UNIVERSITY OF MICHIGAN

Michigan Engineering

NERS/BIOE 481

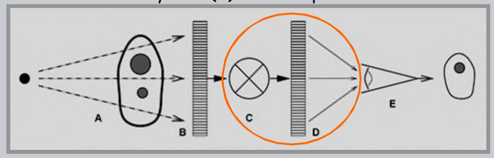
Lecture 12
Image Presentation

Michael Flynn, Adjunct Prof
Nuclear Engr & Rad. Science
mikef@umich.edu
mikef@rad.hfh.edu

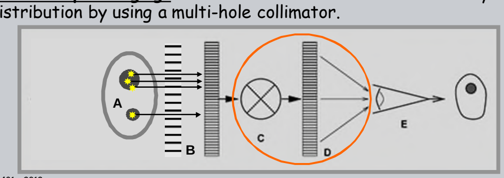
Henry Ford Health System
RADIOLOGY RESEARCH

- General Models

Radiographic Imaging: Subject contrast (A) recorded by the detector (B) is transformed (C) to display values presented (D) for the human visual system (E) and interpretation.



Radioisotope Imaging: The detector records the radioactivity distribution by using a multi-hole collimator.

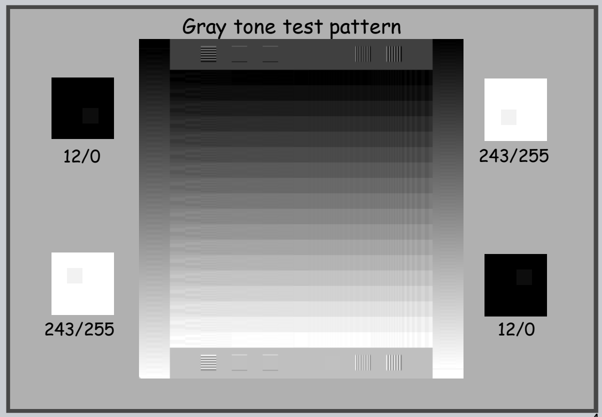


VIII – Image Presentation

VII Computed Tomography
...
B) CT Image Reconstruction (cont.)

VIII Image Presentation
A) DR Processing for Enhanced Display
B) PACS & Display Presentation
C) Light Properties & Units
D) *Display Devices, LCD & OLED (read)*

Display Quality Test Image

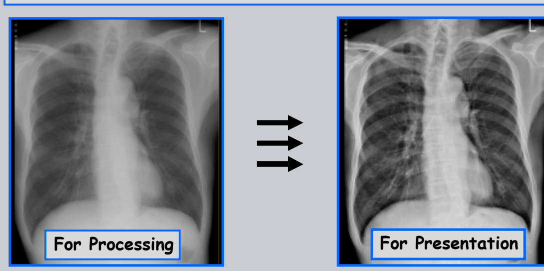


VIII.A – DR Image processing (31 charts)

A) DR Processing for enhanced display
1) Grayscale VOI-LUTs
2) Exposure Recognition (DR)
3) Edge restoration
4) Noise reduction
5) Contrast enhancement

VIII.A. - Five generic processes

⇒ **Grayscale Rendition:**	Convert signal values to display values
⇒ **Exposure Recognition:**	Adjust for high/low average exposure.
⇒ **Edge Restoration:**	Sharpen edges while limiting noise.
⇒ **Noise Reduction:**	Reduce noise and maintain sharpness
⇒ **Contrast Enhancement:**	Increase contrast for local detail



VIII.A.1 - processing sequence

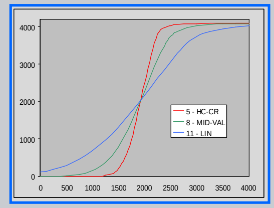
⇒ **Grayscale Rendition:**	Convert signal values to display values
⇒ **Exposure Recognition:**	Adjust for high/low average exposure.
⇒ **Edge Restoration:**	Sharpen edges while limiting noise.
⇒ **Noise Reduction:**	Reduce noise and maintain sharpness
⇒ **Contrast Enhancement:**	Increase contrast for local detail

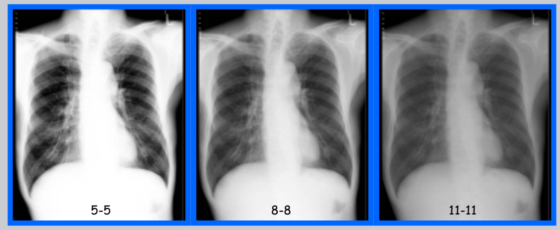
Exposure Recognition → Spatial Processes (·Edge Restoration ·Noise Reduction ·Contrast Enhance) → Grayscale (VOI-LUT)

VIII.A.1 - Grayscale Rendition

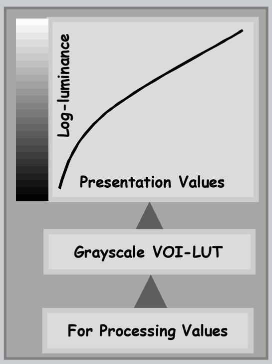
Grayscale LUTs

'For Processing' data values are transformed to presentation values using a grayscale Look Up Table



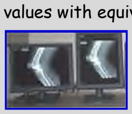


VIII.A.1 - Presentation Values



⇒ The Grayscale Value of Interest (VOI) Look up Table (LUT) transforms 'For Processing' values to 'For Presentation Values.

⇒ Monitors and printers are DICOM calibrated to display presentation values with equivalent contrast.



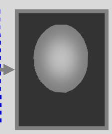
⇒ Images appear the same on all monitors

⇒ The VOI-LUT optimizes the display for radiographs of specific body parts.

VIII.A.1 - DICOM VOI LUT

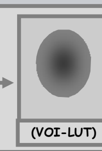
VOI-LUT may be applied by the modality

Exposure Recognition → Spatial Processes (·Edge Restoration ·Noise Reduction ·Contrast Enhance) → Grayscale (VOI-LUT) →



VOI-LUT applied by a viewing station

Exposure Recognition → Spatial Processes (·Edge Restoration ·Noise Reduction ·Contrast Enhance) →



DICOM PS 3.3 2007, Pg 88

When the transformation is linear, the VOI LUT is described by the Window Center (0028,1050) and Window Width (0028,1051). When the transformation is non-linear, the VOI LUT is described by VOI LUT Sequence (0028,3010).

VIII.A.2 – Exposure Recognition

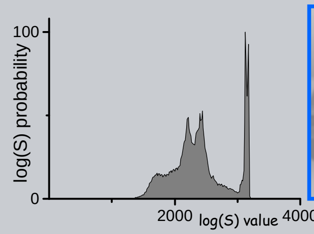
⇒ **Grayscale Rendition:**	Convert signal values to display values
⇒ **Exposure Recognition:**	Adjust for high/low average exposure.
⇒ **Edge Restoration:**	Sharpen edges while limiting noise.
⇒ **Noise Reduction:**	Reduce noise and maintain sharpness
⇒ **Contrast Enhancement:**	Increase contrast for local detail

Exposure Recognition → Spatial Processes (·Edge Restoration ·Noise Reduction ·Contrast Enhance) → Grayscale (VOI-LUT)

VIII.A.2 – Exposure recognition - signal

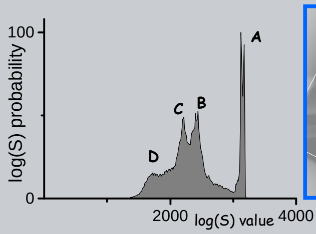
Signal Range:

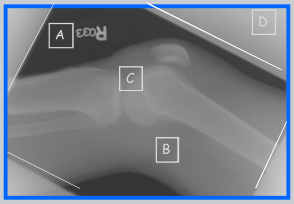
A signal range of up to 10^4 can be recorded by digital radiography systems. Unusually high or low exposures can thus be recorded. However, display of the full range of data presents the information with very poor contrast. It is necessary to determine the values of interest for the acquired signal data.



