

NED-LMD Near-Eye Display Measurement System TEST REPORT

Report Number: NED- 01-15 -20-120

| | | | |
|--------------------------|------------------|-------------------------------|----------------------------|
| Date: | January 15, 2020 | System Model No.: | NED-LMD E100 |
| Customer ID: | SAMPLE | Serial No.: | RN0100 |
| Customer Name: | TEST REPORT | Description: | HighRes Goniometric System |
| Address: | | | |
| Test Device ID: | | Temperature (°C): | |
| Test Device Name: | Epson BT300 | Relative Humidity (%): | |
| | | Technician: | |

List of Measurements Reported:

| S. No. | Test Parameter | Left Eye | Right Eye | Eye Rotation | Pupil Rotation |
|--------|------------------------------|-------------------------------------|--------------------------|-------------------------------------|-------------------------------------|
| 1. | Center Luminance | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 2. | Center Color | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 3. | MTF/Contrast | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 4. | Luminance Uniformity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 5. | Color Uniformity | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 6. | Field of View (by luminance) | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 7. | Field of View (by contrast) | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| 8. | Design Eyebox (by luminance) | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 9. | Design Eyebox (by contrast) | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 10. | Virtual Image Distance | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 11. | Image Distortion | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 12. | Interpupillary Distance | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 13. | Checkerboard Contrast | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 14. | Left Eye/Right Eye Parallax | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 15. | Color Gamut Area | <input checked="" type="checkbox"/> | <input type="checkbox"/> | | |
| 16. | Contrast Map | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |

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TEST PROCEDURES AND RESULTS

1. Center Luminance

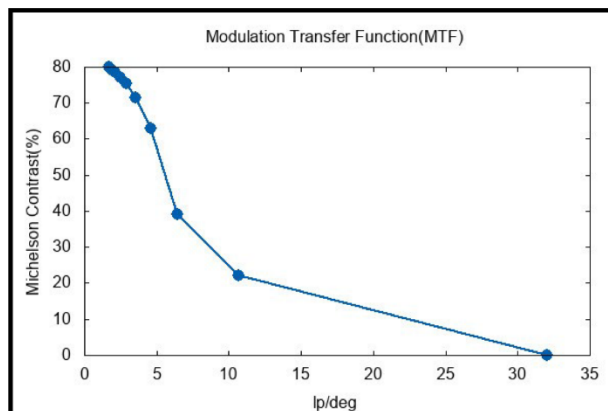
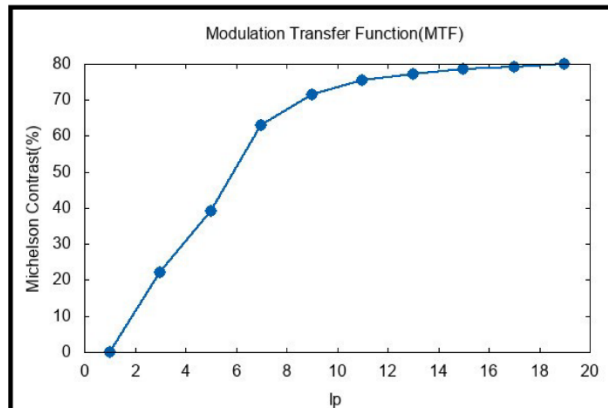
| | |
|------------------------|--|
| Pattern Used: | FS (Full Screen) |
| Pattern Color: | White |
| Rotation Mode: | NA |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | A full white screen image is rendered as the virtual image. The luminance data is collected from the 2 deg the area of the virtual image at the center of DUT. |
| Results: | The center luminance is obtained as 366.0465 cd/m²at the given eye relief. |

2. Center Color

| | |
|------------------------|---|
| Pattern Used: | FS (Full Screen) |
| Pattern Color: | White |
| Rotation Mode: | NA |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | A full white screen image is rendered as the virtual image. The CCT data is collected from the 2 deg area of the virtual image at the center of DUT at a specific eye relief. |
| Results: | The center color is obtained as 6338.2K at the given eye relief. |

