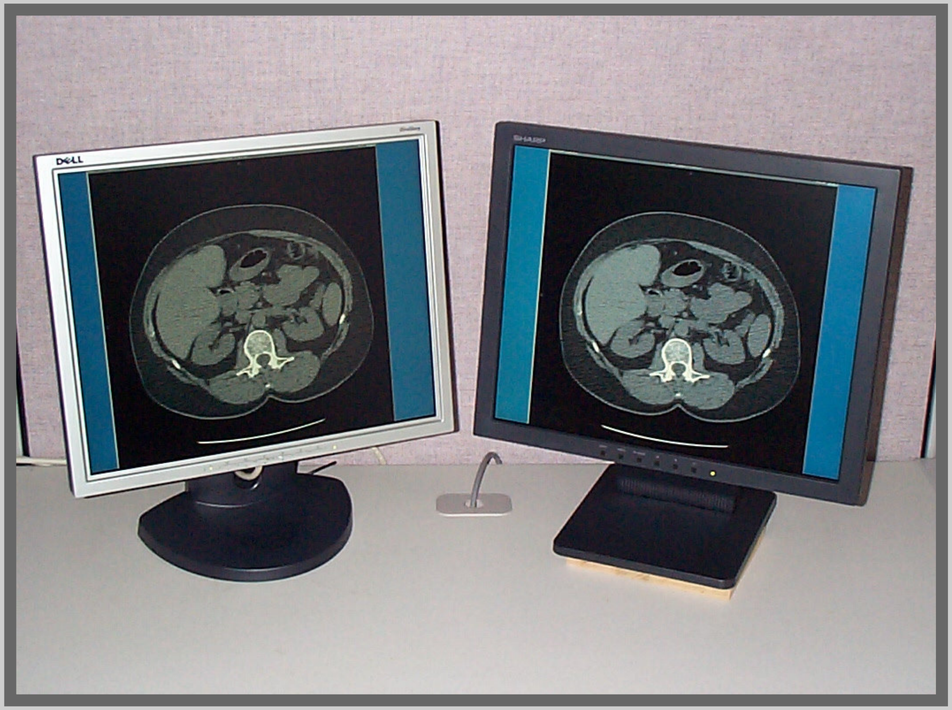
L_{max} - L_{min}	.005	.010	.020	.040	.060 = R_d ,nit/lux	
5000 - 20 nit	1000	500	250	125	83	MAX
2500 - 10	500	250	125	62	42	= ROOM
1000 - 4	200	100	50	25	17	LUX
500 - 2	100	50	25	12	8	
250 - 1	50	25	12	6	4	

Operating Rooms……… 300-400 Lux
Emergency Rooms……. 150-300
Staff Offices…………… 50-180

Clinical Viewing Areas……………. 200-250
Diagnostic Viewing (CT/MR)…… 15 - 60
Diagnostic Viewing (X-ray)……… 2 - 10

D: LCD reflection

- LCD monitors have a complex reflection distribution
- Excellent performance can be obtained if lights sources are located at more that 45 degrees from the surface normal



Display performance measurement

And

Quality Control

(TG 18)

- **Assessment of display performance for medical imaging systems,** Americal Association of Physicists in Medicine (AAPM, Task Group 18)
- Describes standard and objective evaluation methods and criteria for medical displays

TG18 document

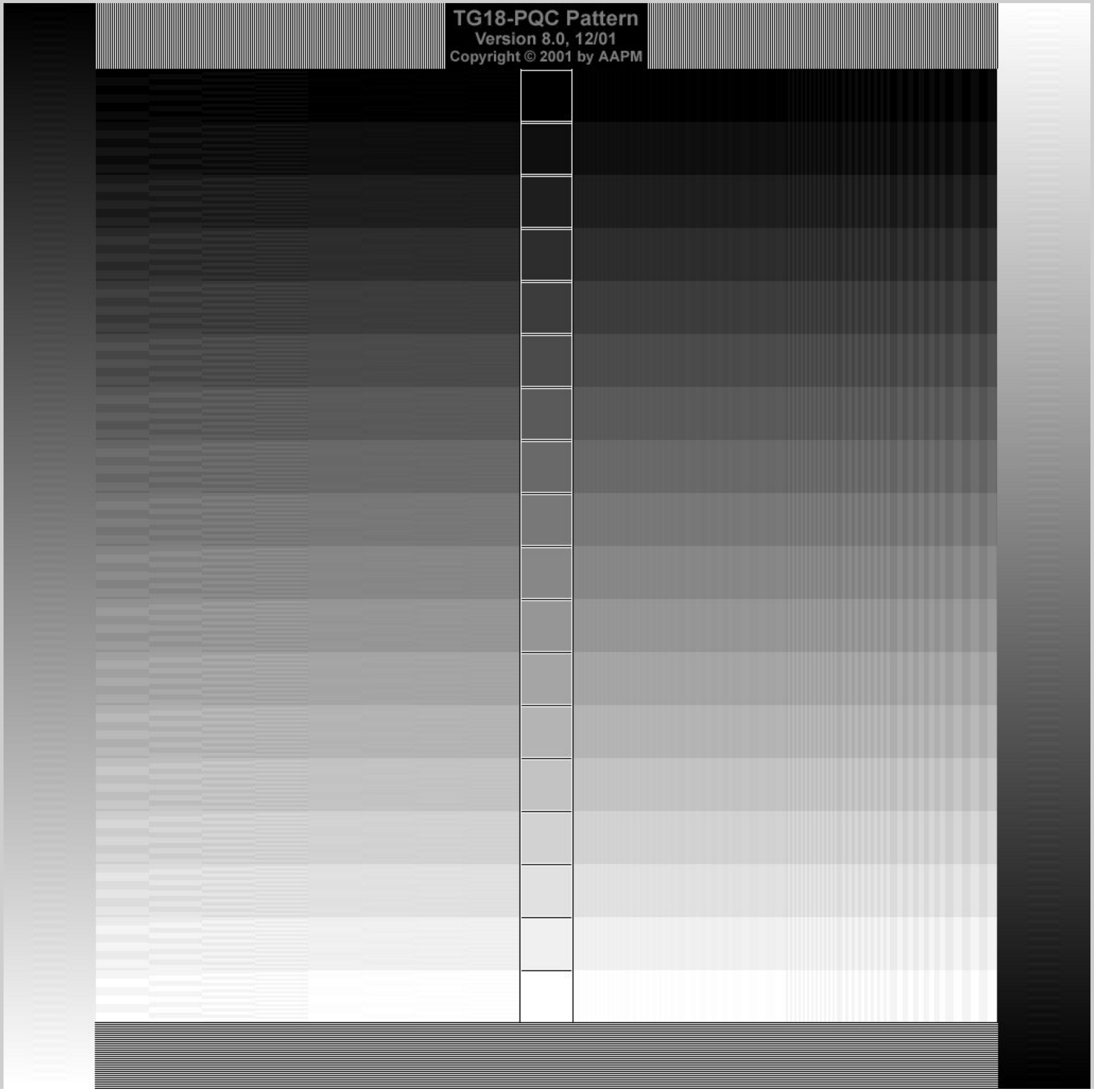
- Reviews current display metrology standards
- Reviews current display technologies
- Describes prerequisites and tools for display assessment
- Defines display assessment methods and procedures
- Specifies performance requirements for medical displays
- Suggests specific acceptance testing and quality control methods

- 2 display classes:
  - Primary: for primary interpretation of medical images
  - Secondary: for review of images for which interpretations are already rendered
- 3 Testing levels:
  - Visual tests
  - Quantitative tests
  - Advanced tests

