DXOMARK AUTOMOTIVE IMAGE SENSOR EVALUATION REPORT

--Sample report--

Raw image sensor and lens evaluation

DXOMARK

corp.dxomark.com

Table of content

Measurement description

1. Flare

Standard compliance

The Flare (also called stray light) measurement is fully compliant with the standard draft IEEE/P2020 published in dec 2022.

Metrics details

$$\text{Flare Attenuation} = 10 \cdot \log_{10}\left(\frac{E_{source}}{E_{flare}}\right)$$

With E_{source} the illuminance received from the light source on the surface of the lens, and E_{flare} the equivalent illuminance received on the sensor:

$$E_{flare} = \pi \cdot \frac{x}{\text{sensitivity} \cdot t}$$

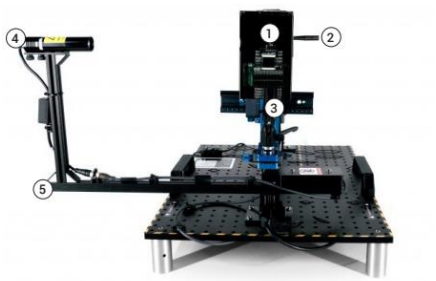
Where:

- t in s is the exposure time
- x in DN is the linearized gray level with dark level compensation
- sensitivity in DN/cd/m²/s is the measured flare sensitivity of the device.

Reference article: *E. Souksava, E. Baudin, C. Greco, HP Nguyen, L. Chanas, F. Guichard, Improvement of the flare evaluation for cameras and imaging applications when using near-infrared lighting, in Electronic Imaging, 2023, pp 319-1 - 319-5.*

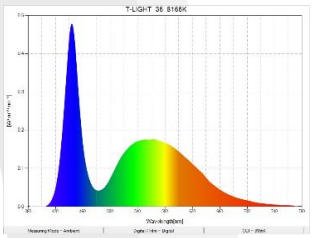
Measurement setup specifications

Flare bench:



1. Device under test
2. Indexed rotation stage to change from horizontal to vertical and diagonal axis,
3. 6 axis alignment stage equipped with 1/4 in. ISO 1222 compatible screw, designed to support any camera and demoboard,
4. Collimated light source with an apparent diameter of 0.95°
5. Motorized arm for rotating the light source between -160° and +160°

Spectrum of the LED light source:



Measurement description

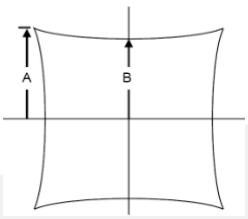
2. Distortion and lateral chromatic aberration

Standard compliance

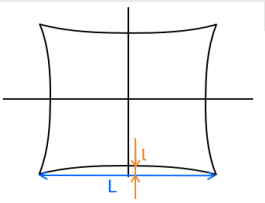
The lens distortion measurement is fully compliant with the standard ISO 17850, and the chromatic aberration measurement is fully compliant with the ISO 19084 standard.

Metrics details

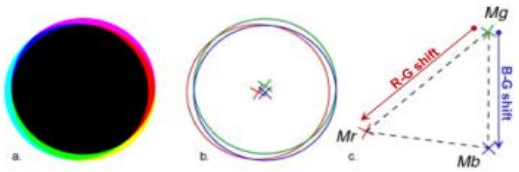
TV distortion: $100 \cdot \frac{A-B}{B}$, with A and B defined on the following figure:



Geometric distortion: $100 \cdot \frac{l}{L}$, with l and L defined on the following figure:

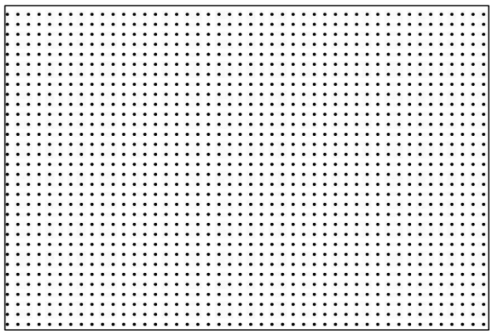


Chromatic aberrations: shift between R and G, and between B and G:



Definition of chromatic aberration profiles

DOT Chart:



Measurement setup specifications

Measurement description

3. Sensor Noise

Standard compliance

The noise measurement is fully compliant with the standard draft IEEE/P2020 published in dec 2022.

Metrics details

Temporal Noise and Fixed Pattern Noise (FPN), as well as dark signal and autocorrelation are computed over 30 frames.

Total noise is computed as the quadratic sum of Temporal Noise and FPN.

SNR is computed as the ratio between mean signal and noise standard variation.

SNR1 in DN or in charge units is the mean signal where SNR is equal to 1.

Signal saturation in DN or in charge units is the maximum signal level of the image sensor. Effective full-well in DN or in charge units is the mean signal value of the maximum of the temporal noise curve.

Dynamic range is computed as the gray level ratio between effective full well and SNR1.

Simplified dynamic range is computed as the gray level ratio between signal saturation and SNR1.

SG (system gain) in DN/e- is the ratio between temporal noise power and mean signal in photonic noise regime. SG is used to convert metrics in DN to charge units.

DSNU is the FPN in the dark.

Temporal-noise distribution is the histogram of the pixel standard-deviation over dark frames.

Noise autocorrelation maps are computed for completing P2020 metrics. Reference article: *J. Buzzi, F. Guichard, Noise in imaging chains: correlations and predictions, IEEE International Conference on Image Processing 2005, 2005.*

Measurement setup specifications

DXOMARK HDR noise target is a 120dB chart made of 30 neutral densities.

The chart is illuminated by a Nanlux Evoke 1200 or a Litepanel Gemini 1x1. Both are DC driven, dimmable, and have a stability over 95%.

Light level is measured using a gossen MAVOLUX 5032B. Temperature test was done using a thermal chamber Binder.

Measurement description

4. Dynamic Range

Standard compliance

The Dynamic Range measurement is fully compliant with the standard draft IEEE/P2020 published in dec 2022.

Metrics details

The CNR (Contrast to Noise Ratio) between a pair of ROIs A and B is defined as:

$$CNR(A,B) = \frac{s_A - s_B}{\sqrt{\sigma_A^2 + \sigma_B{}^2}}$$

Where:

- s_A and s_B are respectively the mean signals of the ROIs A and B
- σ_A and σ_B are respectively the standard deviations of the ROIs A and B

The TCG (Tonal Contrast Gain) is the transfer function between the scene contrast and the image contrast:

$$TCG(A,B) = \frac{\log_2\left(\frac{L_{A,Image}}{L_{B,Image}}\right)}{\log_2\left(\frac{L_{A,Scene}}{L_{B,Scene}}\right)}$$

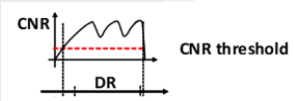
Where:

- $L_{A,Image}$ and $L_{B,Image}$ are the mean signals the ROIs A and B in the image
- $L_{A,Scene}$ and $L_{B,Scene}$ are the luminance values the ROIs A and B in the scene.

Dynamic Range is measured as CDR (Contrast Detection Ratio):

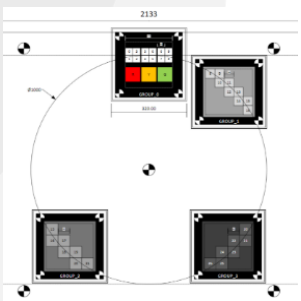
$$CDR_{dB} = 20\log_{10}\left(\frac{L_{max}\,[CNR > 1]}{L_{min}\,[CNR > 1]}\right)$$

Where $L_{max}\,[CNR > 1]$ and $L_{min}\,[CNR > 1]$ are respectively the maximum and the minimum luminance values that verify $CNR > 1$.



Measurement setup specifications

The dynamic range chart is an assembly of 4 light panels, delivering 25 patches that can reach at least 150 dB dynamic.



Measurement description

5. Resolution

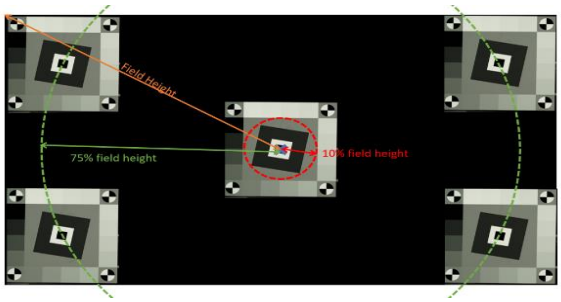
Standard compliance

The Resolution measurement is fully compliant with the standard draft IEEE/P2020 published in dec 2022.

Metrics details

The SFR is computed in a linearized image, thanks to the gray patches in the target. The SFR is then averaged over 30 images of the same target to improve the SNR.

Measurement setup specifications



SFR measurement compensate the target printer MTF. The target MTF is measured compared to a true cutter target, and it is then taken into account during the camera MTF measurement.

Measurement description

6. Flicker Mitigation

Standard compliance

The flicker mitigation measurement is fully compliant with the standard draft IEEE/P2020 published in dec 2022.

Metrics details

The Flicker Modulation Index (FMI) is defined as:

$$FMI = 100 \times \frac{s_{max} - s_{min}}{s_{max} + s_{min}}$$

Where s_{max} and s_{min} are respectively the maximum and minimum values of the measured signal for the considered time-range of the video.

The Flicker Detection Index (FDI) is defined as:

$$FDI = P\left[\frac{s(t) - s_{off}}{s_{off}} \geq \text{th}\right]$$

Where:

- P is the probability.
- $s(t)$ is the measured signal.
- s_{off} is the measured signal when the PMW signal is off.
- th is a minimum threshold above which the LED is considered visible.

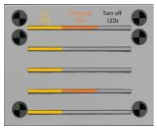
The Modulation Mitigation Probability (MMP) is defined as:

$$MMP = P\left[\overline{s_{ref}}(1-\delta) < s(t) < \overline{s_{ref}}(1+\delta)\right]$$

Where:

- P is the probability.
- $s(t)$ is the measured signal.
- $\overline{s_{ref}}$ is the expected signal.
- δ is a parameter defining the lower and upper bounds of the signal interval in which the device is considered as able to successfully mitigate the LED flickering.

Measurement setup specifications



The flickering is generated by the DXOMARK Led Universal Timer.

This device provides a light modulated by a square signal with frequency in range [50, 2000] Hz, adjustable duty cycle, phase and intensity.

Measurement description

7. Contrast Performance Indicators

Standard compliance

The Contrast Performance Indicators measurement is fully compliant with the standard draft IEEE/P2020 under revision.

Metrics details

The CTA (Contrast Transfer Accuracy) quantifies the ability of a camera to record accurately the contrast in the scene:$CTA = CTA = P[C_{in}.\cdot (1-\delta_{\_}) \leq C_{meas} \leq C_{in}.\cdot (1+\delta_{+})]$

Where:

- C_{in} and C_{meas} are respectively the input contrast in the scene and the measured contrast in the image.
- $\delta_{\_}$ and δ_{+} are the parameters defining the lower and upper bounds of the confidence interval in which the device is considered as able to reproduce accurately the input contrast.

The CSNR (Contrast Signal-to-Noise Ratio) quantifies the ability of a camera to distinguish two objects:

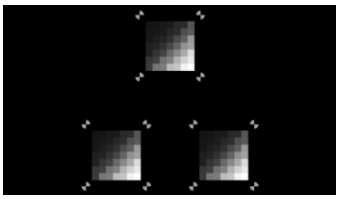
$$CSNR = \frac{\bar{C}}{\sigma_C}$$

Where:

- $\bar{C}$ is the mean of the contrast between two ROIs.
- σ_C is the standard deviation of the contrast between two ROIs.

Measurement setup specifications

The CPI chart is an assembly of 3 light panels, with a 7x7 patches matrix on each chart patches. The whole setup can reach at least 140dB dynamic.



Measurement description

8. Vignetting/Color Lens Shading

Standard compliance

The Vignetting/Color Lens Shading measurement is fully compliant with the standard ISO 17957.

Metrics details

Vignetting Profile: gray level value divided by the gray level value at the vignetting center, for each radial field position and each color channel.

Color vignetting: each channel vignetting divided by green (average of G1 and G2 channels) vignetting.

Measurement setup specifications

Integrating sphere RO-LIS-3CR80 with 5100K.

Chip total size	---
Pixel size	---
Resolution	---
Full frame rate	---
Lens design	---
Lens aperture	---
Lens FOV (diagonal)	---

Testing Conditions

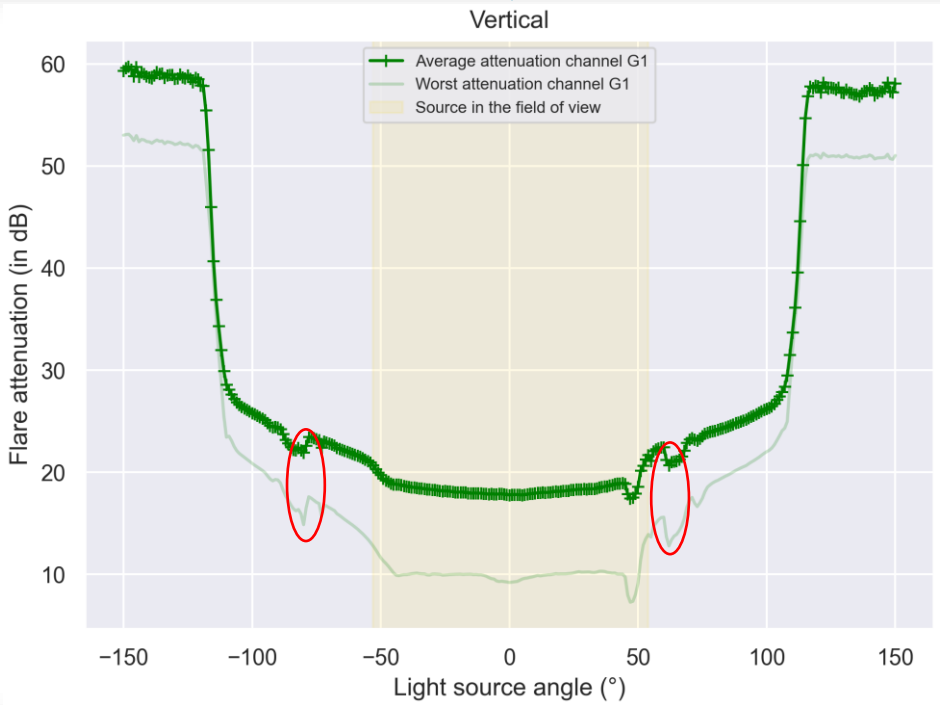
Mode sensor	---
Frame Grabber	---
SW version	---
Output	---

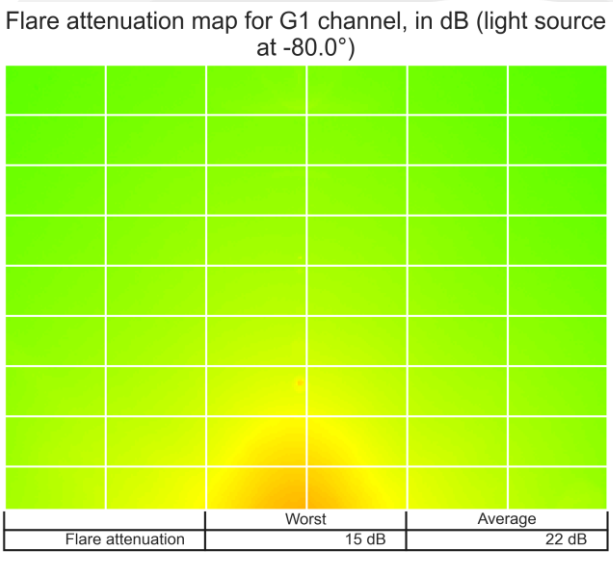
Framerate	---
image resolution	---
Exposure time (ms)	---
gain	---