Exposure Recognition:

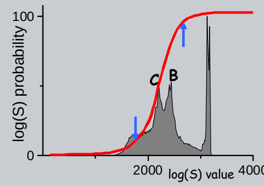
All digital radiographic systems have an exposure recognition process to determine the range and the average exposure to the detector in anatomic regions. A combination of edge detection, noise pattern analysis, and histogram analysis may be used to identify Values of Interest (VOI).



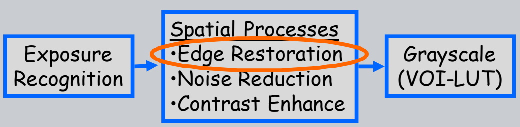


VOI LUT Level and Width:

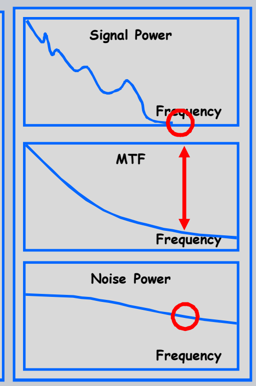
- The values of interest obtained from exposure recognition processes are used to set the level and width of the VOI LUT.
- Areas outside of the collimated field may be masked to prevent bright light from adversely effecting visual adaptation.

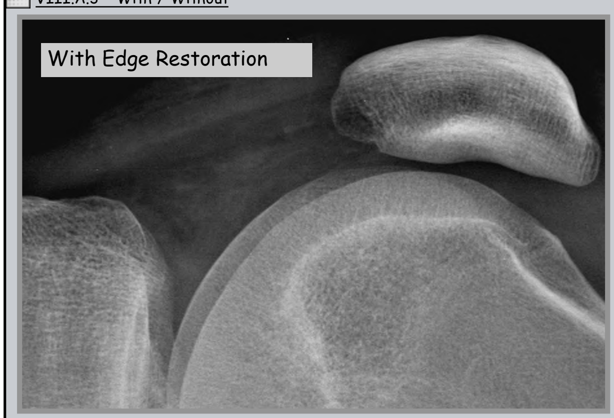


⇒	**Grayscale Rendition:**	Convert signal values to display values
⇒	**Exposure Recognition:**	Adjust for high/low average exposure.
⇒	**Edge Restoration:**	Sharpen edges while limiting noise.
⇒	**Noise Reduction:**	Reduce noise and maintain sharpness
⇒	**Contrast Enhancement:**	Increase contrast for local detail

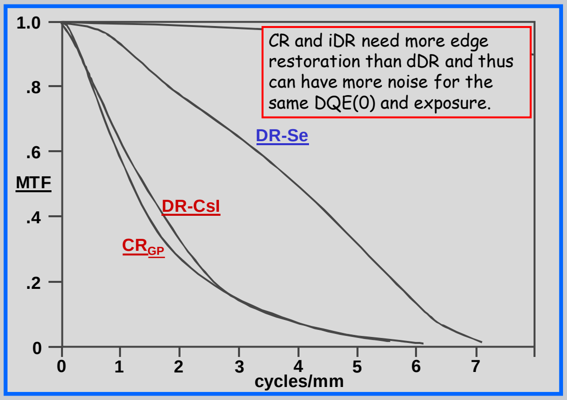


- Radiographs with high contrast details input high spatial frequencies to the detector.
- For many systems the detector will blur this detail as indicated by the MTF.
- Enhancing these frequencies can help restore image detail.
- However, at sufficiently high frequencies there is little signal left and the quantum mottle (noise) is amplified.
- The frequency where noise exceeds signal is different for different body parts/views





VIII.A.3 – MTF – CR, iDR and dDR



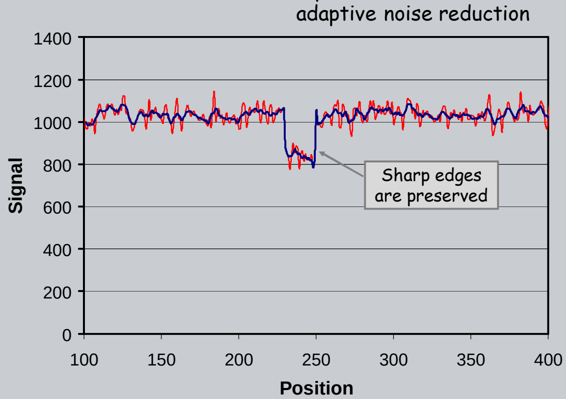
VIII.A.4 – Noise Reduction

⇒	**Grayscale Rendition:**	Convert signal values to display values
⇒	**Exposure Recognition:**	Adjust for high/low average exposure.
⇒	**Edge Restoration:**	Sharpen edges while limiting noise.
⇒	**Noise Reduction:**	Reduce noise and maintain sharpness
⇒	**Contrast Enhancement:**	Increase contrast for local detail

Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

VIII.A.4 – noise reduction: with/wo

Comparison with and without adaptive noise reduction



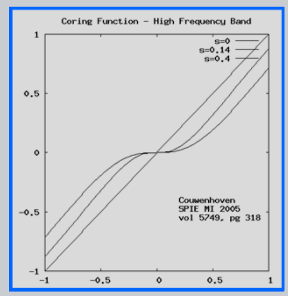
VIII.A.4 – adaptive non-linear coring

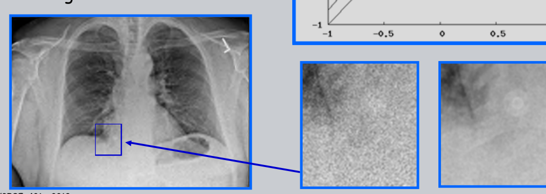
Couwenhoven, 2005, SPIE MI vol 5749, pg318

- High frequency sub-band
- Coring function

$$P = P/(1+s/P^2)$$

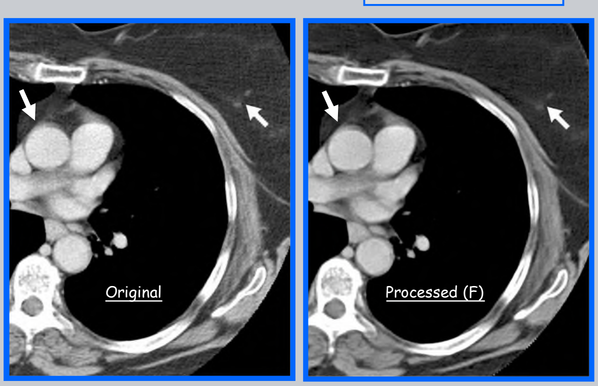
- Adaptation
  - Signal amplitude
  - Signal to noise





VIII.A.4 – Post Processed CT images

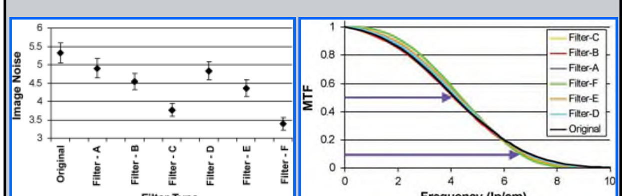
Segmented filtering for noise reduction



Kalra, Radiology, 2003

VIII.A.4 – Post Processed CT images

Segmented filtering for noise reduction



Images are segmented based on structure and separate filters applied to regions with and without structure. The effect varies for a set of filters studied. In general, significant noise reduction is achieved with a slight reduction of high frequency MTF.