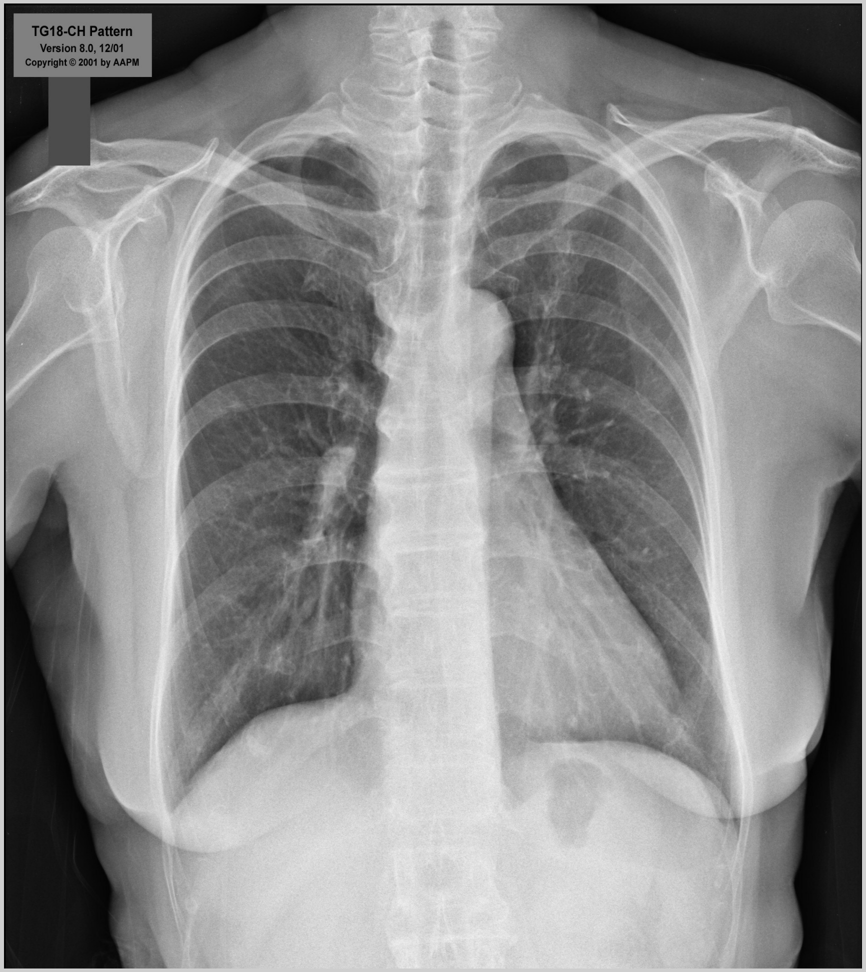
- Instrumentation
  - Luminance and illuminance meters
  - CCD cameras, scientific / photographic
  - Light source, cone device, etc.
- TG18 test patterns
  - Specifically-designed patterns: TG18-XX##

TG18 Test Patterns

The TG 18 test pattern set is available in both tif and DICOM formats

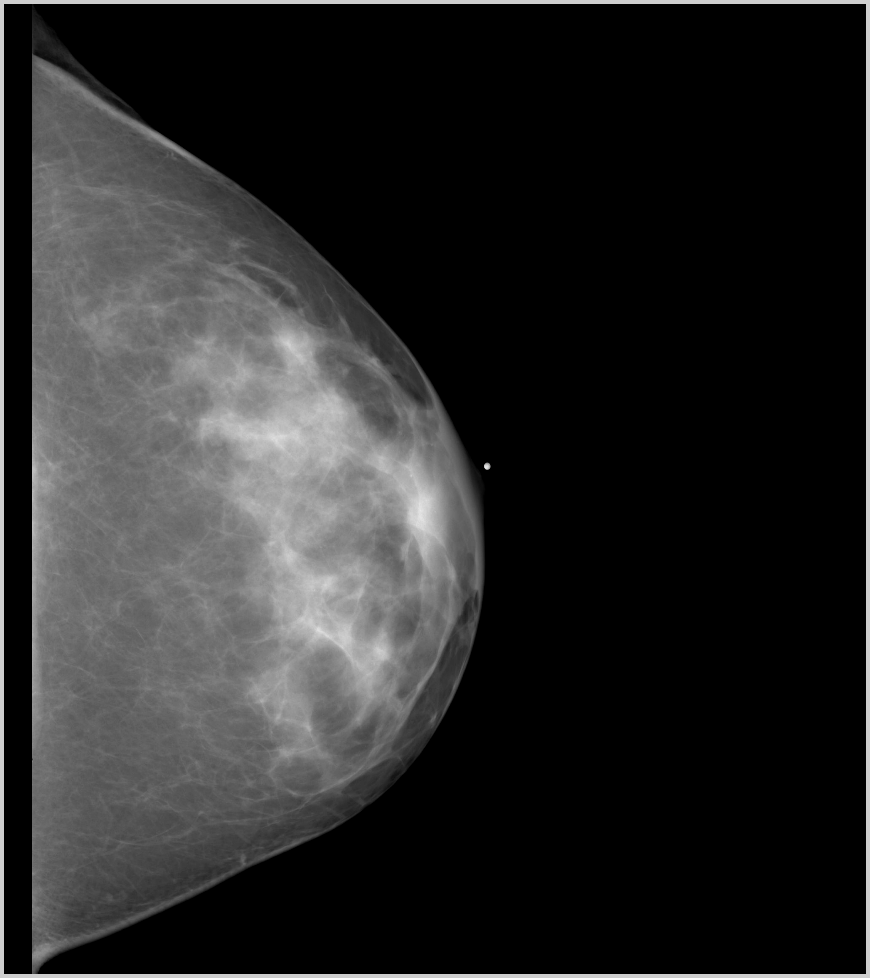


Clinical Test Pattern, TG18-CH



Evaluation elements

1. Degree of difficulty for exam
2. Overall Contrast
3. Overall Sharpness
4. Symmetrical reproduction of the thorax
5. Medial border of the scapulae
6. Reproduction of rib cage above the diaphragm
7. Sharp reproduction of the vascular patterns Sharp reproduction of the trachea and proximal bronchi
8. Sharp reproduction of the borders of the heart and the aorta
9. Sharp reproduction of the diaphragm
10. Visibility of the retrocardiac lung and the mediastinum
11. Visibility of the spine through the heart shadow
12. Visibility of small details in the whole lung
13. Visibility of linear and reticular details out to the lung periphery



Evaluation elements

1. Degree of difficulty for exam
2. Overall contrast
3. Overall exposure/penetration
4. Overall sharpness
5. Overall positioning:
6. Adequate compression
7. Sharp appearance of Cooper's ligaments

- Purchase specification and acceptance tests
  - Should include all key display characteristics
  - All tests should be quantitative
  - Performed by a medical physicist (1-2 hours per display)
- Annual compliance evaluation
  - Redoing of almost all acceptance tests
  - Performed by a medical physicist (1-2 hours per display)
- Monthly/quarterly evaluation
  - Mix of quantitative and visual tests
  - Performed by a QC technician (~ 20 minutes)
  - Results logged for consistency checks
- Daily evaluation (by user)
  - Checks with login test pattern presentations (~ < 1 minutes)
  - clear instructions about who to call