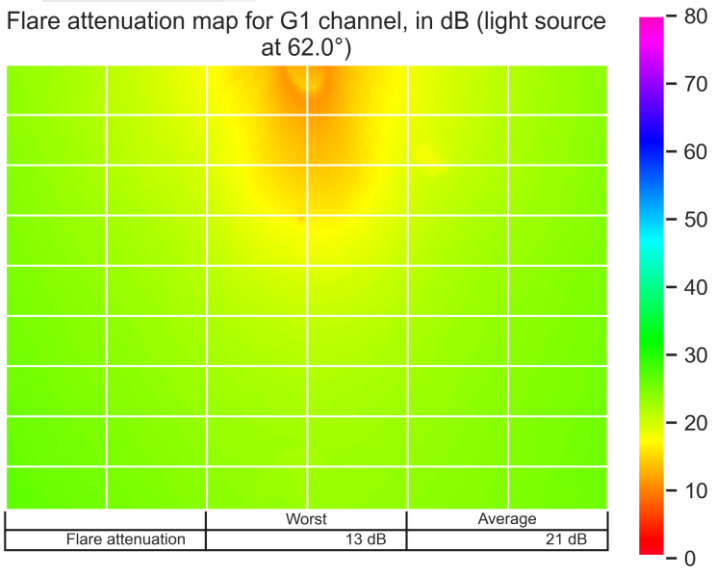
Overall Performance

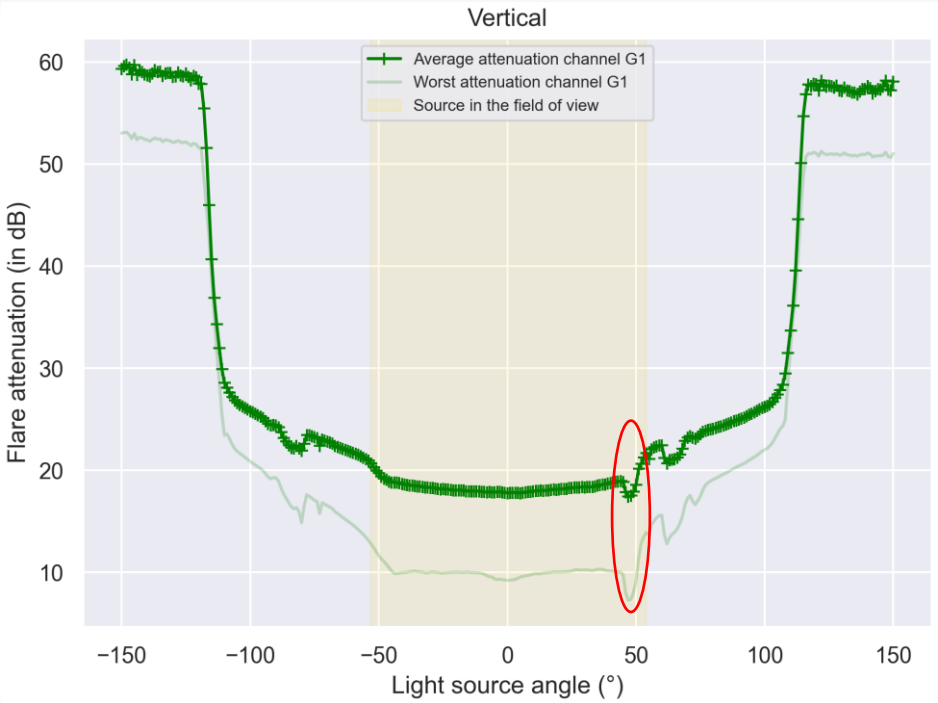
DR (SNR1 40°C)	110 dB
Saturation (D65)	17000 cd/m²
Dark (40°C)	26e-
Full Well Capacity	847860e-
Dark flatness	3.1

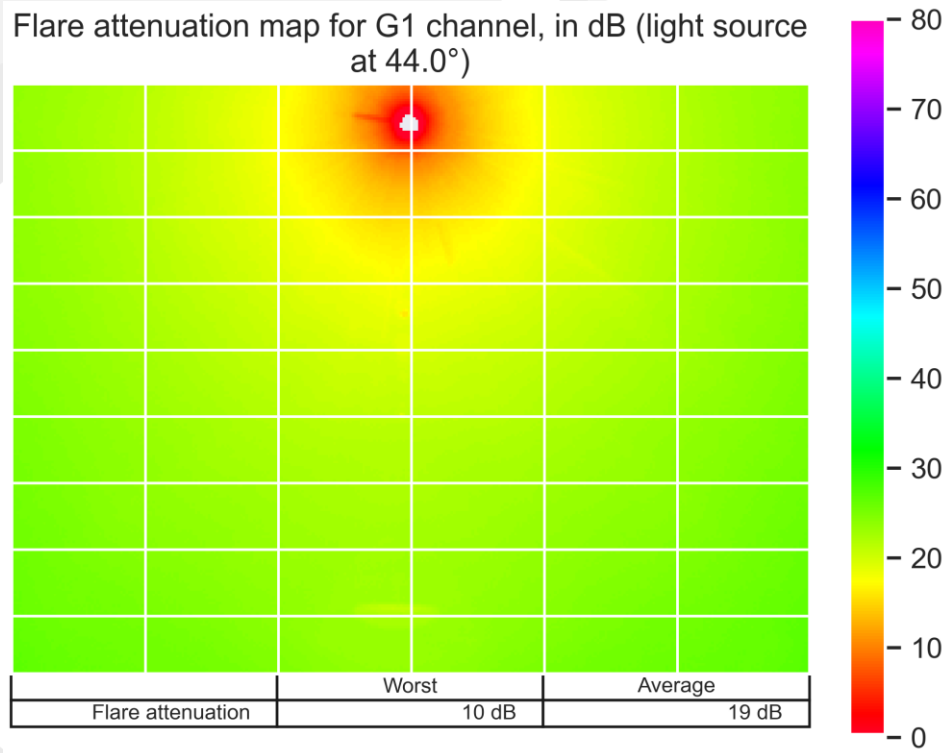
DR P2020	99 dB
Noise Autocorrelation	True Raw

