RADIANT VISION SYSTEMS

Near-Eye Display Testing: Addressing the Measurement Challenges of XR Displays

Mike Caputo | September 16, 2025

Agenda

RADIANT VISION SYSTEMS

- Overview & Background
- Measurement Requirements of AR/VR/MR Displays
- Challenges of Current Inspection Methods
- Radiant Inspection Solution
- Summary

RADIANT
VISION SYSTEMS

A Konica Minolta Company

Light & Color

Automated Visual Inspection

Global Support

Measurement Requirements of AR/VR/MR Displays

Current Market Trends

- Demand is accelerating again after the 2023 slump
- The product mix is tilting toward stand-alone, mixed-reality headsets
- Optics miniaturization—pancake lenses go mainstream
- Waveguide production is scaling for lightweight smart-glasses
- Geographic production is diversifying beyond China

XR Display Quality Challenges

Mura (luminance & color blotches)
Uneven layer bonding, particle contamination or mechanical stress leave localized “clouds” of darker or tinted pixels that break immersion and fail brand QC.

Pixel-level uniformity in microLED
Each µLED is its own emitter, so brightness and chromaticity can vary dramatically across a panel, slashing usable yield unless every sub-pixel is measured and corrected.

Screen-door effect (low fill factor)
Gaps between pixels in high-magnification optics reveal a grid, reminding users they’re looking at a screen rather than a world. The root cause is insufficient pixel density or planarization during backplane fabrication.

XR Display Quality Challenges

Limited field-of-view & edge distortion

Compact Fresnel or pancake optics and undersized panels cap FOV to ~90-120°. Pushing wider angles introduces blur/distortion at the periphery.

Chromatic & other aberrations

Conventional lenses focus red, green and blue at slightly different depths; color fringes destroy text readability. Samsung’s recent achromatic metalens work highlights the manufacturing difficulty of bringing all wavelengths to the same focal plane.

Thermal & brightness uniformity

High-nits microdisplays (≥1 M nits for AR) run hot; junction temperature drift changes color and shortens life, demanding tight thermal paths and active power management.

Measurement Needs

Where do we need to test?

- Display Module Testing
- Optical Module Testing
- Assembled Module Testing

Assembled Module Test

Display Module Testing

- µLED, µOLED, LCD+BLU, LCoS;
- Optical functions: Luminance, Chromaticity
- AOI
- Demura

Teardown

Optical Module Testing

VR (Lens / Lens + Display)

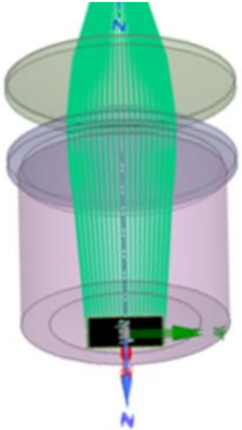
- Optical functions: AOI: Particle, Mura; MTF (Modulation Transfer Function), Luminance, Chromaticity, Contrast, Distortion, Uniformity, etc.
- AA(Active Alignment)
- VID(Virtual Image Distance)

Teardown

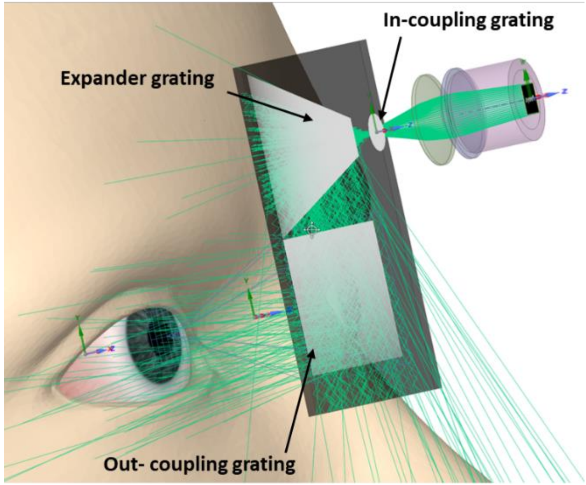
Optical Module Testing

AR (Display + Lens / Display + Lens + Waveguide)

- Optical functions: AOI: Particle, Mura; MTF(Modulation Transfer Function), Luminance, Chromaticity, Contrast, Distortion, Uniformity, etc.
- VID(Virtual Image Distance)



Display + Lens



Display + Lens + Waveguide

Assembled Module Testing

- Optical functions: MTF (Modulation Transfer Function), Luminance, Chromaticity, Contrast, Distortion, Uniformity, etc.
- VID (Virtual Image Distance)

VR Goggles

AR Goggles

Quality Parameters

XR Display Manufacturers’ Requirements:

01

Evaluate Luminance & Color

- Measure luminance and color accurately across the full FOV of my measurements.
- Have the option to capture spectral data through the lens and automatically apply color calibrations as needed

Quality Parameters

XR Display Manufacturers’ Requirements:

02

Achieve Uniformly High MTF Quality

- Uniformly high MTF quality across the full FOV is required
- Capture spectral data through the lens and automatically apply color calibrations as needed

Quality Parameters

XR Display Manufacturers' Requirements:

03

Measure Virtual Image Distance

- Measure VID of AR-device projected image

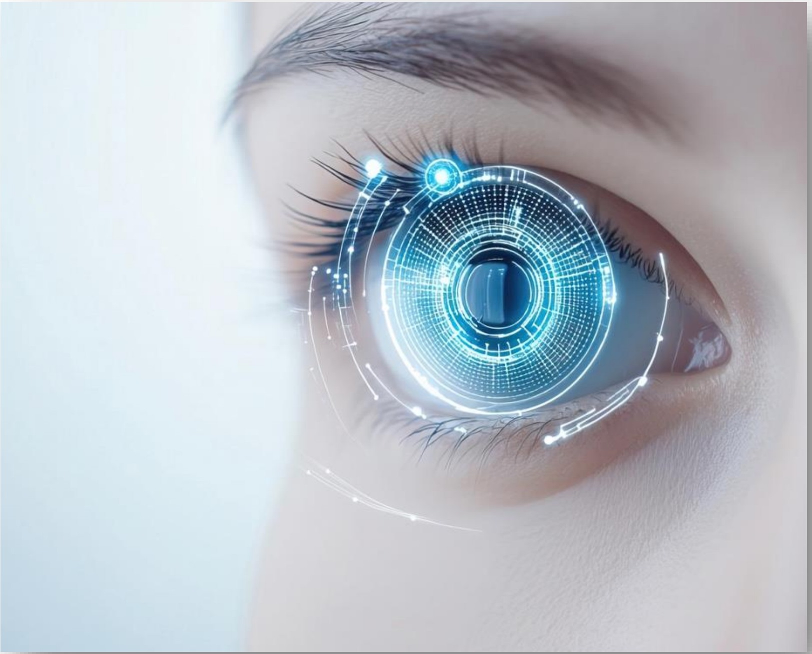
Quality Parameters

XR Display Manufacturers' Requirements:

04

Replicate Human Visual Perception

- Capture Measurements with an aperture that is similar in size to the human pupil



Challenges of Current Inspection Methods

Measurement Challenges of Current Inspection Methods

Multiple measurements are required to measure full FOV

Lens focus and distortion

Lens size is too large for AR/VR headsets

Capturing Full FOV in a Single Measurement

Measurement Challenge

Curved focus planes result in non-uniform MTF across the FOV

Multiple measurements are required to get the best MTF, resulting in slow system takt times

Measuring full FOV without distortion contribution from the lens

Lens Focus & Distortion

Measurement Challenge

Knowing where the lens is focused by looking at an indicator on the system

Testing requirements demand multiple apertures and multiple focus distances.