TG18 website

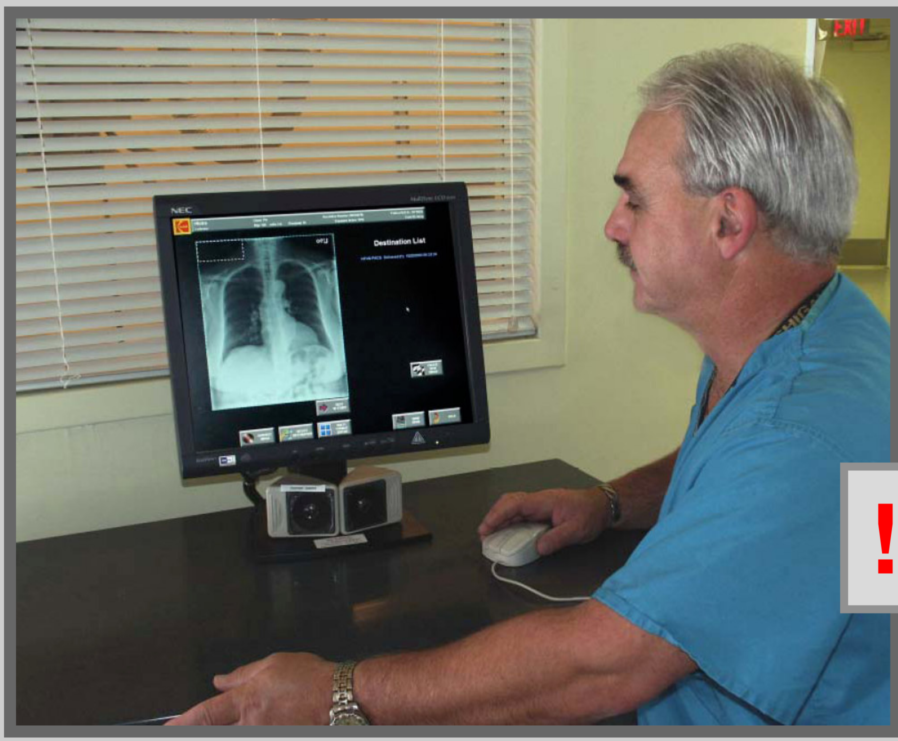
deckard.mc.duke.edu/~samei/tg18

Special issues with DR image presentation on PACS workstations

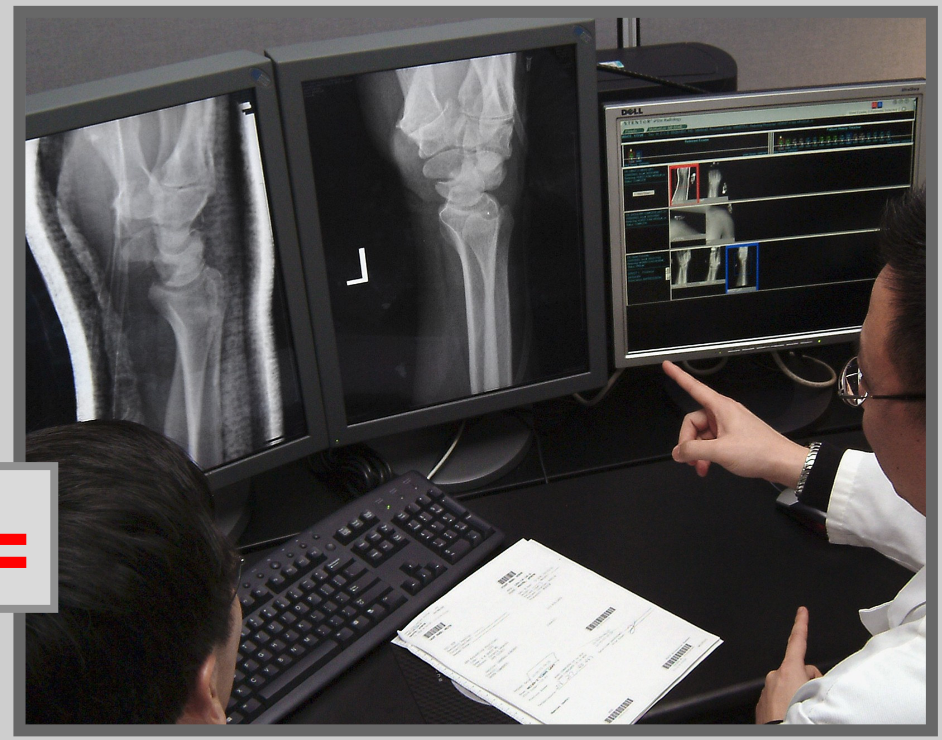
(time permitting)

DR Presentation

- Radiographers/technologists should examine and approve the quality of each radiographic image, adjusting image processing factors if necessary.
- To perform this job, the QC station must be capable of displaying images with comparable quality to that used for diagnostic interpretation.
- Obtaining the desired appearance requires proper PACS integration.

