Display Quality Assurance: Recommendations from AAPM TG270 for Tests, Tools, Patterns, and Performance Criteria

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Display Check

TG270 Goals

- Provide an update to the TG18 report
  - Test methodology
  - Test criteria
  - Test frequency
  - Test patterns

Outline

- Display Classifications
  - Diagnostic
  - Non-diagnostic
- Display Test Patterns
  - Existing Patterns
  - New Patterns
- Display Performance Evaluation

Display Classification

- Four classifications based on use
  - Diagnostic Displays
  - Non-diagnostic Displays (TG18 “secondary displays”)
    - Modality Displays
    - Clinical Specialist Displays
    - Electronic Health Record (EHR) Displays

Display Classification

- Diagnostic Displays (TG18 “primary displays”)
  - Primary interpretation of medical images
  - Improved performance characteristics
    - Luminance stability (both in level and uniformity)
    - Smaller pixel pitch
    - Lower noise
    - Greater bit depth
    - Self-testing functionality
  - Stringent performance criteria
  - High cost
  - Does not include navigation displays

Display Classification

- Modality Displays
  - Displays used during acquisition and generation of medical images
    - May or may not be attached to modality
    - Only displays that show images (not for acquisition control)

- Clinical Specialist Displays
  - Review of images before or independently of primary radiology read
    - ER, surgical environments
    - Patient care decisions, often before primary read by radiologist

Display Classification

- EHR Display
  - Images used to review images following interpretation
    - Referring physicians offices
    - Exam room with patient
    - Pre-surgical planning

- The goal of display QA is consistent image presentation across all displays (image review chain)
  - Similar goals, but different tolerances, tests, frequencies

Outline

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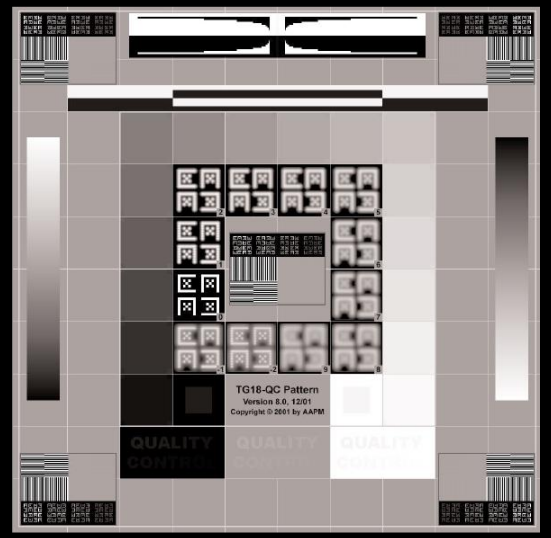
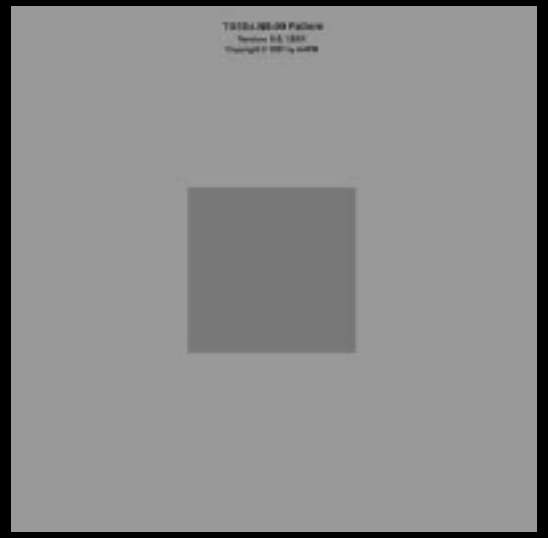
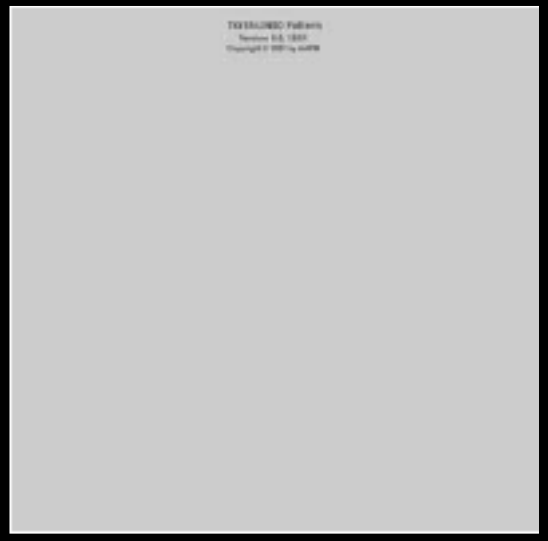
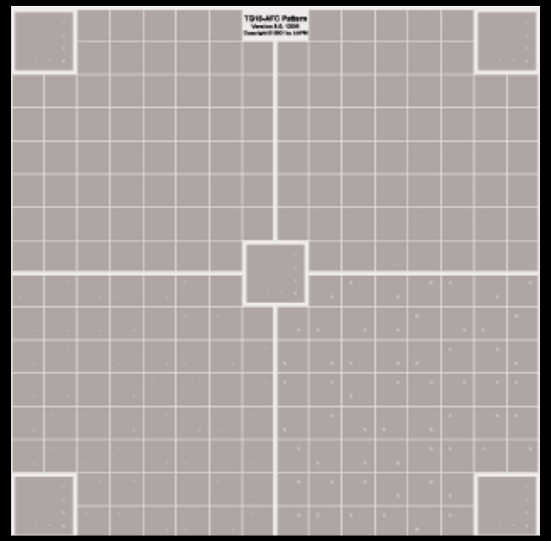
Existing Test Patterns