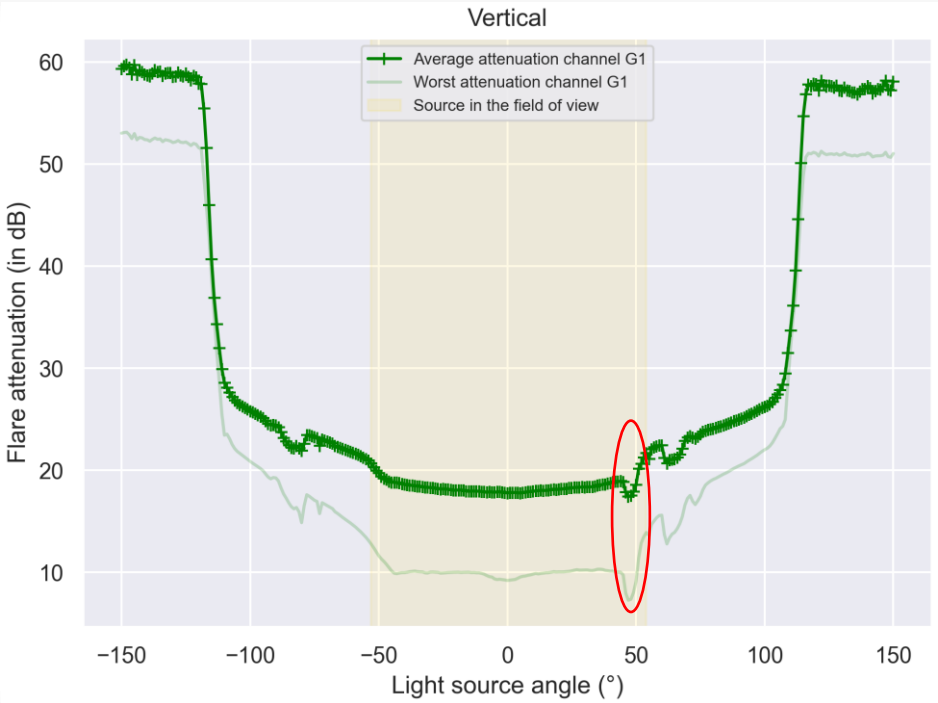


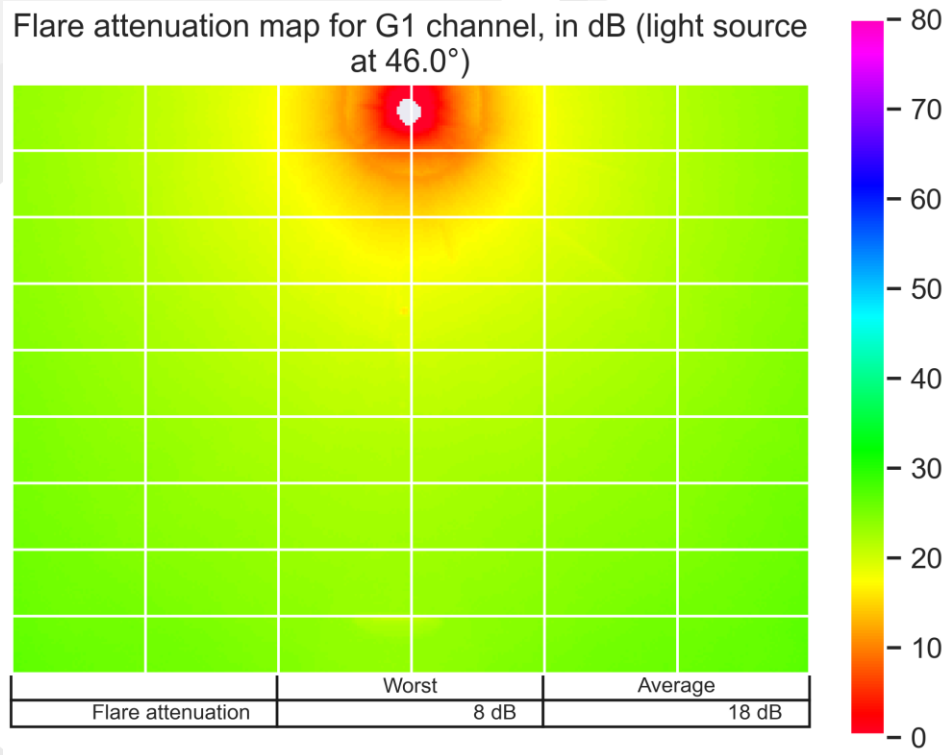


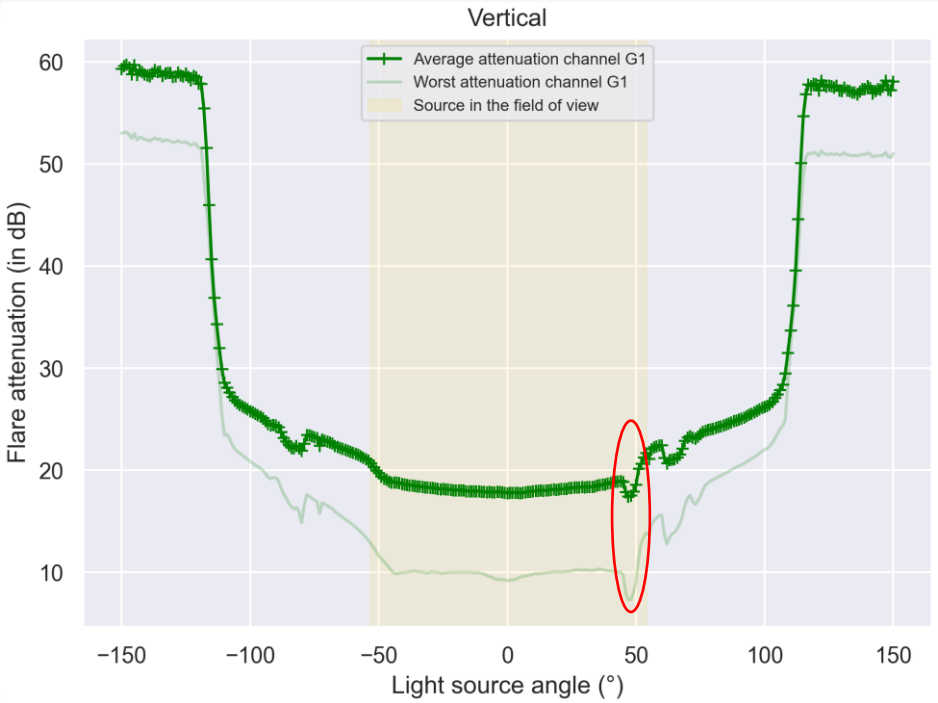


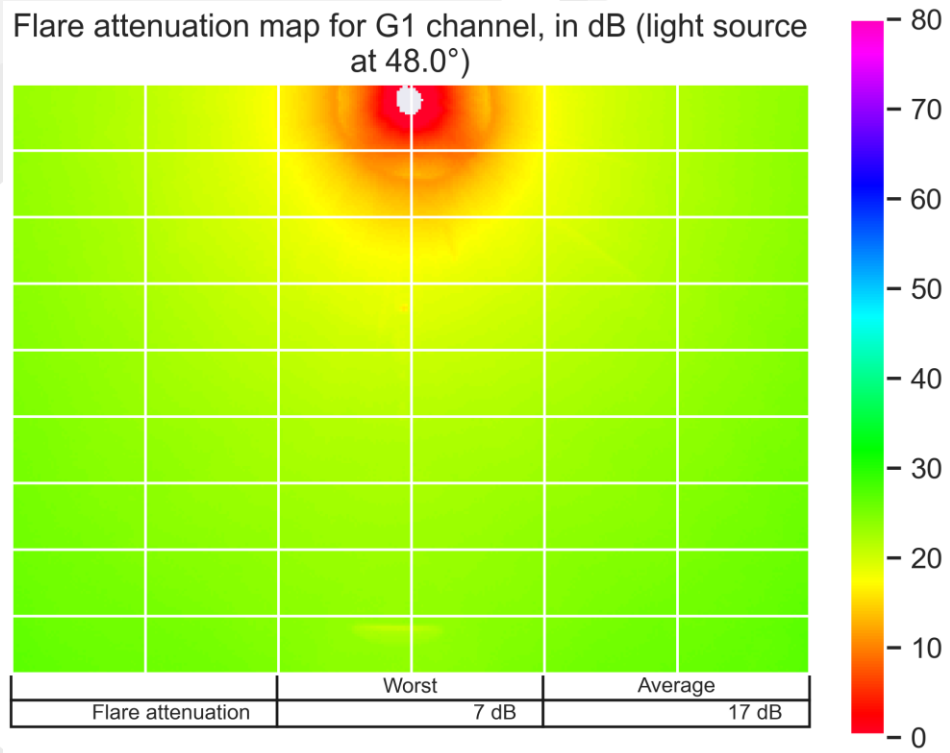


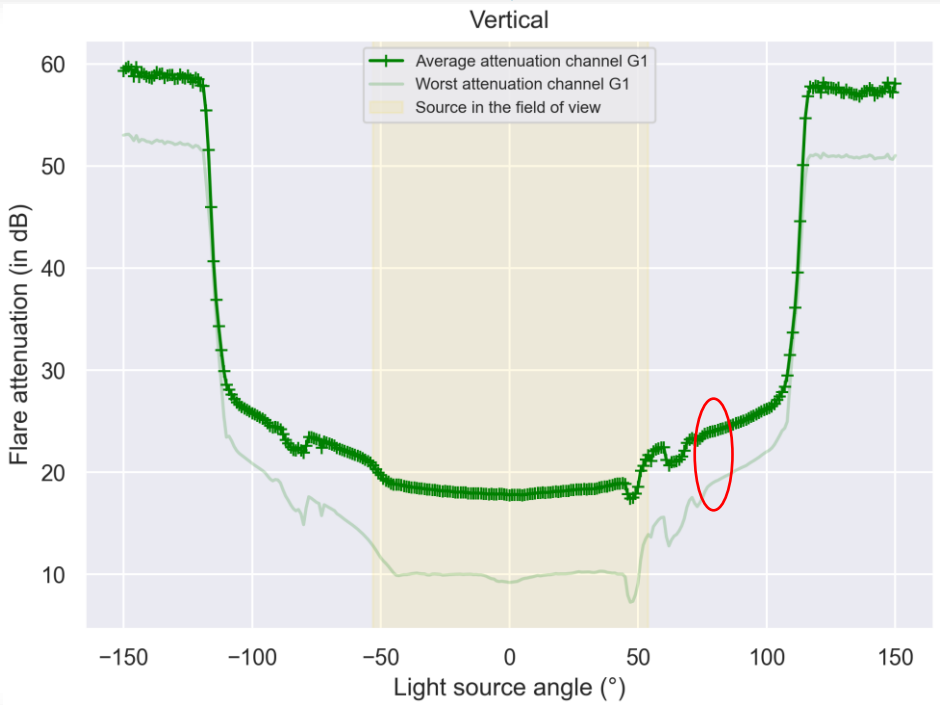


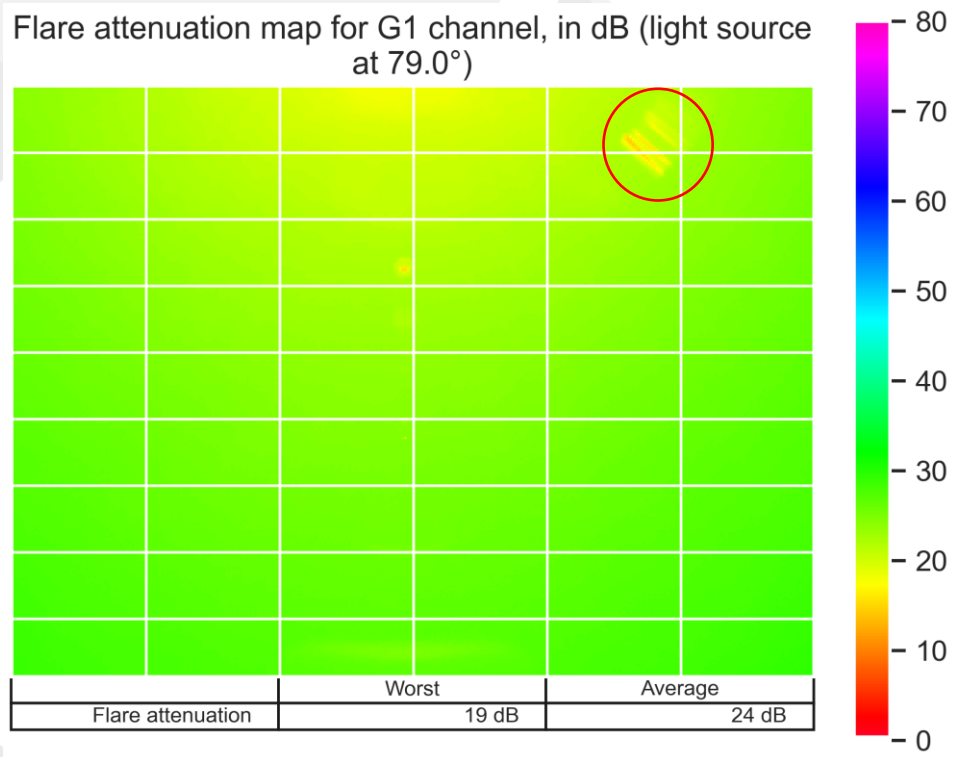


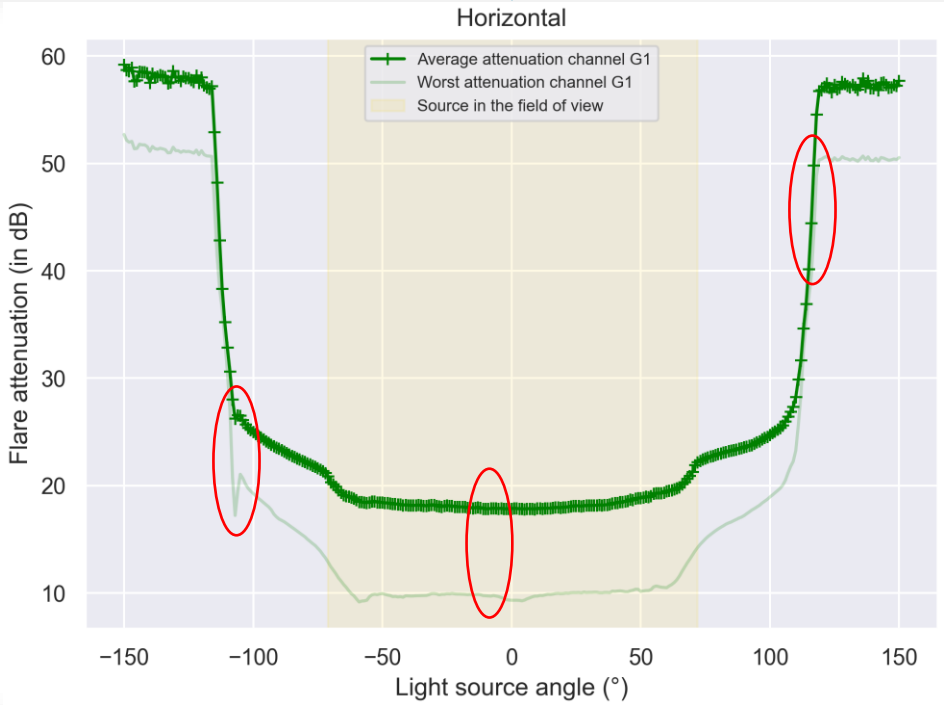


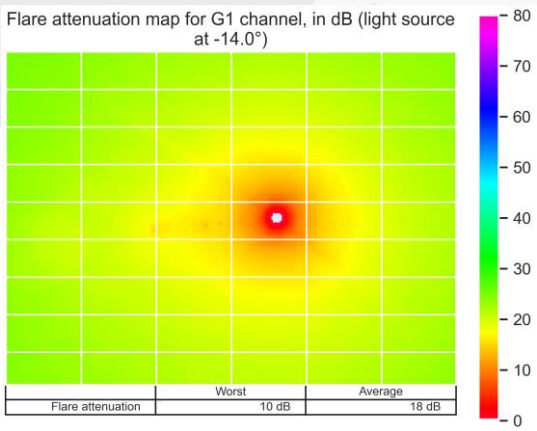


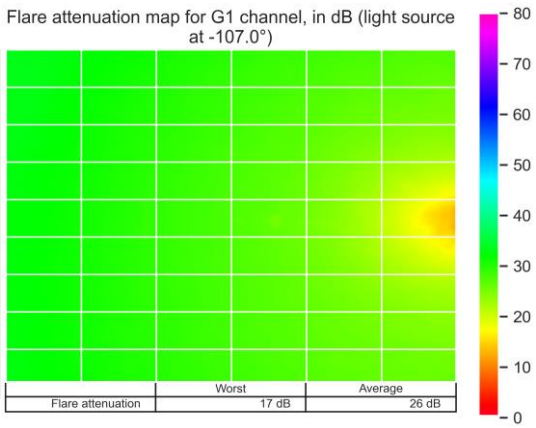


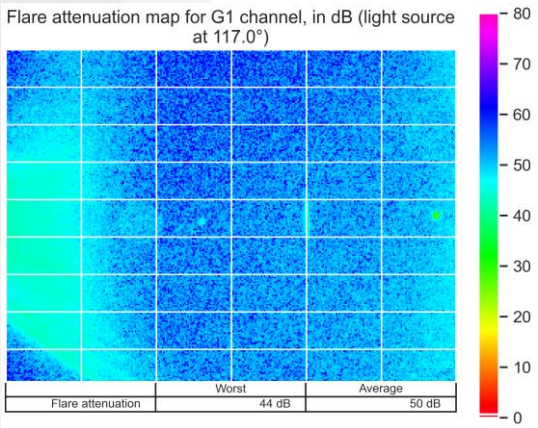


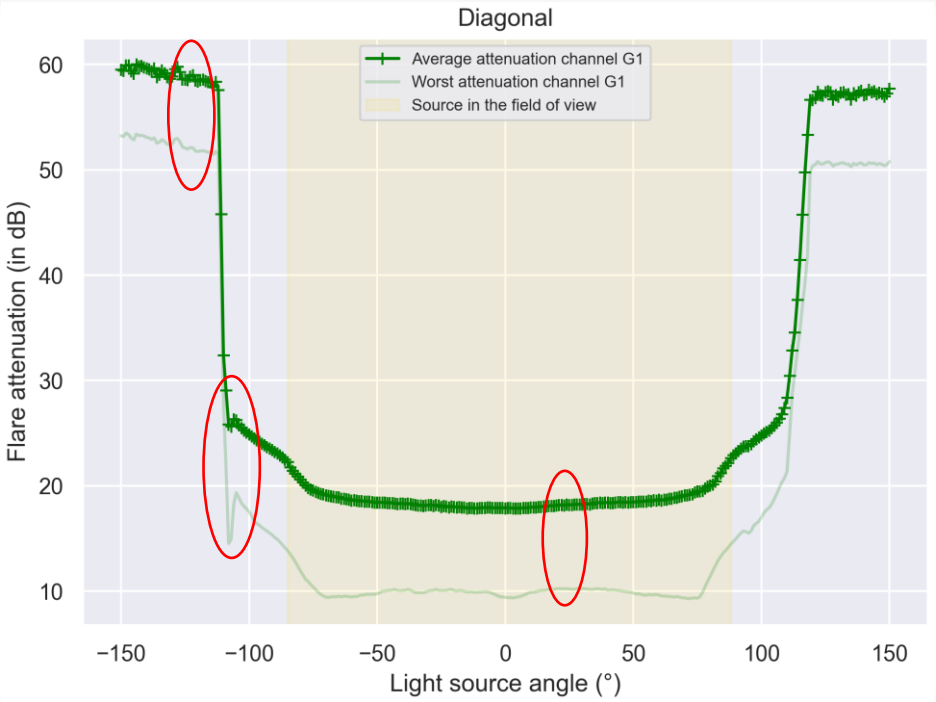


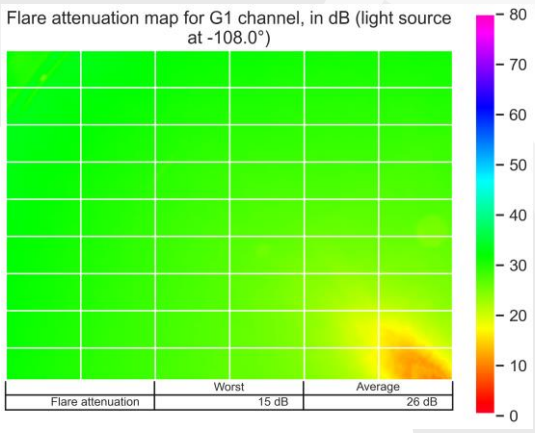


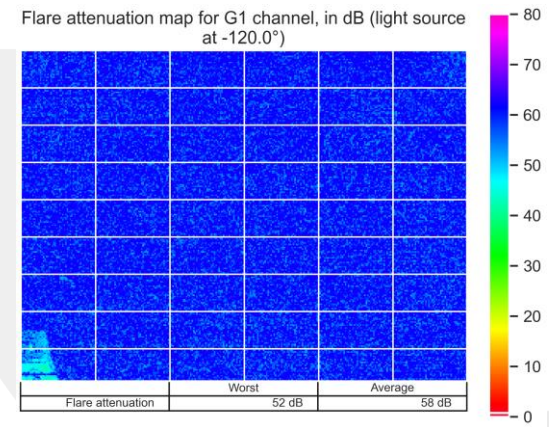


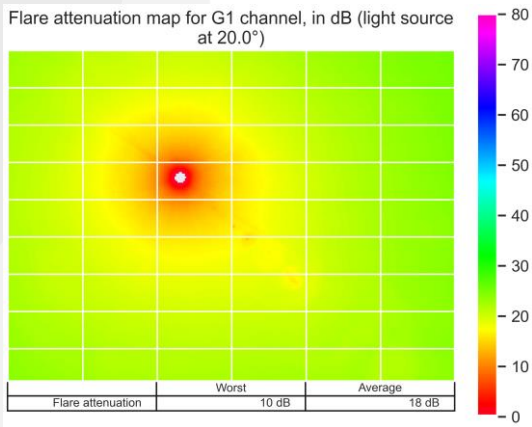


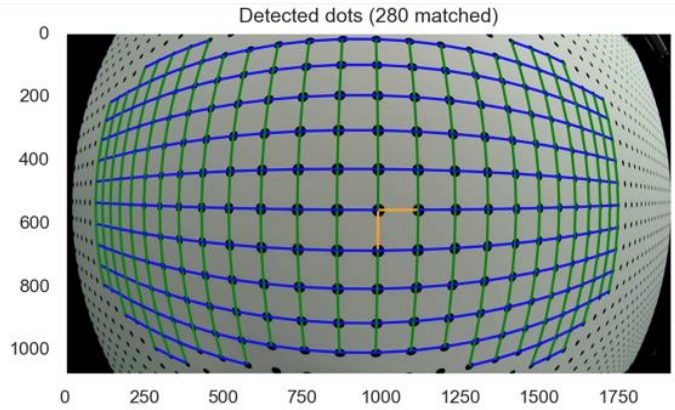


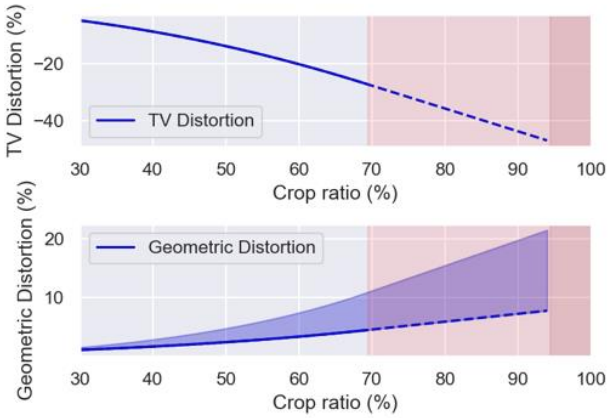


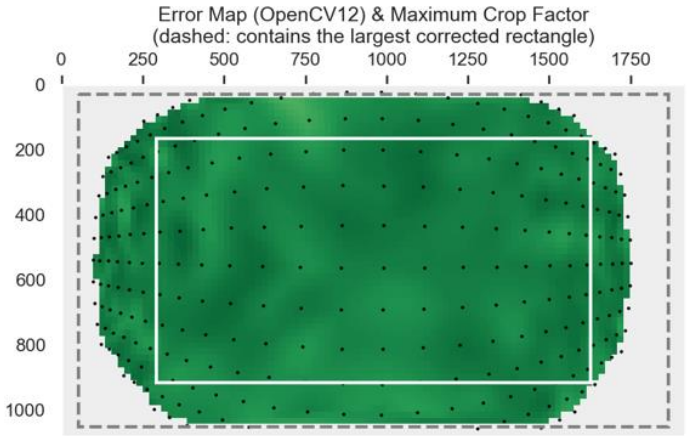


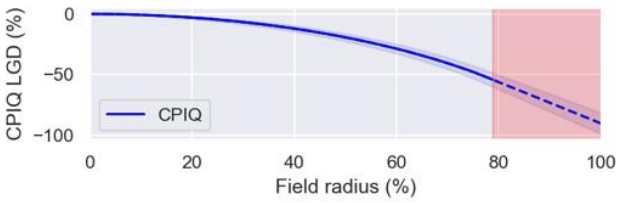


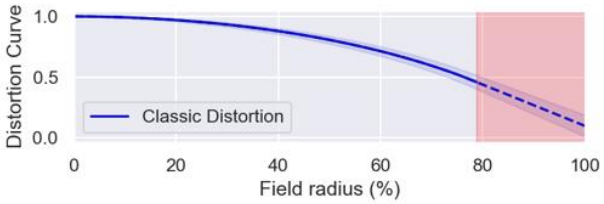


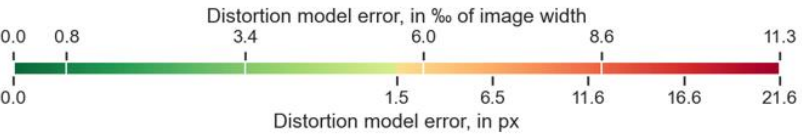






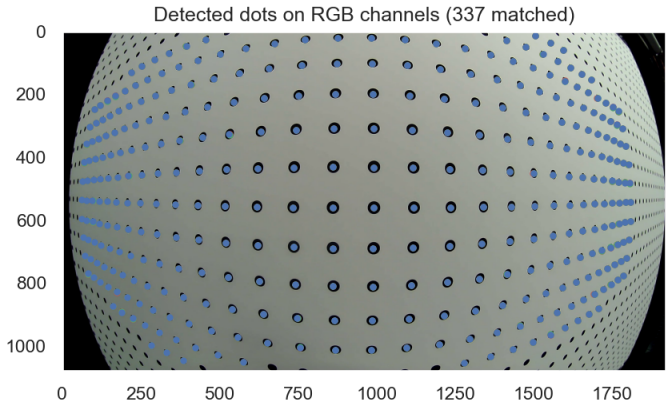


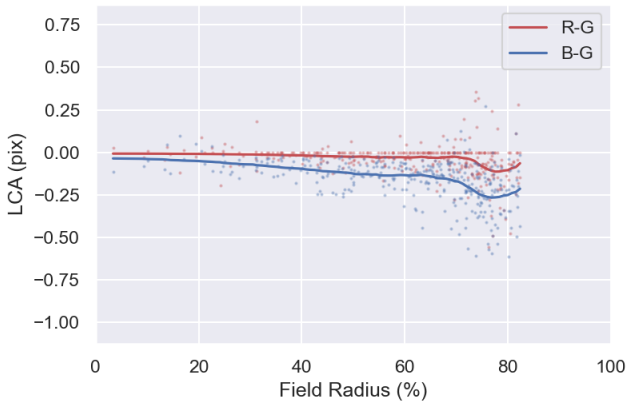


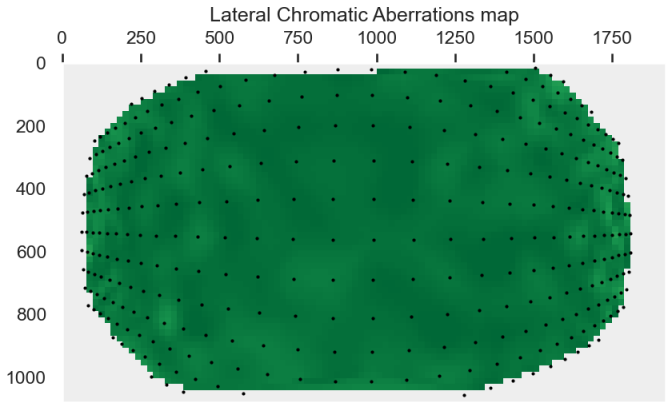


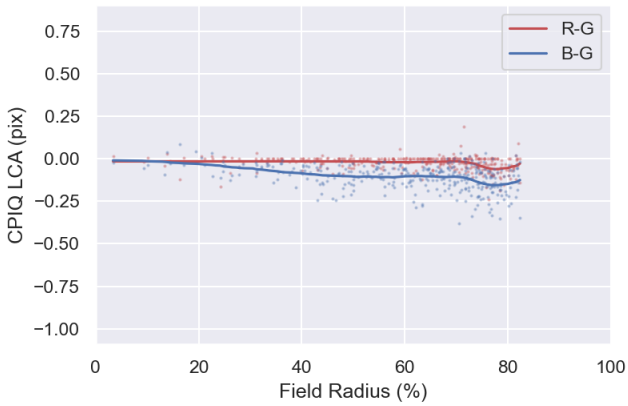
	Results	Results (extrapolated)
