Calibration and Quality Control of Monitors and Displays

S. Jeff Shepard, M.S.
Imaging Physics Department
The University of Texas
M. D. Anderson Cancer Center
Houston, Texas
jshepard@di.mdacc.tmc.edu

Quality Assurance of Primary Display Devices

- Standards
- Performance Criteria
- Test methods (LCD only)
- QA program design and experience

Quality Assurance (ACR)

"A test image, such as the SMPTE test pattern should be captured, transmitted, archived, retrieved, and displayed at appropriate intervals, but at least monthly, to test the overall operation of the system under conditions that simulate the normal operation of the system."

Quality Assurance (ACR)

"As a test of the display, SMPTE pattern data files sized to occupy the full area used to display images on the monitor should be displayed. The overall SMPTE image appearance should be inspected to assure the absence of ***gross artifacts*** (e.g., blurring or bleeding of bright display areas into dark areas or aliasing of spatial resolution patterns). Display monitors used for primary interpretation should be tested at least ***monthly***. As a dynamic range test, both the ***5% and the 95%*** areas should be seen as distinct from the respective adjacent 0% and 100% areas."

Quality Assurance (ACR)

Contradicts SMPTE

512? 1k? 2k?

"As a test of the display, ***SMPTE pattern data files*** sized to ***occupy the full area used to display images*** on the monitor should be displayed. The overall SMPTE image appearance should be inspected to assure the absence of gross artifacts (e.g., ***blurring or bleeding of bright display areas into dark areas*** or aliasing of spatial resolution patterns). Display monitors used for primary interpretation should be tested at least monthly. As a dynamic range test, ***both the 5% and the 95% areas*** should be seen as distinct from the respective adjacent 0% and 100% areas."

CRT only

Adequate?

Experience – CRT QC

- MDIS (Parsons & Kim, 1994)
  - 2k CRT L_{max} decayed 20% in 8 months
  - L_{max} decay correlated with usage ("duty cycle")

10% failure rate (1 of 10) in a 9-month period.

Experience – CRT QC

Baltimore VA (Siegel, 2000) - 2k CRT service logs (17 months)

- Average time to failure 1.7 years
- Average life expectancy 2.4 years
- 20 failures (10 replacements)

All passed the ACR test!

Experience – CRT QC

- Groth D, et al (2001), Mayo Clinic
- Ly CK, (2002), Texas Children's Hospital

AAPM TG18

Samei E, Badano A, Chakraborty D, Compton K, Cornelius C, Corrigan K, Flynn MJ, Hemminger B, Hangiandreou N, Johnson J, Moxley D, Pavlicek W, Roehrig H, Rutz L, Shepard SJ, Uzenoff R, Wang J, and Willis C, ***Assessment of Display Performance for Medical Imaging Systems.*** *Draft report of the American Association of Physicists in Medicine (AAPM) Task Group 18, version 9.0, October 2002.*

Performance Requirements

	ACR	AAPM
Geometric Distortion	No Gross Artifacts	< 2% variation
Reflection	Depends on L_{amb}	Depends on L_{amb}
Max. Luminance	$L_{max} \geq 50$ ft-L ($171\ Cd/m^2$)	$L_{max} \geq 170\ Cd/m^2$
Contrast	5% and 95% SMPTE visible	$CR \geq 250$
Luminance Response	5% and 95% SMPTE visible	$\leq$ 10% of GSDF
Luminance Uniformity	No Gross Artifacts	$\Delta L/L_{avg} \leq 30\%$
Resolution	$\geq$ 2.5 lp/mm	$\geq$ 2.5 lp/mm
Noise	Not Specified	< Displayed radiographic image noise
Veiling Glare	Not Specified	Glare Ratio > 400

Test Patterns

- TG-18 Test Patterns
  - Available in DICOM® format at : http://deckard.mc.duke.edu/~samei/tg18

Procedures (All Class 1)

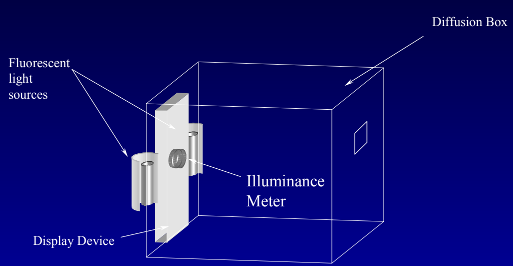
- TG18 - Assessment of Display Performance for Medical Imaging Systems
  - Luminance Response
    - Max Brightness & Contrast Ratio
  - Luminance Uniformity
  - Reflection
  - Noise