- TG18-QC
- TG18-LN
- TG18-UN
- TG18-AFC





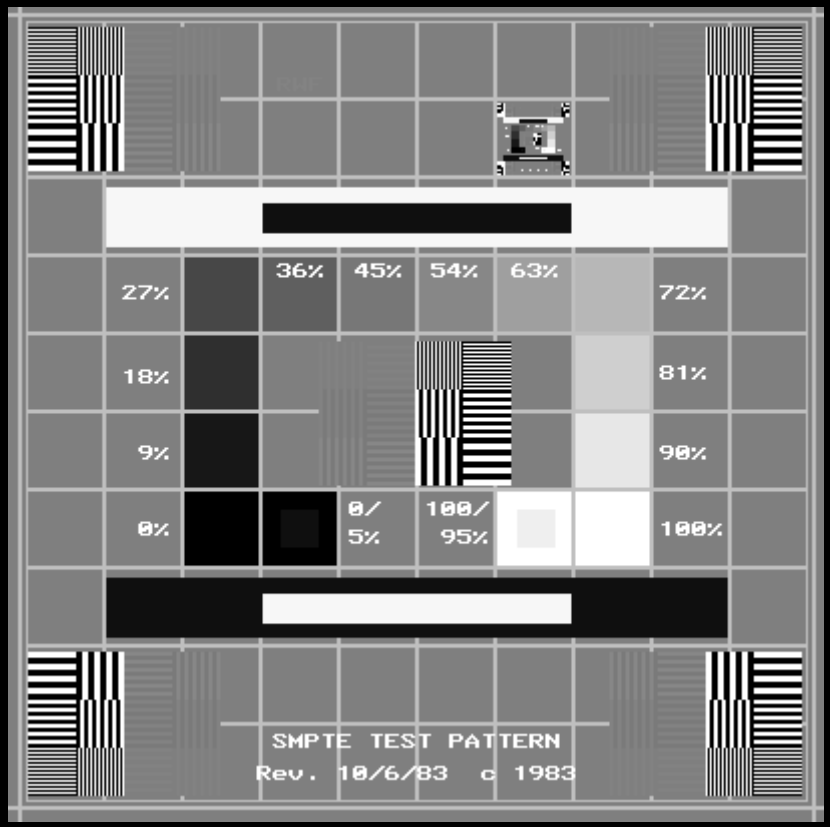




Existing Test Patterns

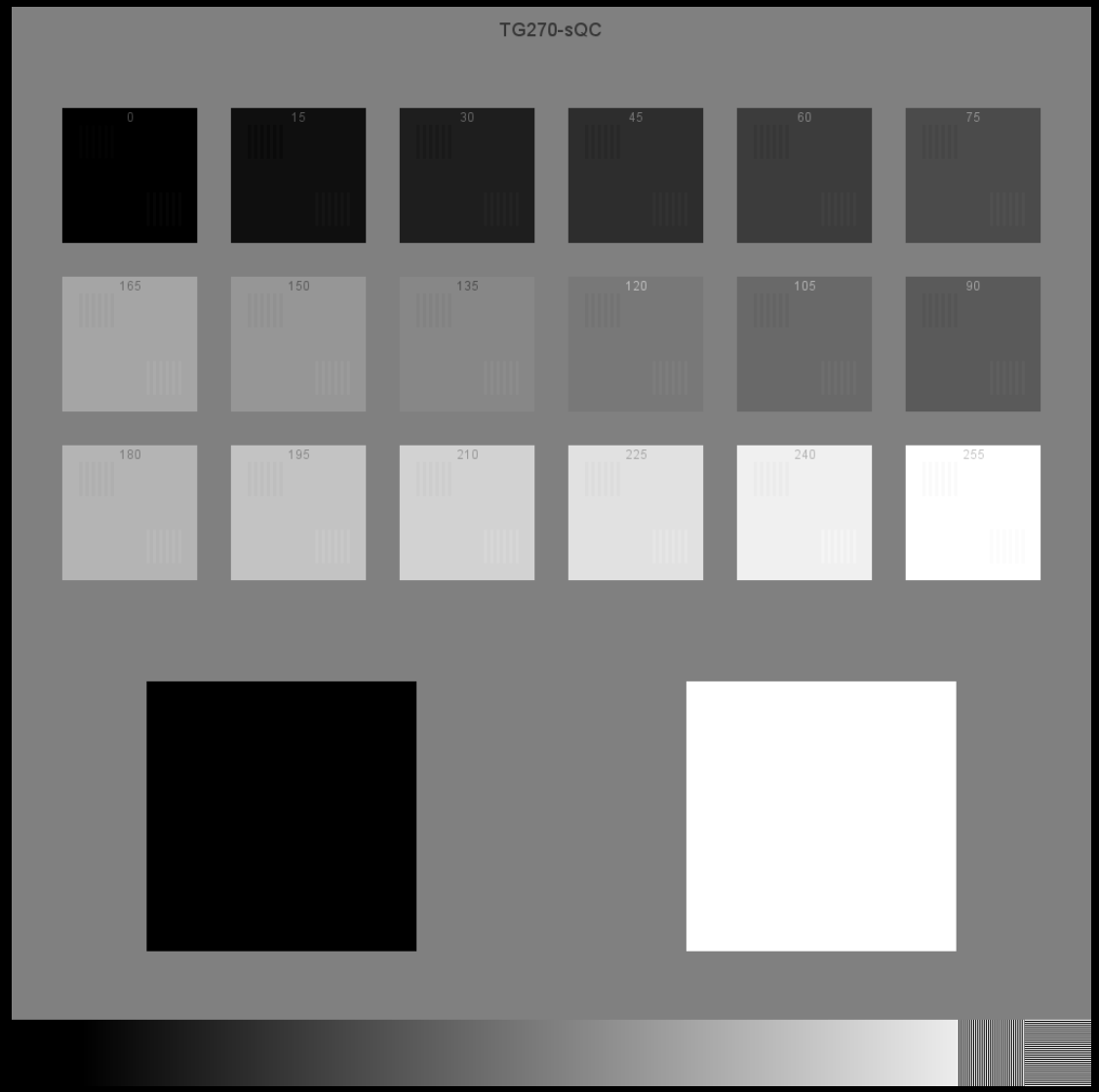
- SMPTE

“As a result of the pattern’s grayscale insensitivity and CRT-specific features, this report considers the SMPTE test pattern deprecated for qualitative display evaluation in favor of either quantitative measurement or updated test patterns.”



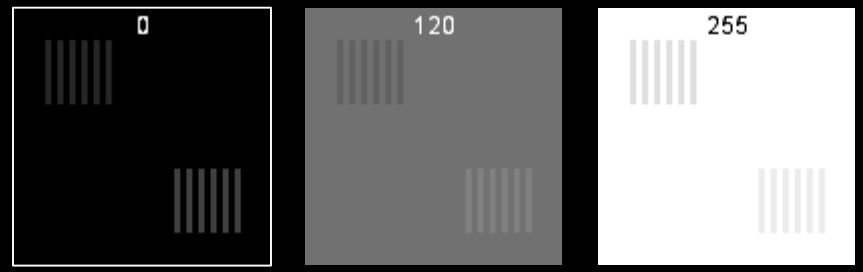
New Patterns – TG270-sQC

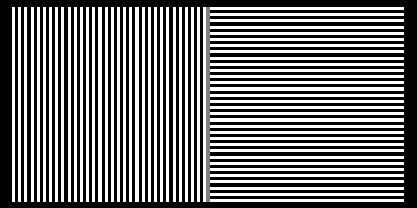
- Simple QC test pattern for routine checks by users, technologists, physicists

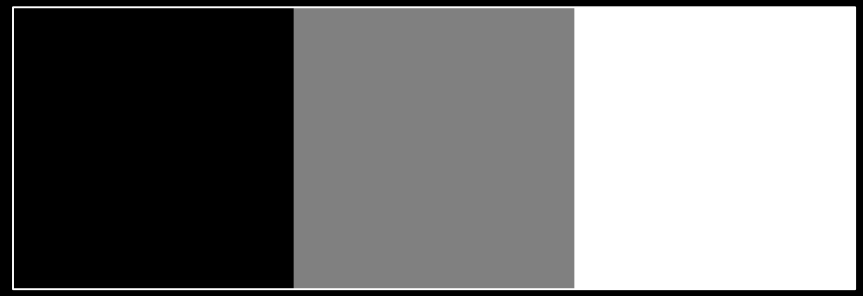


New Patterns – TG270-sQC

- Low contrast test patterns at multiple gray levels
- Spatial resolution verification
- Luminance patches for uniformity and min/max measurements