TV Distortion	-46.83%	-27.27%
Geometric Distortion (avg)	+7.81%	+4.55%
Geometric Distortion (Max)	+21.48%	+11.00%
CPIQ LGD (Max)	-98.73%	-59.81%
CPIQ LGD (JND)	-15.17%	-15.17%

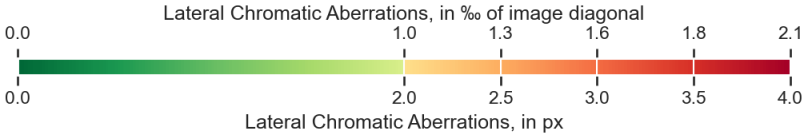
Good fitting of the distortion model (small reprojection error)





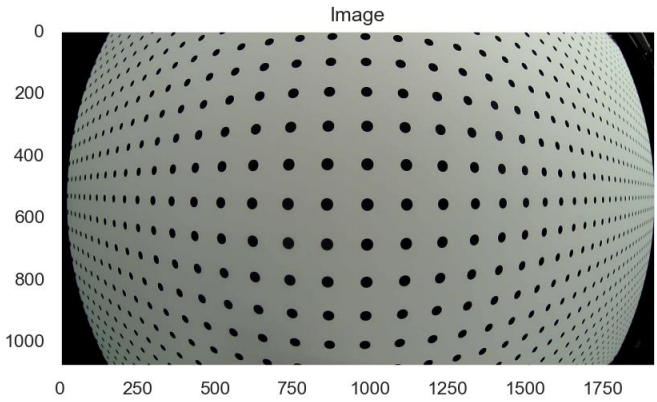


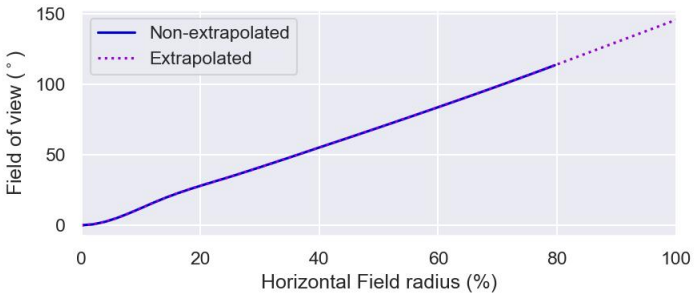


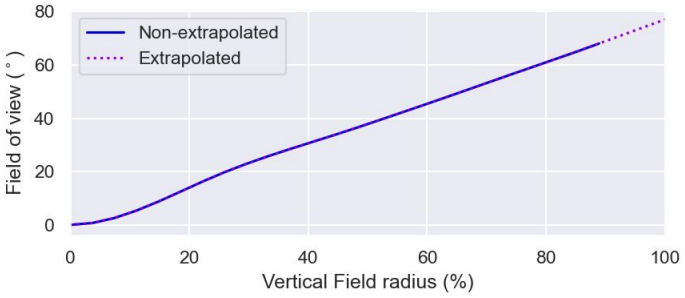


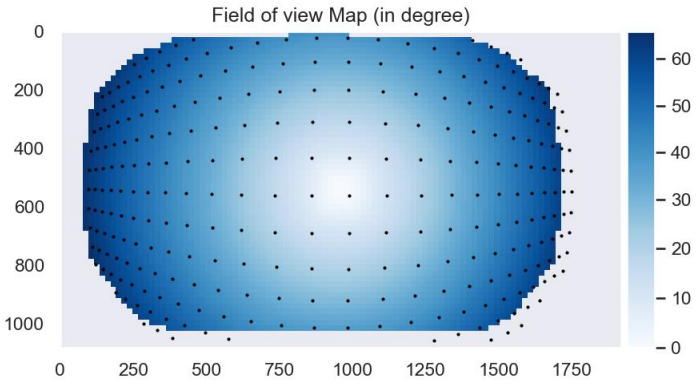
CPIQ Max LCA (Pixels)	-0.15 px
CPIQ Max LCA (Percent)	-0.01 %
CPIQ Max LCA (JND)	0.00

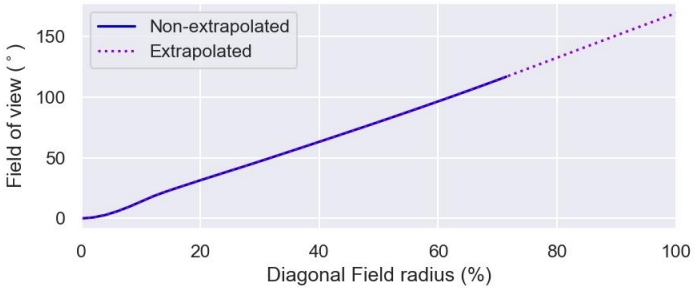
Chromatic Aberrations are negligible (less than 1 pixel in the full measurement area)











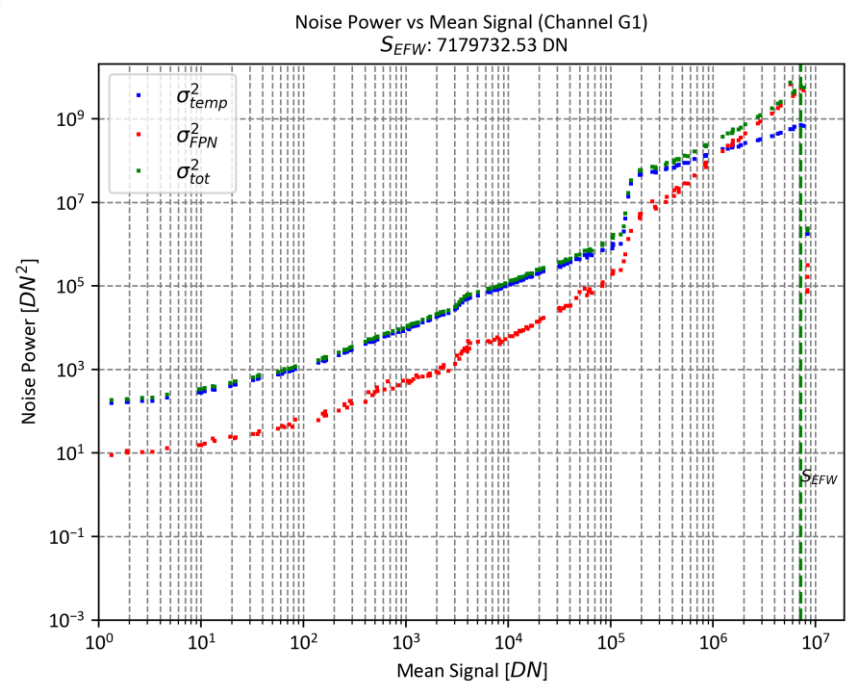
	H. FoV	V. FoV	D. FoV
Non-extrapolated	113.41 °	67.98 °	116.96 °
Extrapolated	145.64 °	77.01 °	169.55 °
	Tilt	Pan	
Orthofrontality	2.5 °	0.68 °	

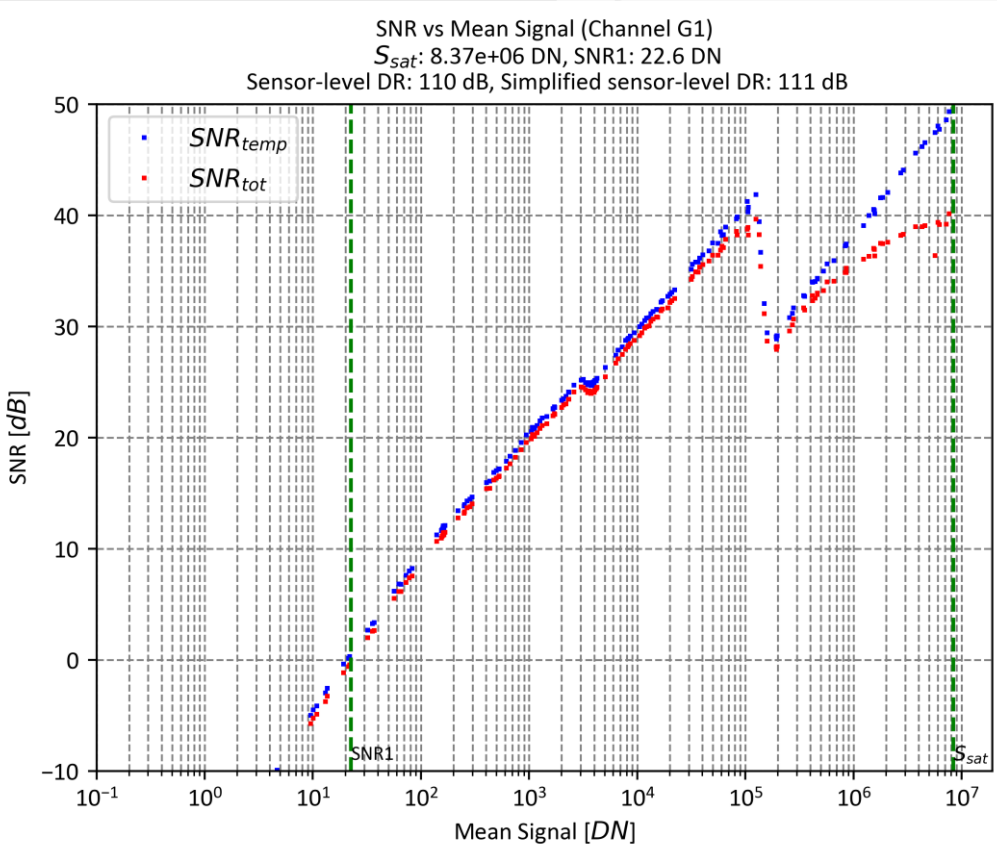
	Horizontal	Vertical	Diagonal
Field of View	145°	77°	170°

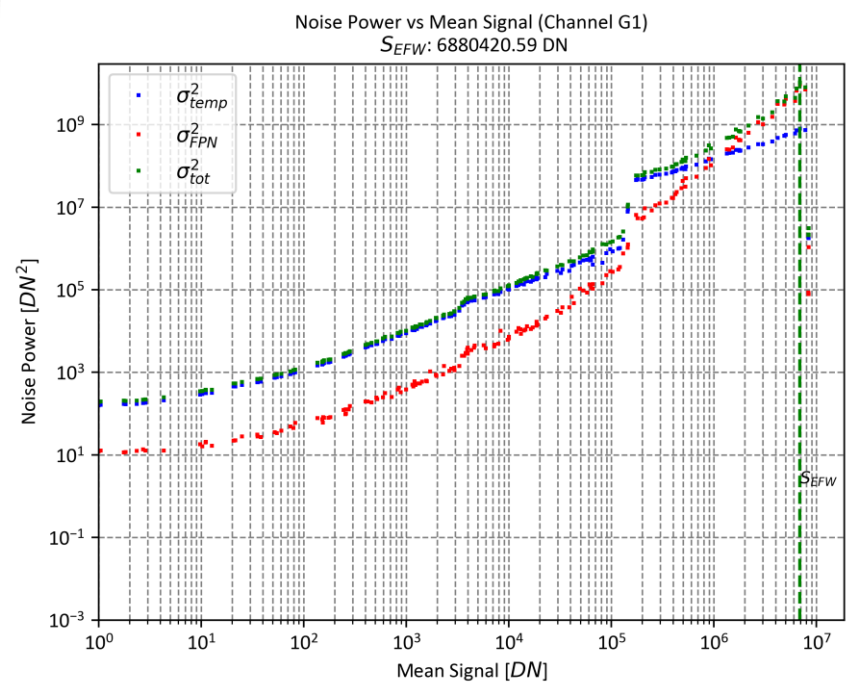
Fisheye lens: The field of view is linear with the field radius