3. Modulation Transfer Function(MTF)

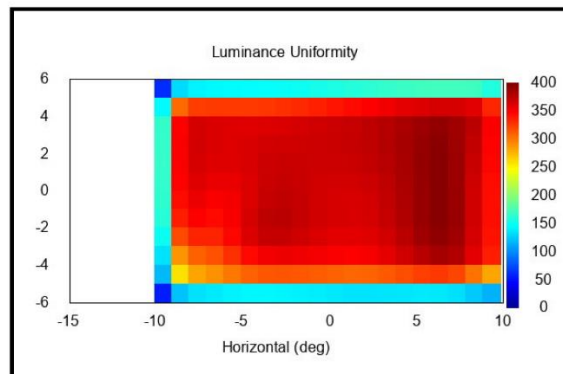
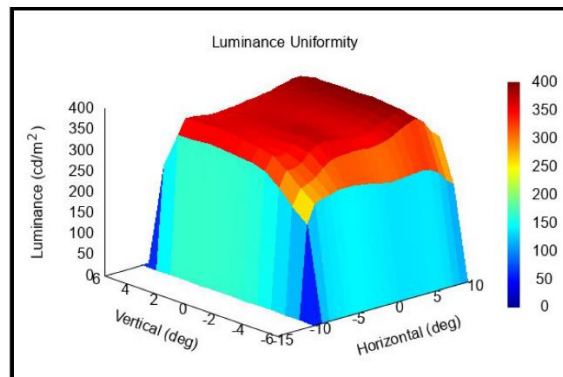
| | |
|------------------------|---|
| Pattern Used: | VBARS (Vertical Bars) |
| Pattern Color: | White |
| Rotation Mode: | NA |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | A VBARS image is rendered as the virtual image with a spatial frequency. Contrast data is collected from the virtual image from the selected region of interest for each measurement. The data collection process is repeated for the user selected range of spatial frequencies. |
| Results: | The maximum contrast is 79.914 % at 1.684211 lp/deg for the given eye relief. |



4. Luminance Uniformity

Pattern Used: FS (Full Screen)
Pattern Color: White
Rotation Mode: Pupil
Left/Right Eye: Left
Eye Relief: 23mm
Procedure: A full white screen image is rendered as the virtual image. Luminance data is collected from the virtual image from the area with the diameter of 2 deg for each measurement. The telescope pointing direction is translated horizontally from -10.15 to 10.15 deg with a step size of 1 deg, and vertically from -6 to 6 deg with a step size of 1 deg using Robot. The luminance map of the entire field of view corresponding to virtual image is generated. The luminance map of the entire field of view corresponding to virtual image is generated and size of the white field is measured by using 50% of peak luminance to define the edges of the virtual image.

Results: The luminance non-uniformity is reported as 44.32168%.

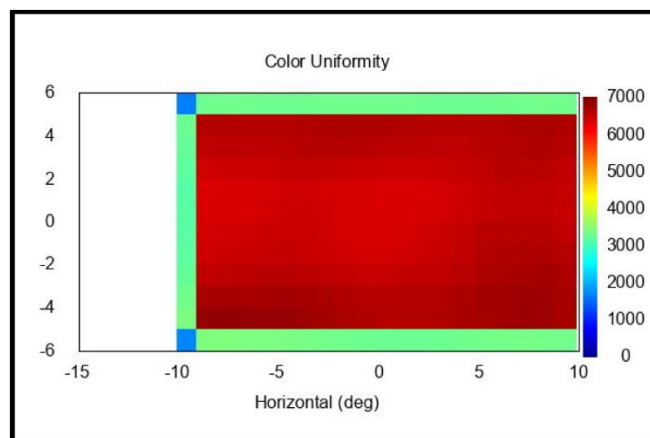
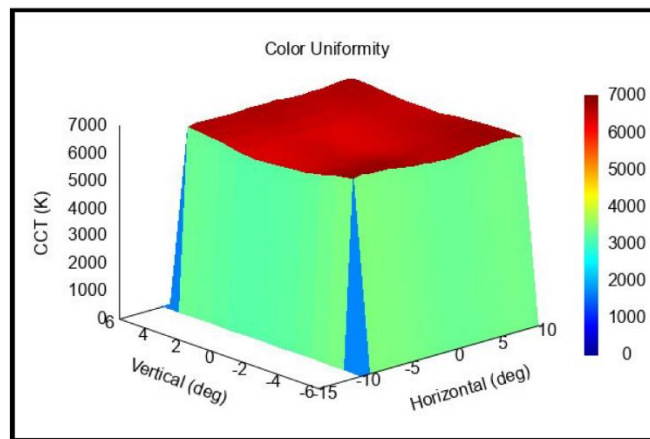


