



AAPM 2004, Pittsburgh, PA

TG18 Display Evaluation Demonstration Workshop

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Workshop participants

Ehsan Samei
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Duke University Medical Center
University of Arizona, Tucson

Manufacturers:

1. BarcoView, LLC
2. Data Ray Corp.
3. Image Smiths, Inc.
4. Image Systems Corp.
5. National Display Systems
6. Planar Systems, Inc.
7. Totoku Electric Co., Ltd.



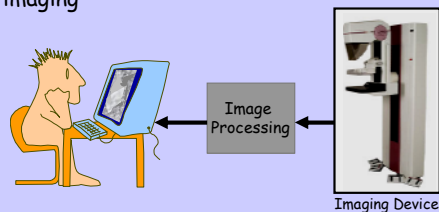
Workshop format

- | | |
|------|-------------------------------------|
| 1:30 | Lecture |
| 2:10 | Moderated review of workstations |
| 2:25 | Group/individual hands-on rotations |
| | |
| 3:20 | BREAK |
| | |
| 4:00 | Lecture (repeated) |
| 4:30 | Moderated review of workstations |
| 4:45 | Group/individual hands-on rotations |



Rationale

- Electronic displays, a key component of digital imaging





Rationale

- Soft-copy display quality is susceptible to variations in hardware, calibration, and to degradations over time
- Poor display quality leads to reduced overall effectiveness of diagnostic imaging, misdiagnosis (lawsuits), quality mismatch leading to inconsistent clinical decisions
- **Monitoring and maintaining display quality is essential for quality patient care**



AAPM TG18

- AAPM task group aimed to define standard and objective methods for
Assessment of display performance for medical imaging systems

Version 9, Oct. 2002

Version 10, Aug. 2004



TG18 Document

- In final editing phase
- Reviews
 - current display metrology standards
 - current display technologies
- Describes
 - Prerequisites and tools for display assessment
 - Assessment methods
- Defines
 - Acceptance testing and quality control criteria



IEC Display WG 36

- TG18 => IEC
- Formed in 2003 to develop an international standard
- Public draft soliciting comments expected before the end of 2004



Current Display Evaluation Standards

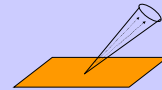
- Diverse - Not standardized
- Do not cover all aspects of display performance
- Often do not indicate acceptance criteria
- Either too subjective or too complicated
- Not yet fully endorsed by the **medical** community



Basics

• Luminance

- Visible light emitting from a surface into a unit solid angle per second



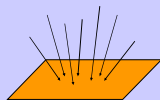
- SI unit: lumens/steradian/m² , **cd/m²** or **nit**
- Conventional unit: foot-lambert = 3.43 cd/m²



Basics

• Illuminance

- Quantity of visible light striking a surface per second



- SI unit: **lumens/m²** or **lux**
- 1 lux striking a perfect white diffuser surface => $1/\pi$ nit



5 Initial steps

1. Display class
2. The purpose of testing
3. Availability of test patterns
4. Availability of required instrumentation
5. Prerequisite steps



1. Display Class

- Primary (i.e., diagnostic)
 - Used for primary interpretation
- Secondary (i.e., clinical)
 - Used for secondary view of medical images
 - Acquisition QC displays

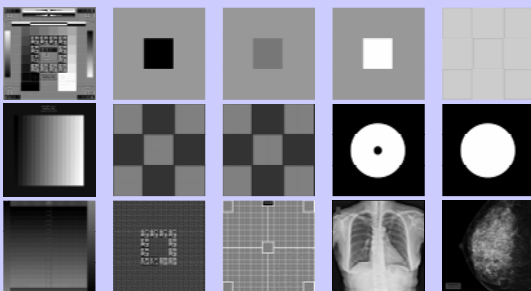


2. Purpose of Testing

1. **Acceptance testing (by medical physicist)**
 - Includes all key quantitative display characteristics (~1 hr)
2. **Annual compliance evaluation (by medical physicist)**
 - Redoing of almost all acceptance tests (~30-45 min)
3. **Monthly/quarterly evaluation (by QC technician)**
 - Mix of quantitative and visual tests (~ 15-20 minutes)
 - Results logged for consistency checks
4. **Daily evaluation (by user)**
 - Checks with a login test pattern (<1 min)
 - Clear instructions about who to call