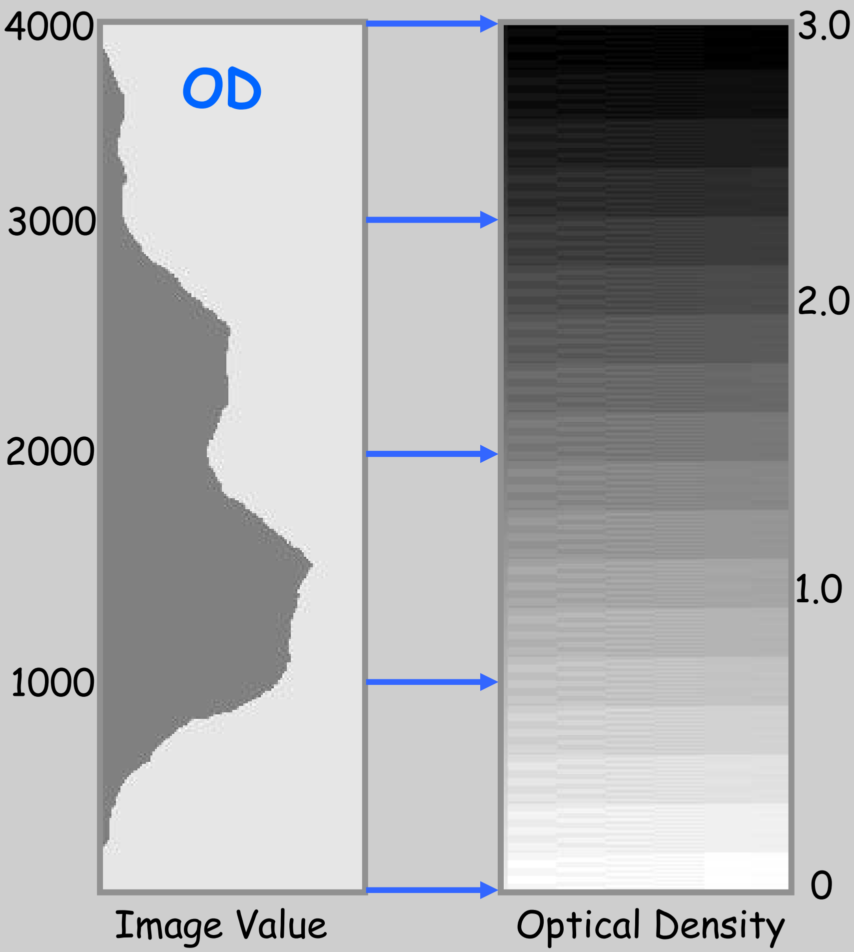


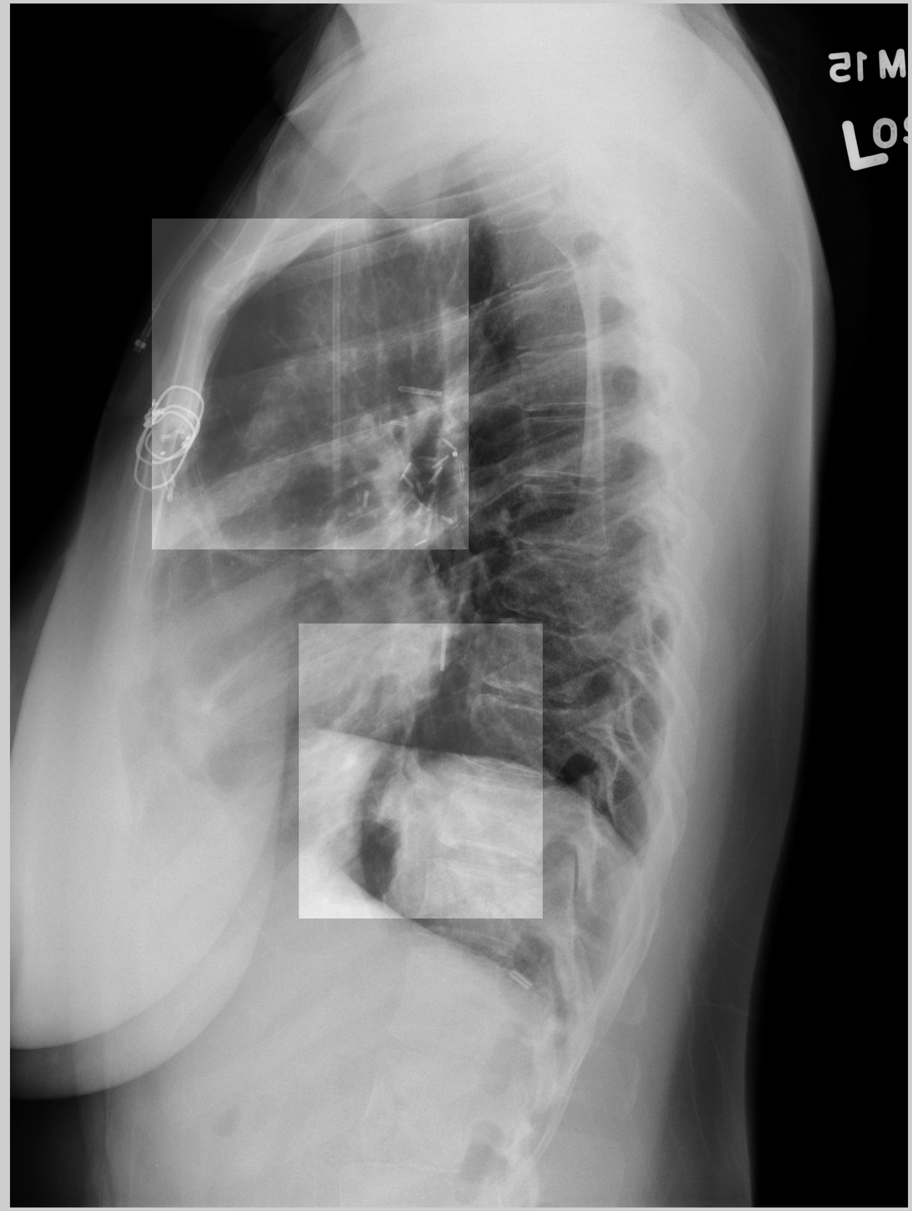
!=



OD values ➔ Film

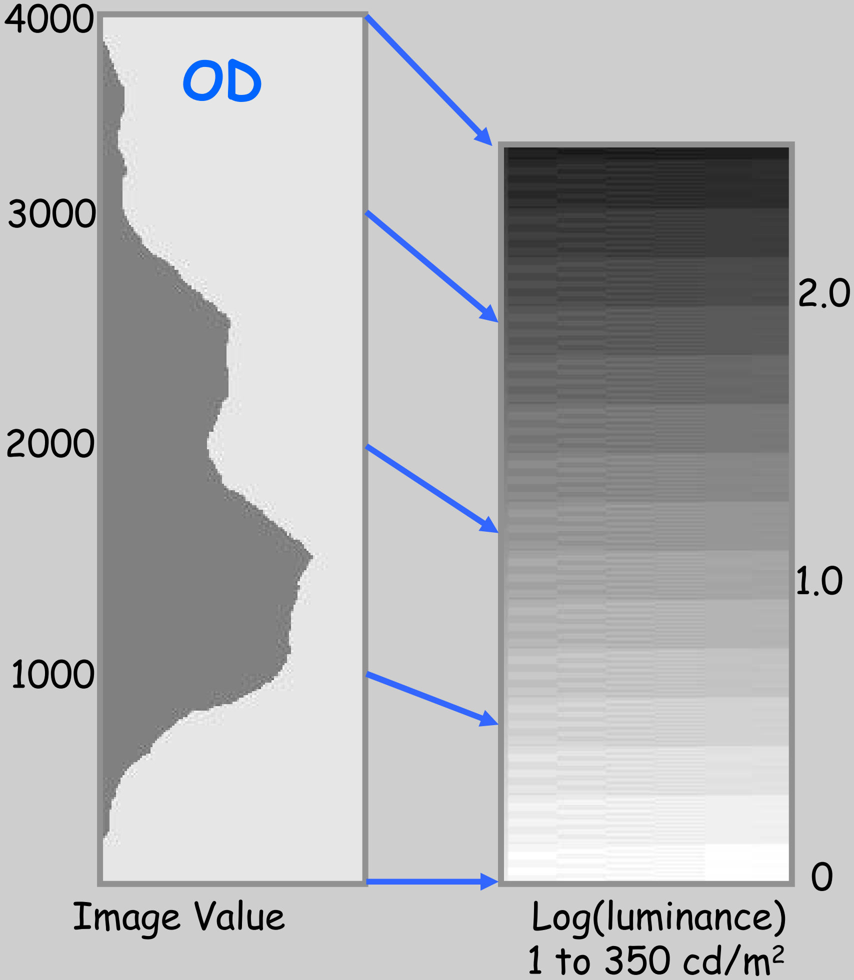
Image presentation values intended for film are printed to optical densities from 0 to 3.0 (+base)