Focusing at any distance that an AR DUT can project, without changing the pupil location

Optics Size

Measurement Challenge

Current measurement optics can be too large in diameter to fit inside an AR/VR headset for measurements

Prescription compensation

Measurement Challenge

Advanced AR devices can incorporate the user's correction prescription. Distortion and prescription compensation are two of the biggest issues in the industry.

Measurement systems must accommodate a range of diopters for accurate results. Software and hardware solutions are often required to achieve the desired results.

Prescription XR Device Designs

Possible methods to accommodate prescription optics in AR/MR/VR headsets:

- Modified headset design to allow prescription glasses to be worn within
  - *Adds weight, discomfort, fit issues, can scratch lenses*
- Prescription lens inserts or swappable lenses
- User-controlled adjustment mechanisms
- Prescription glasses integrated into XR device

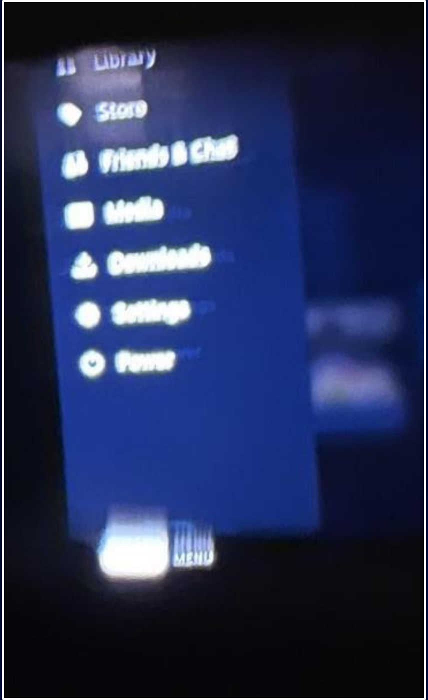
Third-party lens inserts made for XREAL Air 2

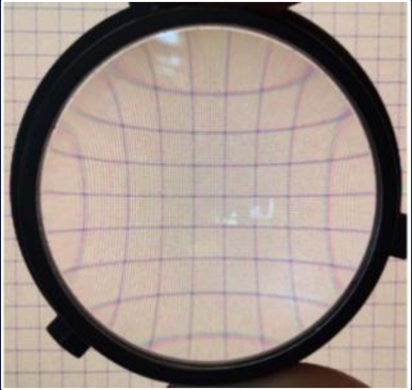
ROKID Max with diopter adjustments for myopia 0 – 5D

Meta Ray-Ban® Wayfarer can be ordered with prescription lenses

Visual Quality Issues

- Blurring
- Distortion
- Poor contrast and brightness
- Diffraction effects
  - *Color separation*
- Dimming
- Ghosting / double images
- Color non-uniformity
- Luminance non-uniformity
- Defects
  - *E.g., pixel defects, lines*
- Dual eye inconsistency





Radiant Solution

Radiant Solution – XRF M30 Lens

New AR inspection, adjustable focus lens, with flat image plane and near diffraction-limited, high MTF quality

- ✓ Captures full FOV in a single measurement
- ✓ Adjusts focus with fixed entrance pupil
- ✓ Replicates human visual perception
- ✓ Compensates for prescription optics
- ✓ Fits within device constraints

**Controllable with Radiant API*

**Compatible with I/Y61, and I61-SC*

**Available in straight and folded configurations*

XRF-M30 Product Specifications

Specifications

Parameter	XRF-M30 Lens
Primary Application	Light and color measurement for near-eye displays (NED) in headsets
Entrance Pupil Diameter*	1mm - 5mm
Focus Range**	.25m to infinity (-4 to +4 diopters)
Imaging System	ProMetric Y61 or I61
Approximate Field of View (H)	± 30°
Approximate Field of View (V)	± 22°
Resolution	0.007° / sensor pixel
Luminance - Minimum	0.01 cd/m²
Luminance - Maximum****	10,000 cd/m² (Y-series); 1,000,000 cd/m² (I-series)

Specifications subject to change without notice.

* Specific calibrated aperture may be selected by the user

** Measured from front of lens.

*** Maximum luminance is for 1 ms. For higher luminance for Y-series, contact Info@RadiantVS.com.

Compatible systems

- ProMetric Y61

  61MP imaging photometer

- ProMetric I61

  61MP imaging colorimeter

- ProMetric I61-SC

  61MP imaging colorimeter with integrated spectrometer

Captures Full FOV in a Single Measurement

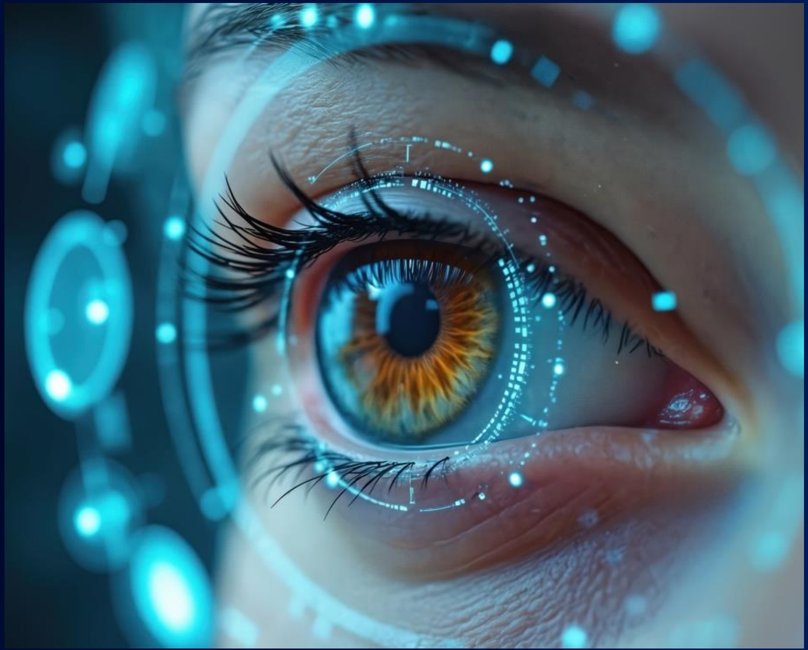
- +/- 30 Degree FOV
- High MTF quality performance
- Flat focus plane measures across multiple field points

Adjusts Focus With Fixed Entrance Pupil Location

- Focus range of .25m to infinity
- Fixed entrance pupil location when focus distance is changed
- Locked aperture and focus distance for shipping

Replicates Human Visual Perception

- Variable entrance pupil 2-4mm in diameter
- Virtual image distance (VID) measurement



Compensates for Prescription Optics

- Focus range of -4 to +4 diopters
- Adjustment for astigmatism
- Both hardware and software compensation options available.