3. Test Patterns



4. Instrumentation

- Luminance meter
- Illuminance meter
- Magnifier
- Mask
- Light source
- Other devices
 - High-grade CCD camera





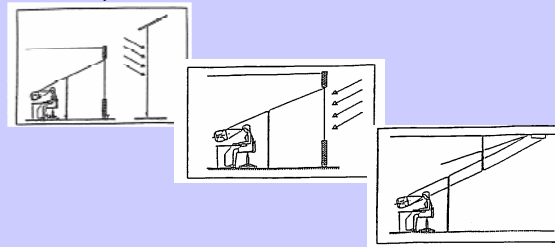
5. Prerequisites

- Display placement
- Absence of strong magnetic fields
- Clean face-plate
- Ambient lighting setup
- Display calibration to GSDF

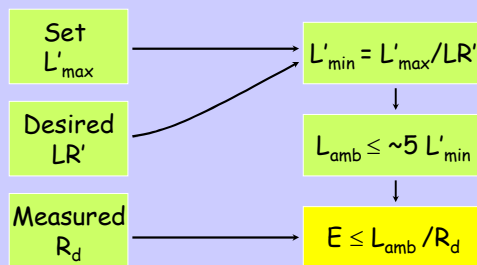


Display placement

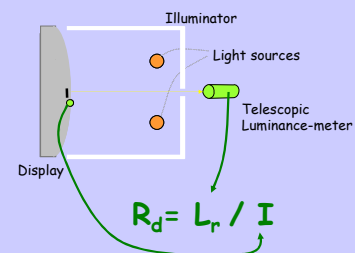
- No specular reflection

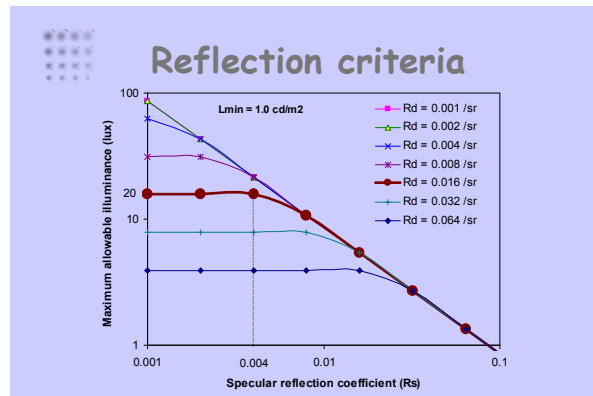


Ambient light flowchart



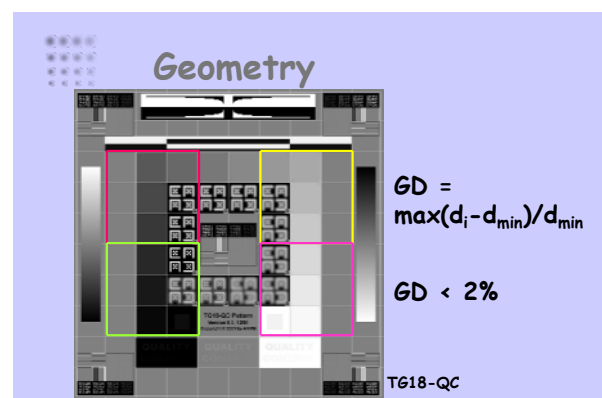
Reflection, diffuse

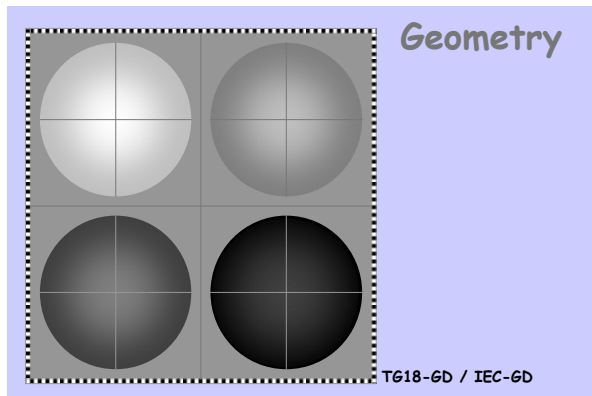




- ### Testing methods
1. Geometry
 2. Reflection
 3. Luminance
 4. Lum. dependencies
 5. Resolution
 6. Noise
 7. Veiling glare
 8. Chromaticity
 9. Other tests

