# Introduction to Current Display Technologies for Medical Image Viewing

## Perspectives for the TG270 Update on Display Quality Control

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No disclosures.

This talk covers currently available display technology.

Any mention of brand names in this talk should not be construed as an endorsement of those products.

## Parsing our Options for Medical Image Display

- Overview of current display technology
  - How different display types work
  - Perceptually relevant hardware characterization
- Designs for the market: display aspects for medical diagnostic image viewing
- What's on the market and market trends





## Technology changes

Not so long ago….

- When AAPM TG18 report was started, most of the soft-copy displays in medical imaging were CRTs.
- LCD and OLED were labeled as "emerging technologies"

American Association of Physicists in Medicine (AAPM) Task Group 18. 2005. Assessment of display performance for medical imaging systems. http://www.aapm.org/pubs/reports/OR_03.pdf./

Image source: http://www.questincstore.com/barco-crt-repair-exchange/

## Today

Image source: https://betanews.com/2011/11/14/cea-keeps-up-search-for-cheap-safe-way-to-recycle-old-monitors-tvs/

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## Today

### Large Format LCD

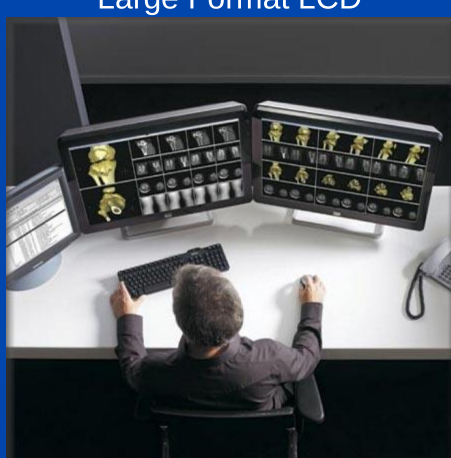

Image source: Barco

### Small Format LCD and OLED

http://amiil.engineering.asu.edu/wiki/doku.php?id=projects:resmd

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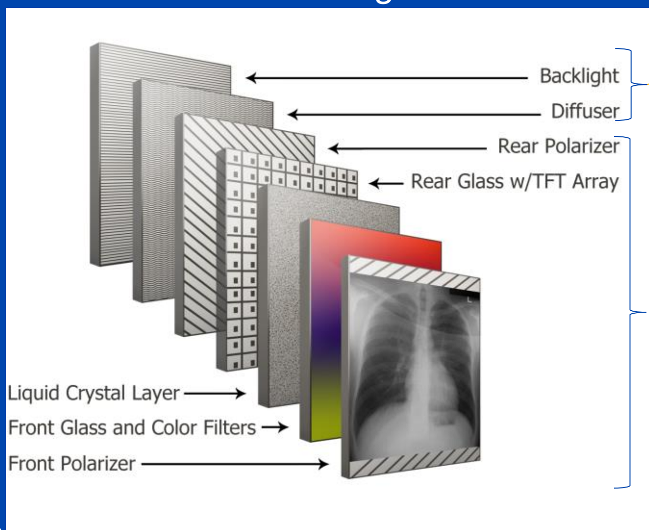
# Liquid Crystal Displays (LCD)

*Image formation*




"backlight"

Creates the uniform light source

"LCD stack"

spatial array of light filters used to create an image.

Pixels are created by TFT array, which locally affects the light polarization determining how much light passes through

TFT = thin film transistor

Image source : Kagadis et al, Radiographics **2013;** 33



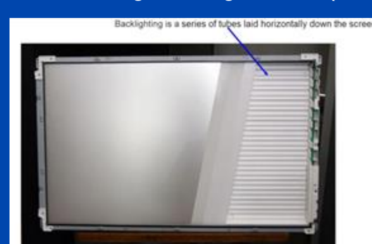
# Liquid Crystal Displays (LCD)

*Luminance*

Light source = backlight

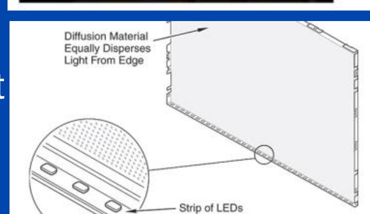
Common backlight configurations (CCFL or LED)