Kalra, Radiology, 2003

VIII.A.5 – Constrast Enhancement

⇒ **Grayscale Rendition:**	Convert signal values to display values
⇒ **Exposure Recognition:**	Adjust for high/low average exposure.
⇒ **Edge Restoration:**	Sharpen edges while limiting noise.
⇒ **Noise Reduction:**	Reduce noise and maintain sharpness
⇒ **Contrast Enhancement:**	Increase contrast for local detail

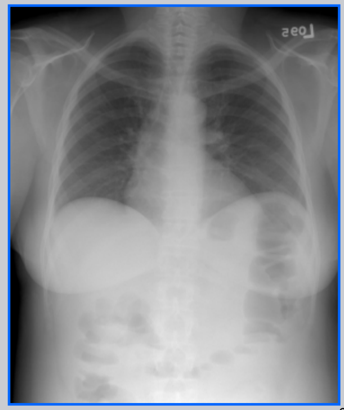
Exposure Recognition → Spatial Processes (•Edge Restoration •Noise Reduction •Contrast Enhance) → Grayscale (VOI-LUT)

VIII.A.5 – Contrast Enhancement

- A wide range of log(S) values is difficult to display in one view.
- Lung detail is shown here with low contrast.

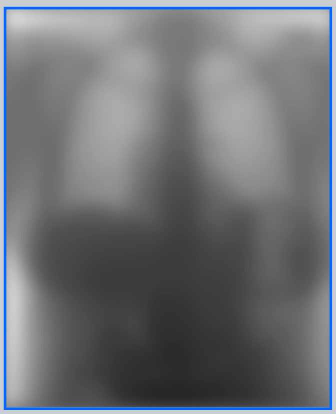
Contrast Enhancement:

Enhancement of local detail with preservation of global latitude.



VIII.A.5 – Unsharp Mask

- A highly blurred image can be used to adjust image values.
- The Unsharp Mask can be obtained by large kernel convolution or low pass filter.
- Note that the grayscale has been reversed.

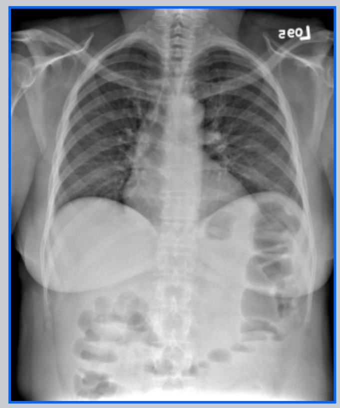


VIII.A.5 – Detail enhancement

The difference between the image and the unsharp mask contains detail.

This is added to the image to enhance detail contrast

The contrast enhanced image has improved lung contrast and good presentation of structures in the mediastinum.

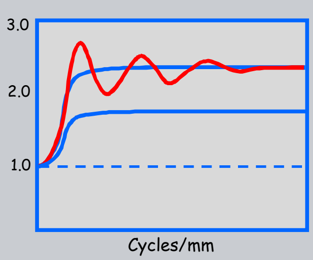


VIII.A.5 – Selecting contrast enhancement

In practice, the amount of contrast enhancement can be selected by first defining a grayscale rendition that achieves the desired latitude, and then applying a filter that enhances detail contrast.

The enhancement gain is adjusted to amplifying the contrast of local detailed tissue structures.

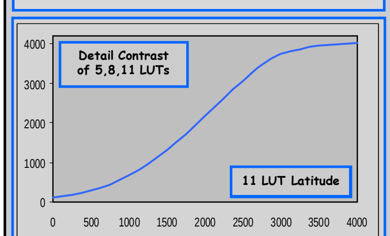
Early methods using large kernels of equal weight had poor frequency response characteristics.

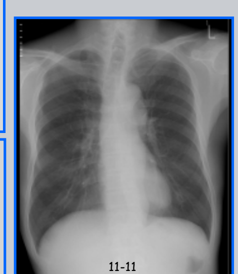


VIII.A.5 – Detail Contrast, Latitude, and Gain

For a specific grayscale rendition,
detail contrast can be progressively enhanced.

- Latitude – the range of the unenhanced LUT.
- Detailed Contrast – the effective slope of the enhanced detail at each gray level.
- Gain – the increase in LUT local slope.





Gain = 0

VIII.A.5 – Detail Contrast, Latitude, and Gain

For a specific grayscale rendition,
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- Latitude – the range of the unenhanced LUT.
- Detailed Contrast – the effective slope of the enhanced detail at each gray level.
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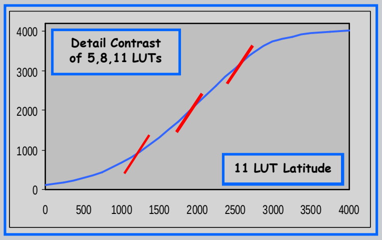
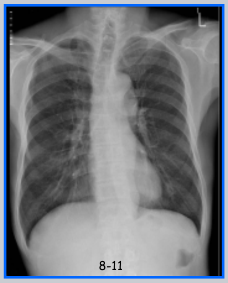




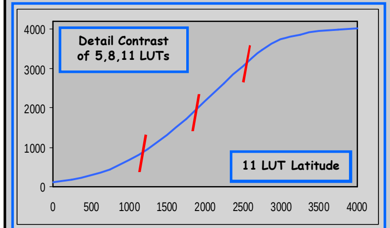
Gain = 1.4

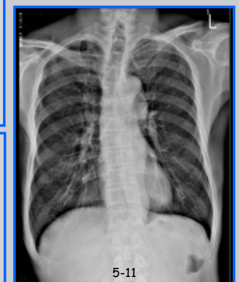
VIII.A.5 – Detail Contrast, Latitude, and Gain

Extended Visualization Processing (EVP, Kodak).

For a specific grayscale rendition,
detail contrast can be progressively enhanced.

- Latitude – the range of the unenhanced LUT.
- Detailed Contrast – the effective slope of the enhanced detail at each gray level.
- Gain – the increase in LUT local slope.





Gain = 2.6

VIII.A.5 – chest

T3-c

- Lat = 1.44
- Con = 3.00
- G = 2.4

VIII.A.5 – foot – contrast enhancement

Contrast enhancement of wide latitude
Musculoskeletal views improves visualization

Latitude 600 – 0X Gain contrast enhancement

VIII.A.5 – foot – contrast enhancement

Contrast enhancement of wide latitude
Musculoskeletal views improves visualization

Latitude 1200 – 0X Gain contrast enhancement

VIII.A.5 – foot – contrast enhancement

Contrast enhancement of wide latitude
Musculoskeletal views improves visualization

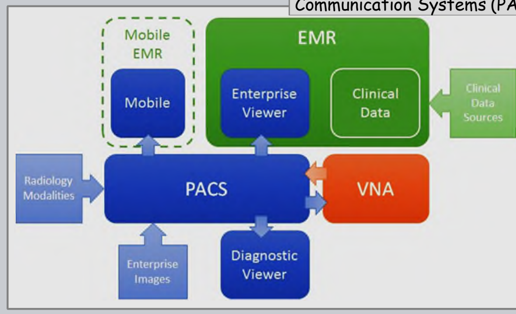
Latitude 1200 – 2X Gain contrast enhancement

VIII.B – Display workstations (18 charts)

B) PACS & Display Presentation
   1) Image management, PACS (5)
   2) Display presentation (9)
      Grayscale calibration
      Pan/zoom & resampling
   3) Tomographic display (4)

VIII.B.1 – Image Management, PACS

Image Management using Picture Archive and Communication Systems (PACS)



Radiation images from all types of devices (DR, CT, NM, PET, ..) are
- Stored in Vendor Neutral Archives (VNA),
- Communicated using specialized network protocols (DICOM) and
- Made available at workstations for interpretation or clinical care review.