Novel Method: Spherical Compensation

Solution Component: XR Macro Lens

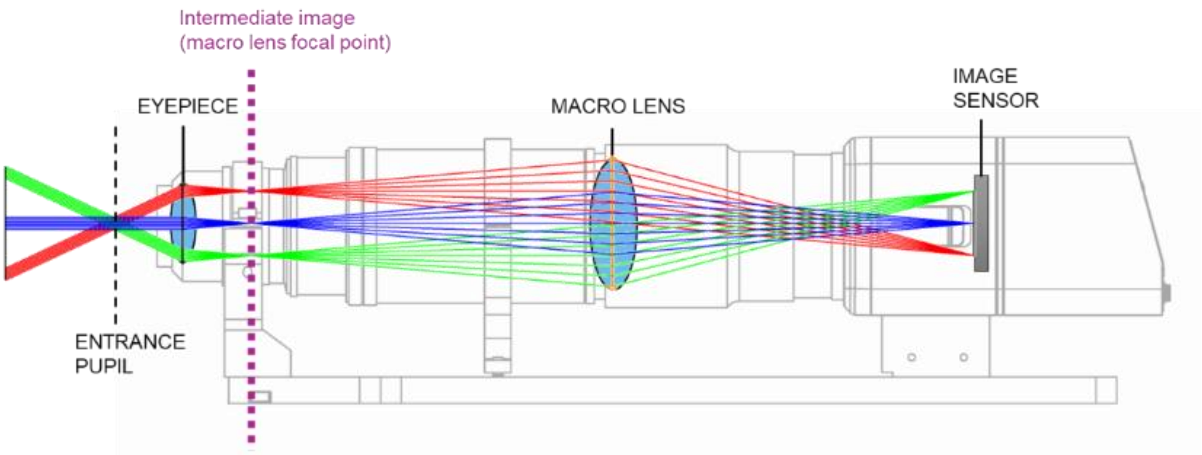


Illustration of system focused at infinity

- Combination of two positive (image-forming) lenses producing an intermediate image where macro lens
- Available FOV: ±23°, ±31°, ±35°, ±57°, and others.
- Corrects for both near- and far-sightedness with negative or positive power

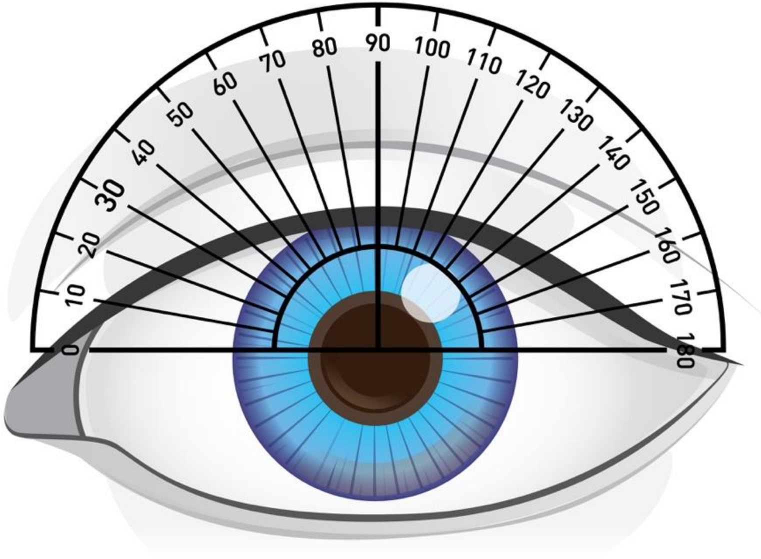
Spherical Compensation Results Summary

- XR macro lens focus position changes as a function of the power of the prescription
- New focus position enables measurement of equivalent MTF as without prescription
- No degradation of measurement capability when prescription lens is introduced
- Advantages:
  - Compact and suitable for production
  - Electronic lens control
  - No external lenses
  - No external moving parts
  - Usable to find prescription if not known

Novel Method: Cylindrical Compensation

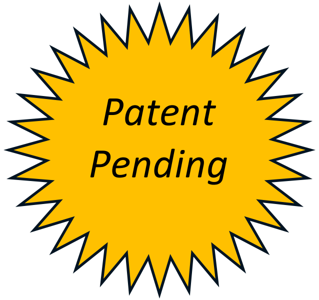
Cylindrical (Astigmatic) Measurement Solution

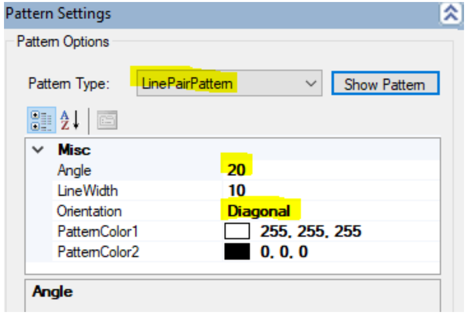
- Software Component
  - MTF Line Pairs
    - To compensate for astigmatism in the prescription, the target edge needs to be measured at the same angle as the astigmatism axis angle
    - A mismatch results in poor MTF, a proper match results in very similar values to no prescription present
- Hardware Component
  - Adjustable Astigmatism Correction Lens

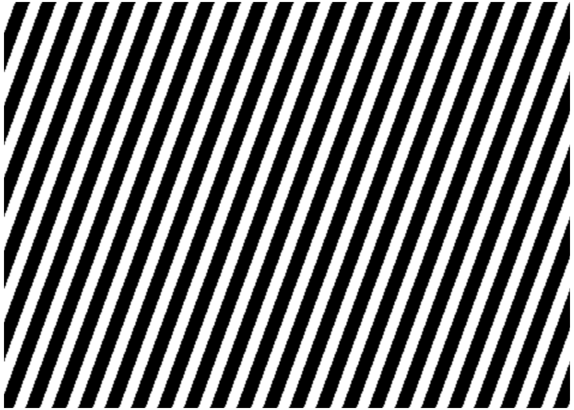


Software Solution

- Astigmatism angle can be 0˚- 180˚
- Line pairs pattern displayed on DUT can be oriented at any angle
- Line pairs MTF can measure contrast at a specific spatial frequency
- Test software includes this pattern display capability and the calculation of MTF







Hardware Solution

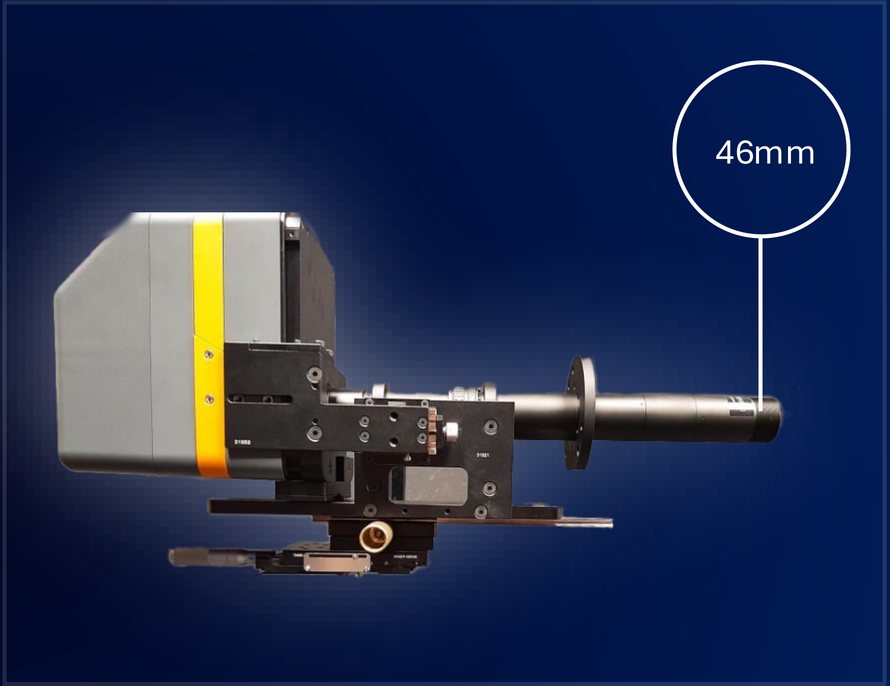
- Cancel out cylindrical (astigmatism) prescription
- Components
  - ProMetric® I61 Imaging Colorimeter (61 MP)
  - XR macro lens with FOV ± 31° in folded (periscope) configuration
  - TrueTest™ Software
  - Adjustable astigmatism correction lens
  - Astigmatism correction lens adapter