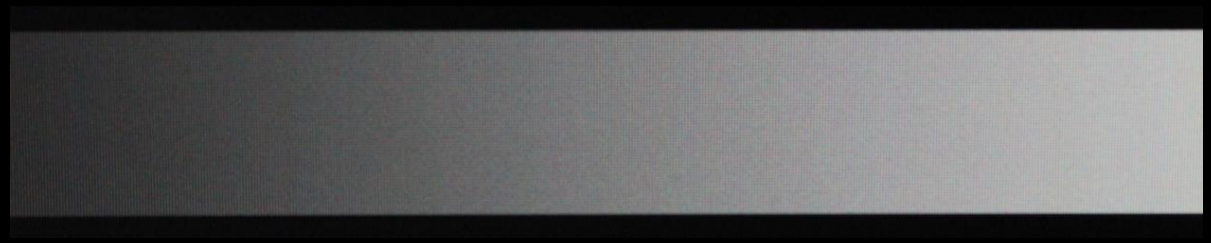




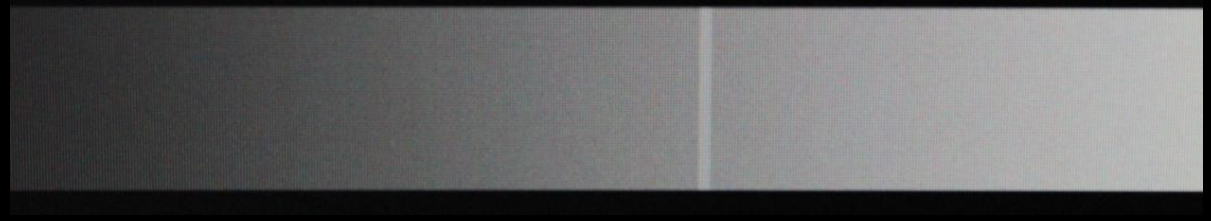


Continuous Gradient Effects

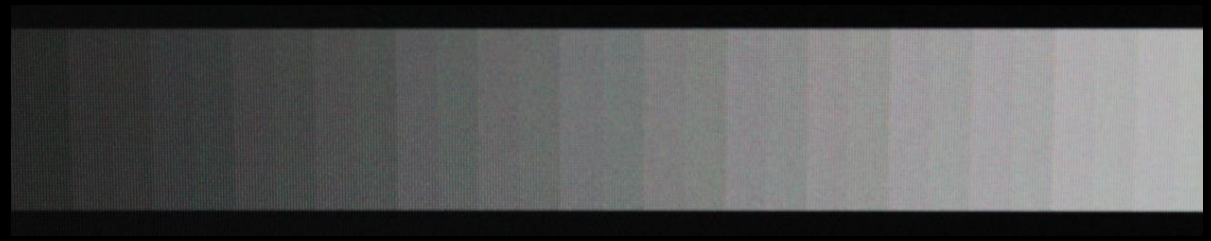
- No issues



- Mis-calibrated gray level

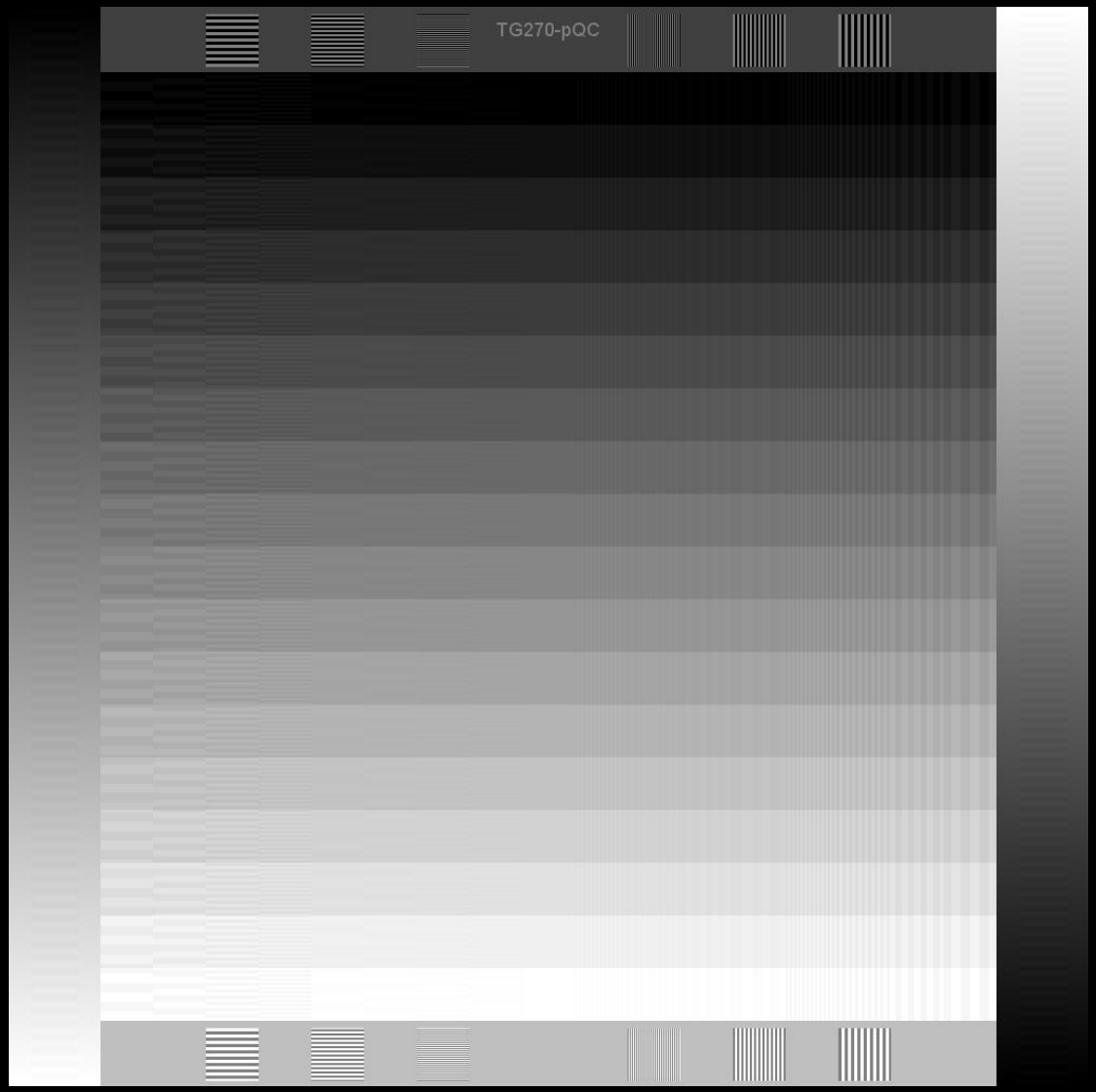


- Bit-depth configuration error



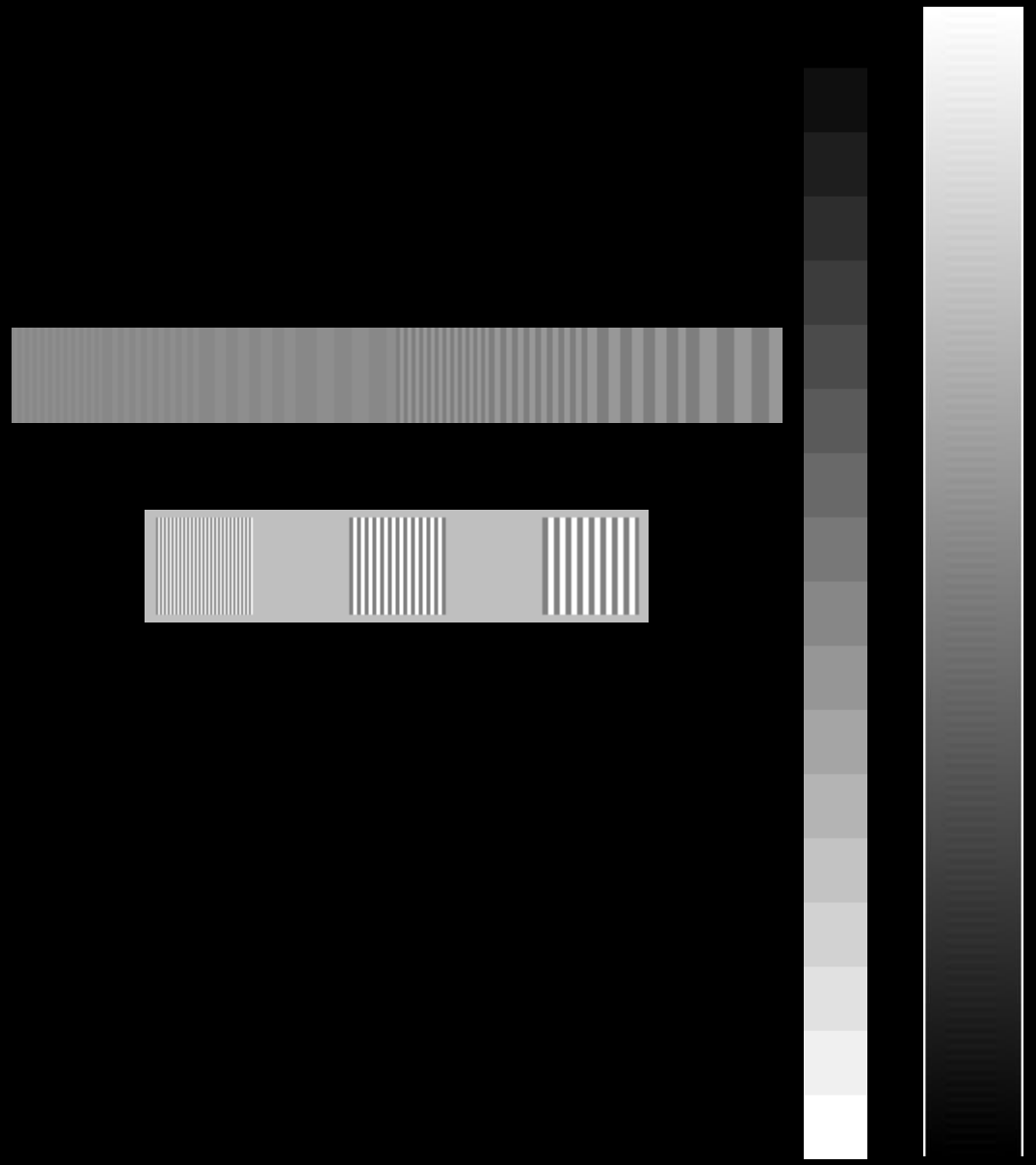
New Patterns – TG270-pQC

- Detailed QC pattern for physicists and other advanced users
- Same gray levels as sQC, but with more contrasts and frequencies
- Use as follow up to quantitative failures for context



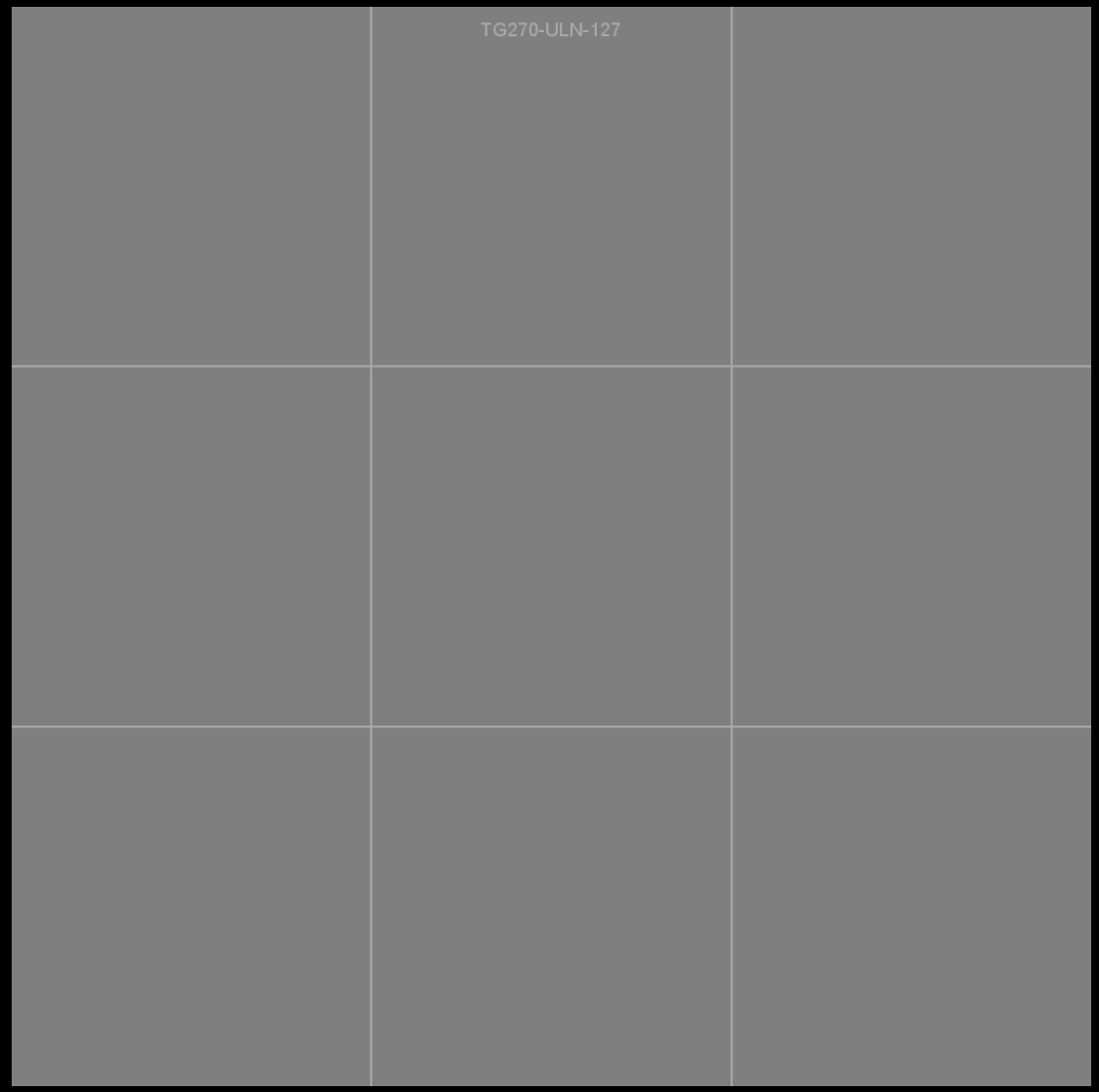
New Patterns – TG270-pQC

- Low contrast patterns at multiple gray levels
- Spatial resolution verification
- Luminance patches for 18-point measure
- Continuous ramp