VIII.B.1 – The DICOM Standard

DICOM is a global standard for informations systems used to:
Produce, Store, Display, Process, Send, Retrieve, Query or Print
medical images in:
radiology, cardiology, dentistry, opthamology, pathology ...

- Defines network communication protocols to transfer images
- Defines object structures for DR, CT, NM, PET, and other studies that groups images in series and studies. Coded metadata in included in each image that includes
  - Patient information
  - Exam protocol information
  - Image presentation information
- Defines file formats and directory structures for media transfer.
- In 2006, ISO approved DICOM as an ISO reference standard (#12052)
- With ~60 members (Manufacturers, Societies, Organizations), the Dicom Standards Committee (DSC) continuously updates the standard.

http://dicom.nema.org/

VIII.B.1 – Xray Technologist work stations

Images are first checked by a Radiographer/Technologist as they are acquired.

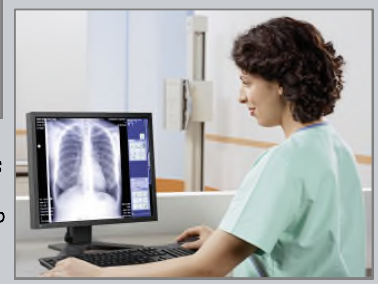
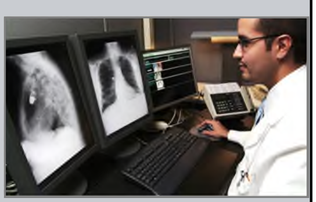
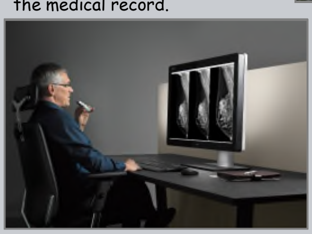


Image display settings may be adjusted prior to sending the study to the PACS system

VIII.B.1 – Diagnostic reading station

- Medical imaging studies are interpreted at Radiologists workstations having multiple high performance display monitors.
- The interpretation is electronically dictated using voice recognition and attached to the medical record.

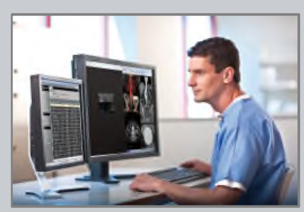


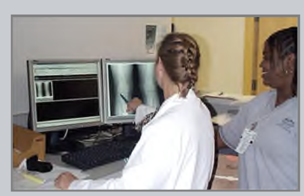


The Radiology workspace typically incorporates a variety of ergonomic features;
- Modest ambient light
- Wide fore deck desks
- Ergonomic seating
- Ambient noise control.

VIII.B.1 – HFHS Clinic stations

- Various clinical caregivers will review medical imaging studies as a part of a patients electronic medical record.
- Both current and prior studies are available from the PACS archive





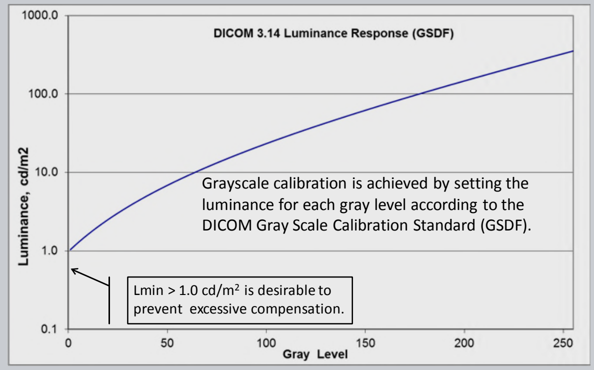
VIII.B.2 - Grayscale Calibration

It is important that images viewed by all persons (technologists, radiologists and clinical physicians) appear the same. This requires that two calibration criteria be met;

1. The luminance ratio (L_{max}/L_{min}) is the same (nominal 350), and
2. The luminance response between L_{min} and L_{max} follows the DICOM Gray Scale Display Function (GSDF)

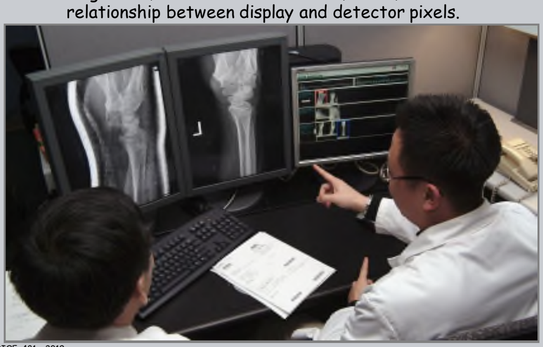
VIII.B.2 - Luminance Response

In L12, we will consider the visual basis for the GSDF



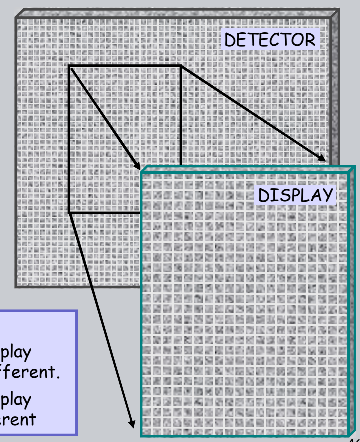
VIII.B.2 - Image pan/zoom

- Image presentation is done with interactive zoom and pan to reveal full detail in areas of interest.
- In general, there is never a direct, or 1:1, relationship between display and detector pixels.



VIII.B.2 - Re-sampling

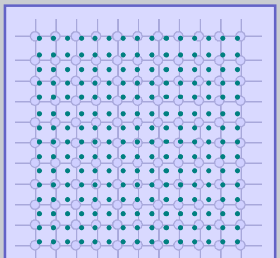
A subset of image values is re-sampled for presentation on a display device.



In General;
- The detector and display pixel spacings are different.
- The detector and display overall size are different

VIII.B.2 - Up-sampling (magnification)

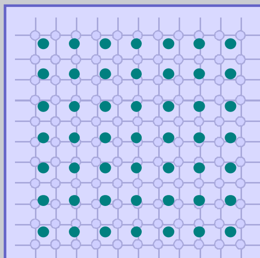
- Up sampling occurs when the number of display values in the region re-sampled is more than the number of recorded image values .
- Up sampling is commonly done with CT & NM.



- Blue circles show an 11x11 array of recorded image pixel values.
- Green solid circles are for a 15 x 15 array of display pixel values

VIII.B.2 - down-sampling (minification)

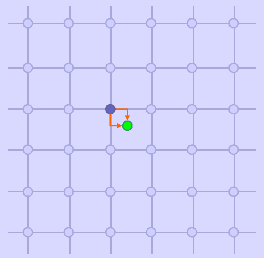
- Down sampling occurs when the number of display values in the region re-sampled is less than the number of recorded image values .
- Down sampling is commonly encountered when a full radiograph is displayed.



- Blue circles show an 11x11 array of recorded image pixel values.
- Green solid circles show a 7 x 7 array of display values.