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Geometry

- Image clips:
 - Whole pattern visible w/o clips
- Clocking distortion:
 - All edge line patterns w/o distortion
- Local distortion:
 - 2 directional measurement per quadrant
 - Max deviation, $\max(d_i - d_{\min}) / d_{\min} < 2\%$ (5% secondary)
- Global distortion:
 - Directional measures added together
 - Max deviation $< 2\%$ (5% secondary)

Testing methods

1. Geometry	5. Resolution
2. Reflection	6. Noise
3. Luminance	7. Veiling glare
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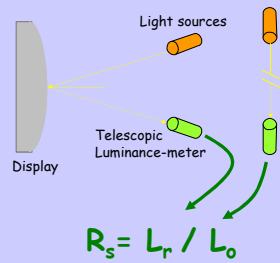
Visual assessment

- Specular:
 - High-contrast white objects should not be visible
- Diffuse:
 - Equivalent visibility threshold of low-contrast targets in a dark field with and without ambient lighting

T618-AD



Reflection, specular



Reflection criteria

The **maximum ambient lighting** should be such that

- **specular reflections** of white objects (with 90% reflection) at low luminance levels is < contrast threshold

$$E < (\pi/0.9) \times (C_r L_{min} / R_d)$$

- contrast reduction due to **diffuse reflection** at low luminance levels < 20%

$$E < 0.25 L_{min} / R_d$$



Testing methods

- | | |
|----------------------|------------------|
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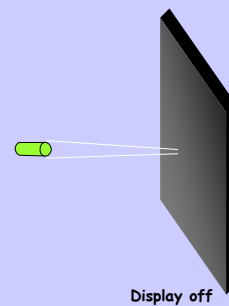


L_{amb}

Measured

OR

$$L_{amb} = E R_d$$





Luminance response

$$L'_{\max} = L_{\max} + L_{\text{amb}}$$

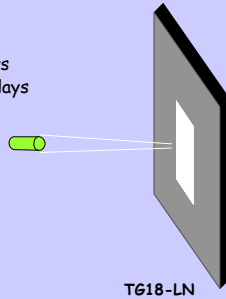
- > 170 cd/m² for primary displays
- > 100 cd/m² for secondary displays
- ~ 5% of desired value

$$L'_{\min} = L_{\min} + L_{\text{amb}}$$

- > 5L_{amb}
- ~ 10% of desired value

$$LR' = L'_{\max} / L'_{\min}$$

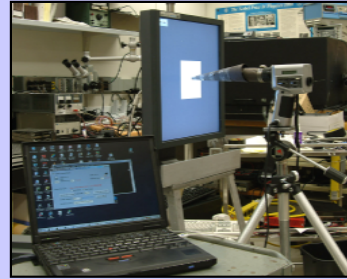
- > 250 for primary displays
- > 100 for secondary displays



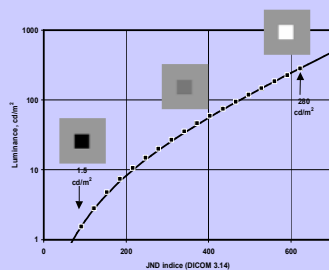
T618-LN



Luminance response



Luminance response



Luminance response

- $L_{\min}$ and $L_{\max}$ mapped to corresponding GSDF JND index (J)

$$J_{\min} = J(L_{\min}) \quad J_{\max} = J(L_{\max})$$

$$\Delta J = J_{\max} - J_{\min}$$

$$J_p = \Delta J / \Delta P$$

- JNDs ascertained corresponding to luminance values by linearly mapping the JND and pixel value (P) spaces

$$J_i = J_{\min} + \frac{P_i J_{\max}}{\Delta P}$$



Luminance response

- Measured and GSDF luminance ascertained as a function of JND

$$L_i @ J_i \quad L_i^d @ J_i$$

- measured and GSDF incremental contrast per JND ascertained

$$\delta_i = \frac{2(L_i - L_{i-1})}{(L_i + L_{i-1})(J_i - J_{i-1})} @ 0.5(J_i + J_{i-1})$$

$$\delta_i^d = \frac{2(L_i^d - L_{i-1}^d)}{(L_i^d + L_{i-1}^d)(J_i - J_{i-1})} @ 0.5(J_i + J_{i-1})$$