5. Color Uniformity

Pattern Used: FS (Full Screen)
Pattern Color: White
Rotation Mode: Pupil
Left/Right Eye: Left
Eye Relief: 23mm

Procedure: A full white screen image is rendered as the virtual image. The Correlated color temperature data is collected from the virtual image from the area with the diameter of 2 deg for each measurement. The telescope is translated horizontally from -10.15 to 10.15 deg with a step size of 1, and vertically from -6 to 6 deg with a step size of 1 deg using Robot. The color map of the entire field of view corresponding to virtual image is generated.

Results: The color non-uniformity is reported as 8.669268%.

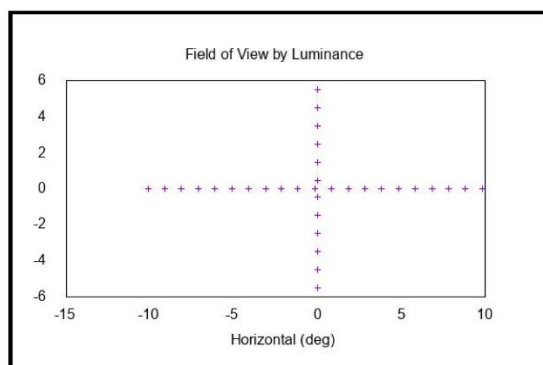
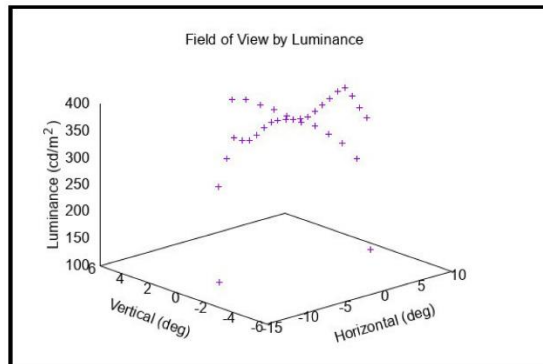


6. Field of View (by luminance)

Pattern Used: FS (Full Screen)
Pattern Color: White
Rotation Mode: Pupil
Left/Right Eye: Left
Eye Relief: 23mm

Procedure: A full white screen image is rendered as the virtual image. Luminance data is collected from the virtual image from the area with the diameter of 2 deg for each measurement. The telescope pointing direction is translated horizontally from -10.15 to 10.15 deg with a step size of 1, and vertically from -5.5 to 5.5 deg with a step size of 1 deg using Robot. The luminance map of the entire field of view corresponding to virtual image is generated. Then size of the FOV is measured by using 50% of peak luminance to define the edges of the virtual image. The horizontal FOV is defined as the combine angle from center to left and right edges of the virtual image. Similarly, the vertical FOV is defined as the combine angle from center to top and bottom edges of the virtual image.

Results: The horizontal FOV is 19deg and vertical FOV is 9deg.