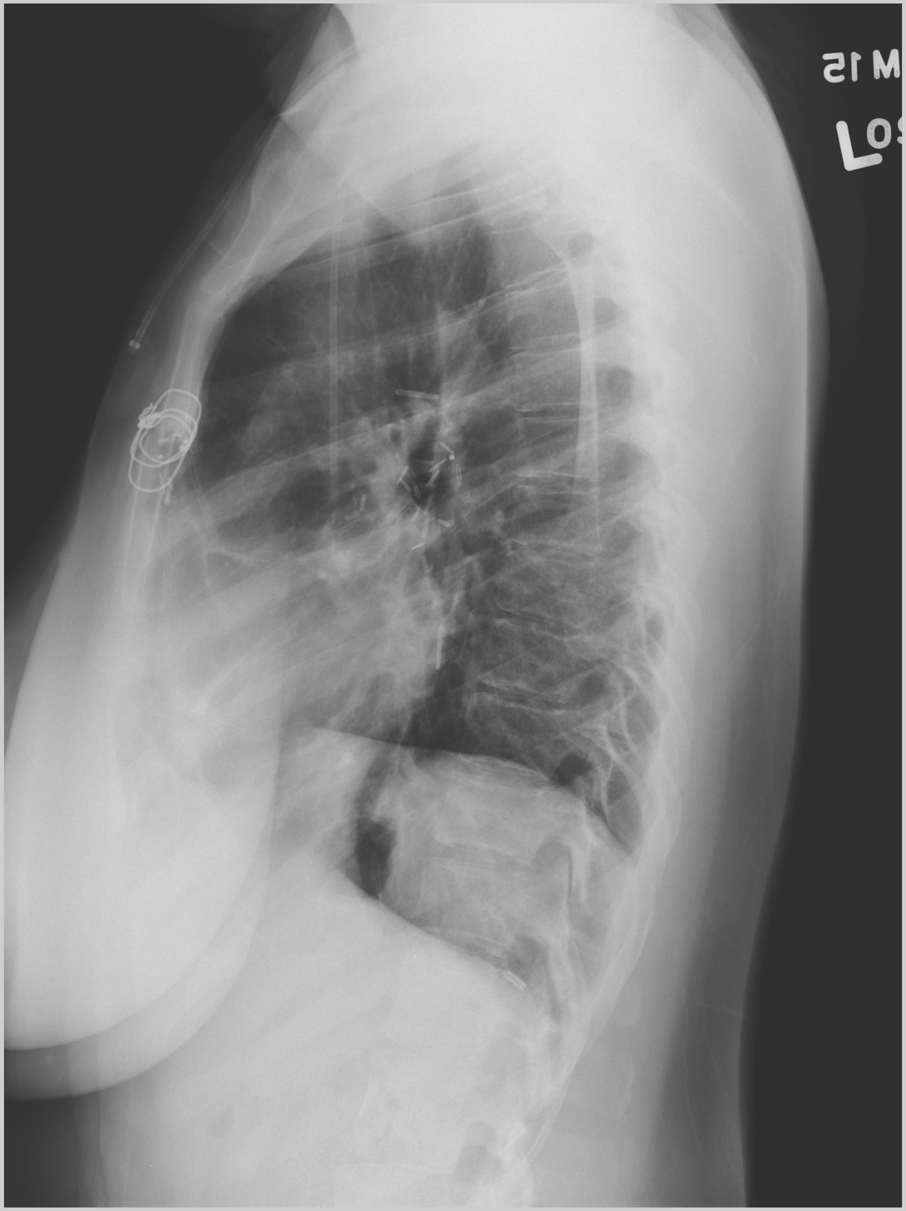




OD values ➔ Softcopy

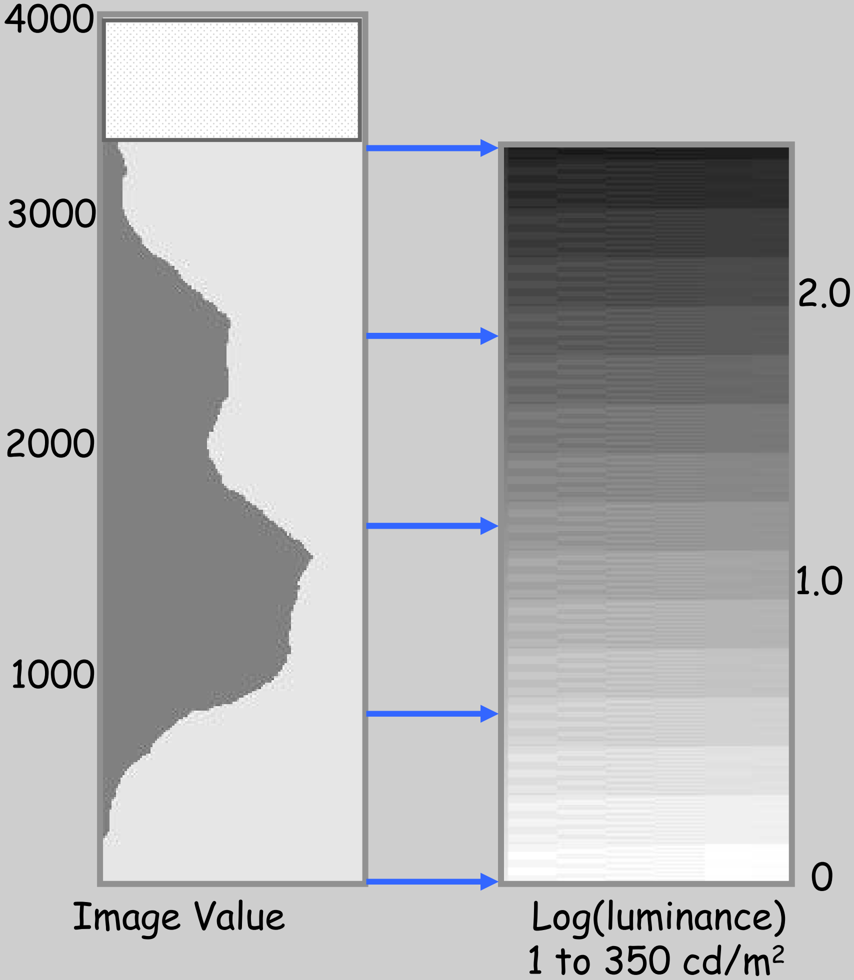
OD values presented on a softcopy display have a luminance ratio of ~350 (i.e. OD range of 2.5)

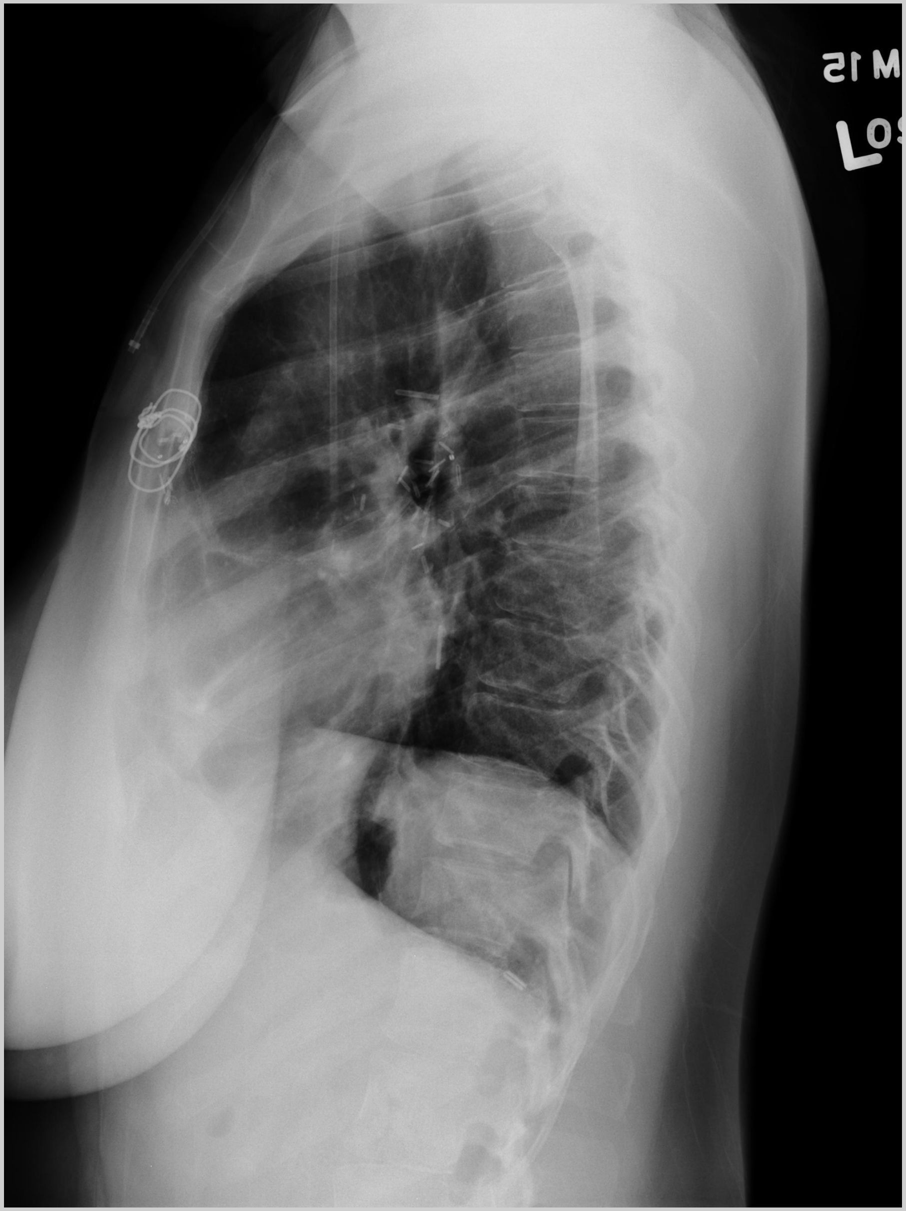




Film & softcopy equivalence

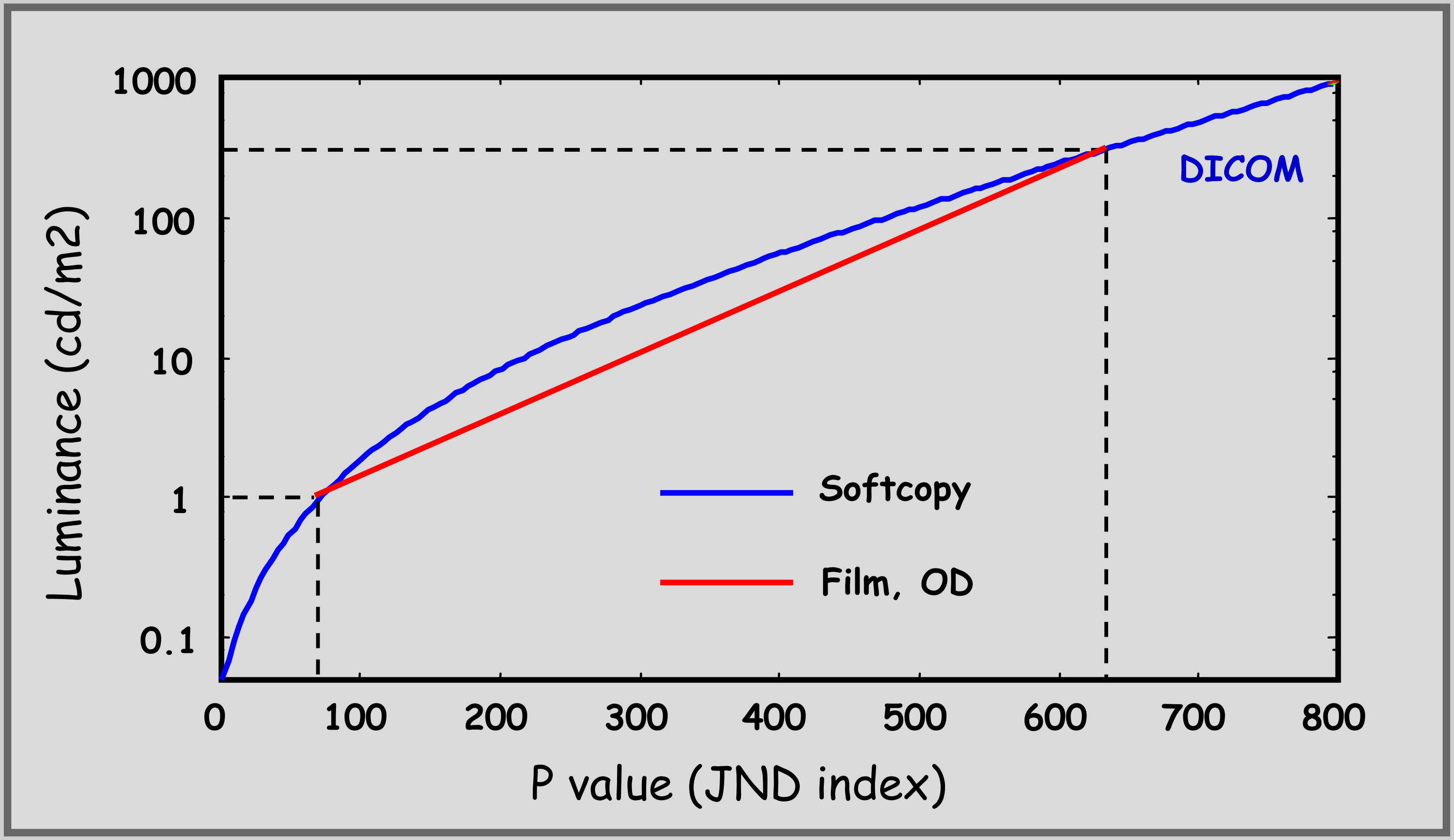
OD values presented on a softcopy display have a similar appearance to film with a modified WW/WL