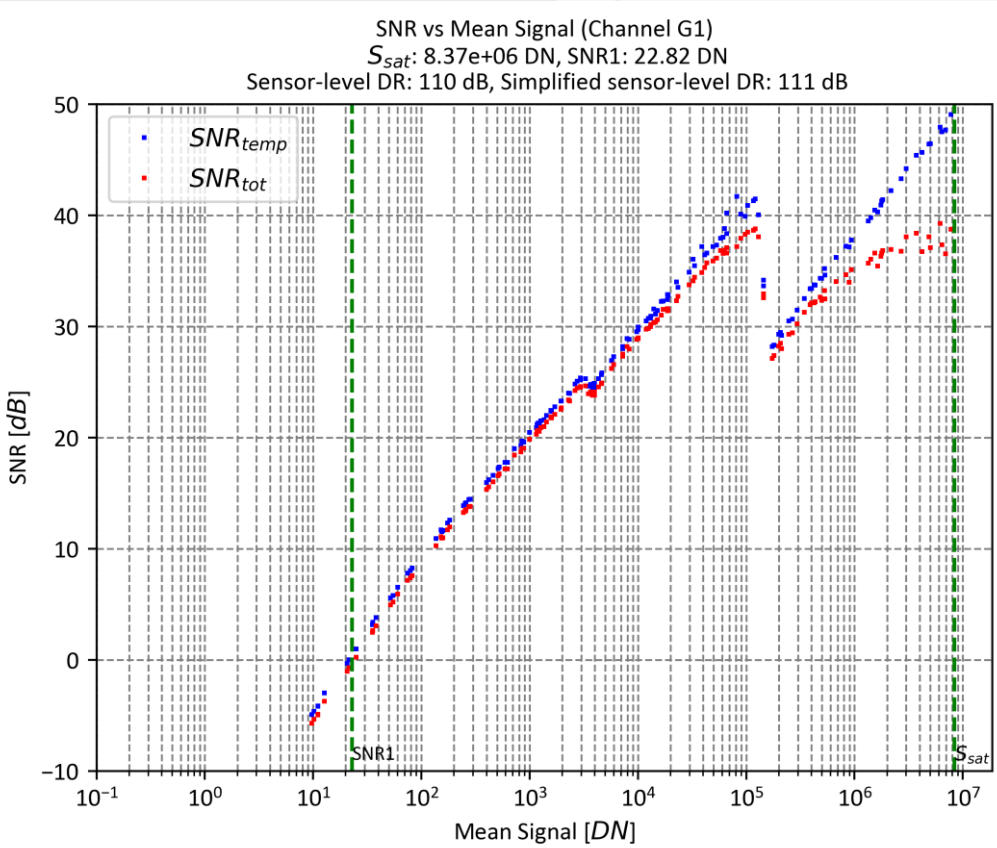
- **Measurement conditions**
  - 6 exposures from 100 to 70 000 cd/m2
  - 30 images per exposure
  - Illuminant D65
  - 5 temperatures from 20°C to 115°C (sensor temperature)

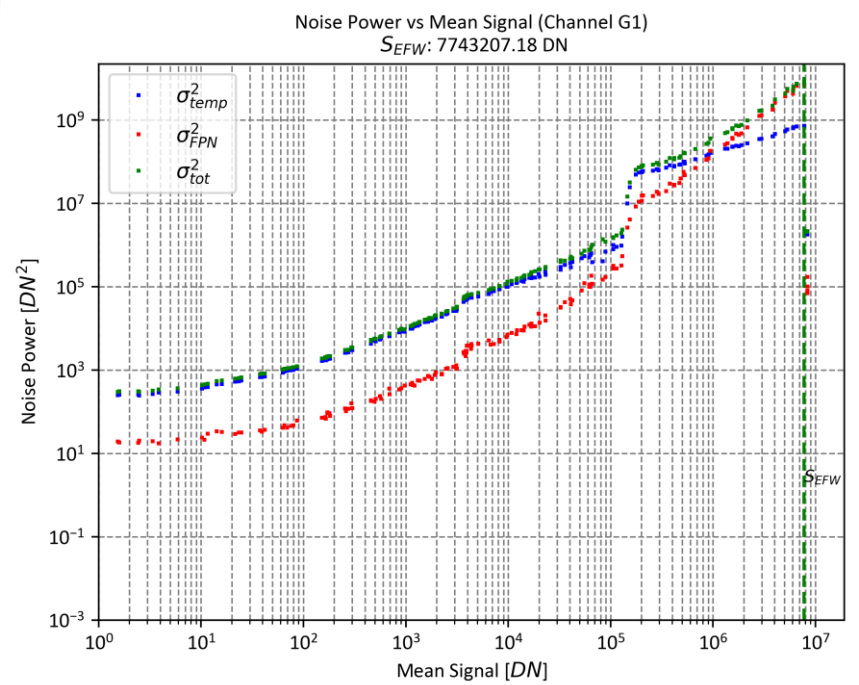
- **Results:**
  - Sensor level dynamic range: 110dB for sensor temperature 40°C
  - With the current lens, the sensor saturates for objects with luminance equal or higher than 17 000 cd/m²
  - The sensor has 3 exposures. The system gain of the first two exposures is the same
  - Autocorrelation graphs show that the raw files are not processed
  - No significant row and column noise
  - SNR is 15dB lower at 115°C sensor temperature, compared with 40°C
  - The dark signal has strong non-uniformity at 115°C