Image © Tele Vue

Cylindrical Compensation Results Summary

- Software Cylindrical Compensation (line edge pattern at angle that matches device's astigmatism axis):
  - Experimental data confirms that when cylindrical astigmatism axis is aligned with slant edge target, MTF values are within ±1% of the control
  - No swapping of lenses, fastest approach
- Hardware Cylindrical Compensation (astigmatism corrector lens):
  - Hardware does correct for astigmatism by collapsing the focus spread between sagittal and tangential edges
  - More comprehensive study of spatial frequencies throughout FOV

Fits Within Device Constraints



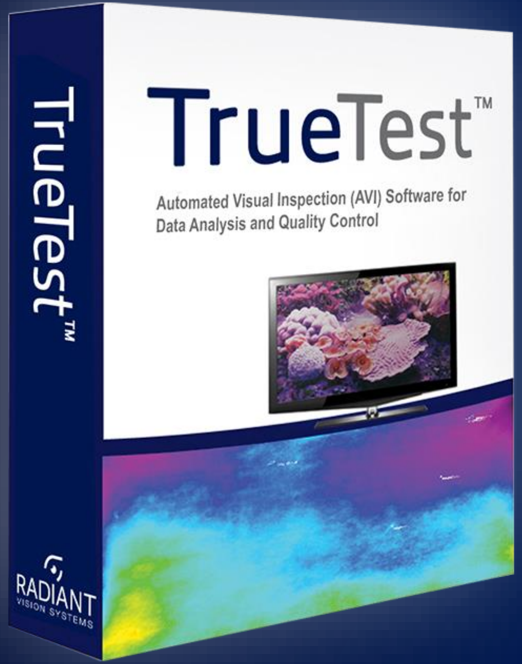
- 46mm in diameter to fit inside an AR/VR headset

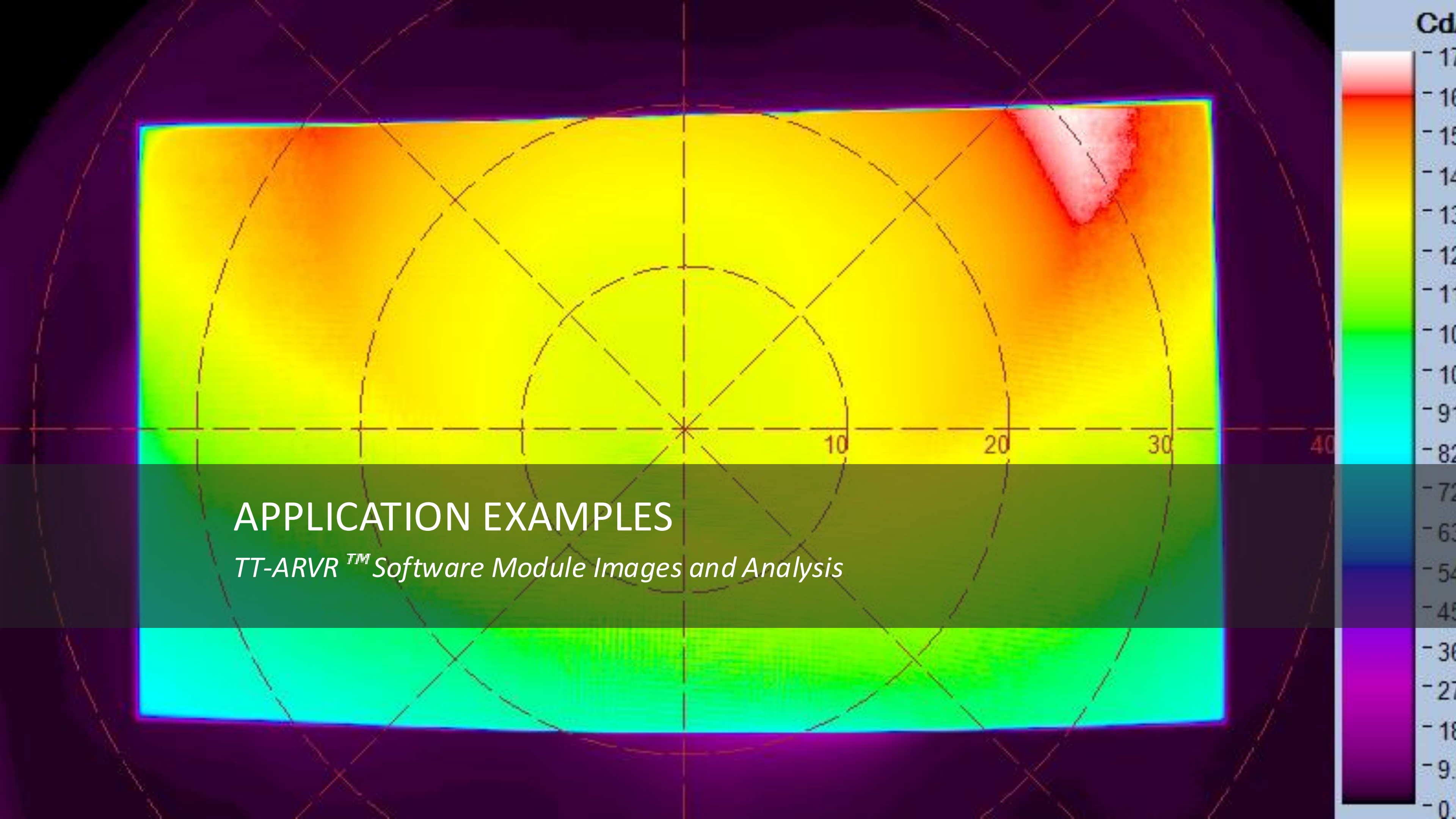
TrueTest™ Software

TT-ARVR™ Software Module

Full suite of display tests:

- ✓Luminance
- ✓Chromaticity
- ✓Uniformity
- ✓Contrast
- ✓Mura (blemishes)
- ✓Pixel/line defects