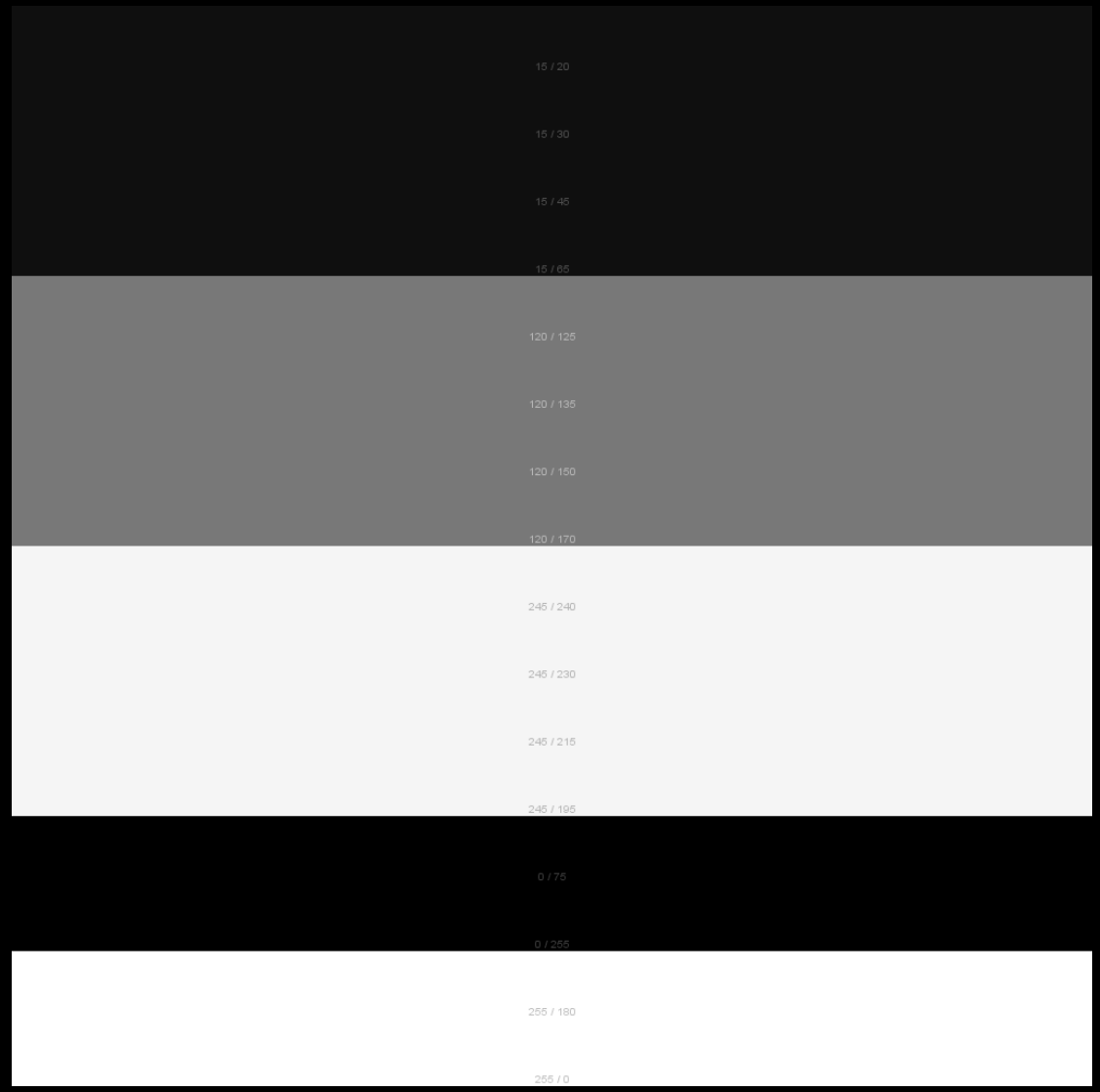
New Patterns – TG270-ULN

- Replaces the TG18 LN and UN pattern series
- Generated for all 256 8-bit gray levels
- Grid for quantitative uniformity measures

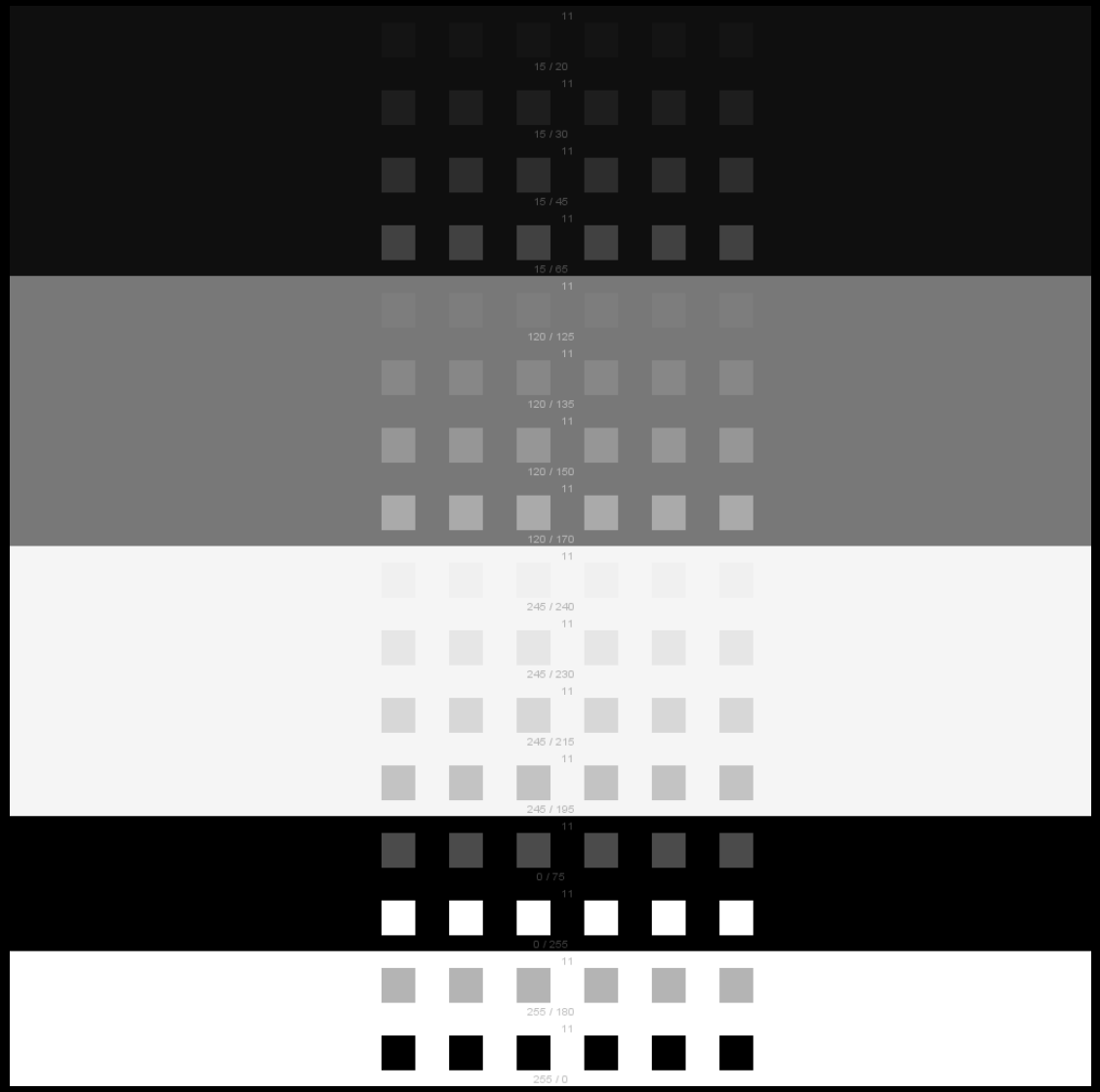


New Patterns – TG270-TR

- Temporal resolution pattern for qualitative evaluation of short-term temporal resolution
- Use to help guide purchasing decisions, display usage, latency effects
- Used with digital camera to capture frames



New Patterns – TG270-TR



New Patterns

- All of the new TG270 test patterns were generated using ImageJ macros (.ijm)
  - Included with TG270 report
  - Available on the TG wiki on AAPM website

Outline

- Display Classifications
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Display Performance Evaluation Tools

- Equipment
  - Photometers and colorimeters
    - Contact and telescopic
    - External and internal
  - Loupe
  - Digital camera