Luminance response

- Maximum deviation between measured and GSDF JND per pixel value calculated = incremental contrast per JND

$$\kappa_\delta = \text{Max} \left(|\delta_i - \delta_i^d| \right)$$

$$\kappa_\delta \leq 0.1 \text{ for primary}$$

$$\kappa_\delta \leq 0.2 \text{ for secondary}$$



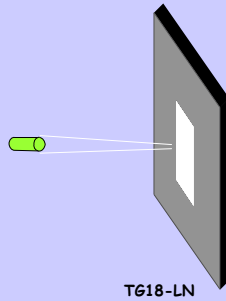
Luminance response

$JND_{\max}$ for $L'_{\max}$

$JND_{\min}$ for $L'_{\min}$

$\Delta L'/L'_{\text{avg}}$ per ΔJND

- < 10% deviation from GSDF's for primary
- < 20% deviation from GSDF's for secondary



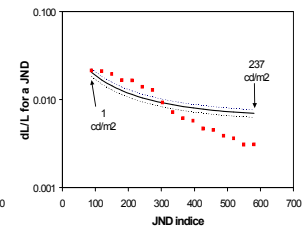
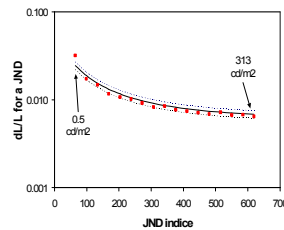
T618-LN

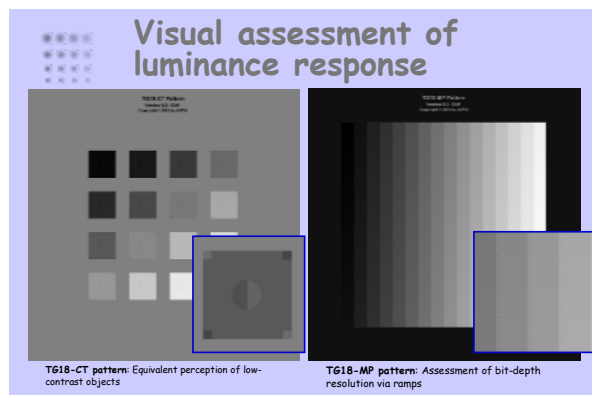
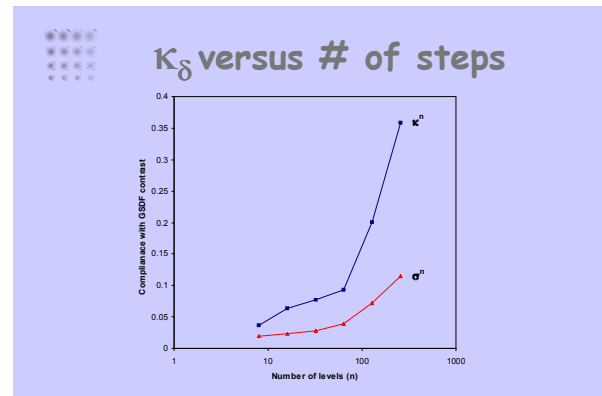
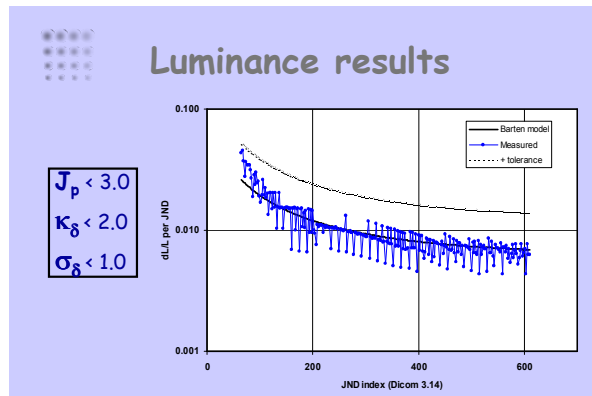