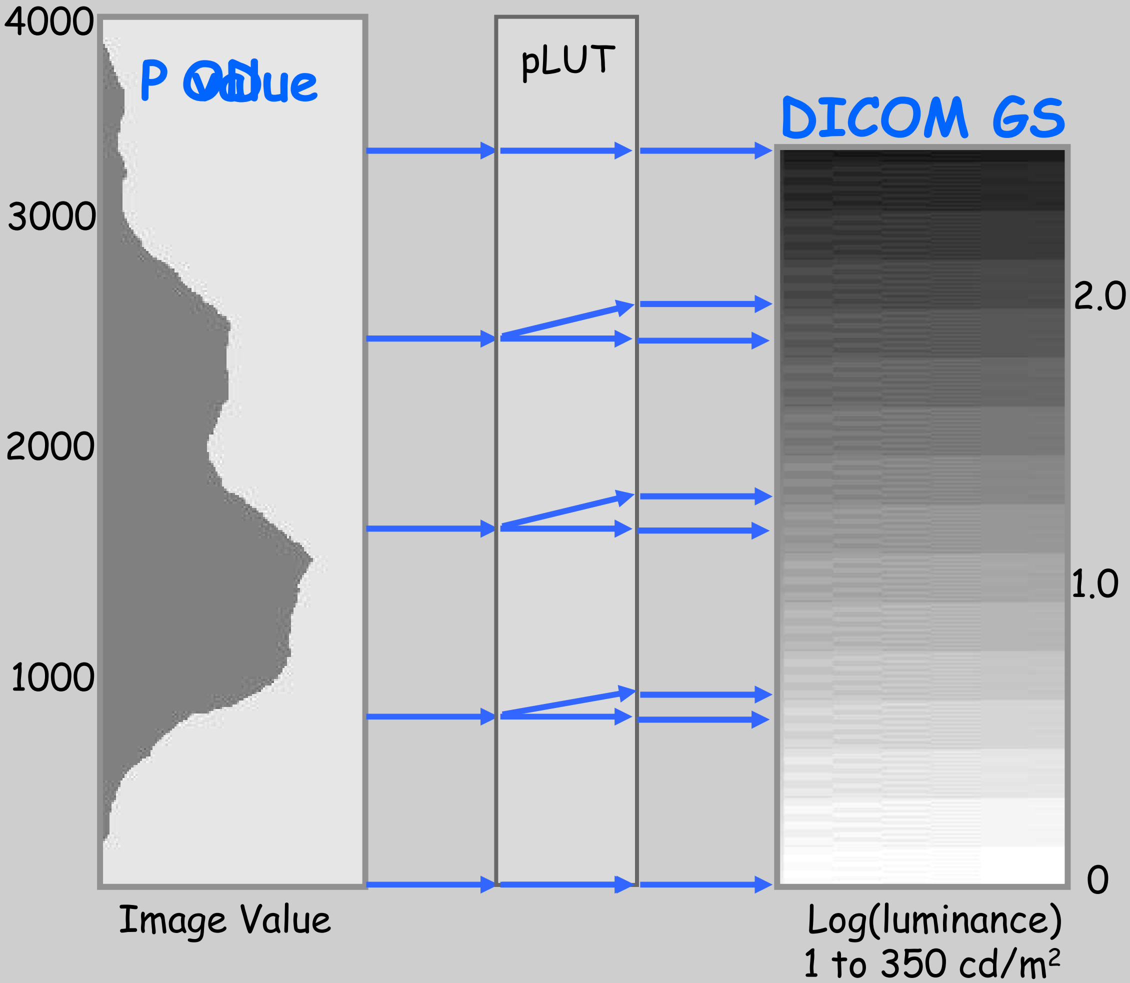
Luminance response – softcopy vs film

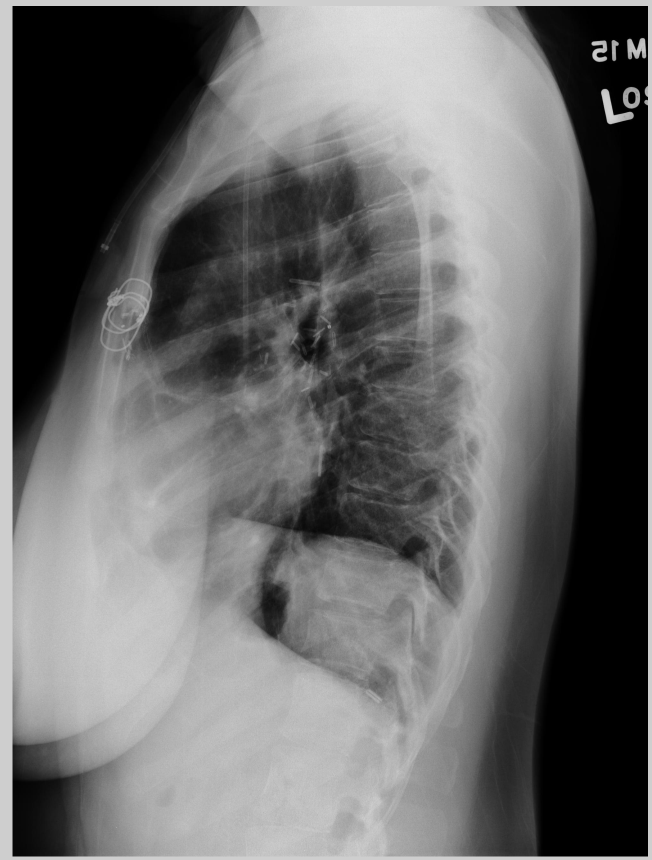
- OD values sent to a film printer produce a luminance response with log(luminance) proportional to image value.
- P values sent to a DICOM calibrated softcopy display produce a luminance response with increase contrast in the darker portions of the image.