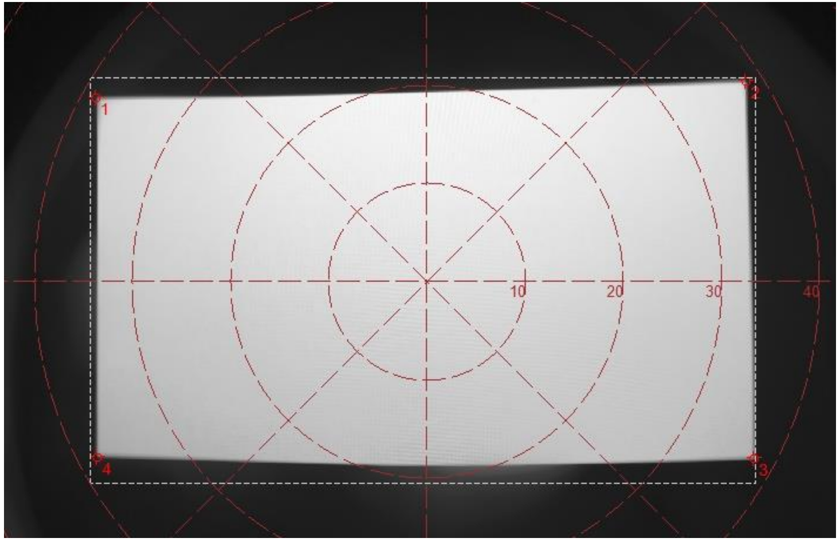
APPLICATION EXAMPLES

TT-ARVR ™ Software Module Images and Analysis

TT-ARVR Software Tests

Test	Color?	Pattern(s)
Field View	Photopic	White 255, or Green
Uniformity	Color	White 255
ANSI Color Uniformity	Color	White 255, Red, Green, Blue
Sequential Contrast	Photopic	Black, White (selected in test)
Distortion	Photopic	9 Dot Distortion Pattern (Red, Green, Blue)
MTF Slant Edge	Photopic	4 Square Pattern (White)
Checkerboard Contrast	Photopic	11x11 Checkerboard (White)

Field View



Reports out the horizontal, vertical and diagonal Field of View of the AR/VR headset. Results reported in degrees.

Analysis Results

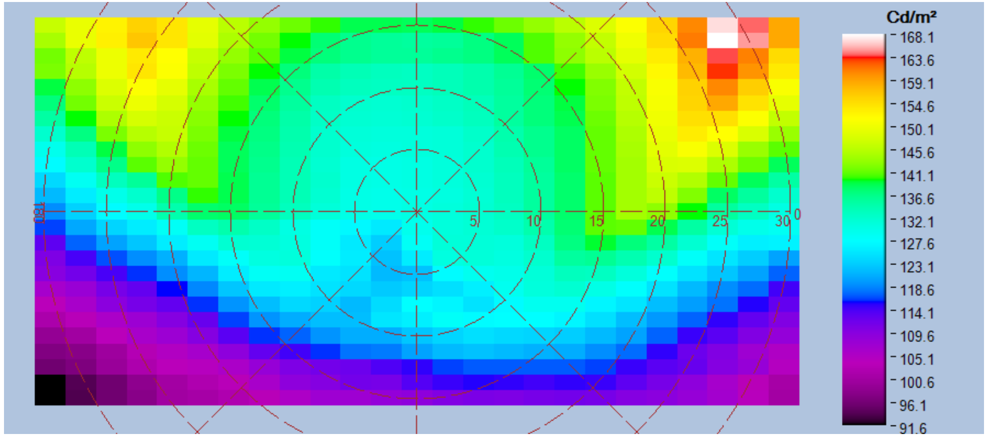
	Analysis Name	Pattern	Serial Number	Result	Value	Unit
1	Field View	Green	4	Horizontal FOV	66.504	Degrees
2	Field View	Green	4	Vertical FOV	37.488	Degrees
▸ 3	Field View	Green	4	Diagnol FOV	76.342	Degrees

Uniformity

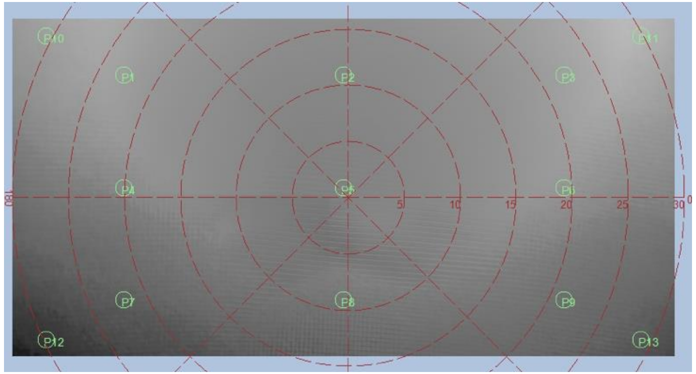
Creates NxN grid on image, and reports out average luminance of each grid point, as well as additional statistics (min, max, difference, etc.)

Analysis Results

	Analysis Name	Pattern Name	Seria	Result	Value	Unit
4	Uniformity	White	4	CCT	8982	
5	Uniformity	White	4	Avg u'	0.2075	
6	Uniformity	White	4	Avg v'	0.4334	
7	Uniformity	White	4	du'	0.0459	
8	Uniformity	White	4	dv'	0.0469	
9	Uniformity	White	4	CenterLv	130.3673	cd/m²
10	Uniformity	White	4	MinLv	91.6055	cd/m²
11	Uniformity	White	4	MaxLv	168.149	cd/m²
12	Uniformity	White	4	AvgLv	130.0462	cd/m²
13	Uniformity	White	4	LvUniformity	54.4788	%
14	Uniformity	White	4	CenterMaxLvU...	77.5308	%
15	Uniformity	White	4	LocalLvUnifor...	94.8738	%
16	Uniformity	White	4	MaxDarkLocal...	-3.0915	%
17	Uniformity	White	4	MaxBrightLoca...	3.2655	%
18	Uniformity	White	4	GlobalContrast	-29.7328	%
19	Uniformity	White	4	Centeru_prime	0.2189	
20	Uniformity	White	4	Centerv_prime	0.4227	
21	Uniformity	White	4	CenterColorDiff...	0.0339	
22	Uniformity	White	4	TopBottomCol...	0.0602	
23	Uniformity	White	4	LeftRightColor...	0.0098	
24	Uniformity	White	4	ColorDifference	0.0657	
25	Uniformity	White	4	LocalColorDiff...	0.0121	
26	Uniformity	White	4	GlobalColorDiff...	0.0642	



ANSI Color Uniformity



13 ANSI points placed on measurement, per ANSI standard. Report out color coordinates at each point, and max color difference. Pass/Fail available.