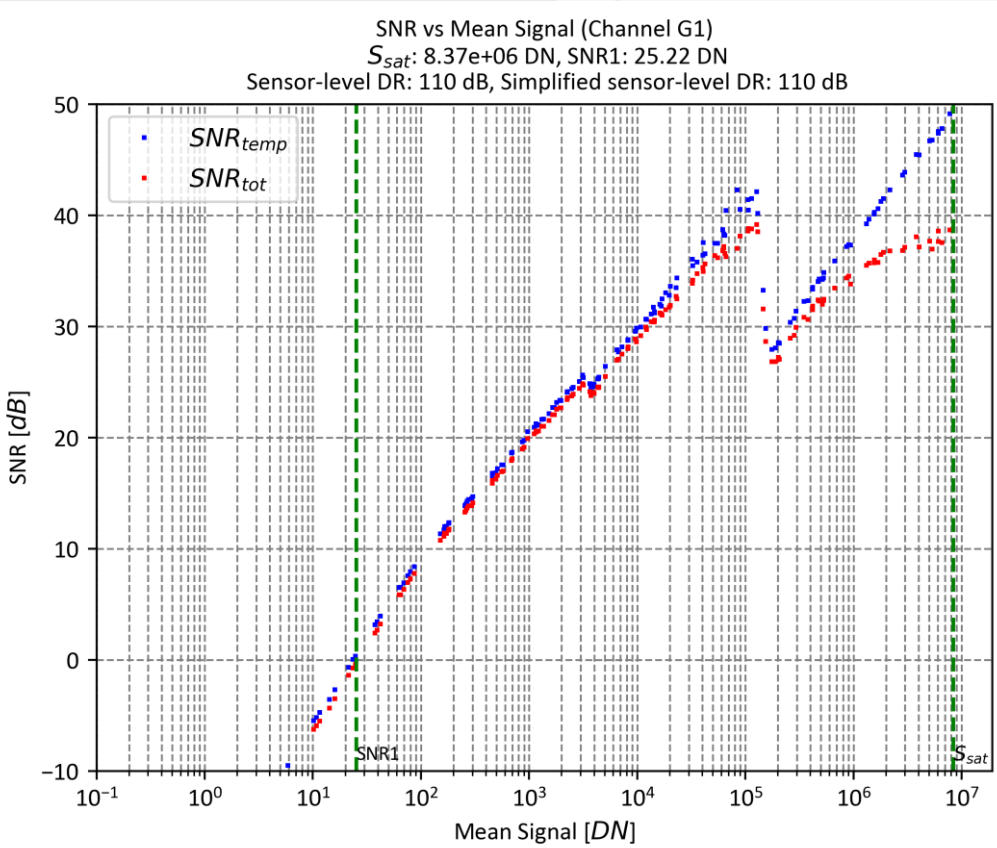


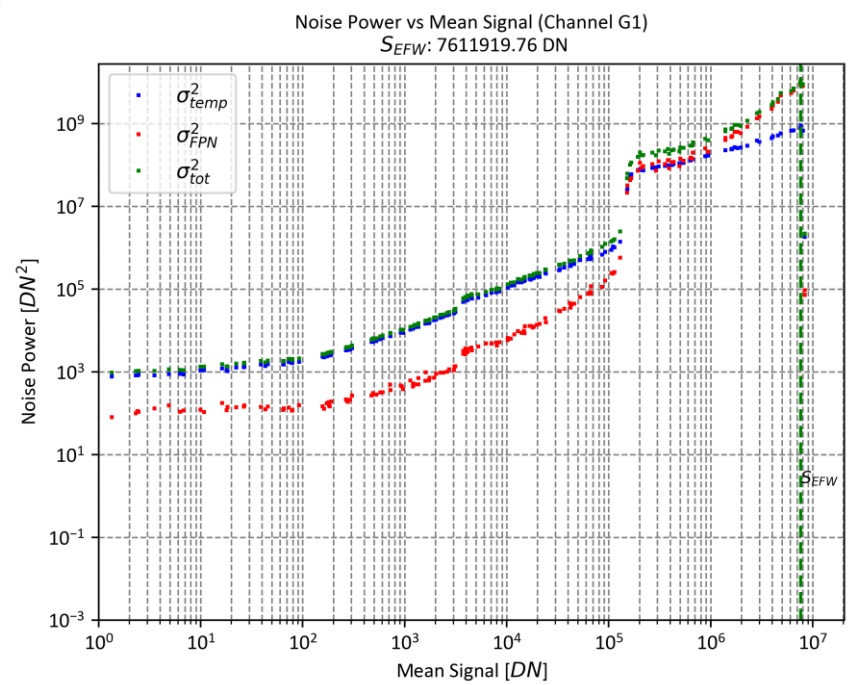


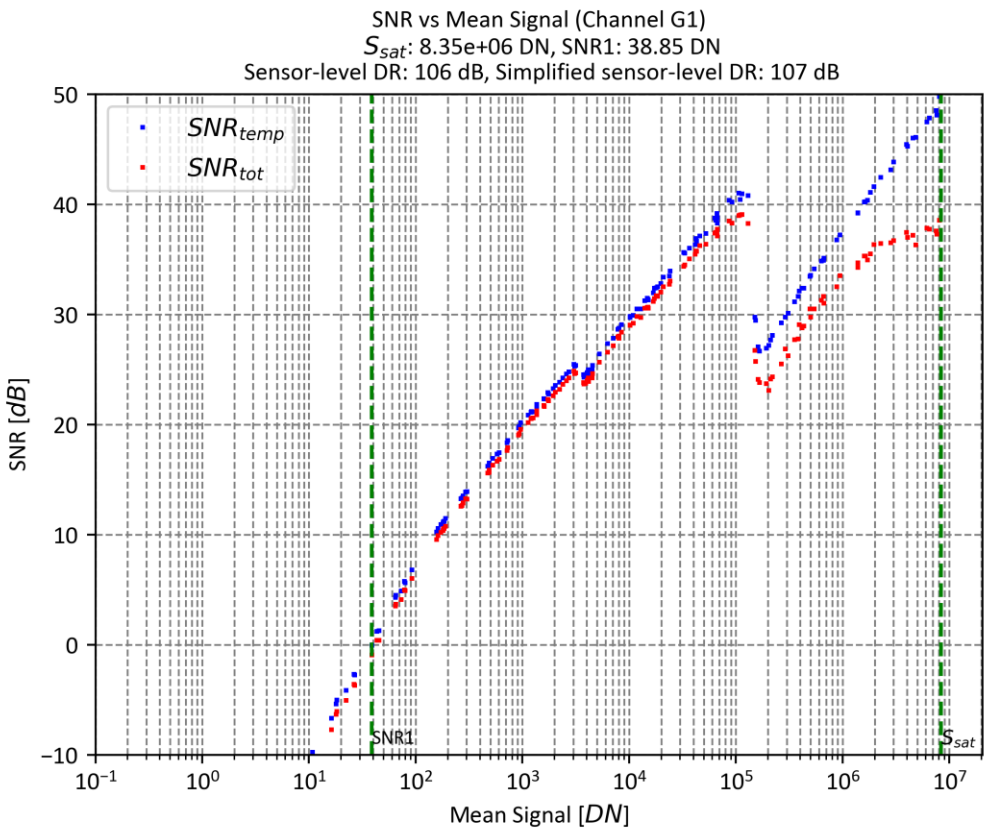


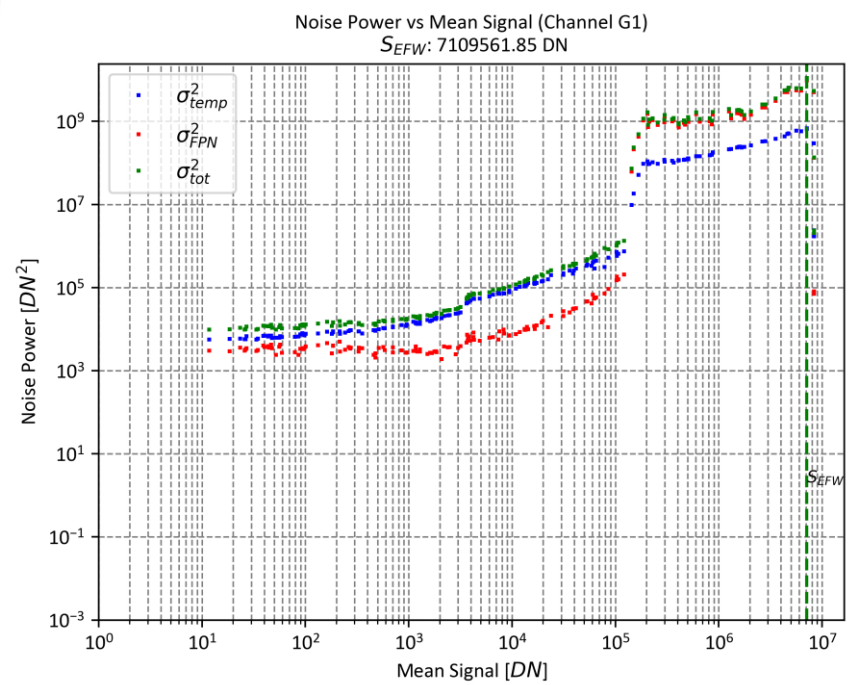


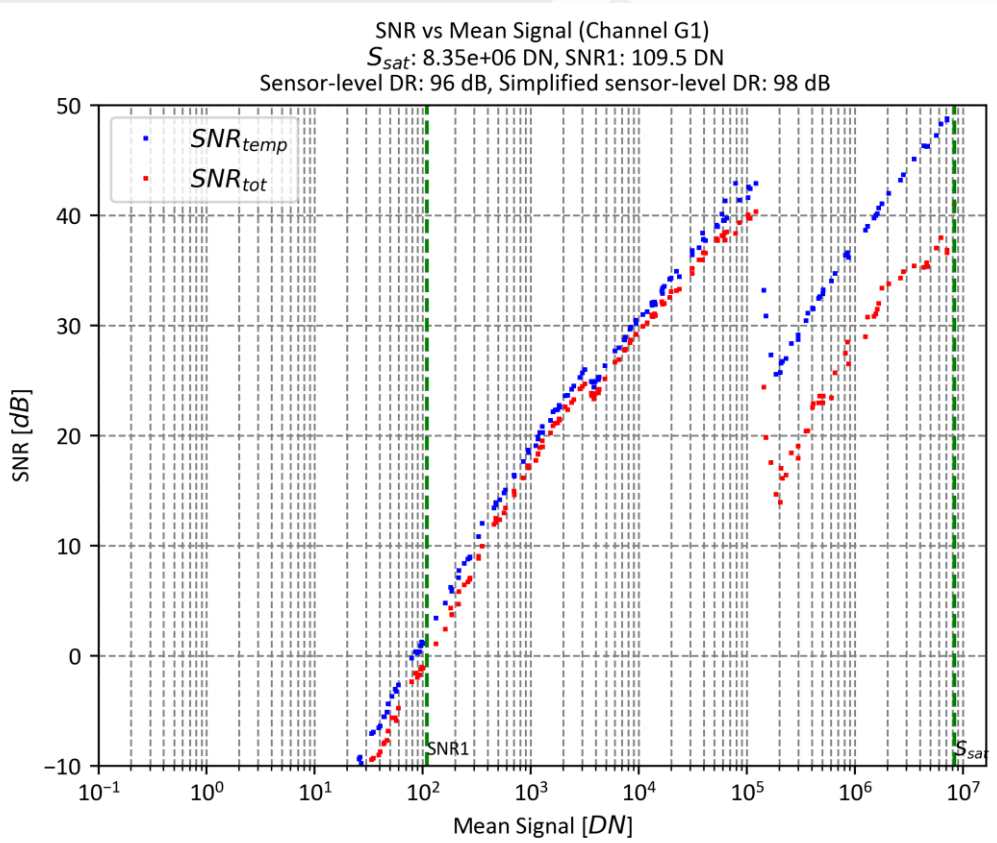






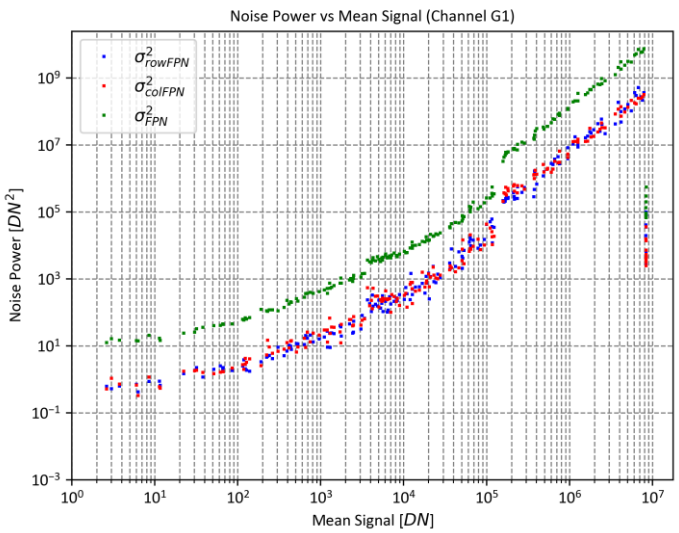


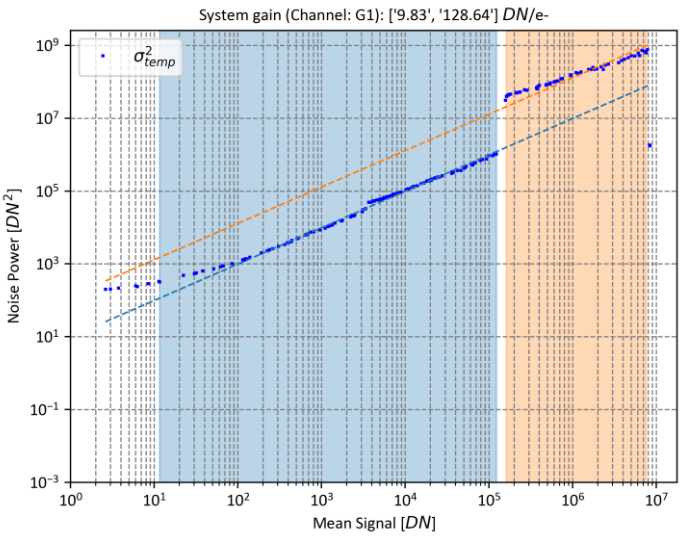


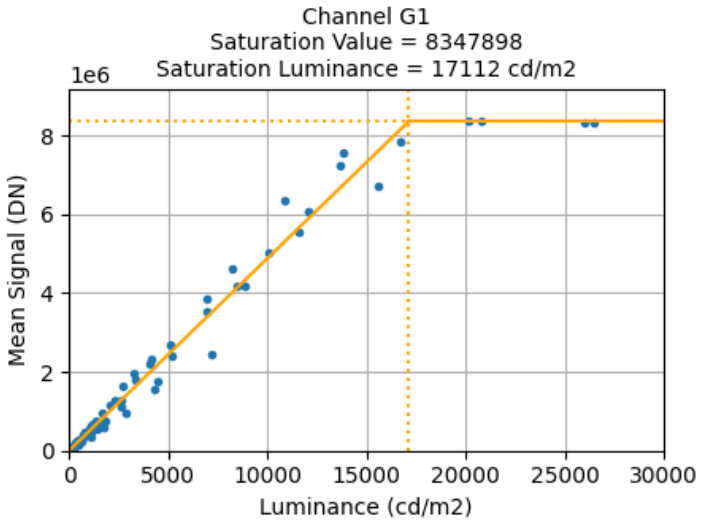


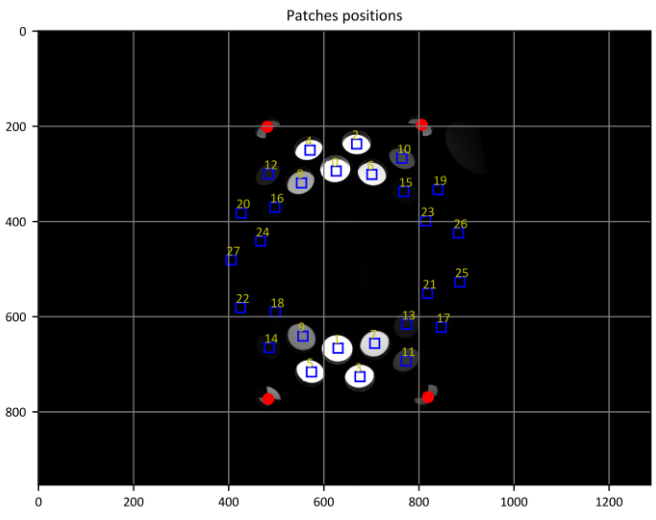
KPIs/Thermal Chamber Temperature (°C)	-8	20	40	60	80
Sensor junction temperature (°C)	23	40	66	87	115
Lower System Gain [DN/e-]	9.94	9.96	9.89	10.28	9.47
KPIs in digital number					
Dark signal [DN]	239.1	239.1	239.9	240.2	180.8
SNR1 [DN]	22.6	22.8	25.2	38.8	109.5
Signal saturation [kDN]	8375	8366	8366	8347	8347
Effective full-well [kDN]	7180	6880	7743	7612	7110
KPIs in charge units					
SNR1 [e-]	2.27	2.29	2.55	3.78	11.56
Signal saturation [ke-]	843	840	846	812	881
Effective full-well [ke-]	723	691	783	741	751
KPIs in dB					
Sensor-level dynamic range [dB]	110.0	109.6	109.8	105.8	96.2
Simplified sensor-level dynamic range [dB]	111.4	111.3	110.4	106.6	97.6

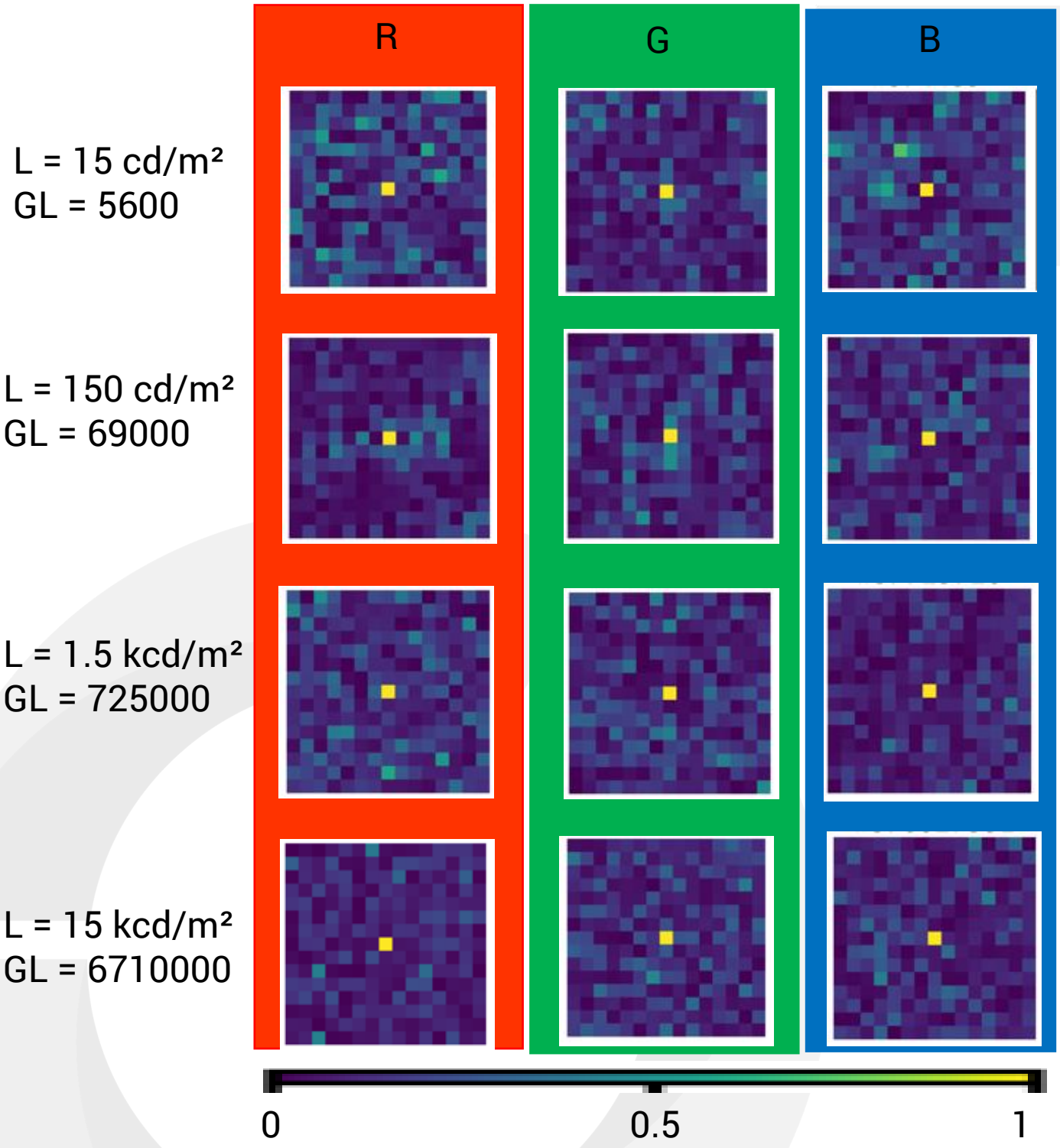
Row and Column fixed pattern noise



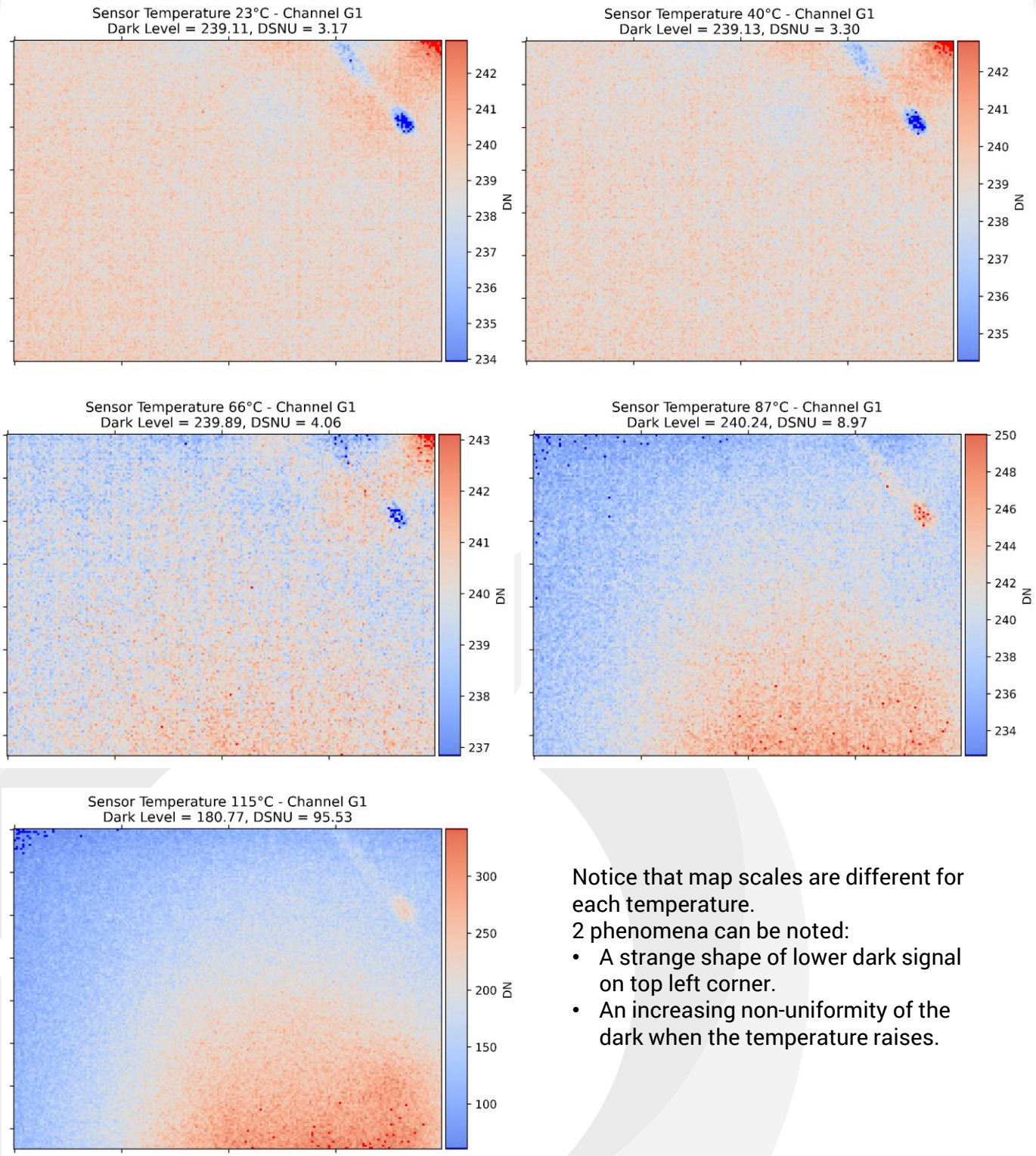






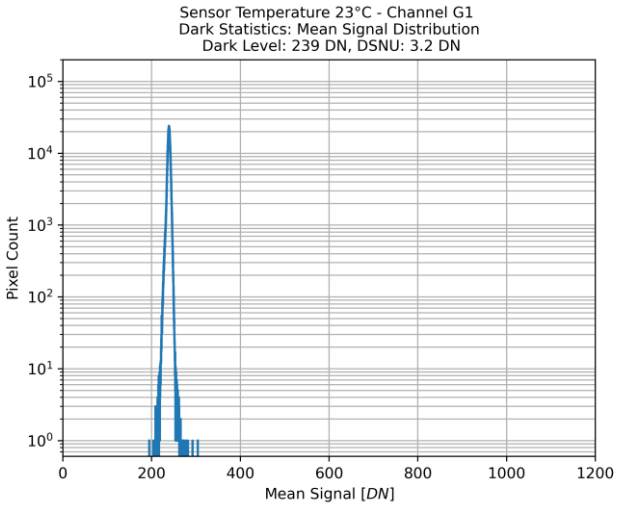


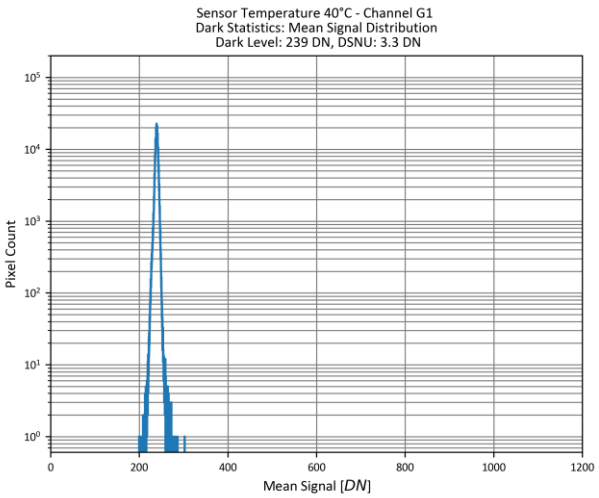
The autocorrelation is a measure of resemblance of a signal and a version shifted of itself. High value means a high correlation.