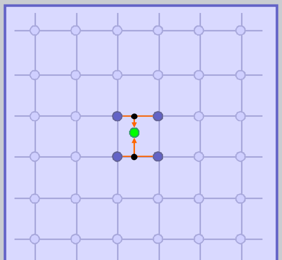
VIII.B.2 - Approximate Interpolation

While fast, nearest neighbor and bi-linear interpolation do not result in optimal image quality due to artifacts and blur.



Nearest Neighbor Interpolation

- Display value (green) is taken as the image value (blue) at the nearest row and column.
- Produces visible block artifacts for large magnification.

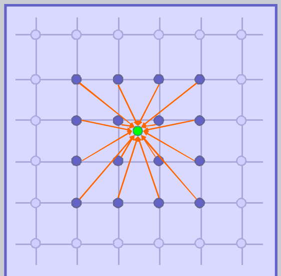


Bi-Linear Interpolation

Image values pairs above & below the display value are linearly interpolated based on the column position (black).

These values are linearly interpolated based on the row position.

VIII.B.2 - Improved Interpolation



Cubic Interpolation

Display value (green) is computed from the closest 16 image values.

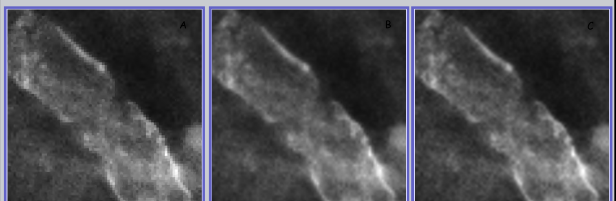
The weighting functions for the 16 image values are intended to estimate a continuous function within the space between the sampled values.

Improved quality can be achieved by estimating display values from the closest 16 image values (4 x 4).

- Spline interpolation
- cubic convolution
- Generalized spline interpolation

VIII.B.2 - Magnification

Magnification: Calcified duct, 4:1 re-sampling 5.25 x 5.25 mm region



Nearest Neighbor | Bi-Linear | Cubic

Minification.

- Advanced interpolation methods can also provide effective minification with noise reduction (low-pass filter).
- Alternatively, minification is often done using multi-scale representations of the image with progressive presentation.

VIII.B.3 – Tomographic Display (4 slides)

C.3 Tomographic (3D) display

1) Window-Level Adjustment
2) Interactive stack sequence
3) Sagittal / Coronal reformatting
4) Volumetric rendering

iSite viewer demonstration

VIII.B.3 – Reformatting 3D Data

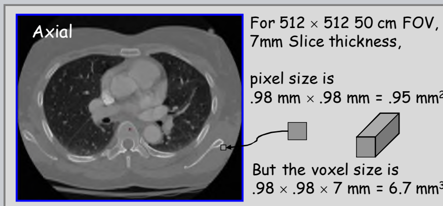
For tomographic data acquired with small slice increments, the data can be considered as a 3 dimensional array and presents in stacks of xy, xz, or yz planes.

Axial | Sagittal | Coronal

512 x 512 50 cm FOV, 7mm Slice thickness,.98 mm x .98mm pixel size

VIII.B.3 – Resampling 3D Data

- When a stack of CT images is reformatted, the Z spacing is commonly different than the x and y spacing.

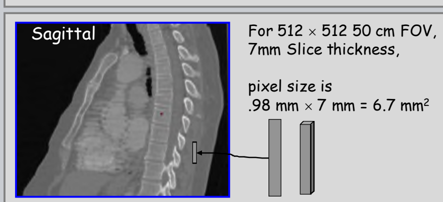


For 512 × 512 50 cm FOV, 7mm Slice thickness,

pixel size is .98 mm × .98 mm = .95 mm^2

But the voxel size is .98 × .98 × 7 mm = 6.7 mm^3

- The sagittal and coronal views need to be resample so that the xz and yz pixels are square.



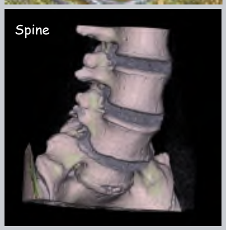
For 512 × 512 50 cm FOV, 7mm Slice thickness,

pixel size is .98 mm × 7 mm = 6.7 mm^2

VIII.B.3 – volumetric rendering

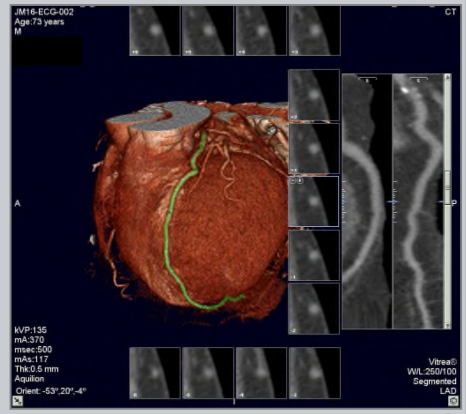
- The surfaces of structures must first be segmented and tesselated (i.e. converted to connected polygons).
- The polygon representation can then be presented as a surface model and rotated to view regions of interest.

examples from teraRecon



VIII.B.3 – Application specific analysis

- Volumetric analysis is often taylored for specific applications;
  - Cardiac
  - Colonoscopy
  - Bronchoscopy
- For cardiac analysis, the results may describe coronary artery narrowing and the degree of calcificiation (coronary artery scoring).

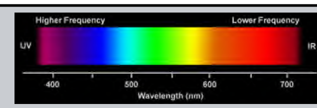


VIII.C – Visual light (12 charts)

C) Light Properties and Units
1) Properties of light (1)
2) Photometric units (11)

See reading #1, Light Units

VIII.C.1 – Properties of light



Light energy E (eV);

$E = h\upsilon = h(c/\lambda)$

where;

h : Planck's constant, 6.626×10^{-34} (J-s)

υ : Frequency of light, Hz

c : Velocity of light, 3×10^{8} m/s

λ : Wavelength of light, m

When E is expressed in eV (electron volts) and λ in nm, the relation betweene eV and λ is;

$E(eV) = 1240/\lambda$

- 1 eV = 1.6×10^{-19} Joules
- 1 Watt = 1 Joule/sec,

-> 1 Watt = 5.04 λ(nm) x 10^{15} photons/sec

VIII.C.2 – Photometric Units

Radiometric light units relate to the energy of photons (watts).
Photometric light units relate to the visibility of photons (lumens)

Radiant flux (Watts)

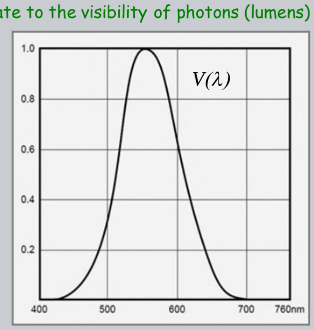
$$Q_e(\lambda) = E_\lambda N(\lambda)$$

$$\Phi_e(\lambda) = dQ_e(\lambda)/dt$$

Luminous flux (lumens)

$$\Phi_e = k_m \int \Phi_e(\lambda) v(\lambda) d\lambda$$

k_m = 683 lumens/watt



The sensitivity of the human eye is defined in terms of the lumens per watt as a function of wavelength.