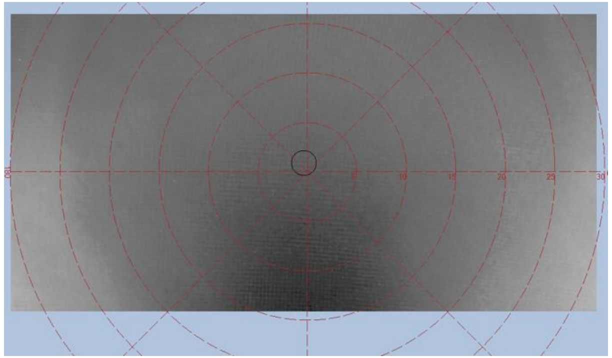
4 patterns measured (White, R, G, B)

Analysis Results

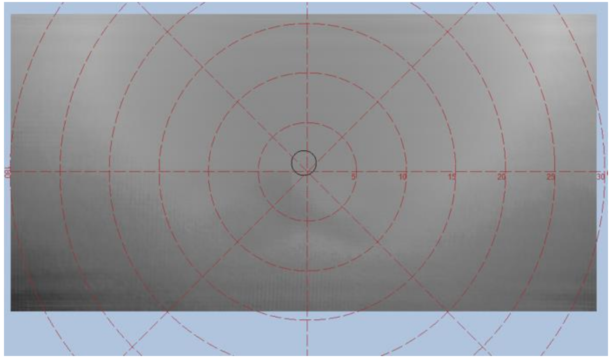
	Analysis Name	Pattern Name	Serial	Result	Value	Unit	Pass/Fail
28	ANSI Color Uniformity	White	4	ANSIColorDiffe...	0.0428		
29	ANSI Color Uniformity	White	4	MaxColorDiffer...	0.0568		
30	ANSI Color Uniformity	White	4	u' Values	0.2044, 0.2365, 0.2098, ...	u'	
31	ANSI Color Uniformity	White	4	v' Values	0.435, 0.4047, 0.4321, 0....	v'	
32	ANSI Color Uniformity	White	4	CCT Values	9111.892, 10605.27, 89...	degrees	
33	ANSI Color Uniformity	White	4	LvValues	149.3253, 132.9969, 15...	cd/m²	
34	ANSI Color Uniformity	White	4	Lv Uniformity	57.6505	%	

Sequential Contrast

Black



White

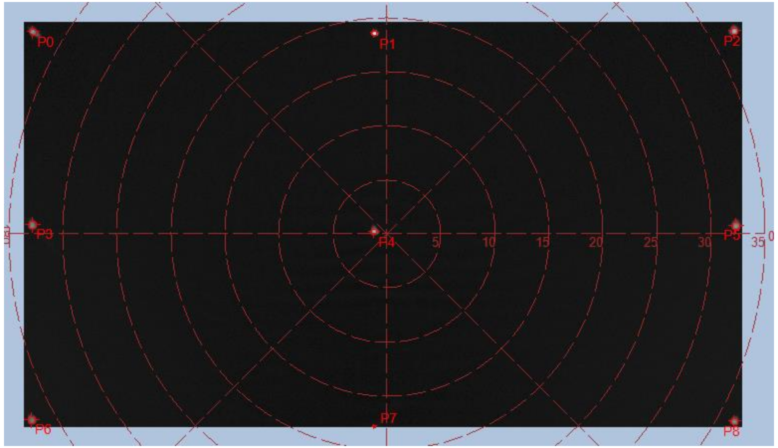


Takes measurement of Black, and White patterns. Compares luminance values in POI at center of image. Computes contrast ratio

Analysis Results

	Analysis Name	Pattern Name	Serial	Result	Value	Unit
35	Sequential Contrast	Black	4	AvgLv1	0.178	cd/m²
36	Sequential Contrast	Black	4	AvgLv2	130.227	cd/m²
37	Sequential Contrast	Black	4	ContrastRatio	731.6	Contrast Ratio

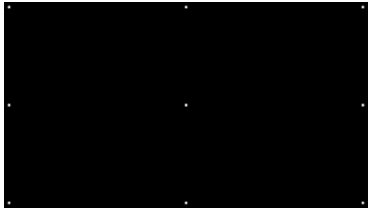
Distortion



Distortion test measures several geometric distortion parameters to determine if the image is off-center, rotated, keystoned, or pin-cushioned/barrel distorted. A pattern consisting of 9 dots (on a 3x3 grid) is displayed and measured. The program finds the center location of the nine dots and then performs measurements between dots to determine if the tests pass or fail.

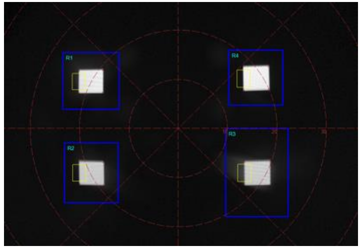
Analysis Results

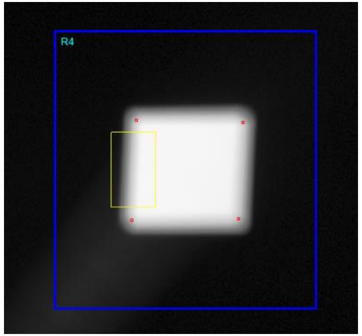
	Analysis Name	Pattern Name	Seria	Result	Value	Unit
4	Distortion	Red - Distortion	4	CenterX	-1.1679	Degrees
5	Distortion	Red - Distortion	4	CenterY	0.1913	Degrees
6	Distortion	Red - Distortion	4	ImageRotation	0.0753	degrees
7	Distortion	Red - Distortion	4	KeystoneHoriz	-0.6929	%
8	Distortion	Red - Distortion	4	KeystoneVert	0.2524	%
9	Distortion	Red - Distortion	4	DistortionLeft	-0.0747	%
10	Distortion	Red - Distortion	4	DistortionRight	-0.2156	%
11	Distortion	Red - Distortion	4	DistortionTop	-0.5419	%
12	Distortion	Red - Distortion	4	DistortionBottom	1.5256	%