7. Field of view (by Contrast)

Pattern Used: VBARS (Vertical Bars)

Pattern Color: White

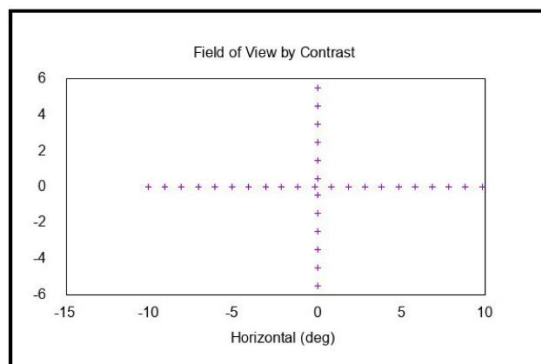
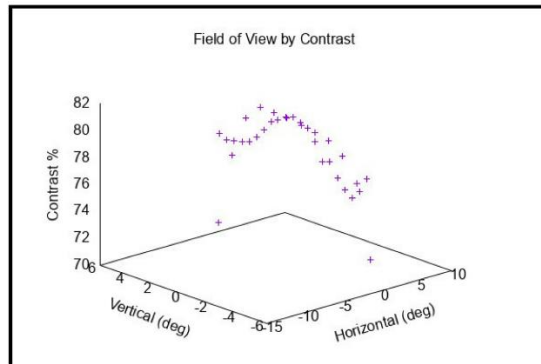
Rotation Mode: Pupil

Left/Right Eye: Left

Eye Relief: 23mm

Procedure: A VBARS/HBARS image is rendered as the virtual image. Contrast data is collected from the virtual image from selected region of interest. The telescope is translated horizontally from -10.15 to 10.15 deg with a step size of 1, and vertically from -5.5 to 5.5 deg with a step size of 1 deg using Robot. The contrast map of the entire field of view corresponding to virtual image is generated at a specified eye relief distance 23mm Then size of the FOV is measured by using 50% of peak contrast/MTF to define the edges of the virtual image. The horizontal FOV is defined as the combine angle from center to left and right edges of the virtual image. Similarly, the vertical FOV is defined as the combine angle from center to top and bottom edges of the virtual image.

Results: The horizontal FOV is 20deg and vertical FOV is 11deg.



8. Eyebox by Luminance)
Pattern Used: FS (Full Screen)

Pattern Color: White

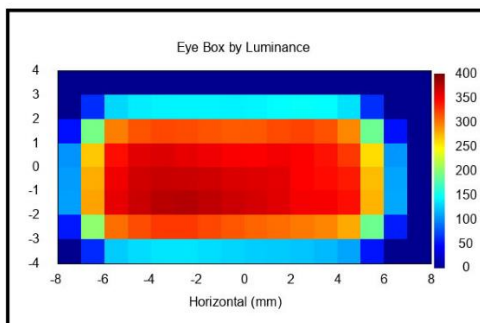
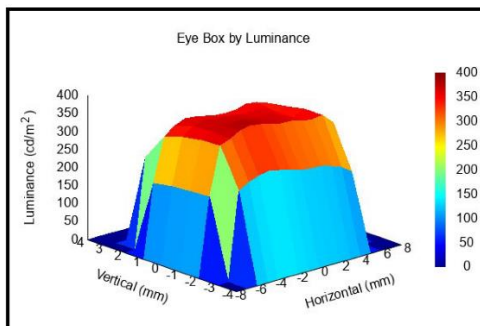
Rotation Mode: Pupil

Left/Right Eye: Left

Eye Relief: 23mm

Procedure: A full white screen image is rendered as the virtual image. Luminance data is collected from the virtual image from the area with the diameter of 2 deg for each measurement. The telescope is translated horizontally from -8 to 8 mm with a step size of 1, and vertically from -4 to 4 mm with a step size of 1 mm using Robot. The luminance map of the entire eye-box corresponding to virtual image is generated. Then size of the eye-box is measured by using 50% of peak luminance to define the edges of the virtual image. The distance between left and right edge of the virtual image is the horizontal eye-box size and distance between top and bottom edge of the virtual image is the vertical eye-box size of the DUT. If eye relief range is selected, the eye relief plane is changed and the horizontal and vertical range scans are repeated.