CCFL bulb array




Older models

Edge-lit LED



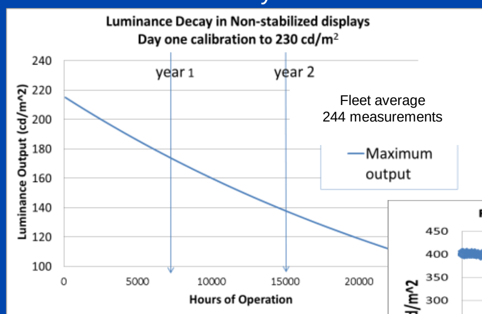

Current models

https://www.gizmodo.com.au/2010/02/60-cheaper-ccfl-lamps-could-outshine-led-backlighting-in-tvs/
http://www.appliancedesign.com/articles/93117-led-backlighting-for-lcds

# Liquid Crystal Displays (LCD)

## *Luminance lifetime*

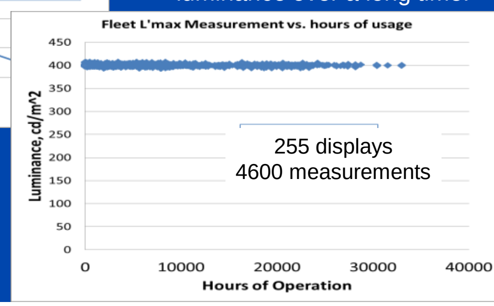
**Consumer grade** backlights are typically not as bright, no headroom, max Luminance decays




Medical grade displays use bright backlights with headroom to maintain calibration over time

| | |
|---|---|
| brightness typical | 1000 cd/m2 |
| calibrated brightness | 500 cd/m2 |

**Medical Imaging Displays** can be maintained at constant max luminance over a long time.



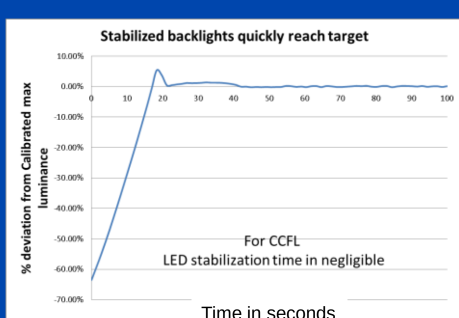



# Liquid Crystal Displays (LCD)

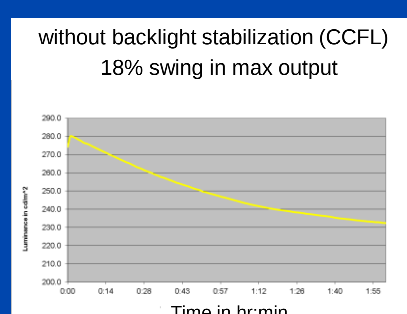
## *Luminance stability*

“Medical-grade” diagnostic displays have backlight stabilization (sensors that monitors backlight output).

Display luminance quickly gets to target and stays there.




Don’t need long warm up times = save your backlight and your time




When are you measuring? Luminance changes. QC headache

## Liquid Crystal Displays (LCD)
*Luminance stability*

- Display luminance loss over time can also be caused by aging of other components.
- What the backlight sensor sees is not what the viewer sees (or a front panel photometer).
  - we saw this when we didn't have integrated photometers and hoped to make our lives easier with reliance on the backlight sensor for stable front panel output. Didn't work that well.
- It's necessary to make front panel measurements on a regular basis and recalibrate the display.

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## LCD image formation
*fixed pixel matrix*

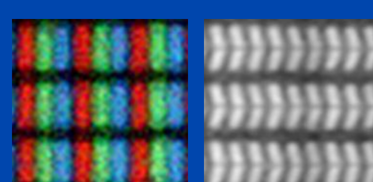
Image is created by blocking the backlight with
*Millions of little shutters*

How much light is transmitted depends on the voltage applied to the pixel.

Minimum Luminance = maximal blocking

Maximum luminance = minimal blocking

Separately addressable subpixels with RGB filters combine to make different colors.



Monochrome may have the same underlying subpixel structures just without the color filters

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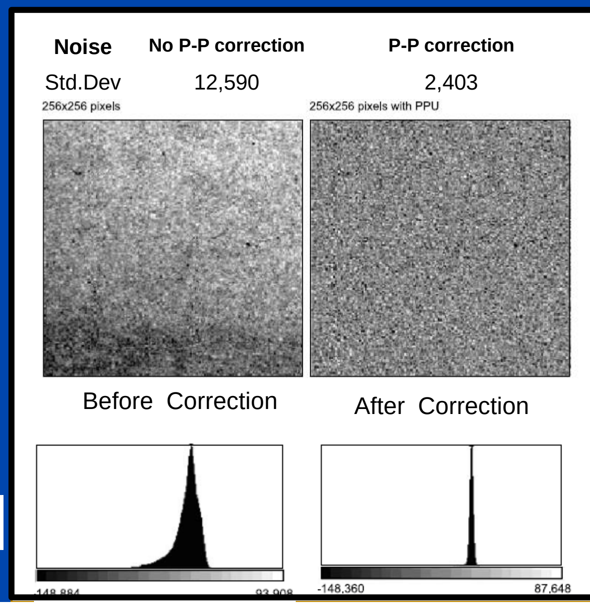
# LCD Noise