Display Luminance

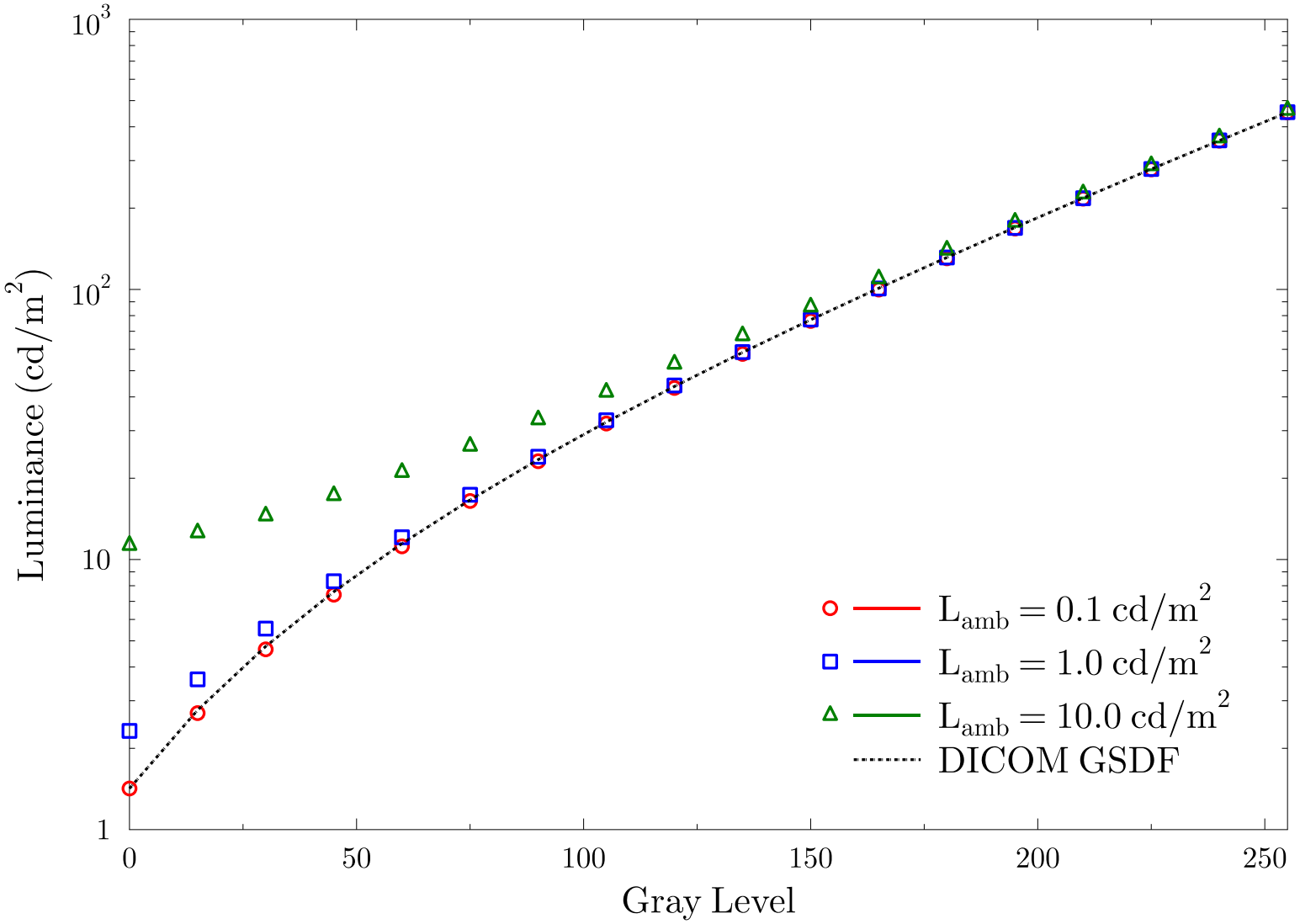
- Assessment of display luminance includes measuring:
  - L_{amb}
  - L'_{min} (L_{min} + L_{amb})
  - L'_{max} (L_{max} + L_{amb})
  - Luminance ratio (L'_{max} / L'_{min})
  - Luminance response function

- Each of these is related to the others. Understanding these relationships is critical to proper display QA.

L_{amb}

- Ambient luminance is due to reflected light from the display
  - Specular reflection
  - Diffuse reflection
- Setting and maintaining proper environmental lighting for consistent and predictable image presentation
- Setting ambient lighting in reading rooms to minimize visual strain
  - 25-50 lux

Display Luminance



L_{amb} and L_{min}

- Avoid Lamb effects from obscuring darkest regions of image

$$L_{min} = 4 \cdot L_{amb}$$

- Approximately 80% of contrast seen with no ambient lighting is still visible with ambient lighting

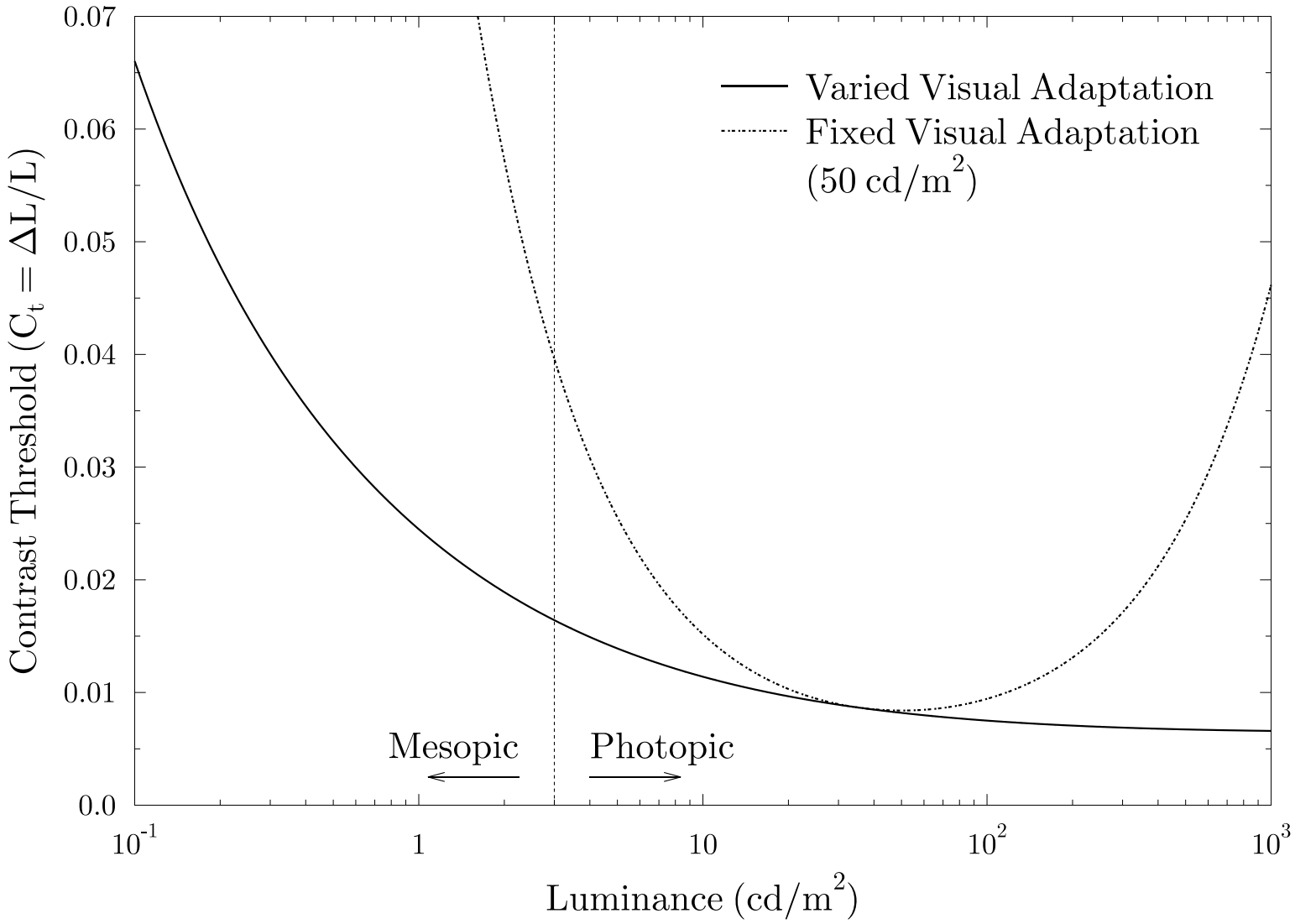
L'_{min}, L'_{max}, LR

- The minimum and maximum luminances are combined with the ambient luminance
  - L'_{min}, L'_{max}
- The ratio gives the luminance ratio LR

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

- Recommended LR = 350
  - Set L'_{max} based on L'_{min} and LR, not maximum of display