Reflection

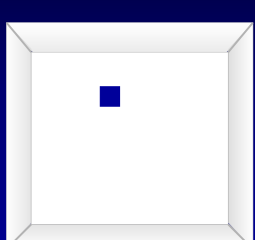
- Diffuse
- Specular

Used to determine maximum tolerable L_{amb} in reading room.

Diffuse Reflectance



Instrumentation: Diffuse Reflectance

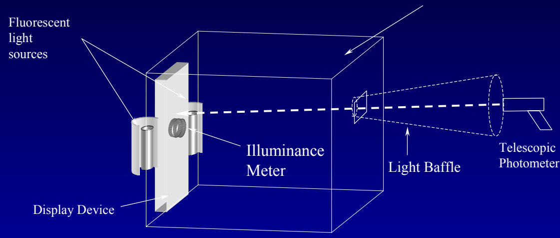


Diffusion Box:

- Matte white finish inside
- 24” cube
- Sight hole in back

Diffuse Reflectance

- Illuminance and
- Luminance of the Reflected Illuminance



Reflection

- Diffuse Reflectance:

$$R_D = \frac{\text{Luminance of reflected illuminance}}{\text{Illuminance of the display surface}}$$

Diffuse Reflection & Ambient Lighting

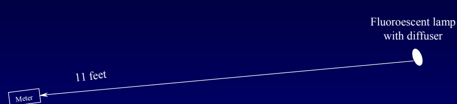
Diffuse reflection effect on L_{min} and contrast:

Monitor Illuminance (Room illumination, E)

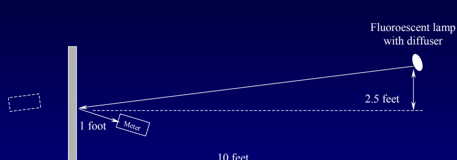
$$E \leq 0.25\ L_{min}/R_D$$

L_{min}	Maximum Room Illuminance (lux)				
(cd/m²)	R_d = 0.005	R_d = 0.010	R_d = 0.020	R_d = 0.040	R_d = 0.060
20	1000	500	250	125	83
10	500	250	125	62	42
4	200	100	50	25	17
2	100	50	25	12	8
1	50	25	12	6	4

Specular Reflectance



Specular Reflectance



Reflection

- Specular Reflectance:

$$R_S = \frac{\text{Luminance of Reflected Image}}{\text{Luminance of the Object}}$$

Specular Reflection & Ambient Lighting

Specular reflection of white background objects:

Maximum tolerable room illumination:

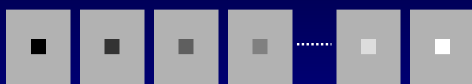
$$E \leq \pi C_T L_{min} / 0.9 R_S,$$

where $C_T = \Delta L / L$ @ L_{min}

L_{max} - L_{min} (cd/m²)	C_t	Maximum Room Illuminance (lux)				
		$R_s = 0.002$	$R_s = 0.004$	$R_s = 0.008$	$R_s = 0.020$	$R_s = 0.040$
20	0.010	349	175	87	35	17
10	0.011	192	96	48	19	10
4	0.015	105	52	26	10	5
2	0.018	63	31	16	6	3
1	0.024	42	21	10	4	2

Luminance Response

- AAPM TG18-LN
  - 17 patterns, uniform 50% background with central 10% incrementally brighter from L_{min} to L_{max} in even steps.