Results: **The horizontal extent of the design eyebox is 13mm and vertical extent is 5mm.**

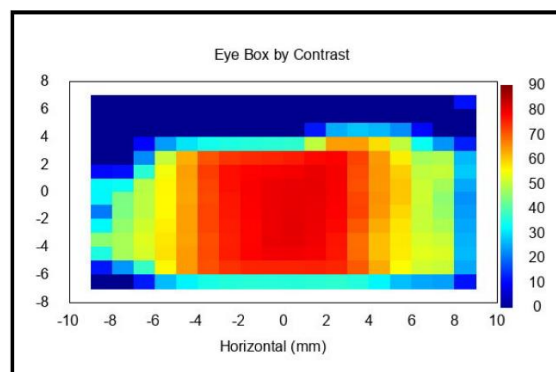
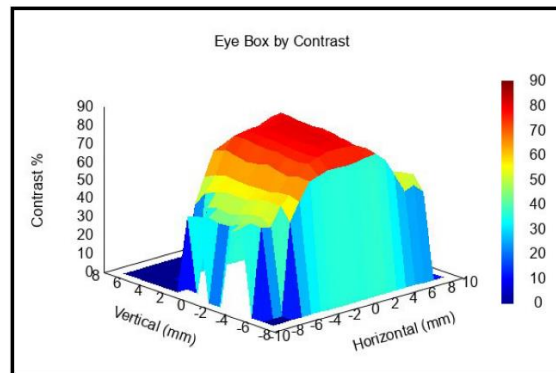


9. Eyebox by Contrast

Pattern Used: VBARS (Vertical Bars)
Pattern Color: White
Rotation Mode: Pupil
Left/Right Eye: Left
Eye Relief: 23mm
Procedure:

VBARS (Vertical Bars)
 White
 Pupil
 Left
 23mm
 A VBARS/HBARS image is rendered as the virtual image. Contrast data is collected from the virtual image. The telescope is translated horizontally from -9 to 9 mm with a step size of 1, and vertically from -7 to 7 mm with a step size of 1 mm using Robot. The contrast map of the entire field of view corresponding to virtual image is generated. Then size of the eye-box is measured by using <50>% of peak contrast/MTF to define the edges of the virtual image. The distance between left and right edge of the virtual image is the horizontal eye-box size and distance between top and bottom edge of the virtual image is the vertical eye-box size of the DUT.

Results: The horizontal extent of the design eyebox is 17mm and vertical extent is 9mm.



10. Virtual Image Distance

| | |
|------------------------|--|
| Pattern Used: | VBARS (Vertical Bars) |
| Pattern Color: | White |
| Rotation Mode: | NA |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | A vertical bars white pattern at selected spatial frequency is sent to DUT to find the best focus position of the telescope at the eyepoint. Using the autofocus routine in the telescope, Michelson contrast is calculated for the different focal positions. Focal plane with largest Michelson contrast is the focus position of the DUT. |
| Results: | The Virtual Image Distance is obtained as 0.01D. |

11. Image Distortion

| | |
|------------------------|--|
| Pattern Used: | FS (Full Screen) |
| Pattern Color: | White |
| Rotation Mode: | Pupil |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | A 9-points dot white image is rendered as the virtual image. These dots are located in the user defined region of interest. A centroided detection algorithm is used to detect the centroid of each dot. The ideal center of each dot is calculated from the known positions of each dot. Finally, the distortion is calculated with respect to the center of the dot located on the optical axis. |
| Results: | Max Horizontal Distortion: -10.18%, Max Vertical Distortion: -3.93% and Max Diagonal Distortion: -9.66%. |

12. Interpupillary Distance

| | |
|------------------------|--|
| Pattern Used: | FS (Full Screen) |
| Pattern Color: | White |
| Rotation Mode: | Pupil |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | <p>A full white screen image is rendered as the virtual image. Luminance data is collected from the virtual image from the area with the diameter of 2 deg for each measurement. The telescope is translated horizontally from -2 to 2 mm with a step size of 1 mm, and vertically from -2 to 2 mm with a step size of 1 mm using Robot. The luminance map of the entire eye-box corresponding to virtual image is generated. The (x, y) coordinate of the maximum luminance value is the eye point. Then, the telescope is moved to another eye carefully by moving back of 15mm, moving up of 0 mm, then moving to the another eye of 65 mm and finally moving down and forward of 0 and 15 mm respectively.</p> <p>The eye point is determined similarly. The distance between these 2-eye points is the interpupillary Distance (IPD).</p> |
| Results: | <p>The eye point of one eye is (-2,-2). The eye point of another eye is (-1,63). The interpupillary distance is 65.00769 mm at the given eye relief.</p> |