Luminance results

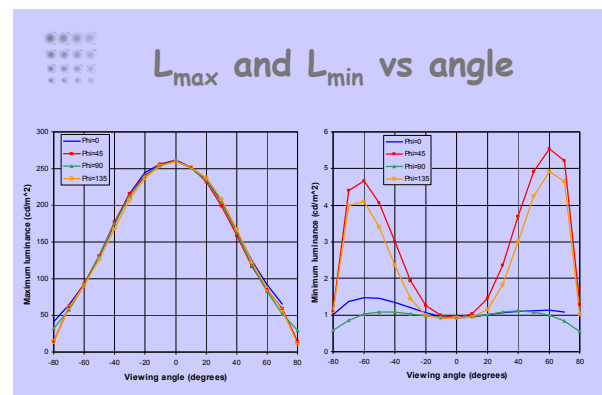
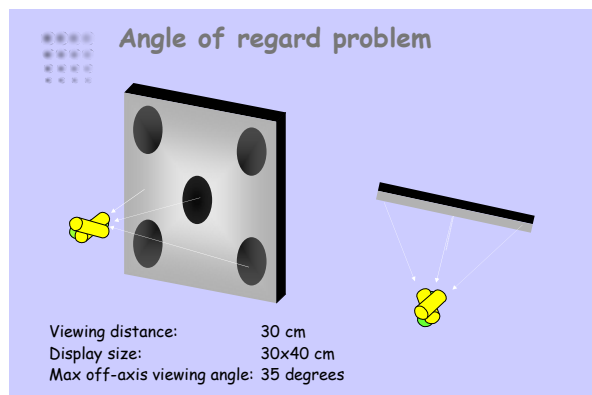
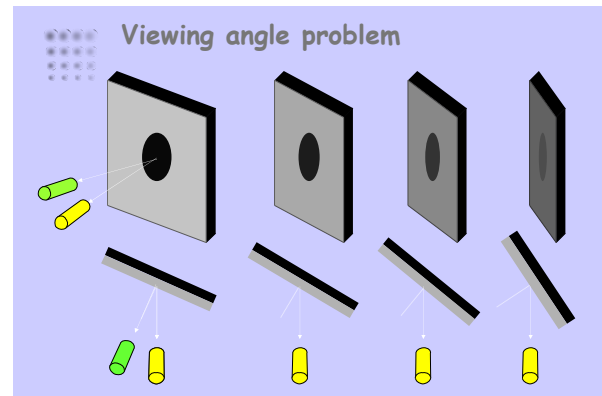
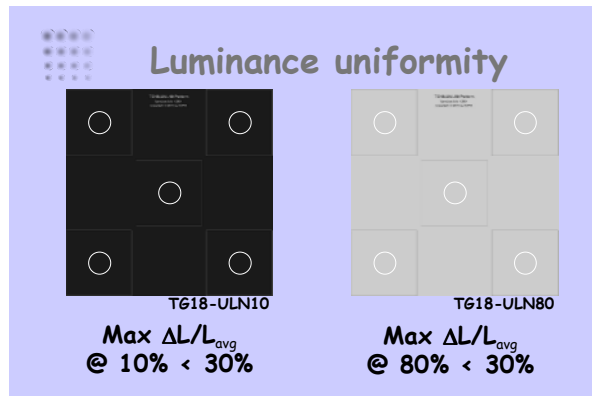
GSDF calibrated