*Variation in pixel responses to the same driving level*

Higher quality panels have greater uniformity and less noise

**Medical grade diagnostic displays often employ Individual pixel correction factors to reduce fixed-panel noise**

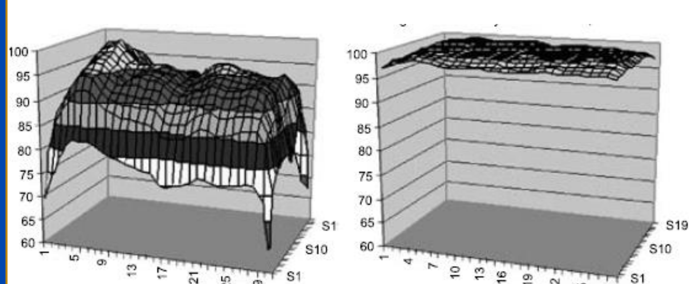



Source images from: Kimpe, T et al. JDI, 18: 3 (2005)

# LCD Non-Uniformity

*Variation in pixel illumination*

Non-uniformity across display




Before Correction

After Correction

Source images from: Kimpe, T et al. JDI, 18: 3 (2005)

**Pixel correction also can correct for non-uniformity in backlight illumination of the LC panel**

## LCDs currently dominate the display market for diagnostic medical imaging

Everything LCD

Images from Barco, Eizo and Double Black product websites

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## LCDs currently dominate the display market for diagnostic medical imaging

What's working?

- Many products have been designed to meet standards put forth by the ACR-AAPM-SIIM Technical Standard for Electronic Practice
- Stable performance: short-term and long-term luminance stability and remaining free from artifacts
- Tools provided for calibration and quality control
- Typical lifetimes 5+ years normal use

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# Organic Light Emitting Diode (OLED) displays

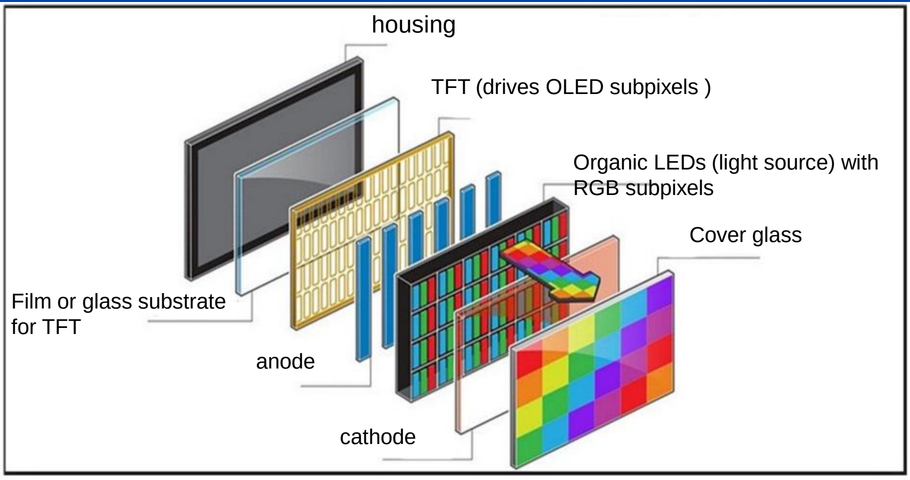



Image source : http://www.oneshothit.com/arena-oled-displays/
( nice image but  poor information on this site)



# OLED Display Image Formation

*fixed pixel matrix*

Each pixel is a separate emissive element (OLED), controlled by a TFT array.

(No backlight)
Black = Black = pixel is off (no light)

Color comes from  either subpixels of RGB OLED (RGBG shown) or White OLED subpixels with color filters .