13. Checkerboard Contrast

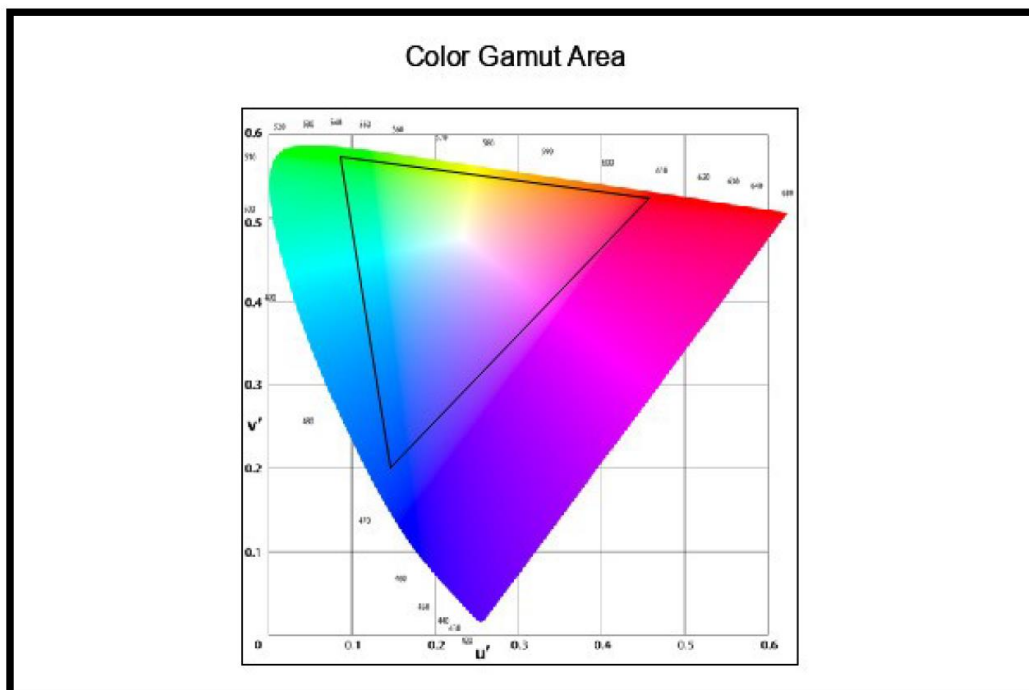
| | |
|------------------------|---|
| Pattern Used: | Checkerboard |
| Pattern Color: | White |
| Rotation Mode: | NA |
| Left/Right Eye: | NA |
| Eye Relief: | 23mm |
| Procedure: | <p>Two full white screen checkerboard images are rendered as virtual images. One is 5x5 checkerboard (Odd row and Odd column) and another one is 5X4(Even row and Odd column). The luminance are measured at the center of boxes from the area with diameter of 2 deg.</p> <p>For odd checkerboard measure at the center of the screen for each of the two (negative and positive) patterns obtaining the black and white luminance directly.</p> <p>For odd/even checkerboards measure the luminance of black and white above and below the center of the screen for both the negative and positive patterns. contrast is calculated from the black and white luminance from the two patterns.</p> |
| Results: | <ol style="list-style-type: none">1. Checkerboard pattern(5x5): The black luminance:15.788 cd/m². The white luminance:362.970 cd/m². The Contrast is: 22.990.2. Checkerboard pattern(5x4): The black luminance:13.037 cd/m². The white luminance:368.532 cd/m². The Contrast is: 28.268. |

14. Left Eye/Right Eye Parallax

| | |
|------------------------|--|
| Pattern Used: | CROSS (Crosshair) |
| Pattern Color: | White |
| Rotation Mode: | Pupil |
| Left/Right Eye: | Left to Right |
| Eye Relief: | 23mm |
| Procedure: | A crosshair image is rendered as the virtual image at the left and right eye points. The horizontal and vertical angles are recorded for both eyes at the eye points. The horizontal angular difference is the divergence, and the vertical angular difference is the and dipvergence. |
| Results: | The divergence is 1deg and dipvergence is -3.5deg |