P value conversion

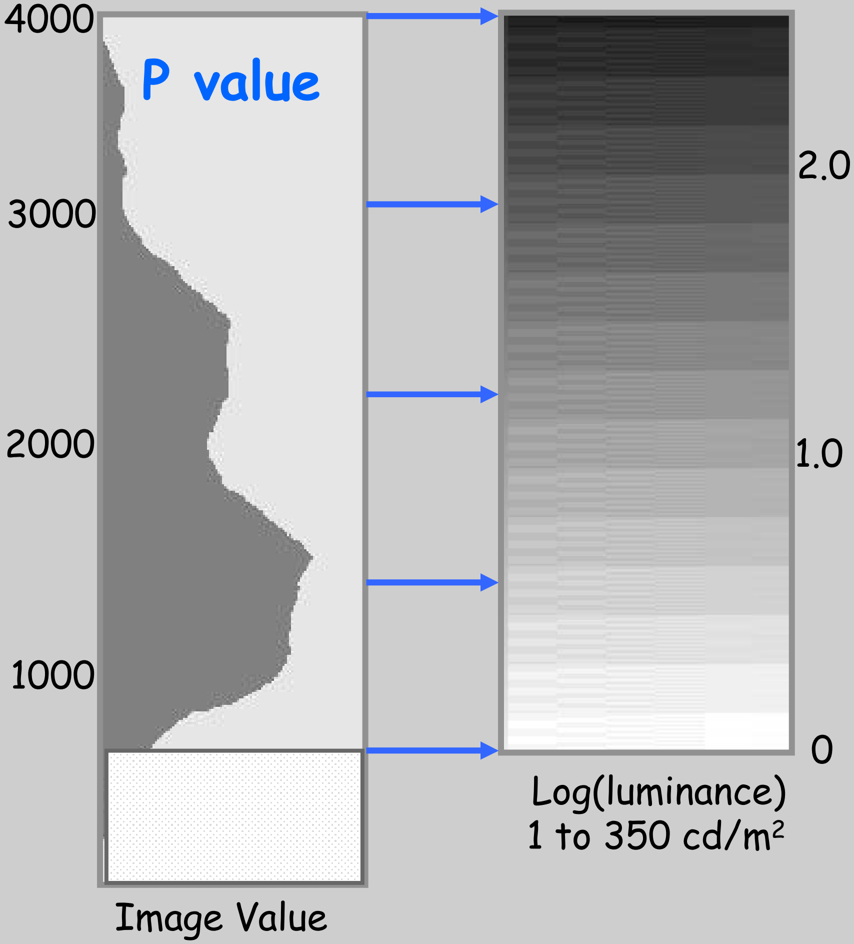
- Configuring the CR/DR modality device to send P values is preferred and obviates the need for a pLUT
- Modalities should be configured to send OD values to a printer and P values to the PACS with equivalent appearance.

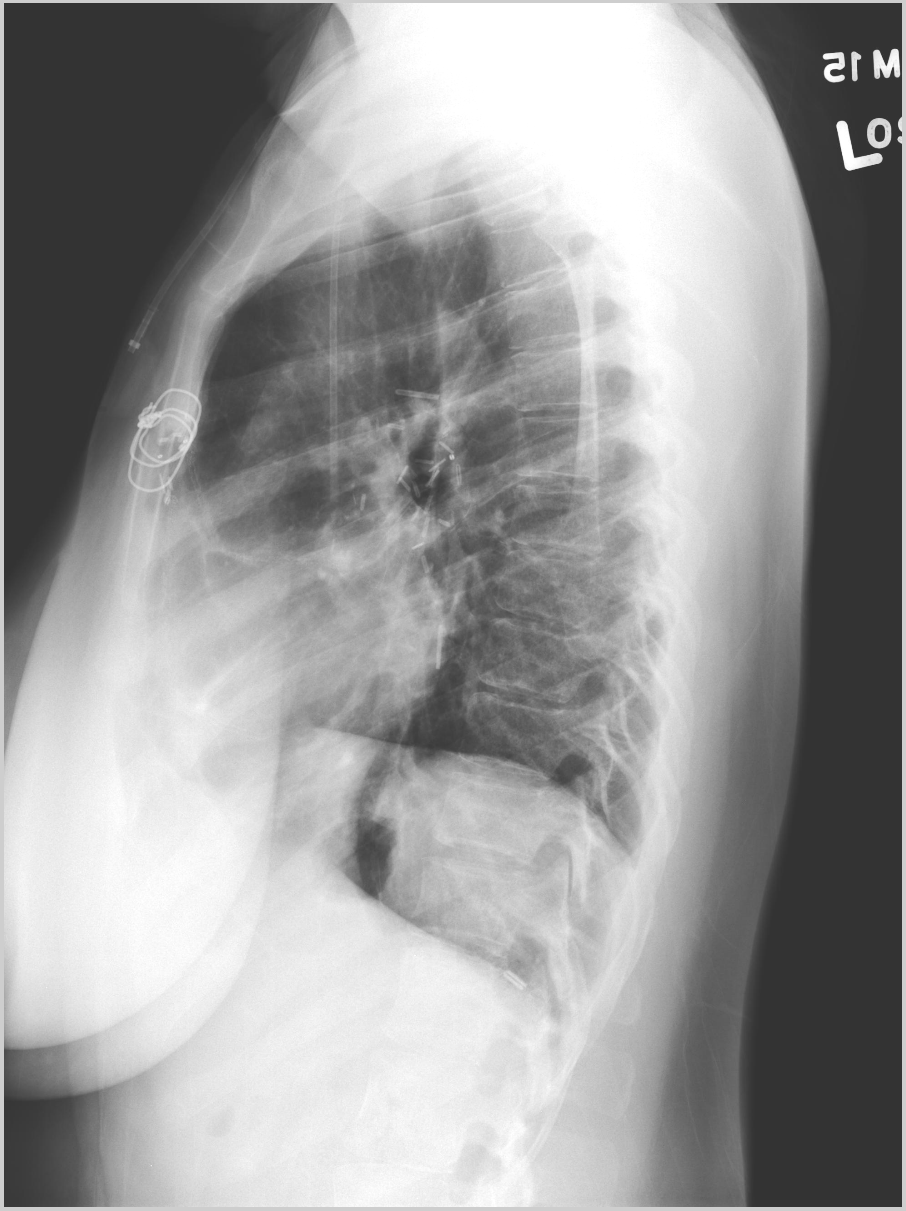




The softcopy "brightlight"

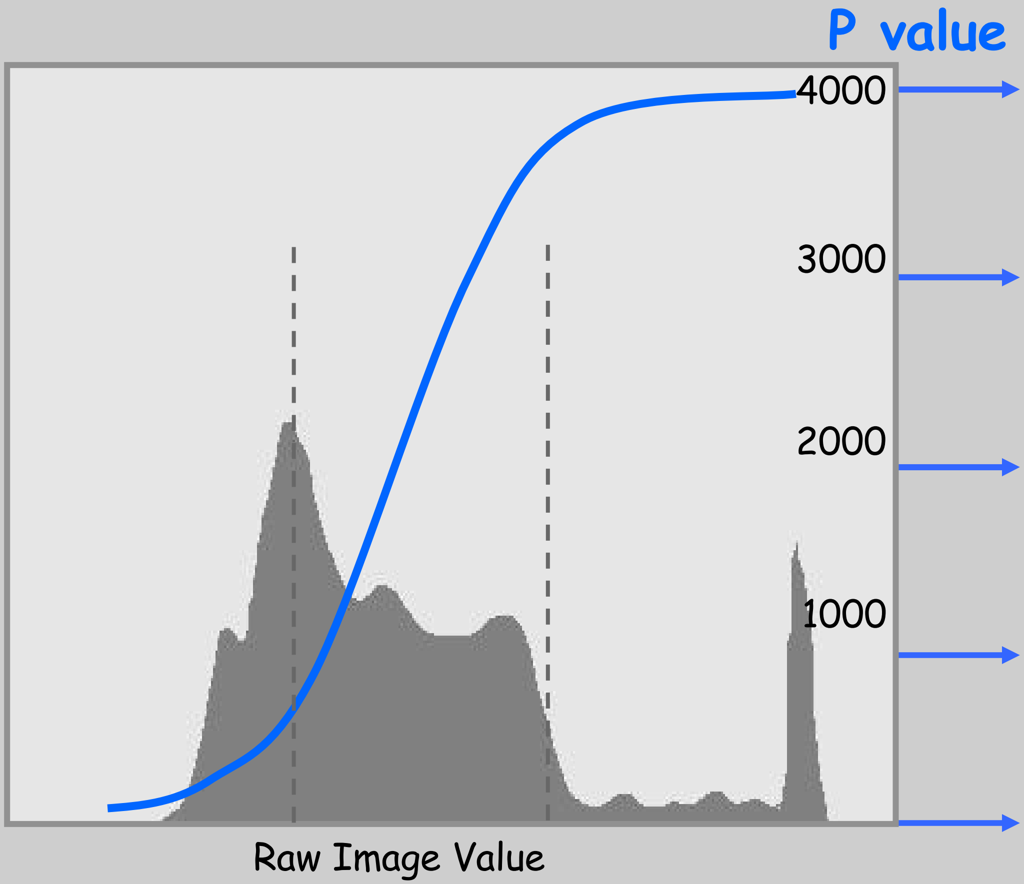
For softcopy display, dark portions of an image are revealed using WL shift. (Brightlight analogy)