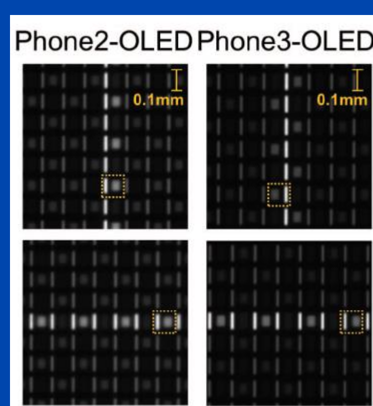
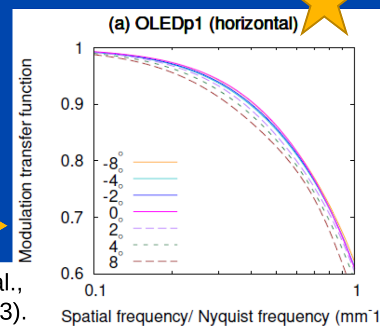


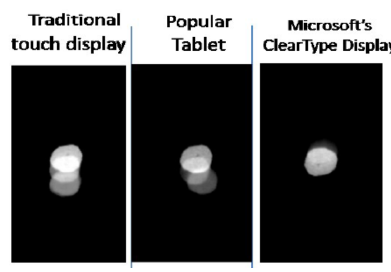

Image source: Yamasaki et al., Spatial resolution and noise in organic light-emitting diode displays for medical imaging applications Opt. Exp. (2013).

## Factors that impact resolution for OLED displays and LCD

- Viewing distance
  (perceived resolution changes with distance)
- Viewing angle
- Luminance level*,**
- Pixel design*,**
- Panel reflections




*Yamasaki et al., Opt. Exp. (2013).




S.Bathiche, et al. SID 2013 DIGEST

**Yamazaki, et al. PLOS One, 2013. 8(11)

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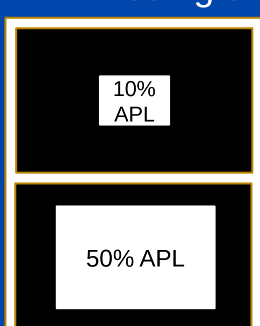
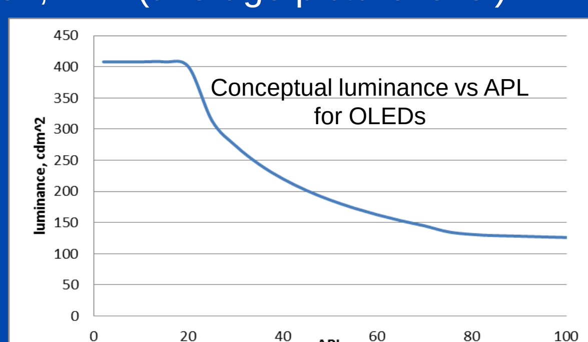
## OLED display challenges

### *"Luminance loading"*

With current technology, the measured luminance in a given area depends on how many pixels are being driven, APL (average picture level)




Luminance limit is produced by current max or intentional capping of the current to protect the OLED pixels

**Ref: Organic light emitting diode (OLED) displays - Part 6-1** IEC 62341-6-1:2017 RLV

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## OLED display challenges
### *Image Retention*

Pixels lose efficiency with use (age). Since each pixel is driven separately, they age separately.

A pixel that was used a lot will be less bright than a pixel that hasn't been driven as much [https://www.oled-info.com/oled-monitor]

*This could also happen in an LCD with an LED-array backlight with local dimming.*



## Where is the OLED display ?

Largest market for OLEDs today
Potential utilization: telerad in a pinch, consult with mobile viewers

Not the standard workhorse for diagnostic medical image viewing and hasn't been designed for that purpose.

# Where is the OLED monitor ?


Dell 30 UltraSharp OLED Monitor

**Pixel Pitch**
0.173 mm x 0.173 mm
**Brightness**
300 cd/m$^2$ (typical)
**Maximum Preset Resolution**
3840 x 2160 = 8MP

Not designed or marketed for image viewing

**Sony** PVM-2551MD
**Pixel Pitch**
0.283 mm x 0.283 mm
**Brightness**
???
**Maximum Preset Resolution**
1920 x 1080 pixels = 2 MP

Available 2012



# OLED display vs LCD display

Summary of Studies:
the OLED medical monitor on the market vs. other OLED handhelds vs. LCD handhelds and workstation displays

| What was found | |
|---|---|
| Luminance Ratio | OLEDs can have very high luminance ratios, but may not be realizable with DICOM calibration. Max luminance of OLED displays are reaching those of LCD, but max output is for limited APL . |
| Luminance Calibration | OLED workstation monitor: up to 50.5% of neighboring display values were not perceptually distinguishable |
| Resolution | OLEDs and LCD were comparable within handheld class OLED workstation had worst resolution (signal contamination between pixels) |

Refs: Yamasaki et al., Opt. Exp. (2013). Elze, et al. Med. Phys. 40 (9), September 2013

## Will we see more OLED monitors for medical image display soon?

Work needs to be done to address some of the significant issues described in order to bring OLEDs as a major player in diagnostic reading rooms…. But perhaps that won't be too far off.