VIII.C.2 – Photometric Units

Irradiance/Illuminance refers to the light flux incident on an area of a surface

Hamamatsu PMT Handbook

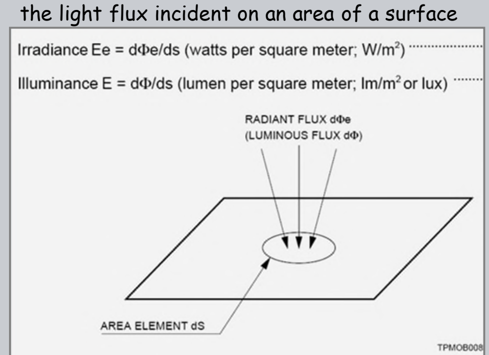


Figure 1-2: Irradiance (Illuminance)

VIII.C.2 – Photometric Units

Emittance refers to the light flux emitted from an area on a surface

Radiant emittance Me = dΦe/ds (watt per square meter; W/m^2)

Luminous emittance M = dΦ/ds (lumen per square meter; lm/m^2)

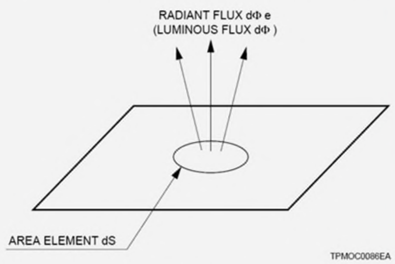


Figure 1-3: Radiant emittance (Luminous emittance)

Hamamatsu PMT Handbook

VIII.C.2 – Photometric Units

Radiant/luminous intensity refers to the light flux emitted per steradian from a point source (*candle*).

Luminous intensity I = dΦ/dw(candelas: cd)

Where

Φ : luminous flux (lumens)

w : solid angle (steradians)

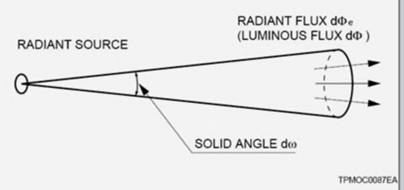


Figure 1-4: Radiant intensity (Luminous intensity)

Hamamatsu PMT Handbook

VIII.C.2 – Photometric Units

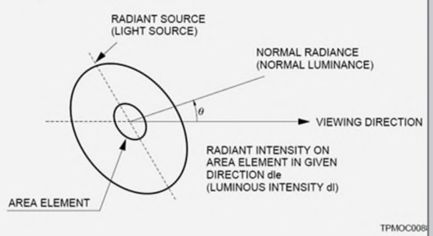
Luminance refers to the light flux emitted from an area on a surface per steradian.

(Note that it is adjusted by the 1/cosine of the viewing angle.)

Luminance, L = (dI/ds)/cosθ candelas/m^2

Where

I: luminous intensity (candelas)

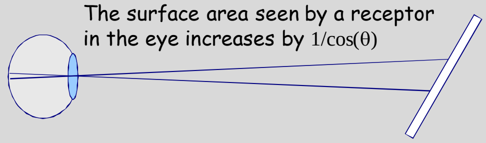


Hamamatsu PMT Handbook

VIII.C.2 – Photometric Units

The luminance indicates how much luminous power will be detected by an eye looking at the surface from a particular angle of view.

The surface area seen by a receptor in the eye increases by $1/\cos(\theta)$



Apparent brightness is independent of distance to the viewing surface;

- The surface area seen by a receptor in the eye increases with the square of the distance.
- The solid angle subtended by the eye lens decreases with the square of the distance.

VIII.C.2 – Photometric Units

Surfaces for which the luminous intensity, $d\Phi/d\omega$ (cd/sr) per unit area, ds, is proportional to the cosine of the emission angle are known as Lambertian emitters.

$$dI_{(\theta)}/ds = \left[(d\Phi/d\omega)_\theta / ds \right] = k\cos(\theta)$$

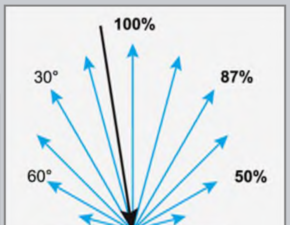


Fig. 6.5 Lambertian surface.

International Light Handbook

- Lambertian emitters are significant in that the luminance, and therefore the apparent brightness, is independent of viewing angle.

$$L_{(\theta)} = \left(dI_{(\theta)}/ds \right) / \cos(\theta) = k$$

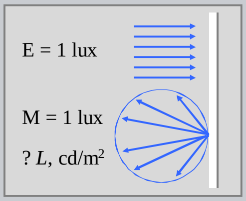
- Lambertian emission results from diffusive surfaces such as projector screens, powdered phosphors, and opal glass.

VIII.C.2 – Photometric Units

Radiometric & Photometric Light Units

	Quantity	Unit Name	Symbol
Φ	Radiant flux	Watts (J/S)	W
	Luminous flux	Lumen	lm
Q	Radiant energy	Joules	J
	Quantity of light	lumen*sec	lm-s
dΦ/ds	Irradiance	Watts/m^2	W/m^2
	Illuminance	Lux (lm/m^2)	lx
dΦ/ds	Radiant emittance	Watts/m^2	W/m^2
	Luminous emittance	lumens/m^2	lm/m^2
dΦ/dw	Radiant intensity	Watts/sr	W/sr
	Luminous intensity	Candelas (lm/sr)	cd
$\frac{dI/ds}{\cos\theta}$	Radiance	Watts/sr/m^2	W/sr/m^2
	Luminance	Candelas/m^2	cd/m^2

Consider a projection screen illuminated by 1 lux. If all of the incident light is reflected back with a Lambertian distribution, what is the luminance?

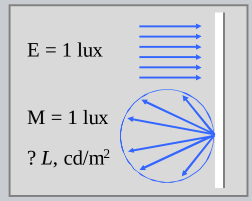


- The emittance after reflection, M in lumens/m^2 is equal to the illuminance, E in lumens/m^2 (lux).
- M can be obtained by integrating the luminous intensity per unit area over a half sphere.

$$dI_{(\theta)}\Big/ds = \left[(d\Phi / d\omega)_\theta \Big/ ds \right] = k\cos(\theta)$$

$$M = d\Phi\Big/ds = \int k\cos(\theta) d\omega$$

Consider a projection screen illuminated by 1 lux. If all of the incident light is reflected back with a Lambertian distribution, what is the luminance?



- Using the expression for $d\omega$ from L03 we can show that $k = M/\pi$;

$$M = \int_0^{2\pi}\int_0^{\pi/2} [k\cos(\theta)]\sin(\theta) d\theta d\phi$$

$$= 2\pi k \int_0^{\pi/2} \cos(\theta)\sin(\theta) d\theta = \pi k$$

- On the prior slide we showed that $L=k$, and since $E=M$, we get: $L = E/\pi$

Note: in L03 $d\omega$ was $d\Omega$ and ϕ and θ were reversed, the variables here are aligned with the reading.

For documentation, the solution for the solid angle integral on the prior page is shown here.

$$\int_0^{\pi/2} \cos(\theta)\sin(\theta) d\theta = \int_0^{\pi/2} \frac{1}{2}\sin(2\theta) d\theta$$

$$= \int_0^{\pi} \sin(2\theta) d\theta$$

$$\theta' = 2\theta, \quad d\theta = \theta'/2$$

$$= \frac{1}{2}\int_0^{\pi} \sin(\theta') d\theta'$$

$$= \frac{1}{2}\left[-\cos(\theta)\right]_0^{\pi}$$

$$= \frac{1}{2}$$

D) Display Devices
1) LCD monitors (14)
2) New technology, OLEDs (7)
3) Graphic controller interface (2)

Liquid Crystal Display (LCD) Technology

Intermediate state of matter:

crystal --T--> liquid --T--> vapor.
(liquid crystal).