15. Color Gamut Area

| | |
|------------------------|--|
| Pattern Used: | Full Screen |
| Pattern Color: | R, G, B |
| Rotation Mode: | NA |
| Left/Right Eye: | Left |
| Eye Relief: | 23mm |
| Procedure: | A full screen pattern is sent to DUT. Color information is collected by sending Red, Green and Blue full screen virtual image to the DUT. The area of the RGB triangle is calculated from CIE 1976(u',v') data. We divide this triangle by the area inside the spectrum locus from 380 nm to 700 nm evaluated at 1 nm intervals, which is 0.1952, and multiply by 100 % to obtain the normalized gamut area. |
| Results: | The Color Gamut Area is 34.70% at the given eye relief. |



16. Contrast Map (alternative: Foveated Contrast Map)

Pattern Used: VBARS (Vertical lines)

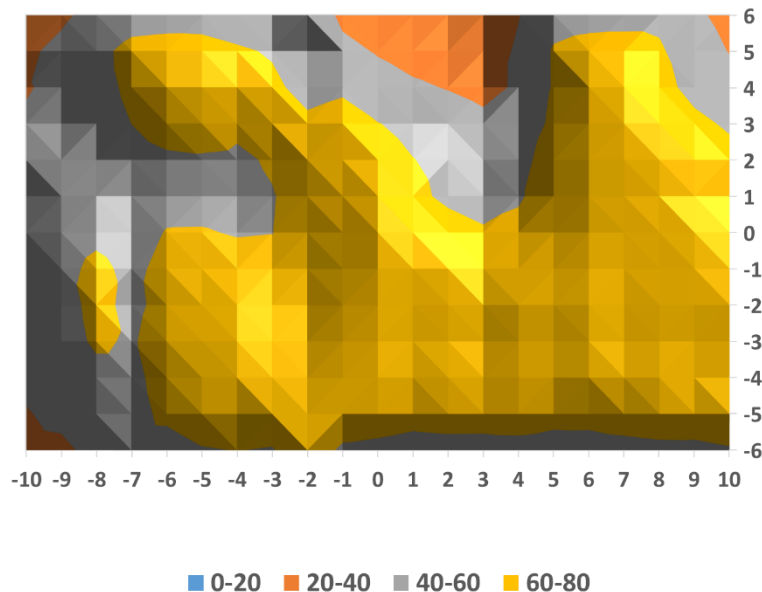
Pattern Color: White

Rotation Mode: Pupil

Left/Right Eye: Left

Eye Relief: 23mm

Procedure: A vertical bars white pattern at selected spatial frequency is rendered as the virtual image. Michelson contrast data is collected from the virtual image from selected region of interest of 2 deg for each measurement. The telescope pointing direction is translated horizontally from -10.15 to 10.15 deg with a step size of 1 deg, and vertically from -6 to 6 deg with a step size of 1 deg using Robot. The contrast map of the entire field of view corresponding to virtual image is generated. The luminance map of the entire field of view corresponding to virtual image is generated and size of the white field is measured by using 50% of peak luminance to define the edges of the virtual image.



Pattern Used: VBARS (Vertical lines)

Pattern Color: White

Rotation Mode: Eye

Left/Right Eye: Left

Eye Relief: 23mm

Procedure: A vertical bars white pattern at selected spatial frequency is rendered as the virtual image. Michelson contrast data is collected from the virtual image from selected region of interest of 2 deg for each measurement. The telescope pointing direction is translated horizontally from -10.15 to 10.15 deg with a step size of 1 deg, and vertically from -6 to 6 deg with a step size of 1 deg using Robot. The contrast map of the entire field of view corresponding to virtual image is generated. The luminance map of the entire field of view corresponding to virtual image is generated and size of the white field is measured by using 50% of peak luminance to define the edges of the virtual image.