**Sony may be JOLED's first customer for its 21.6" 4K medical OLED monitors** June 8, 2017

Last month JOLED announced that it started to sample 21.6" 4K OLED monitors. JOLED plans to develop these OLED monitors for medical applications - it will produce these in low volume at its current 4.5-Gen pilot production line, and will start mass production in 2019.

https://www.oled-info.com/oled-monitor

GE ultrasound with OLED display

http://www.genewsroom.com/press-releases/now-playing-4d-your-heart-281214

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## Image Display Trends (or trended)

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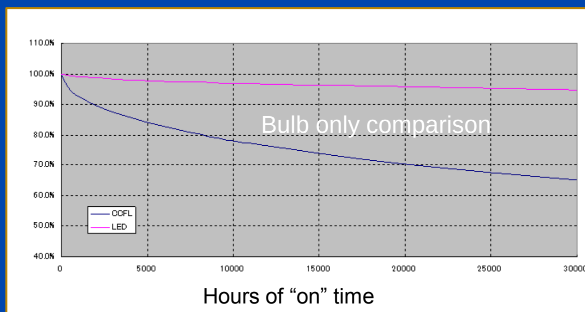
## the Market Place For Diagnostic Imaging

*LED backlights: the better LCD option for longevity*




Source: Eizo, reproduced with permission

LED backlights have superior lifetime and efficiency compared to CCFL

Practice Anecdote:

37,000 hours of operation
And still showing “100% backlight”

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## the Market Place For Diagnostic Displays

*Integrated Photometers and software for automated calibration and QC*

Displays for medical imaging need to be monitored and occasionally re-calibrated to maintain performance.

Integrated photometers, automated QC testing, remote data management software with failure notification tools have the *potential* to make that easier

| PHOTOMETERS | |
|---|---|
| Integrated Photometer:<br>Measures one location<br>Can be used for automated testing | Hand-held photometer:<br>Can measure multiple locations<br>Can be used to “calibrate” integrated photometer<br>And measure display uniformity |

Image source: Eizo

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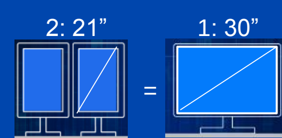
## the Market Place For Diagnostic Displays

*Larger Format Displays*

An increasingly popular option associated with increased efficiency and flexible work space utilization, replacing multiple heads.




| 2: 21" | 1: 30" |
|---|---|
| 2MP | 4MP |
| 3MP | 6MP |
| 5MP | 8MP |
| | 10MP |
| | 12MP (33") |

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Image Source: www.barco.com/en



## the Market Place For Diagnostic Displays

*Color*

Medical images and viewing software increasingly use color to increase information density or for aid in visualization.

*Older generation color LCD lacked the max luminance provided by monochrome. This is no longer the case.*

Many brand options
For 6MP color

| Barco | Double Black Imaging | EIZO Inc. | Quest International, Inc. | Richardson Healthcare |
|---|---|---|---|---|
| Coronis Fusion 6 MP | DBI6MPLED - 6 MP color LED system | RadiForce RX660 | CCL650i2 | Image Systems XLED 6MPC |

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Image Source: https://www.itnonline.com/compare/69711/50503?products=2-7-16-19-28-33

## the Market Place For Diagnostic Displays
*Glossy Screens?*

If this is a trend it is one that should be avoided.

Instead, look for displays with low reflection coefficients.

Image source: http://www.tftcentral.co.uk/articles/panel_coating.htm



## the Market Place For Diagnostic Imaging
*Higher Brightness*

- Diagnostic display on the market have calibrated luminance maxima between 350-1000 cd/$m^2$
  - Higher brightness displays can allow for higher ambient light environments*

    *Accommodated by maintaining the luminance ratio while increasing the black level*
- “Spotlight” modes allow for smaller regions of higher contrast for (akin to a “hot lamp”).

# Tomorrow?

New technology has the potential to help address challenges with increasing integration of more and different information for display (radiologic, path, radiomics data, CAD, etc.)

*Flexible displays:*
*TFT glass replaced by TFT film*

Image source: https://www.digitaltrends.com/home-theater/lg-display-55-inch-flat-oled-panel-sticks-to-wall-with-magnet//

*Augmented reality:*

https://www.novarad.net/opensight/



# As new viewing solutions develop to meet new diagnostic challenges

There is work for physicists with radiologists and other imaging scientists and engineers

To *characterize devices and guide operation and maintenance*

In order to best deliver quality diagnostic tools through:

- Maximizing information delivery
- Consistency in Image Display
- User-focused requirements that work with perceptual and cognitive limitations of the viewer

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# Questions & Discussion