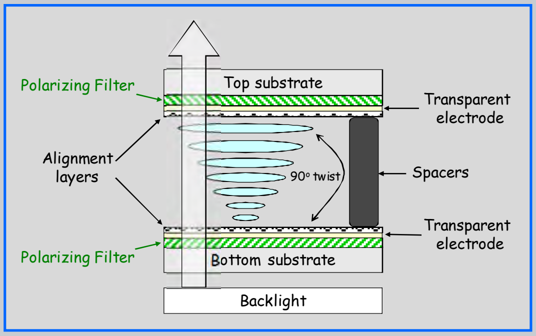
De-localized charge in long organic molecules defines anisotropy:

CH_3O -⟨benzene⟩-CH=N-⟨benzene⟩-C_4H_9.

- Molecules are arranged loosely along main axis (or director).
- Their spatial configuration is determined by elasticity and deformation constants.
- Oriented molecules are often referred to as 'directors'

Alignment of liquid crystal molecules (nematic phase)

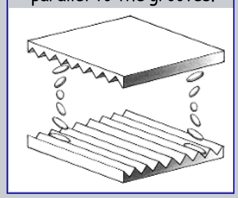
VIII. D.1 - Elements of a TN LC Cell

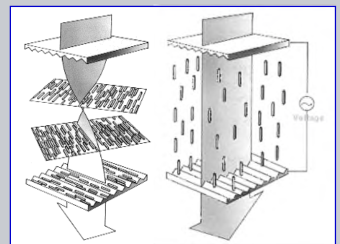


VIII. D.1 - Electro-optical Effect

Twisted Nematic (TN) LC cell

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



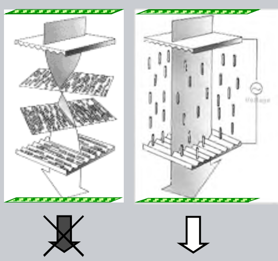


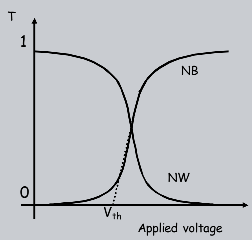
Adapted from Sharp Co. brochure

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

VIII. D.1 - Light Modulation With Polarizer

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



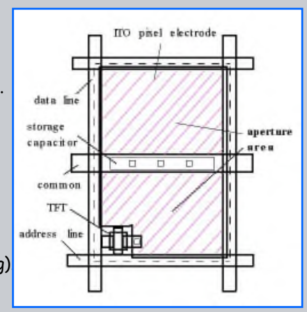


For normally black (NB with aligned polarizers), there is no transmission when voltage is applied.

VIII. D.1 - Active Matrix Design

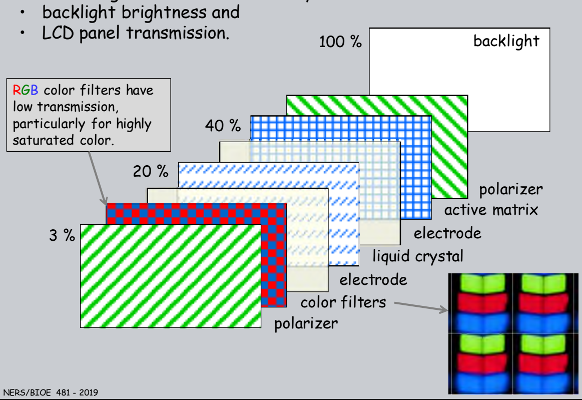
All pixels in a row are changed in sequence.
No flicker even at modest refresh rates.

- 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.



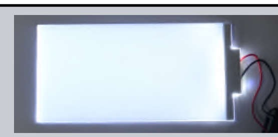
VIII. D.1 - Brightness and Light Transmission

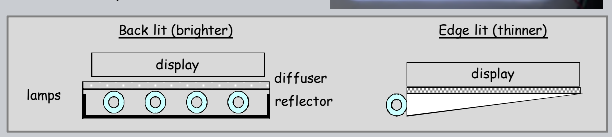
Monitor brightness is determined by
- backlight brightness and
- LCD panel transmission.



VIII. D.1- Backlight

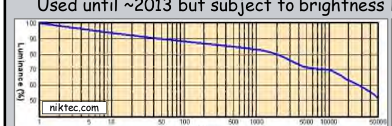
The LCD panel is placed on a backlight with uniform luminance





CCFL : Cold Cathode Fluorescent Lamp

Used until ~2013 but subject to brightness loss and color shift.



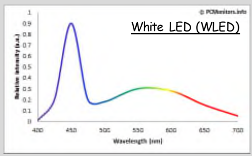
VIII. D.1 - Backlight

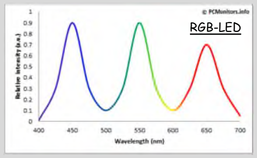
Most new LCD monitors use LED backlights.

- Lower power (~1/2)
- Longer lifetime.

Evolution of LED Backlights

Brightness and color purity are improved with multi element LEDs.





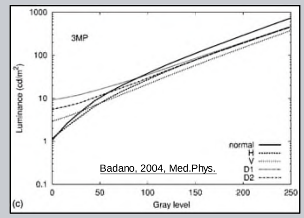
White LEDs are typically a blue LED with broad spectrum yellow phosphor to give the impression of white light. The spectral curve it is a poor match to the transmission of the red and green color filters of an LCD display.

RGB LEDs consist of a red, a blue, and a green LED and can be controlled to produce different color temperatures of white. RGB LEDs for backlighting are found in high end displays.

VIII. D.1 - Luminance Changes With Viewing Angle

Light transmission through the LCD pixel structure varies with emission angle (vertical, horizontal, & diag.)

- For a 3MP medical monitor, the measured luminance response shows only a slight reduction in Lmax in the horizontal direction.
- In the vertical and diagonal directions, Lmin is additionally increased.

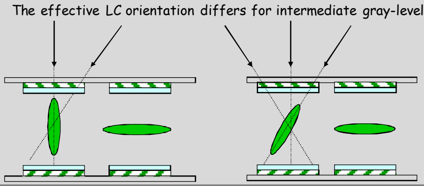


VIII. D.1– The Viewing Angle Problem

Viewing angle problems results from anisotropic LC light modulation.

The viewing angle problem is severe for simple TN pixel structures:

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

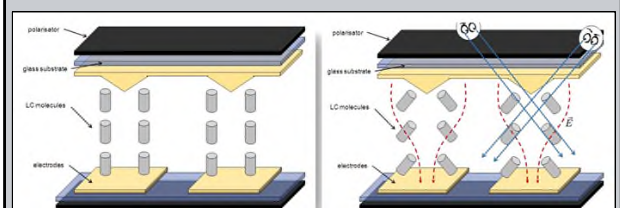


Advanced pixel structures improve viewing angle performance.

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

VIII. D.1- Vertical Alignment (VA)

Panel Technologies (Simon Baker)



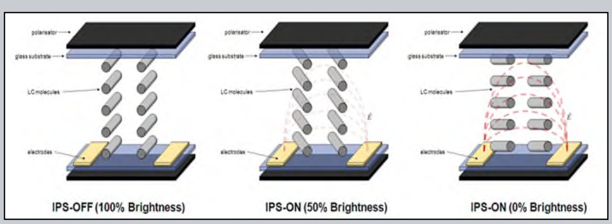
For vertical alignment (VA) designs, a protrusion produces directors that are perpendicular to the display surface. No rubbing processes are employed. The sub pixel has several regions in which the crystals move in opposite directions.