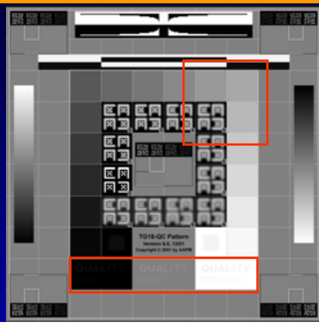


  - Room lights off (total darkness)
  - Measure each step and compare to GSDF

Luminance Response

- $L_{max} > 170$ Cd/m^2
- Response error $\leq$ 10% of GSDF
- $C = L_{max}/L_{min} \geq 250$

Luminance Response (Subjective, TG18-QC)



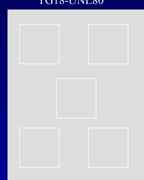
Luminance Response (Subjective, TG18-QC)

Luminance Response (Subjective, TG18-QC)

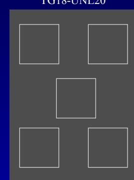
Luminance Uniformity, Chromaticity & Glass Defects

- AAPM TG18-UNL80 and –UNL10
- Measure luminance in the center and 4 quadrants of two uniform test patterns.
  - 80% of L_{max}
  - 20% of L_{min}

TG18-UNL80



TG18-UNL20



Luminance Uniformity, Chromaticity & Glass Defects

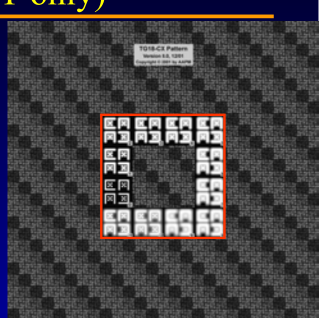
- On each monitor, compare each reading to the average of all 5:

$$|L_i/L_{avg} - 1| \leq 0.3$$

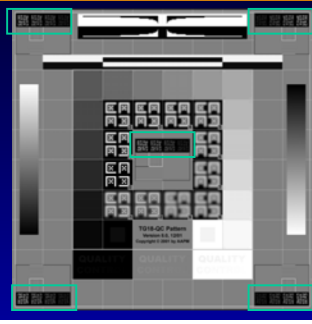
- Color Matching (TG18-UNL80)
  - Measure color with color photometer or
  - Visually compare monitors for matching color at each workstation
- Glass Defects

Resolution (CRT only)

- AAPM TG18-CX
- Match observed sharpness of small Cx patterns to simulated blur of large Cx patterns
- Passing score is ≤ 4



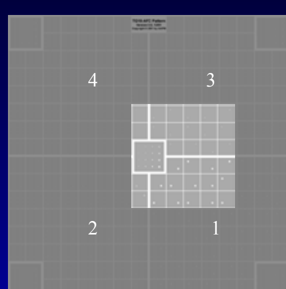
Resolution (TG18-QC)



AAPM 2004

Noise

- TG18-AFC
- Count # quadrants in which most squares show the corner object
- Passing score is ≥ 3



AAPM 2004

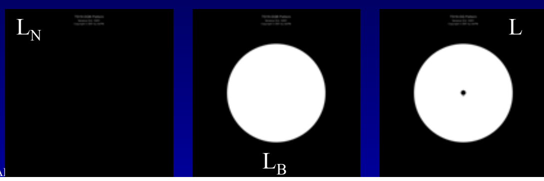
Procedures (CRT only)

- Resolution
- Geometric Distortion
- Veiling Glare

AAPM 2004

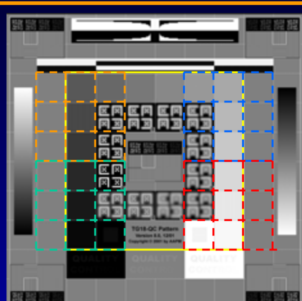
Veiling glare (CRT only)

- Measure black level in center of all-black field (L_N)
- Measure white level in center of all-white field (L_B)
- Measure black level in center with surrounding at peak white (L)



Geometric Distortion (CRT only)

$\leq 2\%$



Veiling glare (CRT only)

Calculate Glare Ratio:

$$R_G=(L_B - L_N)/(L - L_N)$$

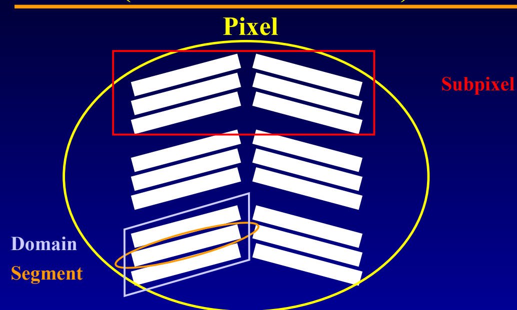
R_G should exceed 400 *(ideal is ∞)*.