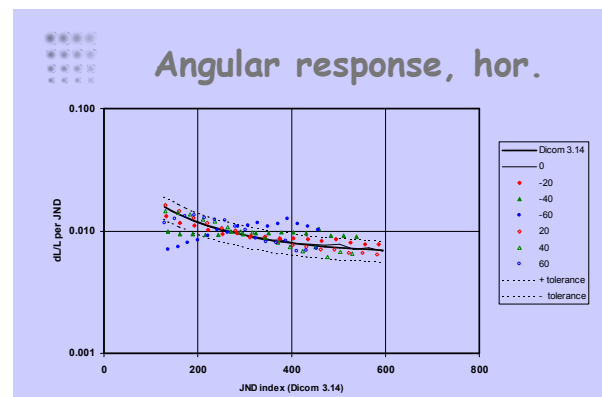
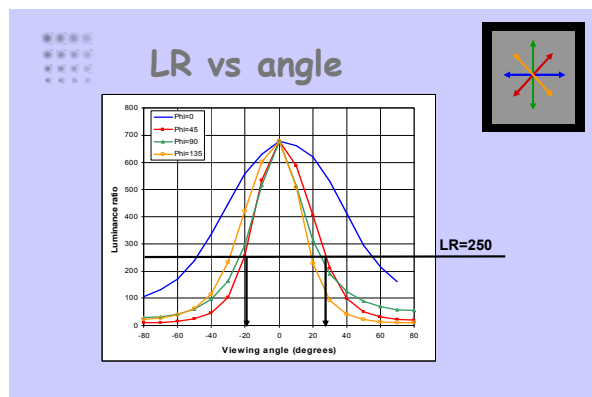
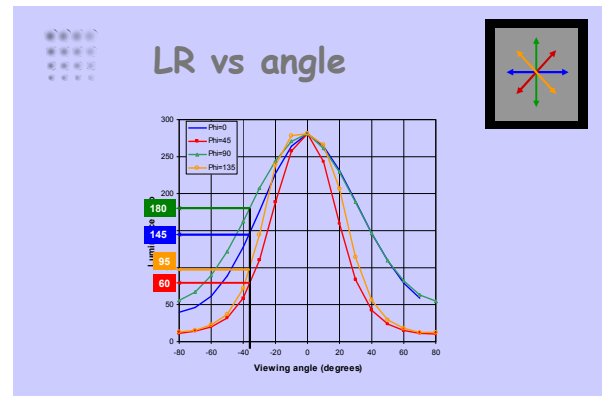
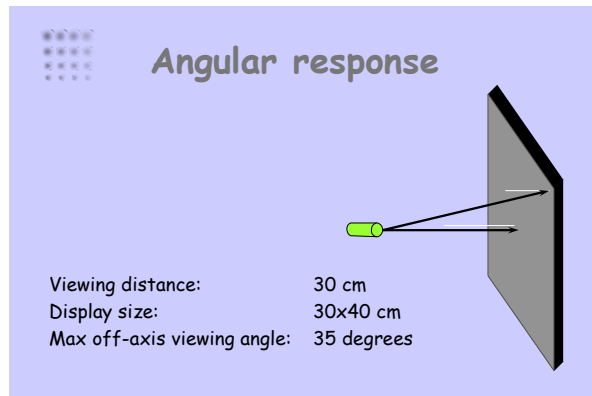
Uncalibrated





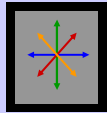
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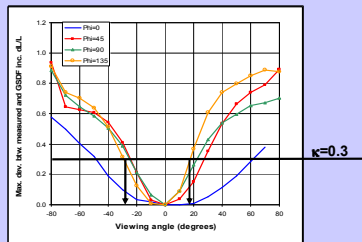




GSDF calib. angular tolerance



	mLCD
	3mpx
L_{min}	0.87
L_{max}	715.1
LR	820
α (0.3)	± 23
β (250)	± 25



(assumed perfect on-axis calibration)