The DICOM VOI LUT sequence

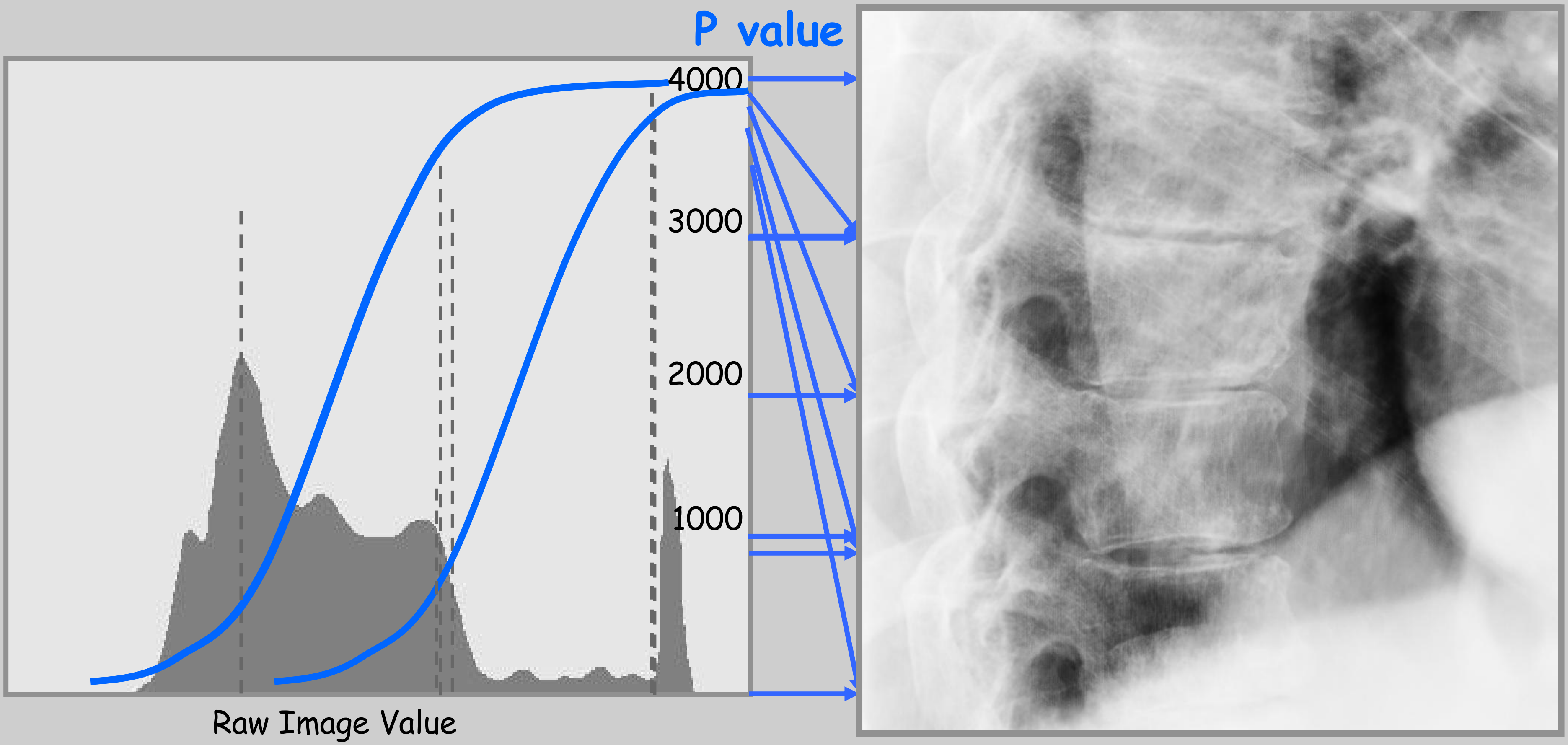
- CR/DR modalities store processed data as 'raw' values that are proportional to log (exposure).
- Raw values are converted to P values using a value of interest (VOI) look up table (LUT).



1 to 350 cd/m²

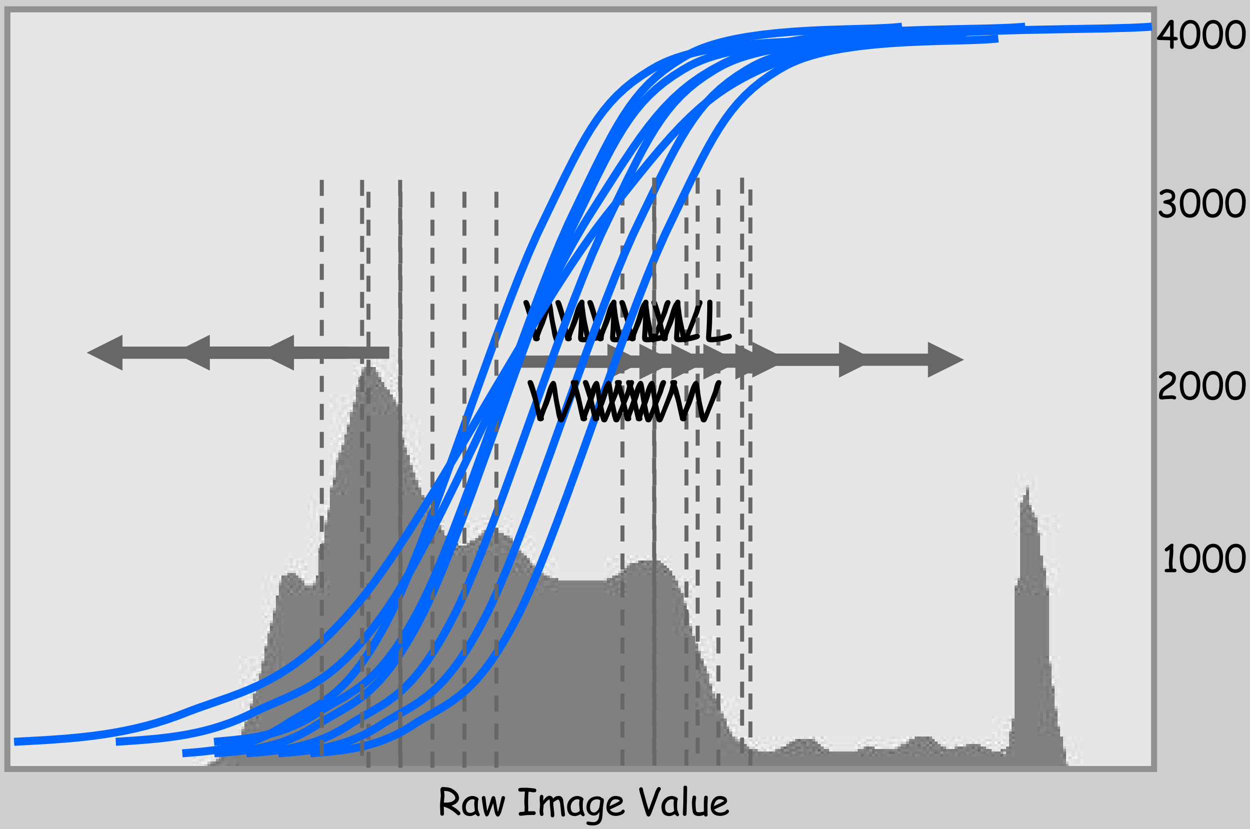
A better WW/WL for CR/DR

- Shifting the Window Level (WL) to inspect highly penetrated regions renders gray levels with a poorly shaped portion of the VOI LUT.
- Shifting the LUT to the values of interest improves contrast.



When communicating images to a PACS systems, processed images with RAW value units should be be sent along with value of interest LUT sequence values.

PACS workstations should be capable of translating or stretching the VOI LUT to make contrast and brightness changes



Recommendations

- Calibrate your monitors using a DICOM grayscale with a specified luminance ratio (~350)
- Be sure the processing of your CR/DR devices produces images intended for your luminance ratio.
- Configure your modalities and PACS to send and receive VOI LUT sequences based on P values

However, many reputable CR/DR suppliers have not released software support for P-values and many reputable PACS suppliers do provide functions to shift and stretch VOI LUT sequences!

	VOI LUT	P Value
CR / DR	✓ y	
PACS		✓ y

Henry Ford Health System

RADIOLOGY RESEARCH

Softcopy Display:

Technology, Performance & Quality

Michael Flynn

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Henry Ford Health System