Display Luminance

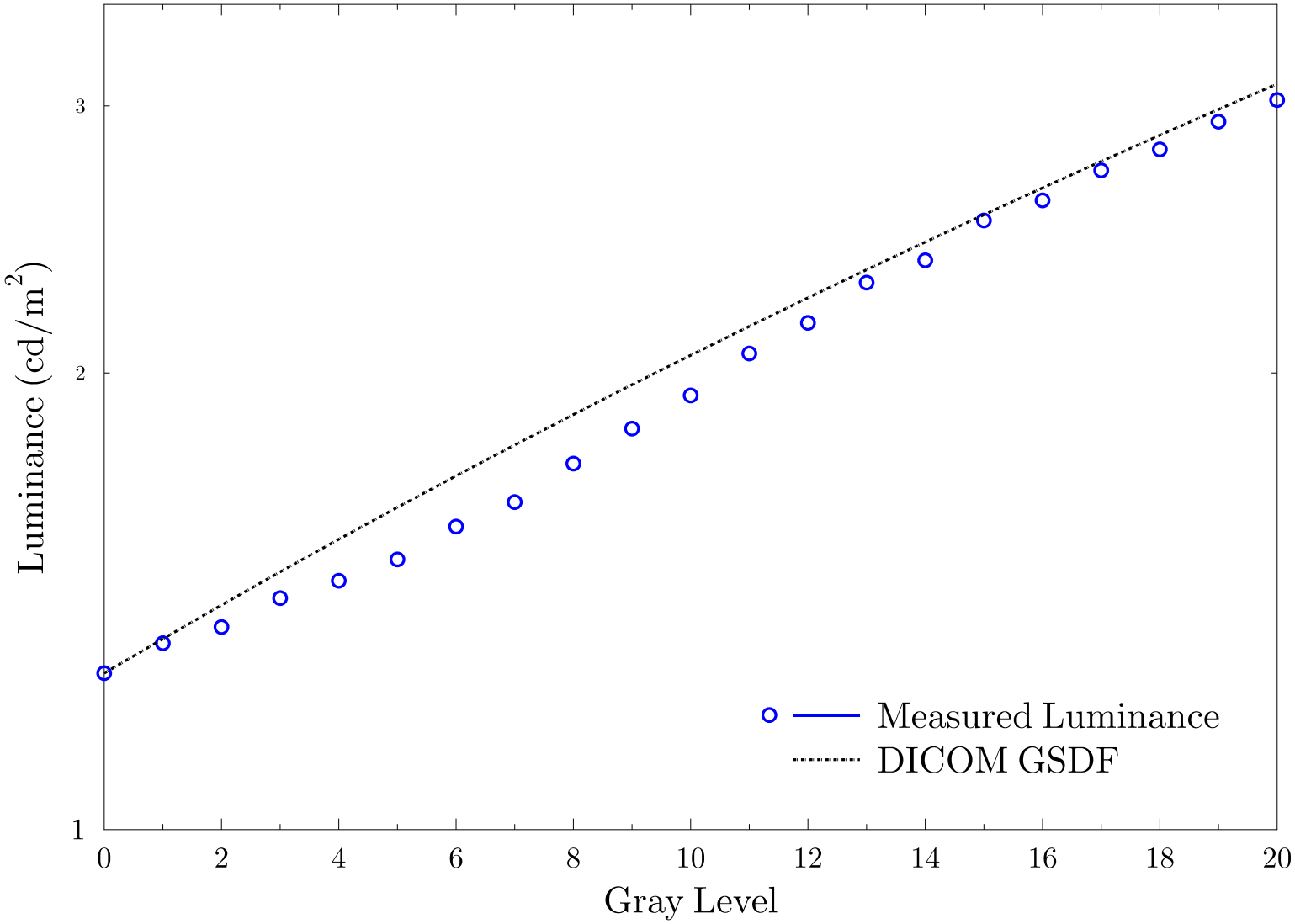


Luminance Response Function

- Measurement of luminance response function
  - 18-point (TG18 methodology)
  - 52-point
  - 256-point
  - 11-point (SMPTE pattern)

- Analysis of luminance should be of L’, which includes the effects of ambient luminance

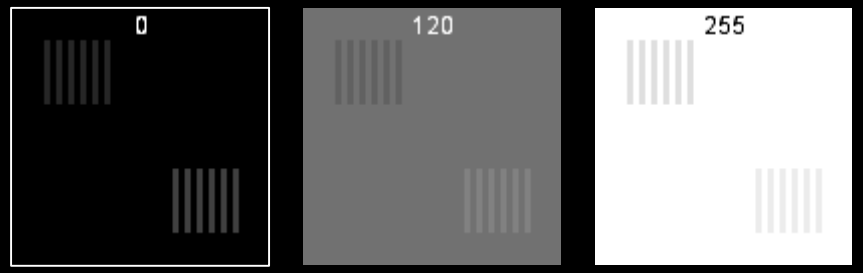
Display Luminance



Luminance Response Function

- Confirm conformance with DICOM GSDF
  - Mean JND/GL
  - dL/L per JND
  - Both to within 10% for diagnostic displays, 20% for non-diagnostic

- More frequent qualitative verification
  - Test pattern based
    - TG270-sQC, TG270-pQC, TG18-QC
    - Verify contrast performance at multiples levels (especially in the darks)



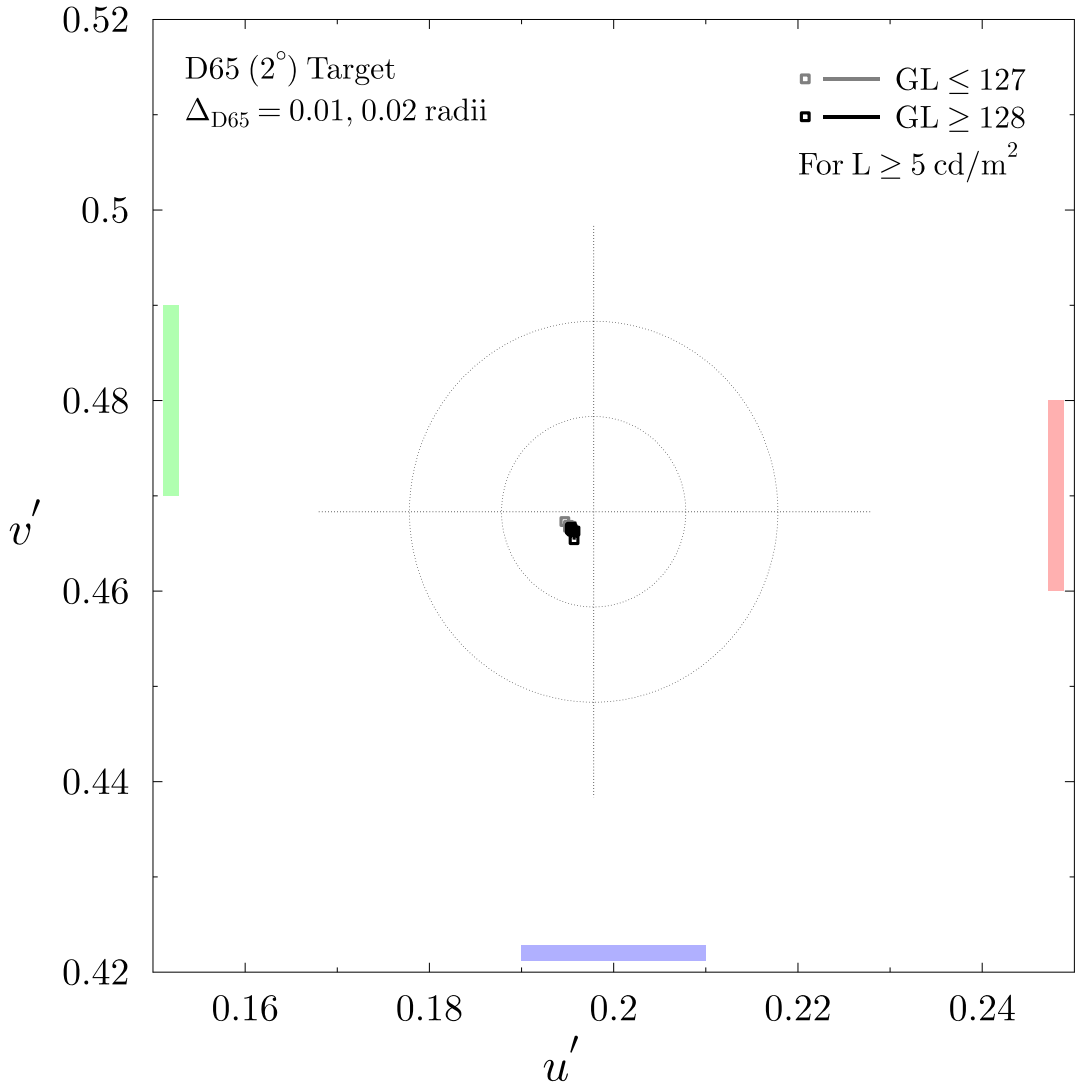
Display Color (White Point)

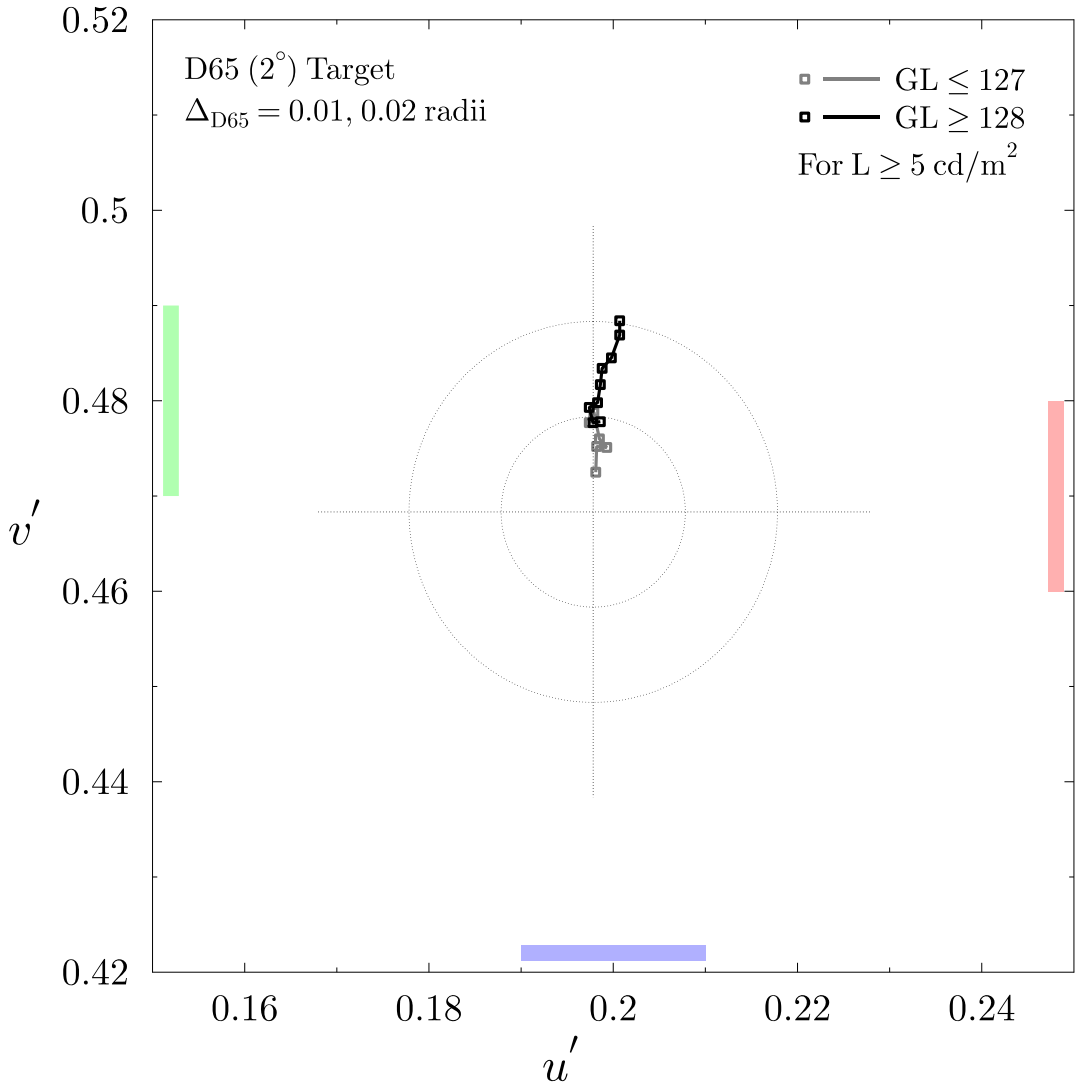
- Color of the light output by the display throughout the grayscale
- Evaluate by measuring the color difference