Procedures (LCD only)

- Pixel Defects

Pixel Definition (Dual domain LCD)

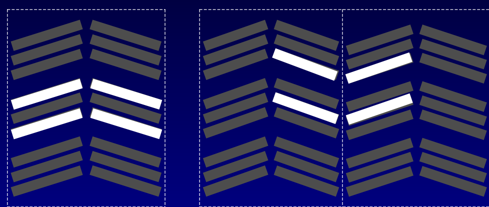
Pixel Definition (Dual domain LCD)



Dead Pixels (LCD)

- Dead Pixel count (LCD)
  - One bad segment in any subpixel is a "bad" subpixel
  - Adjacent bad segments in different subpixels may be ok

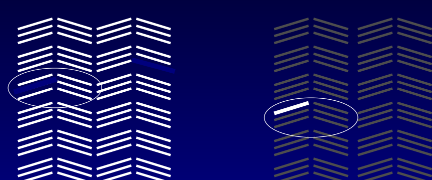
Dead Pixels (LCD)



4 bad elements
1 bad subpixel

4 bad elements
4 bad subpixels

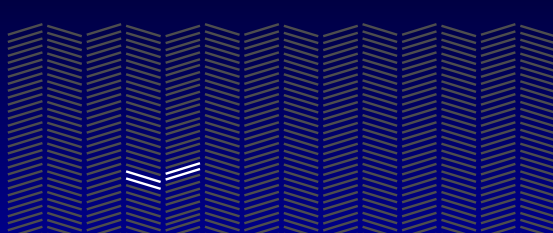
Dead Pixels (LCD)



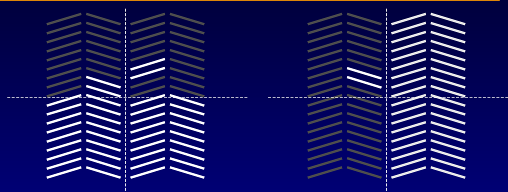
80% white

20% white

Dead Pixels (LCD)



Dead Pixels (LCD)



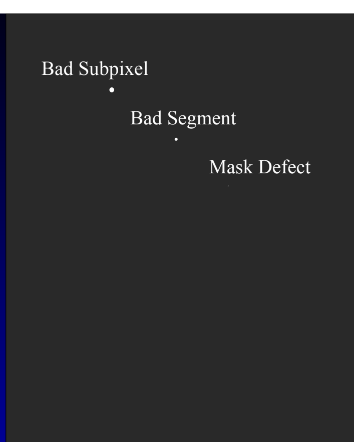
Alternating horizontal lines- for row ID (TG18-LPH)

Alternating vertical lines – for column ID (TG18-LPV)

Dead Pixels (LCD)

Mask Defect

TG18-UNL10



Dead Pixels (LCD)

- Performance expectations vary by manufacturer
  - Total number of bad subpixels (≤ 15)
  - # Bad subpixels per "1-cm circle" (≤ 3)
  - Maximum # adjacent bad subpixels (≤ 3)

QC Program

- Acceptance tests
- Annual tests
- Monthly tests
- Daily tests
  - LCD vs CRT
  - Performed "under the supervision of a Medical Physicist" by individuals who "develop and maintain familiarity with the tests".

Acceptance Tests

- Reflection
- Quantitative Luminance Response
  - L_{max}, Contrast Ratio
- Ambient Lighting (Reflection and Min. Luminance)
- Luminance Uniformity, Chromaticity & Glass Defects
- Noise
- Pixel defects

Acceptance Tests (CRT)

- Resolution
- Geometric Distortion
- Veiling Glare
- L_{min}

Annual Tests

- Repeat all acceptance tests except reflection (reset ambient lighting to acceptance levels)

Monthly - Quarterly Tests

- Cleanliness (glass cleaner and soft cloth)
- Ambient Lighting (reset to acceptance)
- Subjective Luminance Uniformity, Chromaticity (matching monitors) & Glass Defects
- Pixel Defects

Monthly / Quarterly Tests

- Self-Calibrating Displays (Quarterly)
  - Subjective luminance response (TG18-QC)
  - L_{max} and L_{min}
    - (Contrast ratio)
- Non Self-Calibrating Displays (Monthly)
  - Luminance response (measured)
    - Contrast ratio