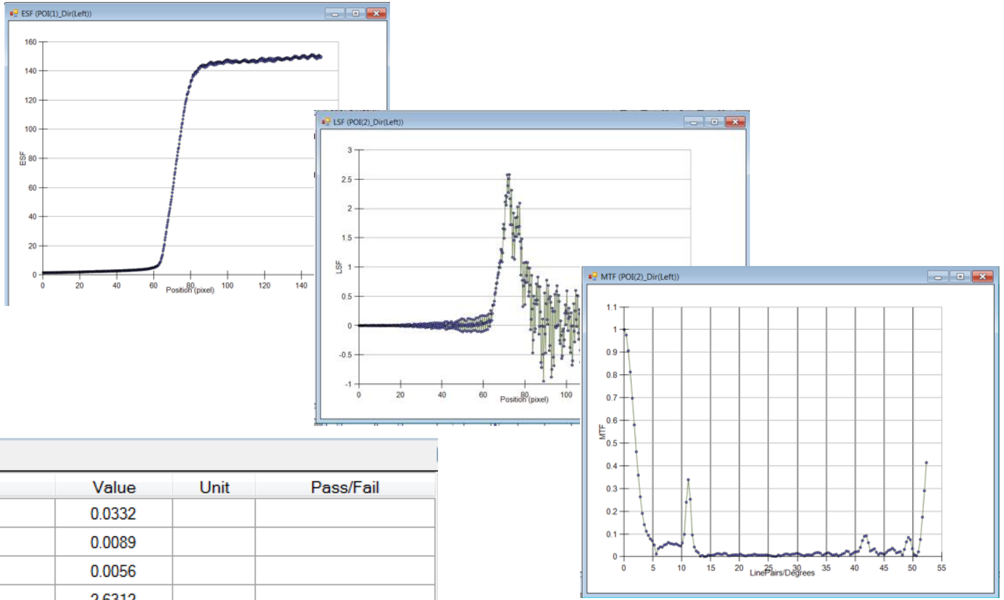


Pattern used in test

MTF Slant Edge



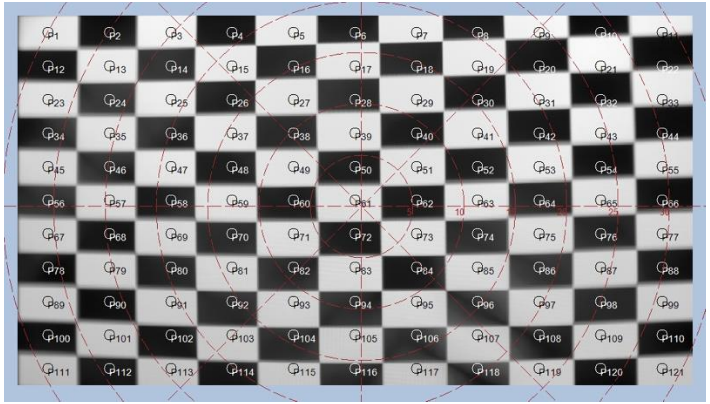


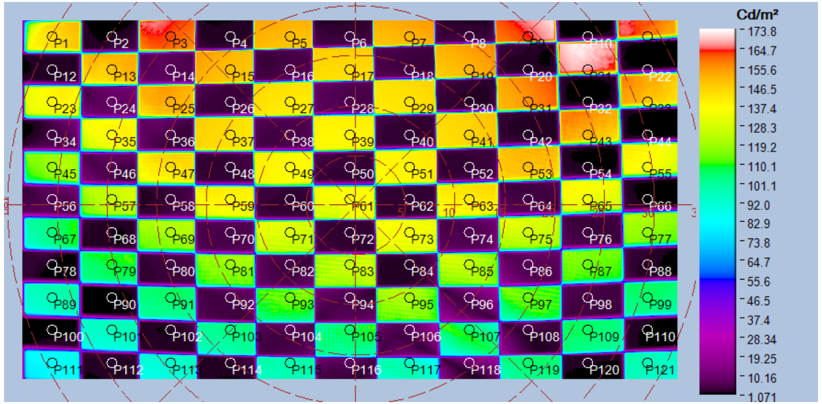


Analysis Results

	Analysis Name	Pattern Name	Serial	Result	Value	Unit	Pass/Fail
36	MTF_SlantEdge	White - MTF	4	POI(1)_Dir(Left)_MTF_@freq10	0.0332		
37	MTF_SlantEdge	White - MTF	4	POI(1)_Dir(Left)_MTF_@freq15	0.0089		
38	MTF_SlantEdge	White - MTF	4	POI(1)_Dir(Left)_MTF_@freq20	0.0056		
39	MTF_SlantEdge	White - MTF	4	POI(1)_Dir(Left)_Freq_@MTF20%	2.6312		
40	MTF_SlantEdge	White - MTF	4	POI(1)_Dir(Left)_Freq_@MTF10%	3.06		
41	MTF_SlantEdge	White - MTF	4	POI(2)_Dir(Left)_MTF_@freq5	0.0622		
42	MTF_SlantEdge	White - MTF	4	POI(2)_Dir(Left)_MTF_@freq10	0.0578		
43	MTF_SlantEdge	White - MTF	4	POI(2)_Dir(Left)_MTF_@freq15	0.0056		
44	MTF_SlantEdge	White - MTF	4	POI(2)_Dir(Left)_MTF_@freq20	0.01		
45	MTF_SlantEdge	White - MTF	4	POI(2)_Dir(Left)_Freq_@MTF20%	3.0769		

Checkerboard Contrast





Analysis Results

	Analysis Name	Pattern Name	Serial	Result	Value	Unit
17	CheckerboardContrast-ARVR	White - Checkerboard	4	AvgLv1	127.9981	cd/m²
18	CheckerboardContrast-ARVR	White - Checkerboard	4	Lv1Values	143.8, 162, 149.8, 151.4, 163.6, 124.5, 148.6, 149.5, 144.5, 151.2, 163.4, 137.5, 152.1, 141.5, 143.1, 155.8, 143.8, 137, 143....	cd/m²
19	CheckerboardContrast-ARVR	White - Checkerboard	4	AvgLv2	4.0909	cd/m²
20	CheckerboardContrast-ARVR	White - Checkerboard	4	Lv2Values	1.8, 2.1, 3.5, 3.8, 12.2, 1.9, 6.4, 4.8, 4, 2.7, 17, 8.3, 3.2, 5, 2.4, 2.6, 4.1, 4.4, 4.6, 2.6, 2.3, 2, 5.4, 2.9, 3.2, 3.1, 1.9, 5.8, 3.3, 2.8, 2....	cd/m²
21	CheckerboardContrast-ARVR	White - Checkerboard	4	ContrastRatio	31.288493974431	CR

Summary

Radiant Solution Benefits

- Reduces takt time by capturing the full FOV of a device in a single measurement
- Measures virtual image distances within an AR display
- Ensures image quality by providing a focus range of -4 to +4 diopters to compensate for prescription optics
- Replicates visual perception with an aperture that is similar in size to the human pupil

Radiant XR Measurement Solutions

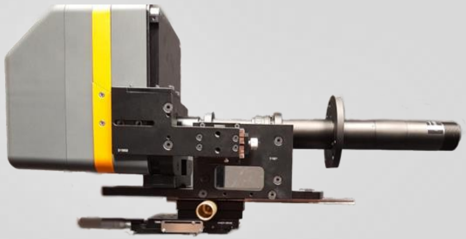
AR/VR Lens

- Form factor fits inside XR headsets
- Front aperture replicates human pupil size and position
- FOV ± 60°

XRE 35 Lens

- Replicates human eye in XR headsets
- Folded (periscope) and non-folded configurations

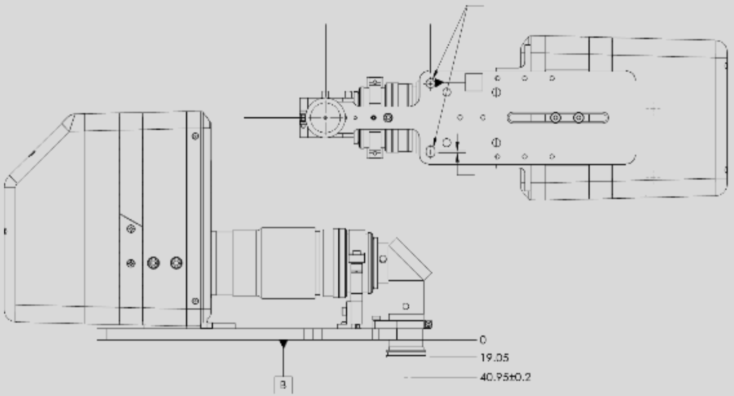
XRF 30M Lens



- Flat image plane
- Improved MTF
- FOV ± 30°

Radiant XR Measurement Solutions

Tailored Configurations

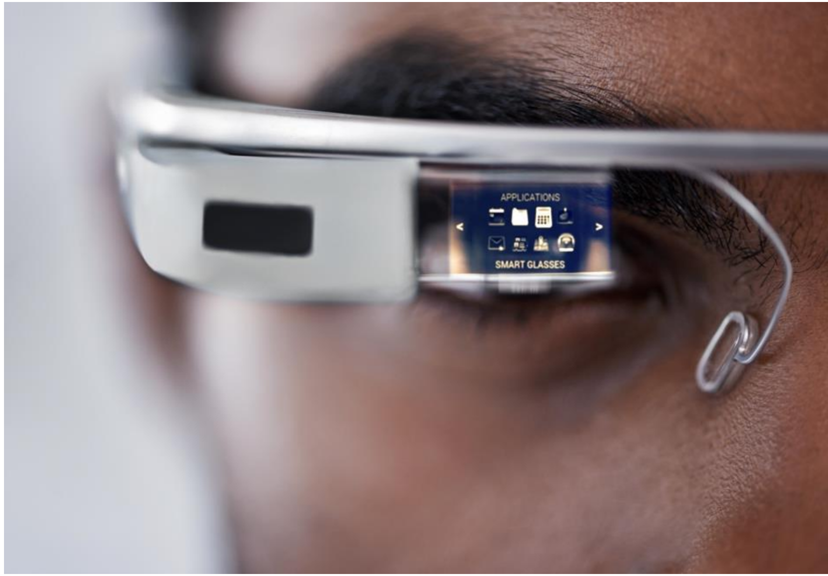


- Modular components enable Radiant to configure an XR measurement solution to meet unique specifications
- Electronic lens and aperture control
- Customer FOV configurations include ± 23°, ±32°,±35°, ± 57°

The Radiant Optics team will work with customers to configure lens solutions to meet their application needs.