$$\Delta = \sqrt{\left(u'_1 - u'_2\right)^2 + \left(v'_1 - v'_2\right)^2}$$

- Compared against
  - Other display
  - Standard illuminant (e.g., D65)
  - Full brightness (TG196 methodology)

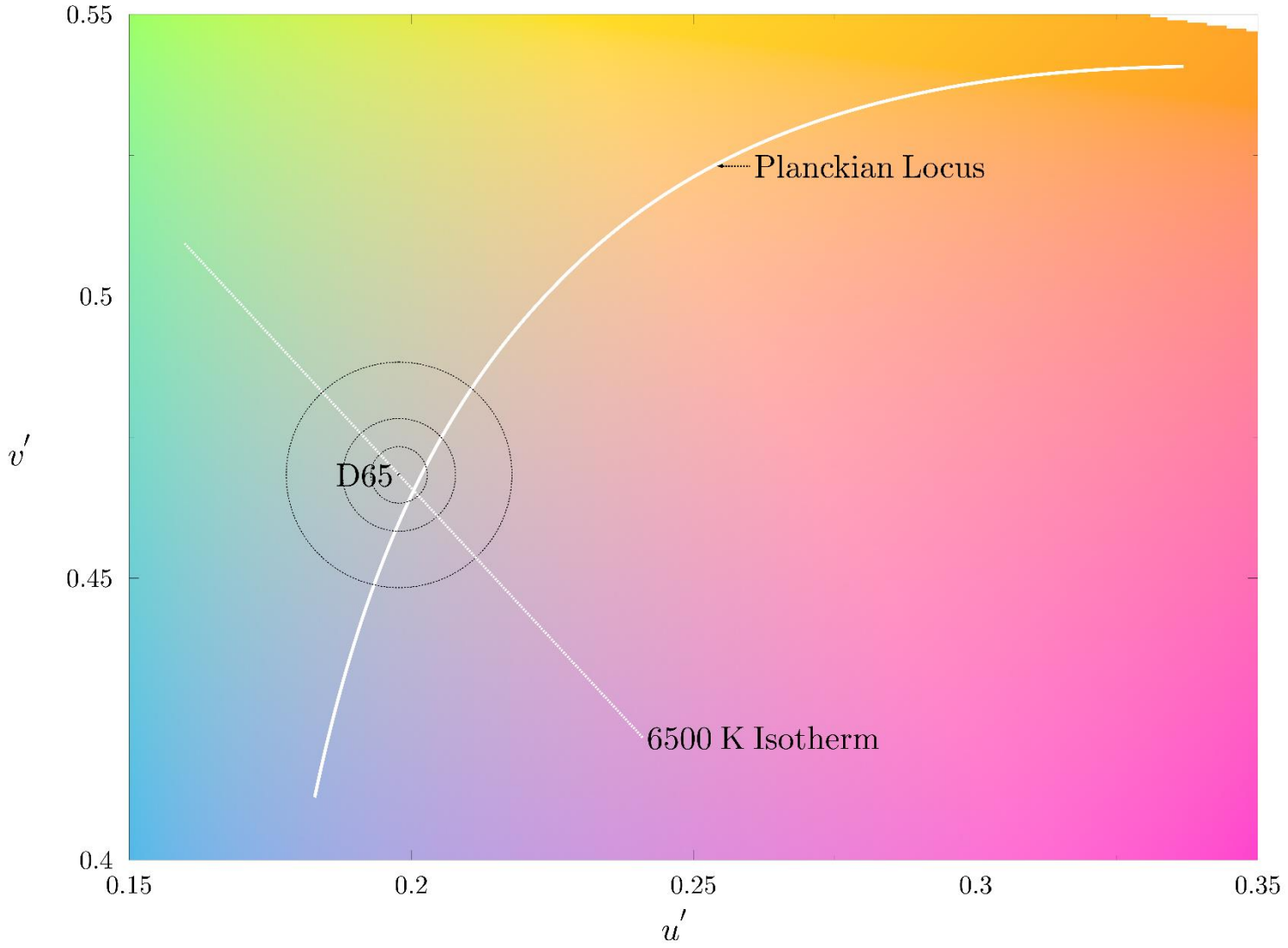
Display Color (White Point)





Display Color (White Point)

- Standard illuminant (e.g., D65) should be used instead of correlated color temperature (CCT)
  - CCT is defined as multiple points in color space
  - The maximum difference between the points is large



Display Color (White Point)

- Comparing two displays

	Optimal Limit	Acceptable Limit
Same Workstation	$\Delta(u',v') \le 0.005$	$\Delta(u',v') \le 0.01$
Same Image Review Chain	$\Delta(u',v') \le 0.01$	$\Delta(u',v') \le 0.02$

- Comparing display to standard illuminant

	Optimal Limit	Acceptable Limit
Diagnostic Display	$\Delta_{D65}(u',v') \le 0.005$	$\Delta_{D65}(u',v') \le 0.01$
Non-diagnostic Display	$\Delta_{D65}(u',v') \le 0.01$	$\Delta_{D65}(u',v') \le 0.02$

Display Uniformity

- Display uniformity evaluated both quantitatively and qualitatively
  - Quantitative assessment for global uniformity issues across display
  - Qualitative assessment for local non-uniformity

- Global uniformity is less important for clinical image review
  - Global non-uniformity is low frequency, likely not to be confused with anatomy
  - Local non-uniformities are common failures with flat panel displays, and are of similar size/contrast as image features

Display Uniformity

- New methodology for evaluating global uniformity

$$\mathrm{LUDM} = \max\left(100 \times \frac{\left|\mathrm{L}_n - \mathrm{L}_{\mathrm{med}}\right|}{\mathrm{L}_{\mathrm{med}}}\right)$$

- Evaluates all measured points against the median value
  - Measure 9 points (corners, edges, center)
  - Median less affected by outliers
  - LUDM < 30% for passing. At 15%, clinical impact should be evaluated visually

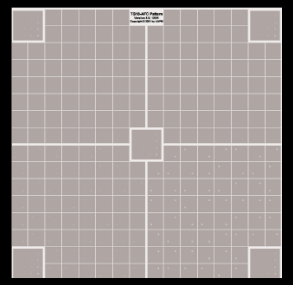
Display Uniformity

- Local non-uniformities
  - Mura
  - Bad pixels (stuck pixels)
  - Image burn-in
- Evaluated qualitatively
  - Must be done on site
  - Use multiple gray levels to evaluate

Display Uniformity

Display Noise

- Qualitative noise assessment for product evaluation
  - Test pattern (e.g., TG18-AFC) for pixel-by-pixel variation



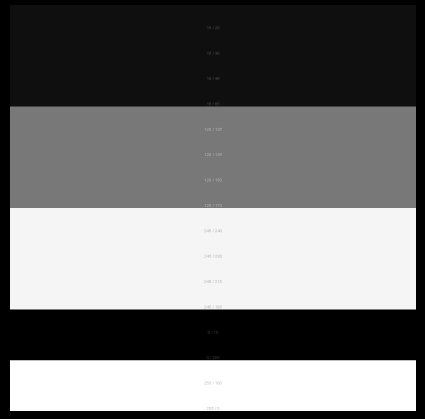
  - Use clinical images for evaluation of clinical impact