Monthly / Quarterly Tests (CRT)

- Resolution
- Geometric Distortion

Daily Tests

- Ambient Lighting (reset to acceptance)
- Subjective Luminance Response (TG18-QC)
- Cleaning (glass cleaner and soft cloth)

Performed by the user

Daily Tests (CRT)

- Resolution (TG18-QC)
- Subjective Geometric Distortion (TG18-QC)
- Subjective Luminance Response (TG18-QC, “Quality Control”)

Experience – LCD QC

Henry Ford Hospital

(Mike Flynn and Don Peck – verbal communication)

- Acceptance
  - 11 of 80 returned for debris in glass (black artifact) and repaired
  - Some dead pixels, but acceptable
- Annuals – None to date

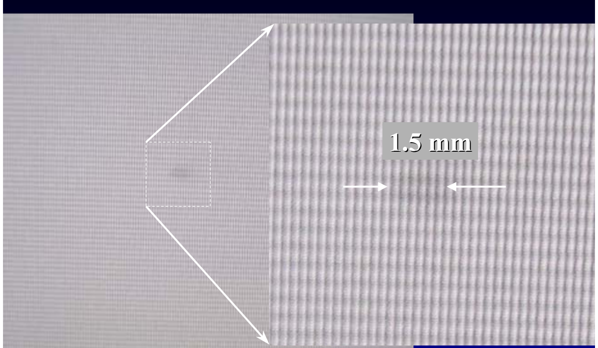
Experience – LCD QC

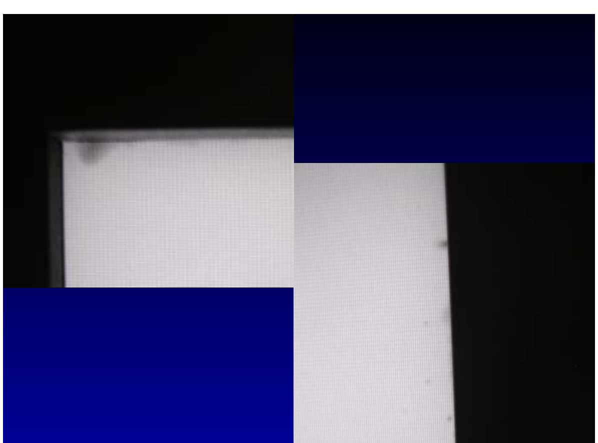
UT M. D. Anderson Cancer Center

- OEM’s self-calibration proved to be stable over several weeks (Thompson, et al, 2003).
- Acceptance tests on 101 3Mp LCD displays
  - 6 panel failures
    - 2 for color mismatch
    - 3 for uniformity artifacts (acceptable after repair)
    - 1 physically damaged (scratched)
  - 3 bad graphics cards (DOA)

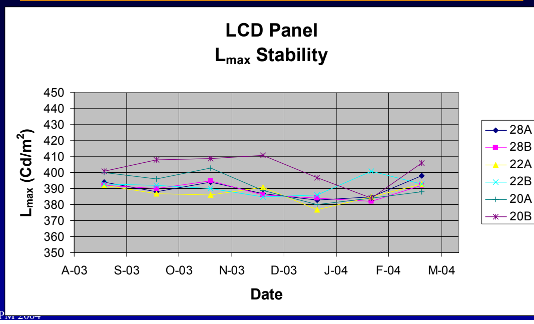
Experience – LCD QC

- Annual tests on 30 panels (to date)
  - 2 failures
    - 1 for a single point pixel defect
    - 1 for artifacts around edges
  - No change in L_{max}, L_{min} or calibration LUT

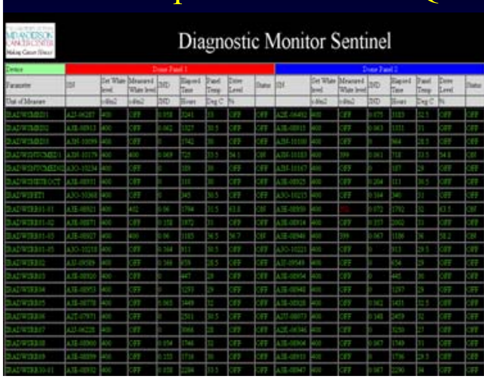




Experience – LCD QC



Experience – LCD QC



Remote status monitoring eliminates need for daily QC.