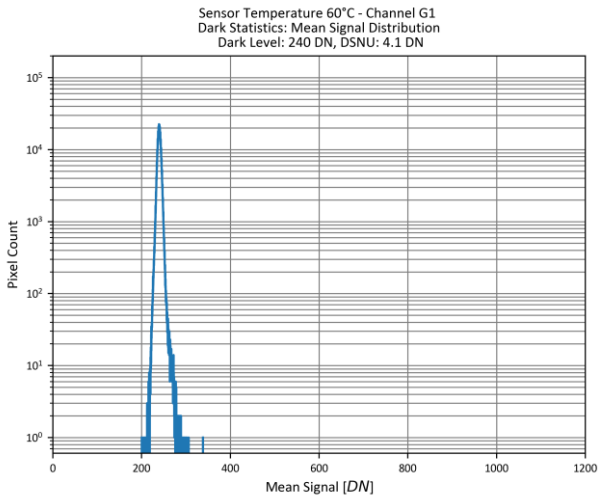


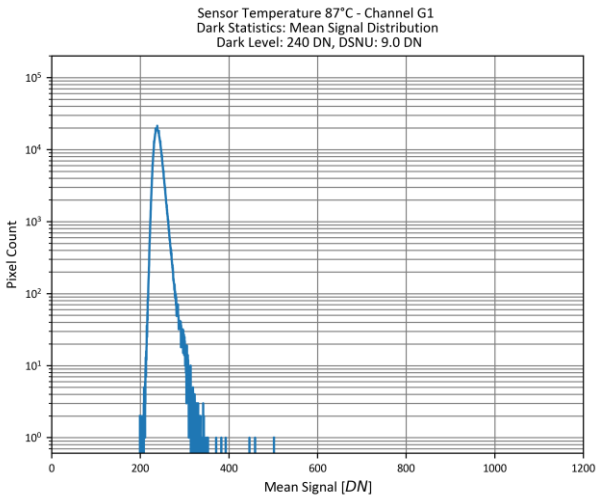
Notice that map scales are different for each temperature.
2 phenomena can be noted:

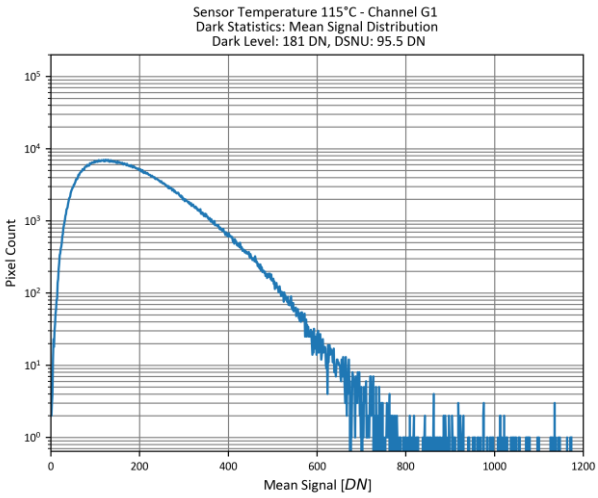
- A strange shape of lower dark signal on top left corner.
- An increasing non-uniformity of the dark when the temperature raises.



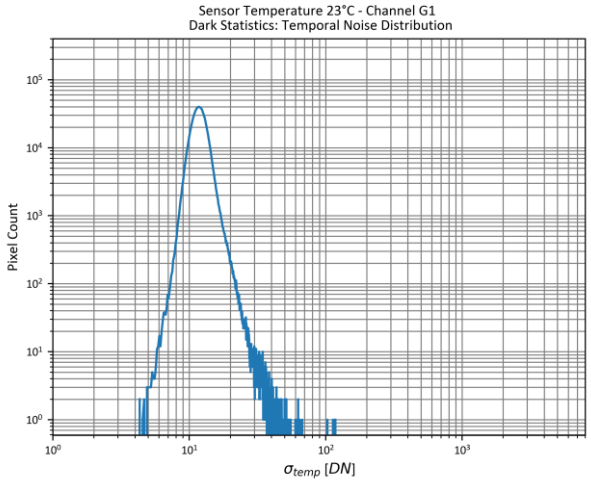


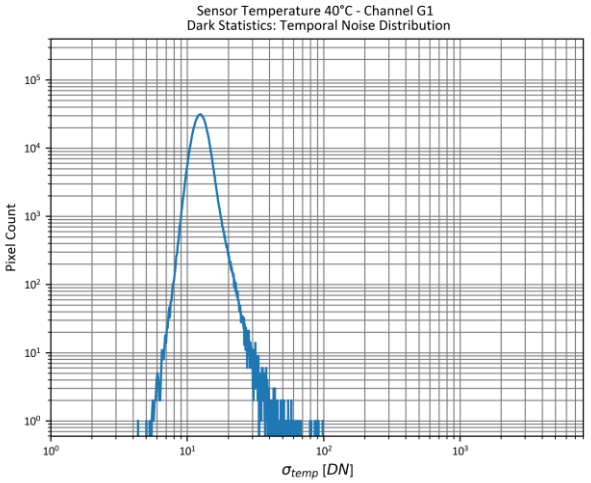


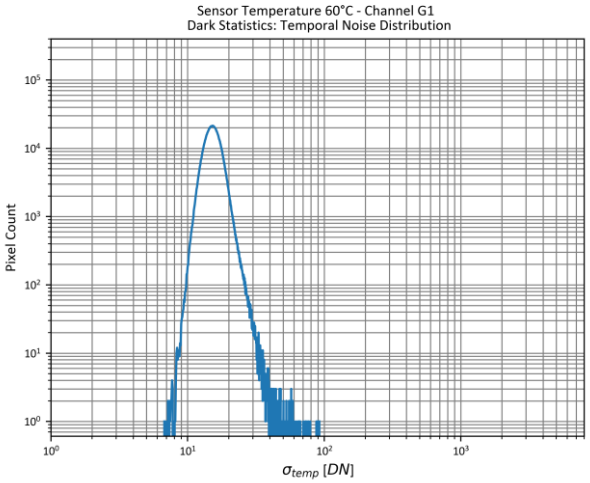


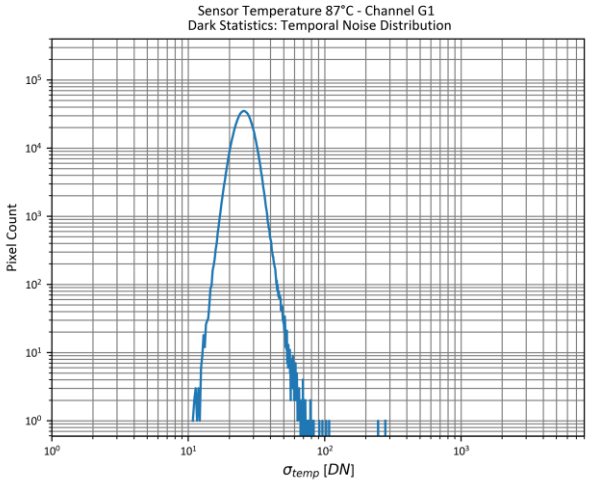


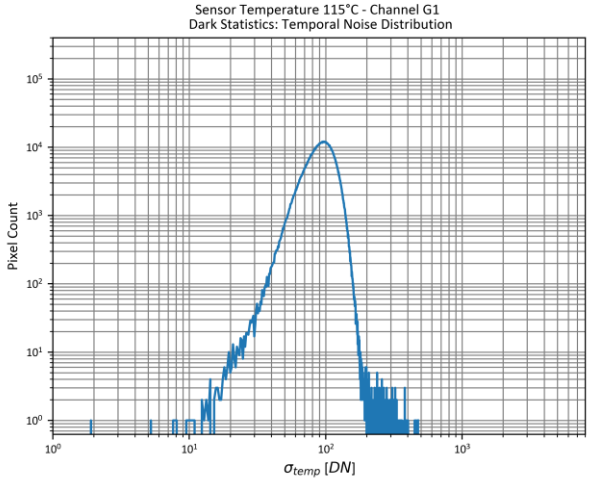
The graphs are at the same scale for each temperature.





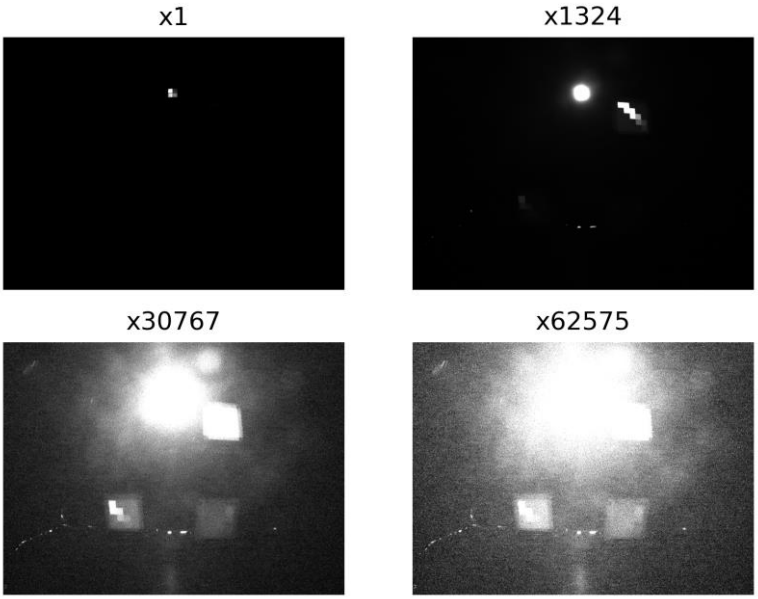




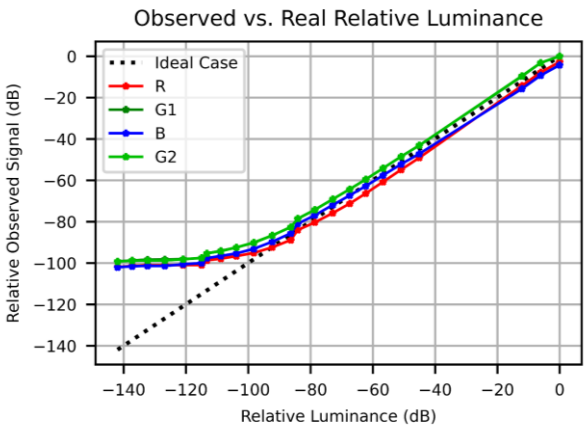


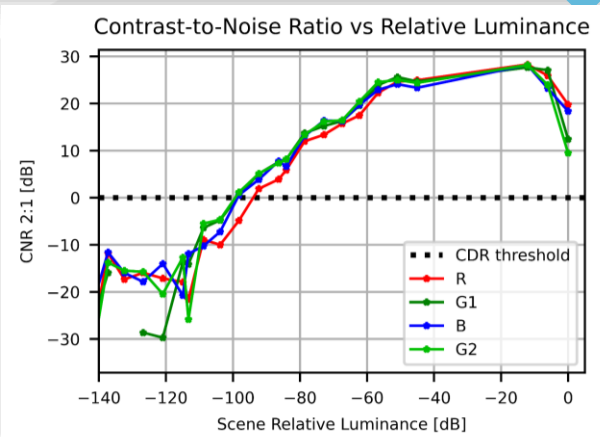
The graphs are at the same scale for each temperature.

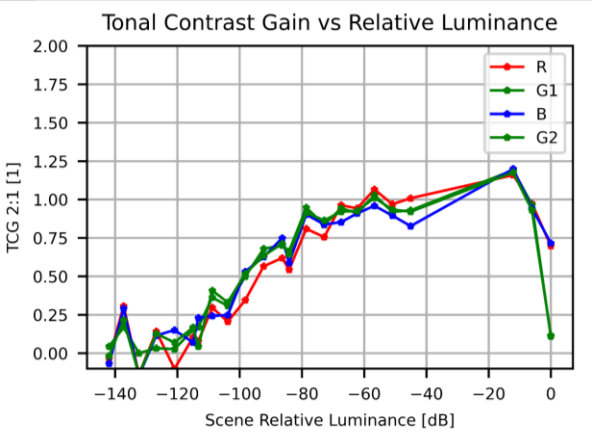
Image preview with different amplification factors



150dB setup with maximum scene luminance 37000 cd/m²



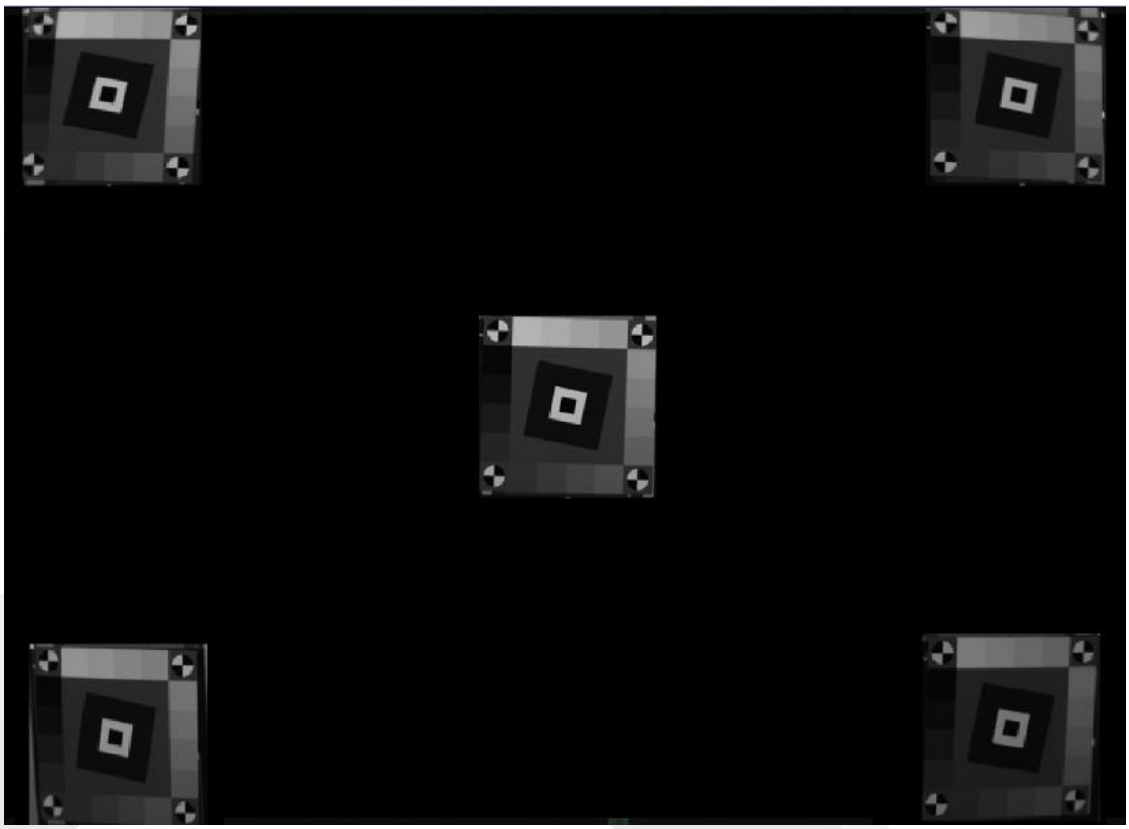




	R	G1	B	G2
CDR (dB)	94 dB	99 dB	99 dB	100 dB

The P2020 dynamic range (CDR) value is only 10dB lower than the sensor level dynamic range, which means that the lens is well fitted to the sensor.

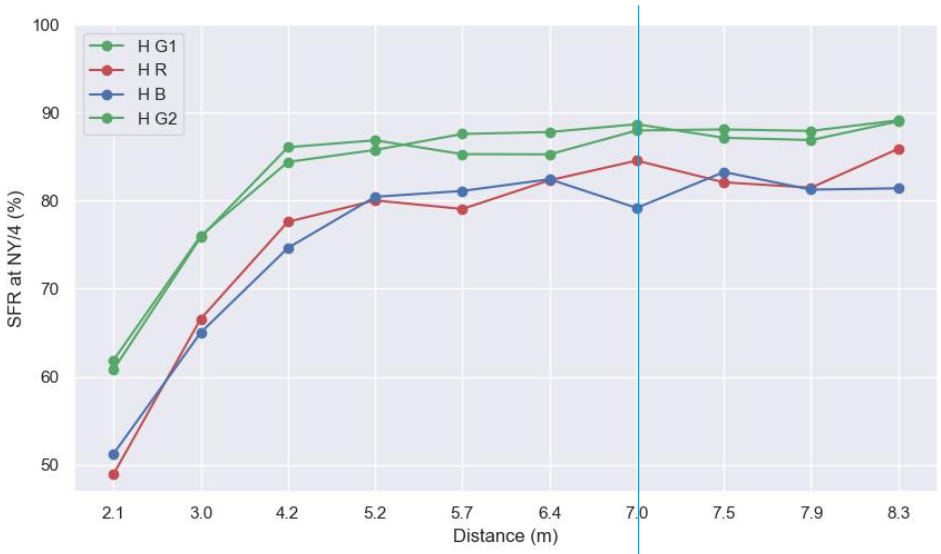
The measurement is performed for different positions in the field of view of the device.

