Developed by the “German Automotive Work Group Displays” standard body (including BMW, Volkswagen, Audi, Daimler, and Porsche), and published by the German Flat Panel Display Forum (DFF), the Black Mura Standard is a standard measurement method for evaluating uniformity in automotive displays. The Black Mura Standard is an open test method that can be addressed by any measurement equipment that meets the standard criteria. Radiant TrueTest Software offers several advantages for testing to the Black Mura standard. Paired with a Radiant ProMetric® Imaging Colorimeter or Photometer, TrueTest Software provides a comprehensive solution for production-level display testing.

Characterizing Mura Effects

“Mura” (Japanese for “unevenness”) manifests as large patterns of inconsistent luminance across a display. These defects may be the result of process flaws that occur during the assembly and optical bonding stages for liquid crystal displays (LCDs) and organic light-emitting diode (OLED) displays; for example, when pressure and substrate inconsistencies are introduced that affect how light is emitted through the layers.

Because mura occurs randomly and to varying degrees of severity, it is difficult to characterize and grade against specific tolerances of acceptability. For this reason, standard measurement criteria have been established to ensure all manufacturers of German automotive displays employ the same parameters to acquire equivalent data to determine automotive display uniformity given the presence of mura.

A test method for identifying and grading the effect of mura on display uniformity—as described in the DFF Black Mura Standard—includes measurement of mura in a black test image (black mura), and overlaid with a background gradient (black mura gradient). Measurement is performed using a photometric imaging system and analysis software.

Applying the Black Mura Test Method

Using a ProMetric Imaging Colorimeter or Photometer and TrueTest Software, testing to Black Mura Standard can be done using the following steps for setup and measurement.

Setup Phase

1. Maximize the Field of View
   Position the display to fill the camera FOV to meet measurement requirements of one CCD pixel per display pixel, minimum.

2. Check the Angular Dependency of the Display
   Test the outer corner of the display at an extreme angle, then at a zero-angle by shifting the display. The luminance difference between measurements must be less than 5%. If it is not, the camera must be positioned at a greater distance from the display.

3. Check the Alignment of the Display
   The display must be centered at the camera’s optical axis, with no rotation or tilt (where Δx and Δy are less than 0.1 mm; and axial rotation, horizontal tilt, and vertical tilt are less than 0.5°). Display orientation can be checked using the Software Alignment Window in TrueTest Software. Using a test image, angular and offset measurements are calculated by localizing the five dots (seen in the image on the following page).
4. **Defocus to Remove Interference of Moiré**
Measurement is performed on a grill test pattern. The camera lens must be defocused to achieve a specific modulation depth (60-90%) of the luminance cross section of the grill pattern. During this process, the software auto-defocuses the camera lens via electronic control in several iterations to reach the correct level. Visual inspection is required to ensure moiré is removed; the electronic lens can easily be refocused, enabling subsequent measurements.

5. **Check Pulse Width Modulation**
During this step, the software measures a rectangular area at the center of the display ten times to check variation in luminance between measurements. When testing LCDs, the backlight should be set to a maximum luminance value. Variation in luminance between measurements should be less than 10%.

### Measurement Phase

#### 1. Capture the Bright-State and Dark-State Display
During the Black Mura test, the display is measured with a solid white test pattern and a solid black test pattern, to calculate the following data:

<table>
<thead>
<tr>
<th></th>
<th>White</th>
<th>Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Luminance</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Min. Luminance</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Max. Luminance</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Luminance Uniformity %</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Max. Gradient relative to:</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

#### 2. Run Pass/Fail Analyses
The Black Mura test uses measurements to determine pass/fail for displays based on:
- Average Luminance (bright-state display)
- Contrast Ratio (bright vs. dark display)
- Maximum gradient relative to white
- Maximum gradient relative to black

Values calculated from bright- and dark-state displays are used to pass and fail displays based on Black Mura Gradient standard tolerances.
TrueTest Software Advantages

TrueTest Software offers several additional benefits for display measurement when used for display mura analysis, which enable manufacturers to expedite the measurement process and perform comprehensive tests from the same camera and software solution.

Characterizing All Mura Types

The test method defined in the Black Mura Standard offers guidance on identifying and grading mura, but does not differentiate between various mura types. TrueTest Software employs specific algorithms to test the unique characteristics of each type of mura present in a display, allowing manufacturers to perform pass/fail analyses based on the presence of specific effects as needed. Mura types identified by TrueTest TrueMURA™ module include:

- Black Mura
- Blob Analysis
- Butterfly Mura
- Corner Light
- Diagonal Line Mura
- Edge Mura
- LED Mura
- Line Mura
- Random Mura
- Spot Mura

TrueMURA module for TrueTest also provides advanced image analysis algorithms for computing JND (“Just Noticeable Differences”), a detection algorithm based on U.S. patent 7,783,130, “Standard Spatial Observer” (SSO) technology, licensed by Radiant Vision Systems from the National Aeronautics and Space Administration (NASA). To accurately discern acceptable tolerances of mura—effects that are just noticeable by a human observer—TrueMURA leverages JND to match human observation, ignoring mura that cannot be distinguished by humans and ranking mura that is noticeable into categories that match those assigned by humans to be used for pass/fail.

Gradient Filter

To improve measurement accuracy, TrueTest Software is capable of removing display gradient; a common issue in displays, which can cause additional anomalous visible effects that must be taken into account when analyzing mura. TrueTest normalizes broad gradient changes across the display using a built-in gradient filter, applied to images before mura testing to ensure that gradient is not a factor of the calculation.
TrueTest Software applies automatic registration of the active display area (RADA), which rotates and crops the display area for image processing. Refraction of light through display layers, causing effects like moiré, is largely affected by angle. For this reason, orientation of the measurement system relative to the display may be deliberately misaligned to prevent moiré effects. In these cases—or cases where the optimal orientation and positioning does not account for discrepancies in display rotation, or causes negative space around the display — RADA is able to report corner pixel locations in the display and automatically rotate and crop images for precise measurement of the intended display area at normalized X,Y positions.

**Automatic Moiré Removal**

In situations where moiré is still captured in display images, TrueTest Software offers Dynamic Filtering for automatic moiré removal. The Black Mura Standard test method proposes moiré removal by defocusing of the image, but this causes blurring and can lead to inconsistencies in the ability of the measurement system to identify the location or severity of mura in the display. TrueTest’s Dynamic Filtering preserves a sharp image for analysis, which enables high-resolution testing (critical for additional tests like line defects or stuck on/off pixels).

**Test Sequencing for Multiple Analyses**

Testing for black mura is usually only one part of a more elaborate display test, which may include overall luminance and color uniformity testing, dead (stuck on/off) pixels and line defects, checkerboard contrast, identifying additional types of mura, and other tests. TrueTest Software offers comprehensive display tests within a test sequencing framework, giving the user the freedom to apply one test or multiple tests in series. Using TrueTest API, a Radiant display test system can be integrated to control test images that are served to the display, synchronizing test images with software test sequences for fully-automated analyses, which enables production-level testing.

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Moiré removal by defocusing (left) versus automatic moiré removal by TrueTest Software’s Dynamic Filtering.