Experience – LCD QC

- No need for resolution, geometric distortion, or veiling glare – ***EVER!***
- Self-calibrating displays
  - Verify stability
    - over the course of a day
    - daily over the course of several months
  - Eliminates need for quantitative luminance response test except annually
  - Use quarterly subjective tests to identify graphics card failures.

Acknowlegement

- Raimund Polman (PACS Programmer/Analyst)
  - Diagnostic Monitor Sentinel (SNMP Client/Server)
- Tyran Mercer (PACS Research Technologist)
  - Acceptance test data
  - LCD artifact images
- David Clayton, BSRT (QC Dosimetrist) & Blake Cannon, BS (Graduate Student)
  - Monthly QC data

Bibliography

- RES. 11, American College of Radiology (ACR) Standards for Teleradiology, Standards and Accreditation Committee, ACR, 2002, http://www.acr.org/departments/stand_accred/standards/pdf/teleradiology.pdf, accessed May 17, 2004.
- RES. 6, American College of Radiology (ACR) Technical Standard for Digital Image Data Management, Standards and Accreditation Committee, ACR, 2001, http://www.acr.org/departments/stand_accred/standards/pdf/teleradiology.pdf, accessed May 17, 2004.
- Samei E, Badano A, Chakraborty D, Compton K, Cornelius C, Corrigan K, Flynn MJ, Hemminger B, Hangiandreou N, Johnson J, Moxley D, Pavlicek W, Roehrig H, Rutz L, Shepard SJ, Uzenoff R, Wang J, and Willis C, Assessment of Display Performance for Medical Imaging Systems, Draft report of the American Association of Physicists in Medicine (AAPM) Task Group 18, Version 9, October 2002, http://deckard.mc.duke.edu/~samei/tg18

Bibliography

- NEMA PS 3.14, Digital Imaging and Communications in Medicine (DICOM) Part 144: Greyscale Standard Display Function. National Elecrical Manufacturer's Association (NEMA), Rosslyn, VA, 2000, (http://www.nema.org)
- Honeyman JC, Frost NM, Staab EV. Initial Experience with PACS in a Clinical and Research Environment. SPIE Medical Imaging V, San Jose, CA, February 1991.
- Parsons DM, Kim Y. Quality Control Assessment for the Medical Diagnostic Assessment Support (MDIS) System's Display Monitors. SPIE Medical Imaging 2164: 186-197, 1994.
- Seigel EL, Reiner BI, Cadogan M. Frequency and Impact of High-Resolution Monitor Failure in a Filmless Imaging Department. J Digit Imaging 13(3):114-118, 2000.

Bibliography

- Groth D, Bernatz S, Fetterly K, Hangiandreou N, Cathode Ray Tube Quality Control and Acceptance Testing Program: Initial Results for Clinical PACS Displays. Radiographics (21) 2001, pp 719-732.
- Ly CK, Softcopy Display Quality Assurance Program at Texas Children's Hospital, J Digit Imaging 15 Suppl 1, 2002 pp 33-40.
- Compton K, Factors Affecting Cathode Ray Tube Display Performance, J Digit Imaging, 14 (2) June 2001, pp 99-106.
- Samei E, Shepard SJ, Fetterly KA, Kim HJ, Roehrig H, Flynn MJ, Clinical verification of TG18 methodology for display quality evaluation. Proceedings of SPIE 5029 (2003), pp 484 – 492.
- Roehrig H, Willis CE, and Damento MA. Characterization of Monochrome CRT Display Systems in the Field. J Digit Imaging 12(4):152-165, 1999.

Bibliography

- Thompson SK, Willis CE, Polman R, and Homann KI, Validation of a Self-Calibrating Active-Matrix Liquid Crystal Display System. J Digit Imaging 16 (Suppl 1) 2003, pp 19-21.
- SMPTE RP133, Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hardcopy Recording Cameras, Society of Motion Picture and Television Engineers (SMPTE), White Plains, NY, 1991.

AAPM 2004