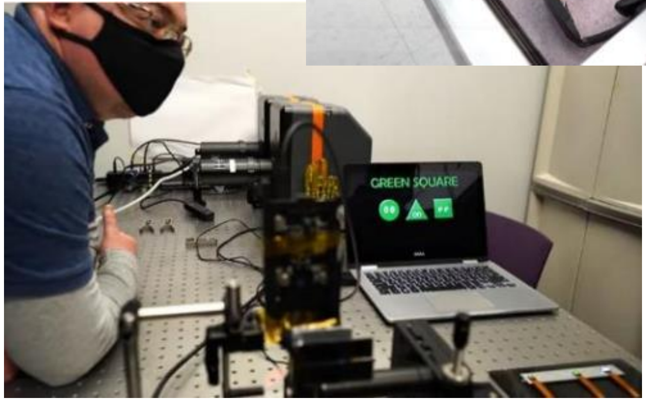
Conclusions

- Spherical compensation achieved using **XR macro lens** with software-controlled electronic focus:
  - Wide focus range capability
  - Proven to provide accurate MTF for nearly all myopia/hyperopia prescriptions (-10D to +4D)
- Cylindrical compensation achieved via:
  - **Line Pairs Measurement:** in correct orientation, provides rapid cylindrical compensation, identifies many device optical issues for a given spatial frequency
  - **Adjustable astigmatism corrector lens:** effective and efficient way to measure multiple cylindrical orientations and spatial frequencies



Conclusion: Efficiency in Device Production

- Spherical and cylindrical software approaches can be combined to measure prescriptions that include both types of refractive error
- XR macro lens form factor enables simultaneous stereoscopic (dual-eye) inspection



Radiant imaging colorimeter used for display testing in AR production. Images © Vuzix

Why Choose Radiant?

Superior Hardware

High-resolution photometric imaging for rapid and repeatable luminance measurement at all light levels

Software

Dynamic registration, pre-programmed test parameters, and multiple analyses performed from a single image

Color Accuracy

CIE-matched tristimulus (x,y) filters for precise chromaticity measurement, NVLAP-accredited ISO-17025 calibration lab

Experience

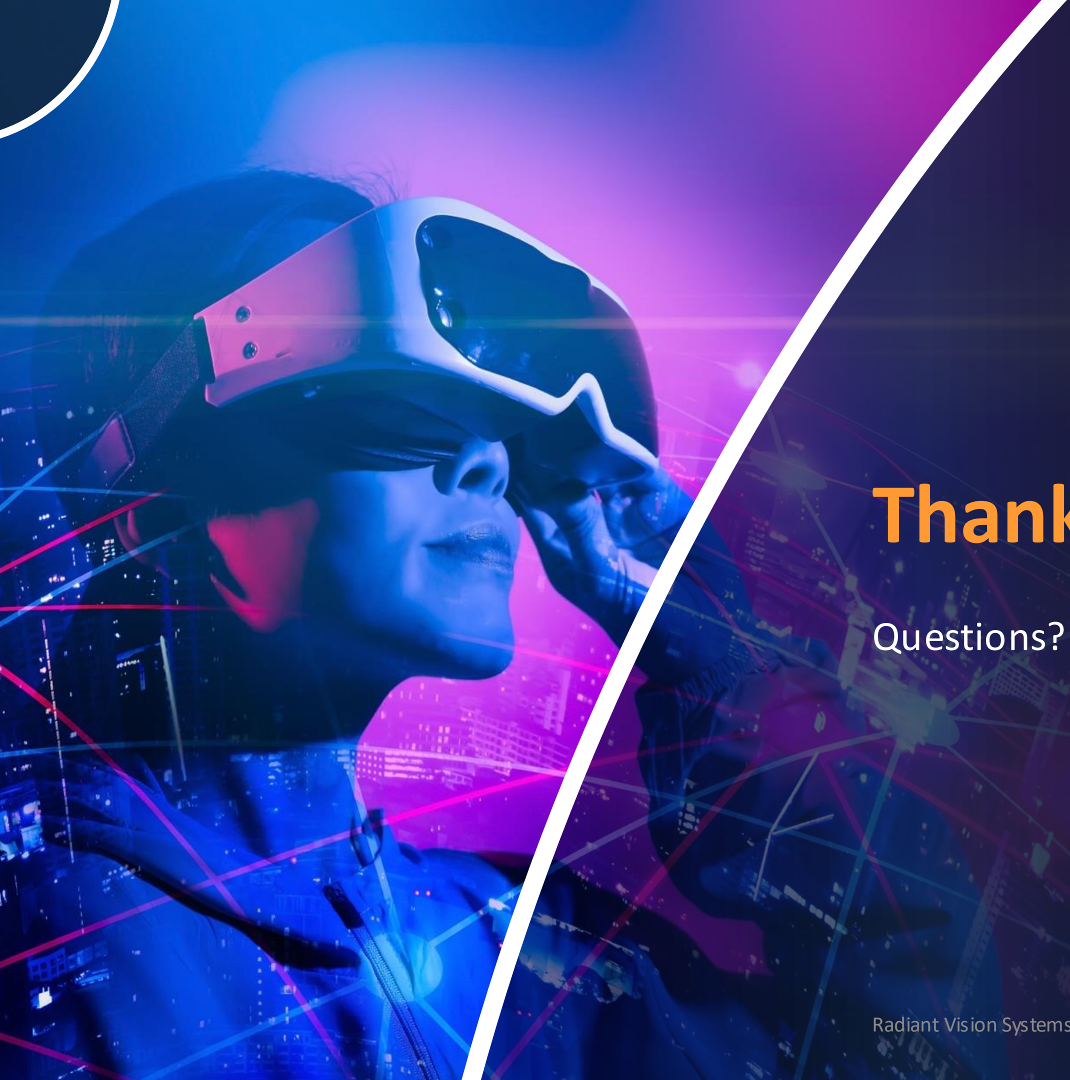
30+ years improving quality inspection and product yields for major global brands in consumer electronics, automotive, and aerospace industries

Service & Support

Worldwide application engineering staff for support when and where you need it

Customization

Collaborative approach to tailor solution and reporting for your needs



RADIANT VISION SYSTEMS

Thank you!

Questions? Contact Info@RadiantVS.com