- Wide horizontal and vertical viewing angle.
- Excellent low luminance response (deep black).
- Switching times are ~1/2 that of IPS designs.
- Numerous pixel structure variations:

P-MVA, S-MVA, A-MVA - S-PVA, cPVA

VIII. D.1 - In Plane Switching (IPS)

Panel Technologies (Simon Baker)

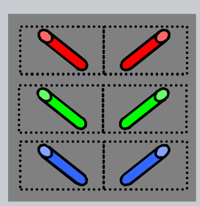


For in-plane switching (IPS) designs, the rubbing directions are the same on the top and bottom of the cell. When an electric field is applied, the directors remain in plane producing improved viewing angle response.

- Viewing angle performance is typically better than VA.
- Response times of current generation products is good.
- 10 bit high performance panels are now available.
- Numerous pixel structure variations:

S-IPS, AH-IPS, E-IPS, H-IPS, p-IPS - PLS, S-PLS

VIII. D.1 - Multi-domain Cells



Dual domain pixel structure

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

The domain areas are defined with different alignment using

- Sequence of differential rubbing treatments and photolithographic steps.
- Patterned alignments with differential UV light exposure.

Dual domain pixel structures are now widely used for VA and IPS panels.

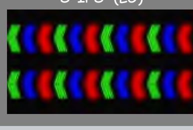
VIII. D.1 - LCD pixel structure ID

- Monitor manufacturers (i.e. Dell, HP, NEC, …) do not specify the panel supplier (LG, Samsung, ..) or the pixel structure.
- Macro photographs or a high power loupe can be used to identify the structure.

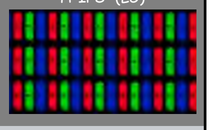
S. BAKER

PVA (Samsung)

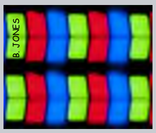
S-IPS (LG)



H-IPS (LG)



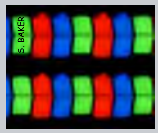
?



Samsung Plane to Line structure (PLS) which is similar to IPS.

- Left: Apple iPad retinal display
- Right: Samsung Galaxy Tab 10.1

PanelTechnologies(S.Baker)



LCDTech: Pixel Structures

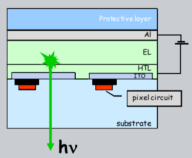
VIII. D.2 – Other Display Technologies

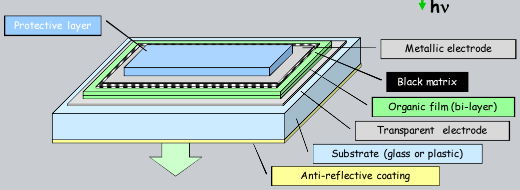
OLEDs

Organic Light Emitting Devices

VIII. D.2 – 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.





VIII. D.2 – OLED early history

OLED technology has a long history,
but manufacturing problems has prevented commercialization.

- 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.
- → 2010
  - Manufacturing problems prevented commercialization

VIII. D.2 – OLED potential

Manufacturing problems have gradually been resolved and display devices introduced which offer significant long term potential

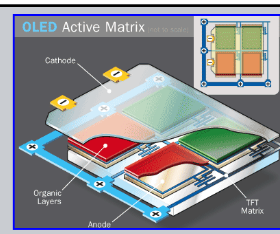
- Simple fabrication process ⇒ low cost
- Light weight, flat and thin ⇒ portable
- High resolution (50 μm)
- Emissive device ⇒ wide viewing angle
- High brightness, and contrast
- Fast response time ⇒ video rate
- Low drive voltage ⇒ low power
- High luminance efficiency ⇒ low power

- Ink jet printing technology developed at MIT has been commercialized by Kateeva. An OLED manufacturing line (Gen 8) is now being produced (Kateeva YIELDjet platform).
- Emitting material that perform as well in solution as in the more typical powder form are still needed.

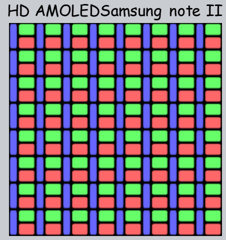
Kateeva.com

VIII. D.2 – Small display products

Active Matrix OLED, AMOLED, displays are now available in small devices such as smart phones.

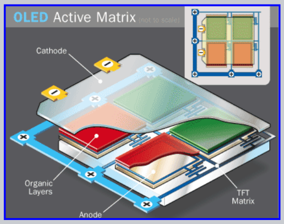


HD AMOLEDSamsung note II



Full HD AMOLED (Samsung Galaxy s4 & s5)

VIII. D.2 – Small display products



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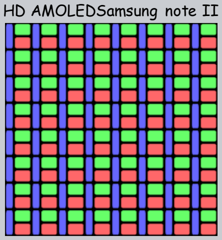
HD AMOLEDSamsung note II



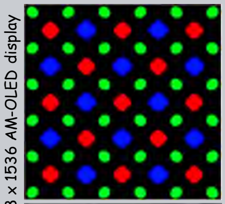
Full HD AMOLED (Samsung Galaxy s4 & s5)

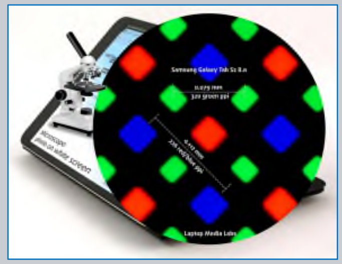
VIII. D.2 – Tablet display products

Samsung has recently introduced tablets with penTile pixel structure in a diamond orientation.

- More close spaced green emitters with 0.079 mm spacing.
- Red/Blue spacing of 0.112 mm

2048 x 1536 AM-OLED display





Samsung Galaxy Tab S2 8.0

VIII. D.2 – 2014: OLEDs come of age

In 2014 OLED technology became a factor in the full format display market.

- Samsung Galaxy Tab S
  - 2560 x 1600 AMOLED
  - 8.4 and 10.5 inch models
- LG and Samsung introduce 55" OLED TVs.
  - LG 55EM9700 (LG)
  - S9C Series (Samsung)

OLED displays are now common in handheld devices and beginning to be available for laptop and desktop monitors (2019).

LG 55EM9700

S9C Series

http://www.oled-a.org
http://www.oled-info.com

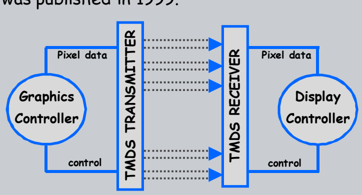
VIII. D.3 – Other Display Technologies

Graphic Controller Interface

DVI, HDMI, Display Port

VIII. D.3 - Digital Display Controllers

- LCD and other panel display technologies have discrete arrays of pixels that should be controlled using digital image data.
- Intel, Compaq, Fujitsu, HP, IBM, NEC, and Silicon Image organized a Digital Display Working Group to define digital connectivity specifications (www.ddwg.org). The standard was published in 1999.



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

Silicon Image's PanelLink technology for Transition Minimized Differential Signaling (TMDS) provides the basis for DVI.

VIII. D.3 - Digital Display Controllers

DVI is used for HDMI connections now used for HD TVs. HDMI additionally incorporates the audio signal.

DVI to HDMI converter

HDMI connector

- DisplayPort is designed to replace DVI.
- DisplayPort is a digital display interface standard put forth by the Video Electronics Standards Association (VESA). It defines a digital audio/video interconnect, intended to be used between a computer and its display.
- A high bandwidth (17.3 Gb/s, v1.2, 2009) supports 30 bit graphics with high resolution,

  3840 × 2160 × 30 bpp @ 60 Hz
- Version 1.3 (9/2014) increases bandwidth to 32.4 Gb/s supporting 5120×2880 displays.

DisplayPort connector
(Note HDMI similarity)

DisplayPort is currently royalty free, while the HDMI royalty is 4 cents per device and has an annual fee of $10,000 for high volume manufacturers.