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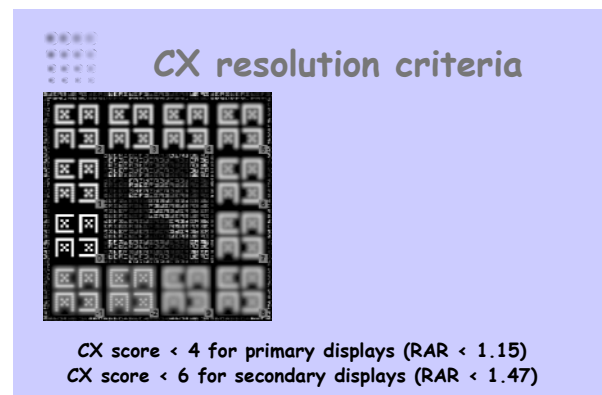
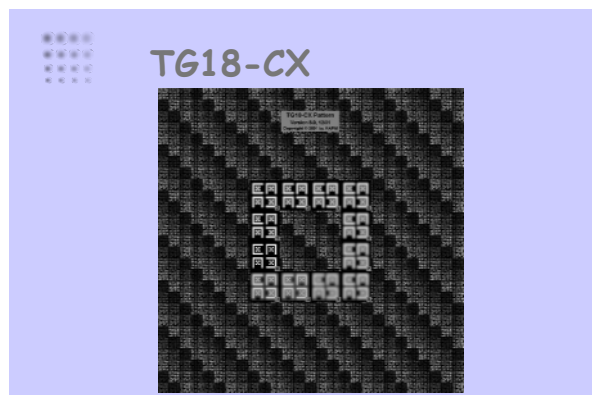
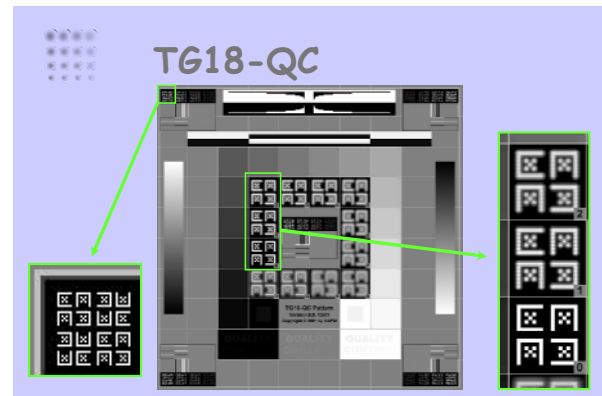
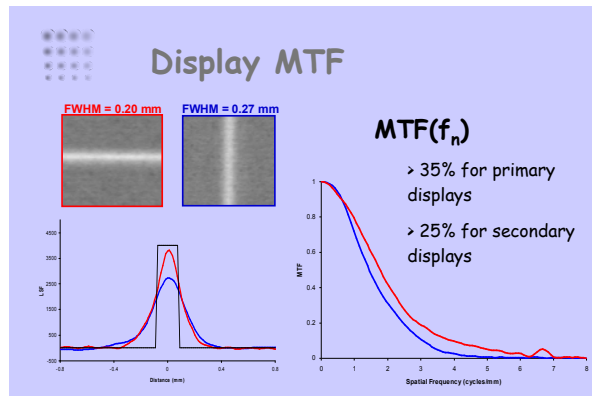


TG18-RV50



Resolution evaluation





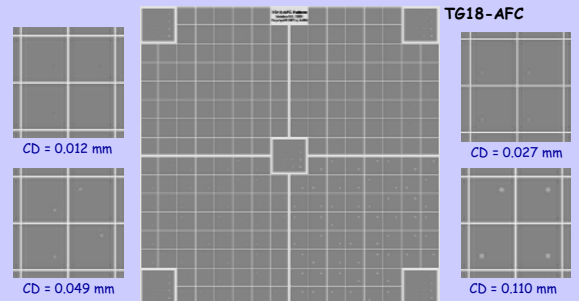


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Noise



Noise

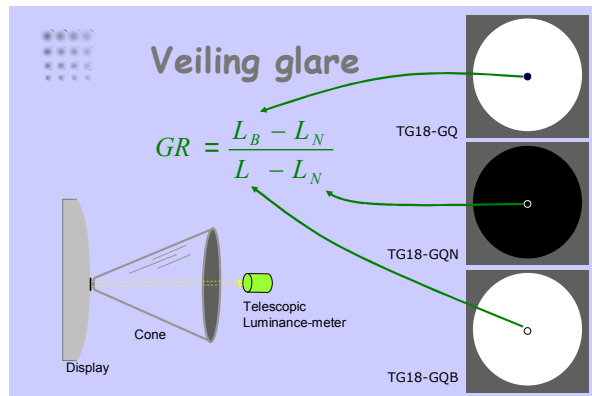
- Noise in radiographic imaging
250,000 quanta/mR-mm²
X 1 mR/exposure
X 0.2² mm²/pixel
X 0.25 detected quanta/incident quanta
= 3,500 detected quanta/pixel
~ 2% relative noise
- Assuming display noise < 1/3 quantum noise
~ 0.7%
w/ threshold SNR ~ 3
CD threshold ~ 0.023 mm (Rose model)
w/ 0.018 C/PV (8 bit) and
w/ 0.15 mm/display pixel (5 Mpx)

square target	PV	CD value
pixels	contrast	(mm)
1	8	0.024
2	4	0.024
3	3	0.027
4	2	0.024
5	2	0.030



Testing methods

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Glare criteria

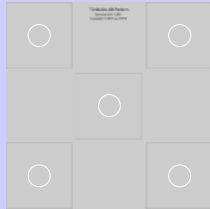
- **Visual test**
 - 3rd target (96/4096 PV contrast) visible in both patterns for primary displays
 - 5rd target (160/4096 PV contrast) visible in both patterns secondary displays