- Unnecessary for routine display quality assurance

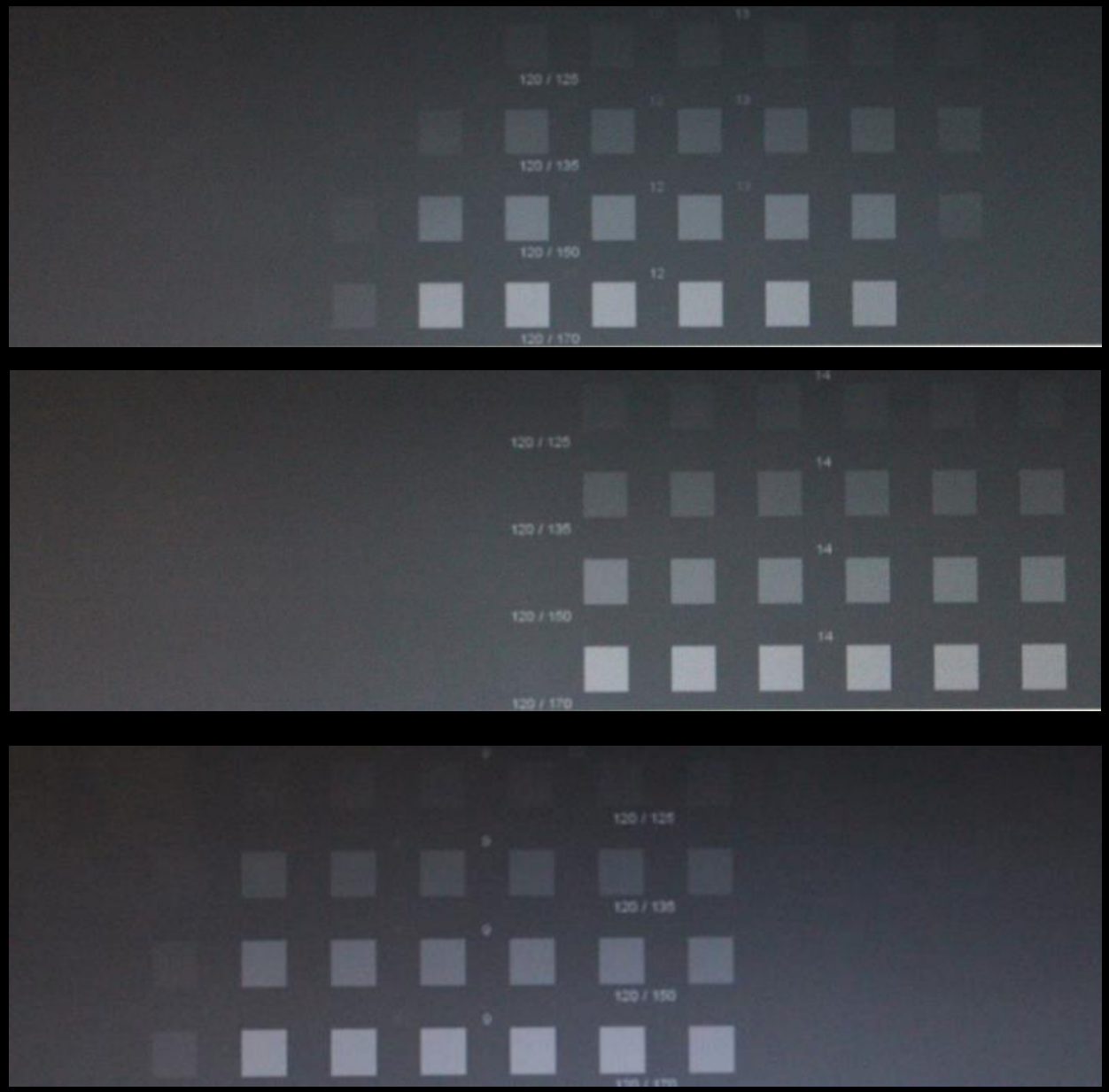
Display Temporal Performance

- Several scales of temporal performance
  - Long term (luminance stability, uniformity)
  - Medium term (warm up time, image retention)
  - Short term (response time, input latency)

- Qualitative evaluation of short term performance
  - Evaluate impact of display performance on the viewing of dynamic images
    - Fluoroscopy, ultrasound, etc.

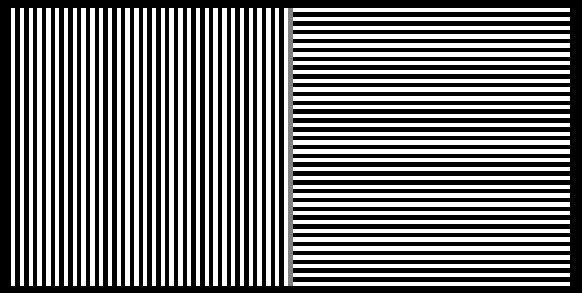


Display Temporal Resolution

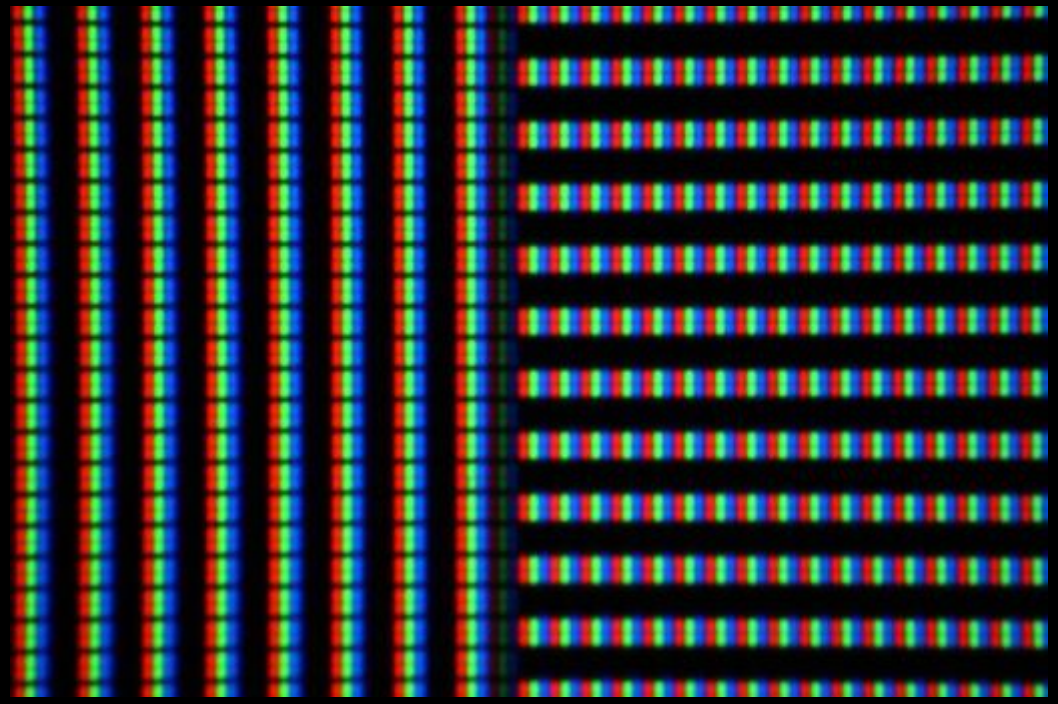


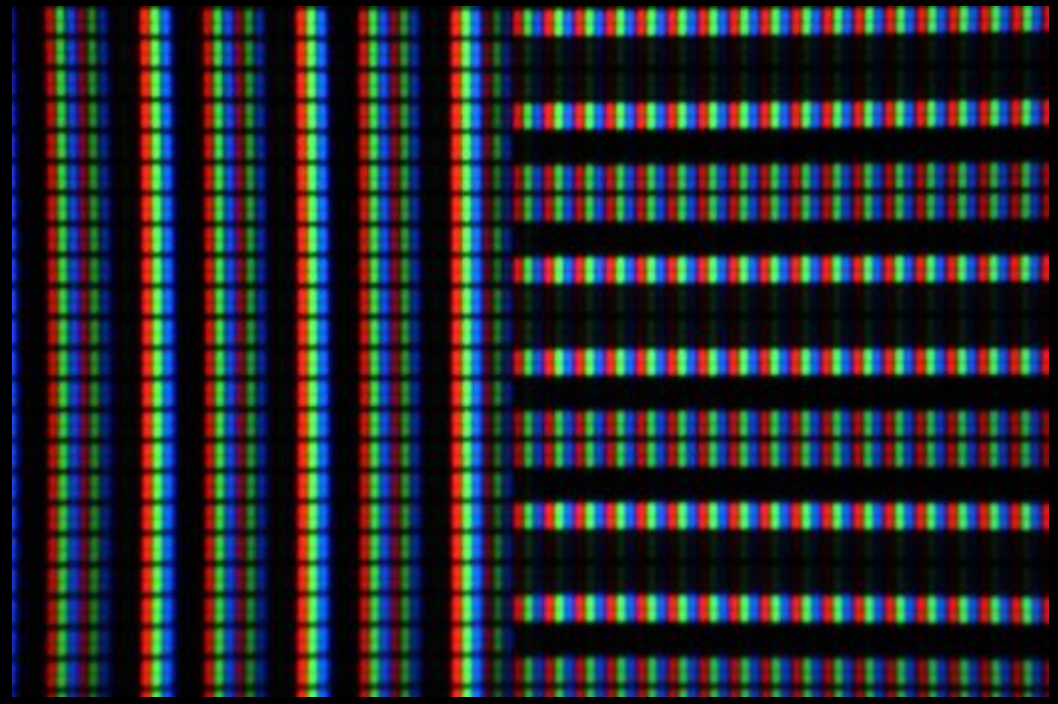
Display Spatial Resolution

- Modern flat-panel displays have discretized pixel structures, with little light dispersed into neighboring pixels
- Quantitative measures of spatial resolution unnecessary assuming:
  - Advanced pixel structure (e.g., IPS, VA)
  - Digital graphic interfaces (e.g., DVI-D, DisplayPort)
- Visual verification of driver settings to native display resolution
  - Magnifier, loupe is helpful



Display Spatial Resolution





Display Spatial Resolution

- Pixel pitch selected depending on use and viewing distance
  - Minimize the appearance of pixel structure
  - Radiologist workstation recommended distance of 65 cm
    - Minimize eye strain
  - Other workstations often have larger viewing distance
    - Larger pixel pitch is acceptable

	Radiologist Workstation	**Modality, Other Clinical Workstation**
Pixel Pitch	< 210 µm	< 250 µm

Conclusion

- Display QA for flat-panel displays is an important part of general QA across all of medical imaging
- Awareness of current standards and guidelines is critical for appropriate QA

Status of Report

- Report draft circulating for comments
- Goal is final draft before RSNA 2017

- Intention is to incorporate report into other TG reports
  - No need to re-state display testing in every modality testing guideline
  - Replace references to TG18 in future reports

Thank you