Testing methods

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Chromaticity



TG18-ULN80

$$u' = 4x/(-2x + 12y + 3)$$

$$v' = 9y/(-2x + 12y + 3)$$

$$CU = \sqrt{\Delta u'^2 + \Delta v'^2}$$

$$CU < 0.01$$



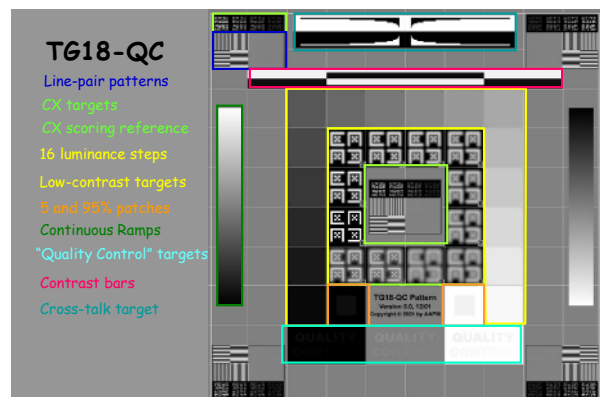
Testing methods

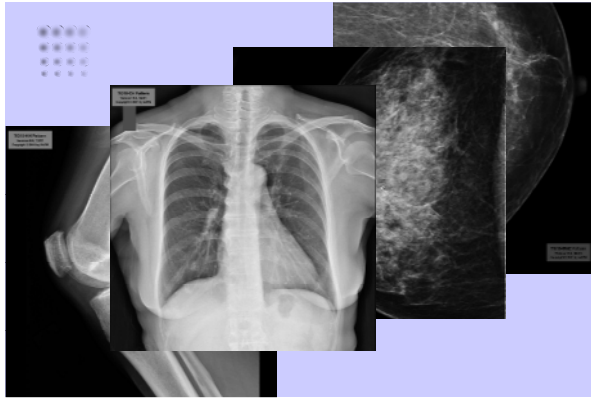
1. Geometry
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Overall display QC

- Display artifacts
- More visually-based and oriented toward QC
- "Clinical" test patterns
 - TG18-CH
 - TG18-KN
 - TG18-MM1
 - TG18-MM2
- Comprehensive test pattern: TG18-QC





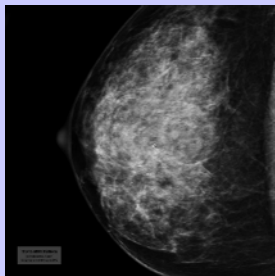
TG18-CH



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, the trachea and proximal bronchi, the borders of the heart and the aorta, and the diaphragm
8. Visibility of the retrocardiac lung and the mediastinum
9. Visibility of the spine through the heart shadow
10. Visibility of small details in the whole lung
11. Visibility of linear and reticular details out to the lung periphery

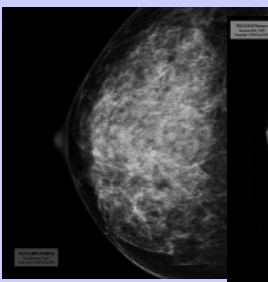
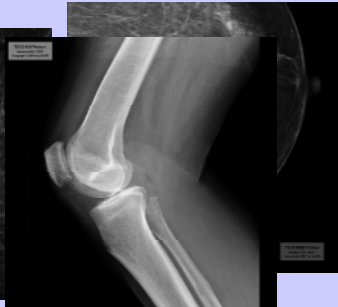
TG18-MM1



Evaluation elements

1. Degree of difficulty for exam
2. Overall contrast
3. Overall exposure/penetration
4. Overall sharpness (no blur)
5. Overall positioning - nipple in profile
6. Adequate compression
7. Sharp appearance of Cooper's ligaments
8. Structure of the clip and the presence of the gap at its apex
9. Appearance and visibility of subtle microcalcifications
9. Visibility of structures at the margins of the breast

TG18-MM and TG18-KN



TG18 info

deckard.duhs.duke.edu/tg18



Workshop participants

Ehsan Samei
Hans Roehrig

Duke University Medical Center
University of Arizona, Tucson

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