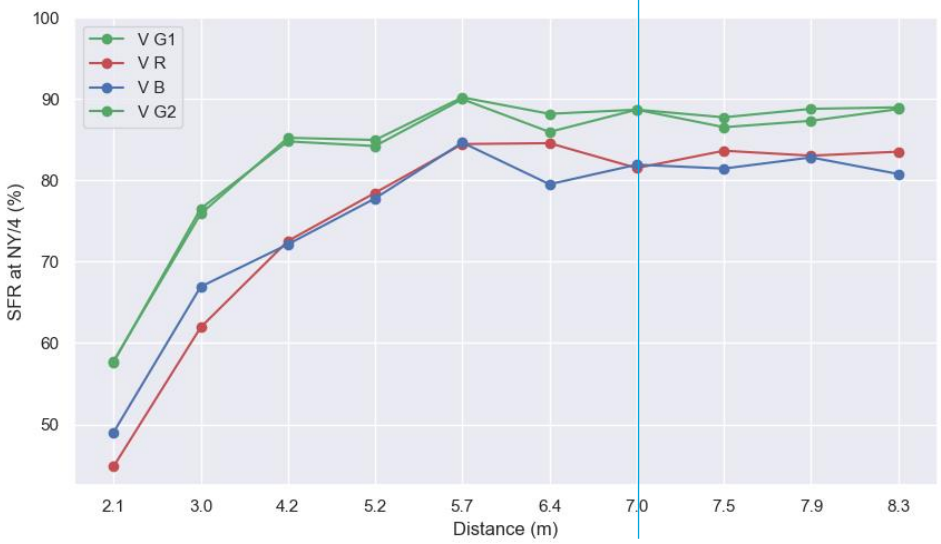


- **Measurement conditions:**
  - Illumination: D65 360lux
  - Through focus to find the best sharpness in the center
  - DUT to chart distance: 7m
  - Number of images averaged: 30
  - Viewing condition for acutance computation:
    - Distance: 600mm
    - pixel pitch: 0.254mm

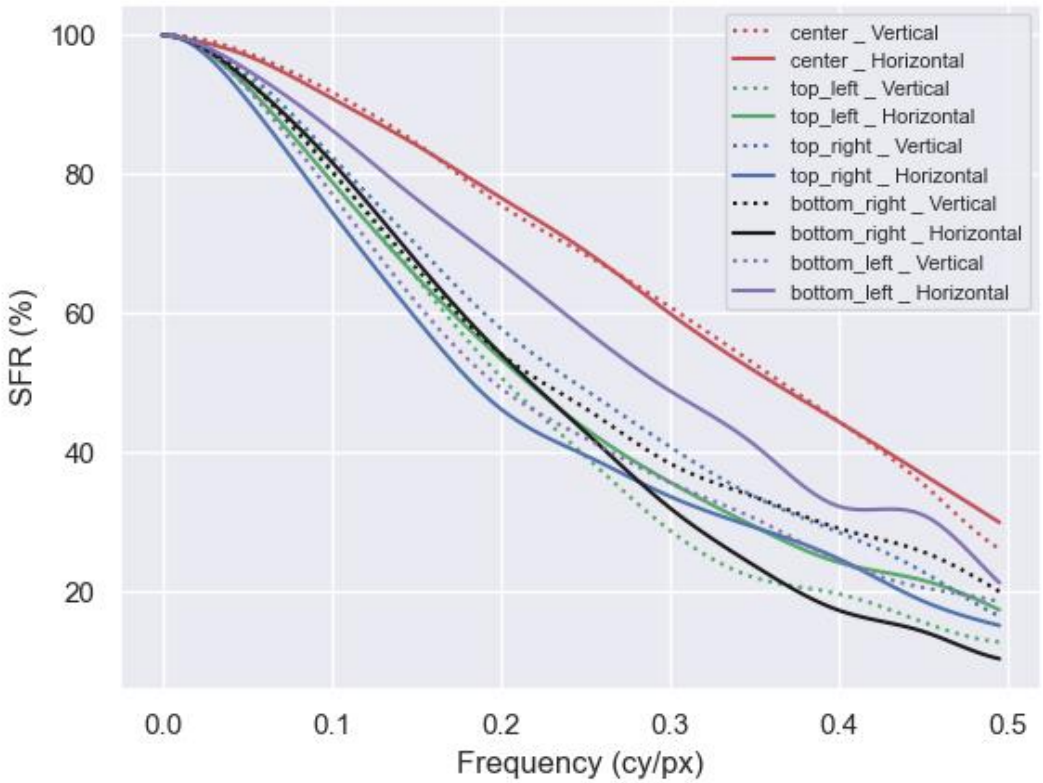
- Through Focus

- Chosen position for best focus is 7m.





- MTF at 7m, chart illumination : D65 360 lux



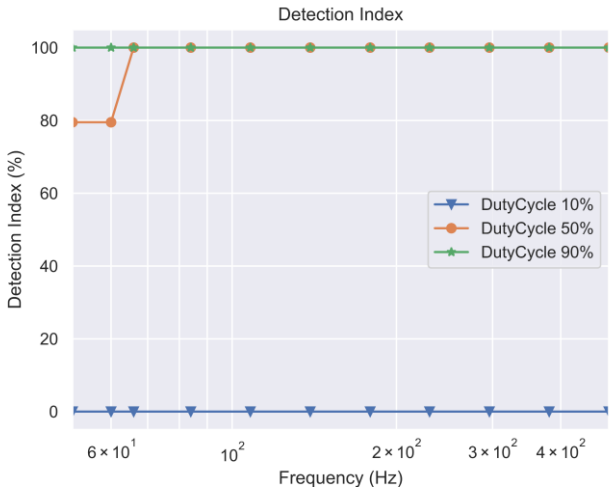
	center Vertical	center Horizontal	top_left Vertical	top_left Horizontal	top_right Vertical	top_right Horizontal	bottom_right Vertical	bottom_right Horizontal	bottom_left Vertical	bottom_left Horizontal
SFR10 in cy/px	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
SFR50 in cy/px	0.37	0.36	0.2	0.22	0.24	0.18	0.23	0.22	0.2	0.29
Acutance	0.78	0.78	0.6	0.61	0.65	0.58	0.63	0.61	0.6	0.71
SFR@0.5Nyq in %	68.48	69.02	39.5	43.47	49.03	39.61	46.37	42.96	42.07	57.64
SFR@0.25Nyq in %	88.45	87.65	73.04	72.01	76.23	66.82	73.45	74.84	69.26	81.45
SFRMax in %	100.0	100.0	100.01	100.0	100.0	100.0	100.01	100.0	100.01	100.0

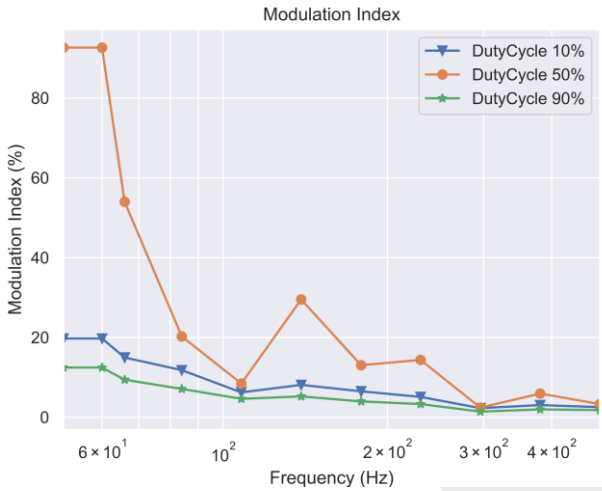
	Vertical	Horizontal
Corner Variance SFR50 in %	19.54	37.43
Corner Variance Acutance in %	8.36	18.2

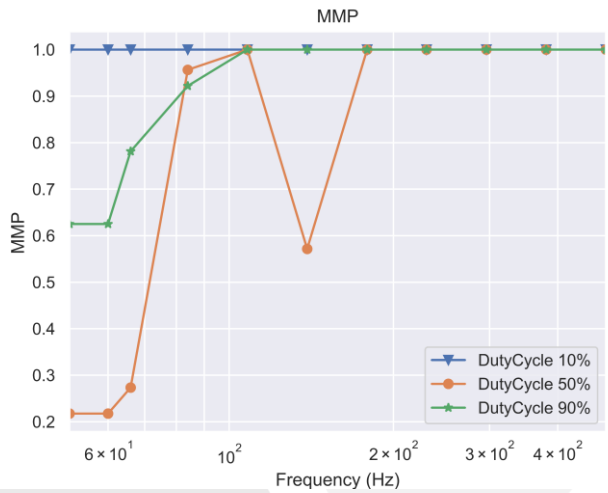
- **Measurement conditions:**
  - 10 LED PWM frequencies in Hz: 50, 51, 60, 66, 84, 108, 139, 179, 230, 296, 381, 490
  - 3 LED PWM duty cycles: 10%, 50%, 90%
  - 3 test conditions:
    - Background at 10000 lux, LED light intensity at 3000 cd/m²
    - Background at 180 lux, LED light intensity at 90 cd/m²
    - Background at 0.5 lux, LED light intensity at 6 cd/m²

- **Results:**
  - The exposure time is 10ms:
    - Significant flickering for frequencies below 100Hz (1 / exposure time)
    - Limited flickering for high frequencies
  - No other visible LED flicker mitigation effect
  - The response to flickering is the same for the 3 tested lighting conditions

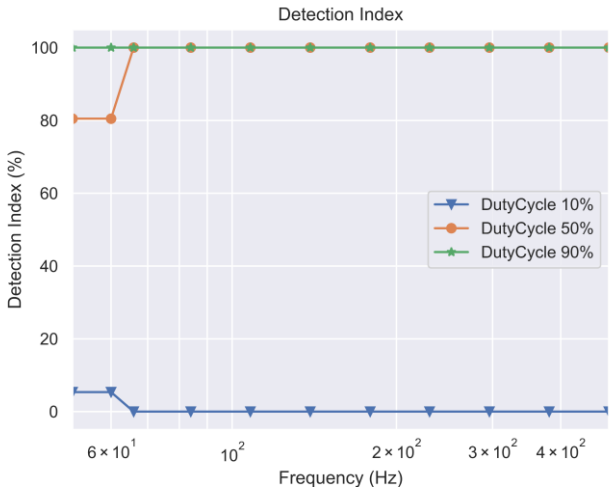
Background at 10000 lux, LED light at 3000 cd/m²

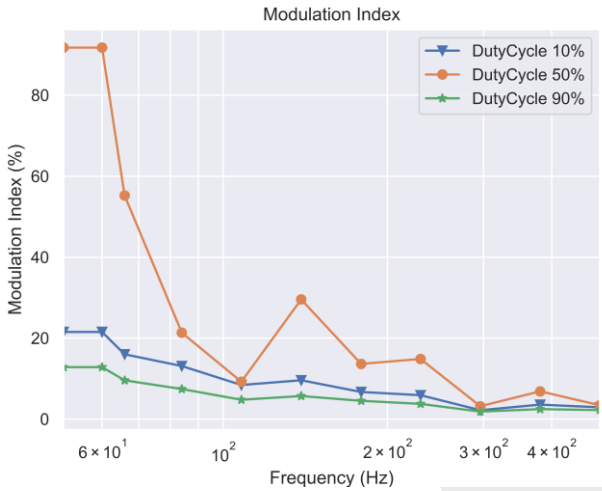


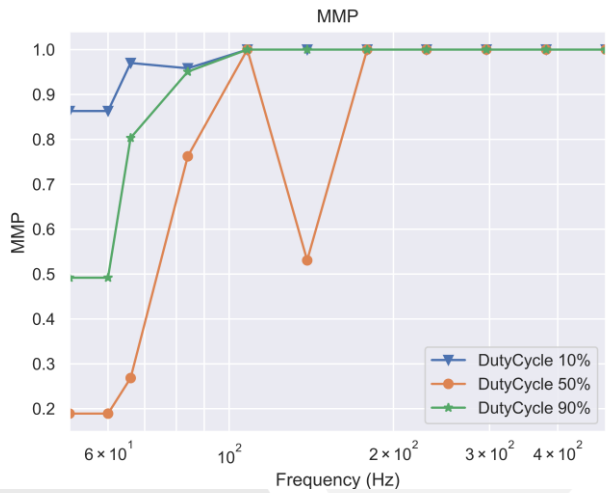




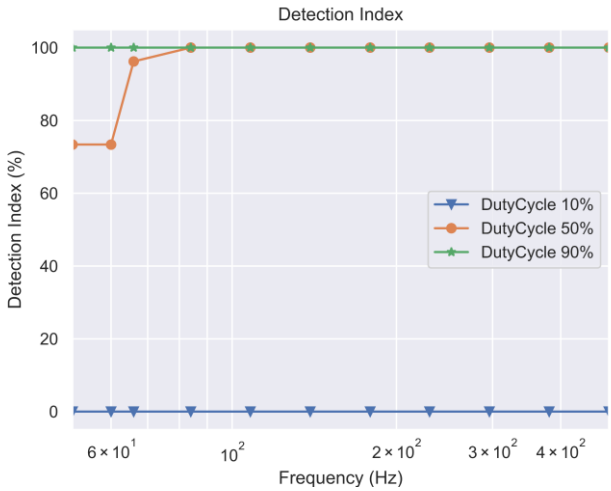
Background at 180 lux, LED light at 90 cd/m²

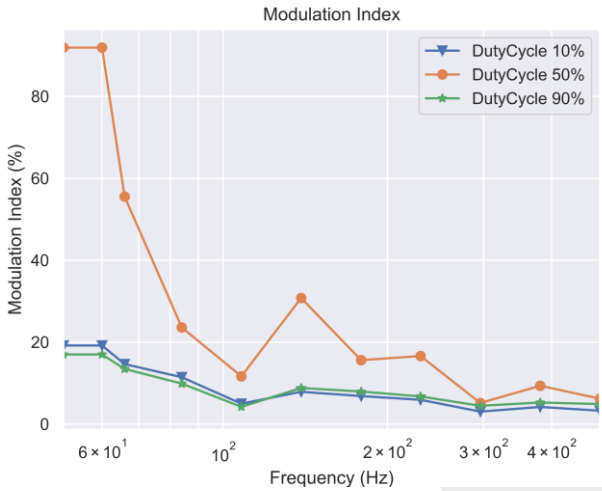


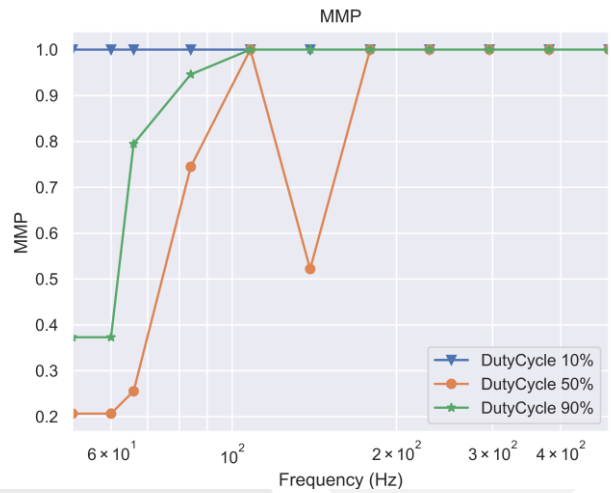


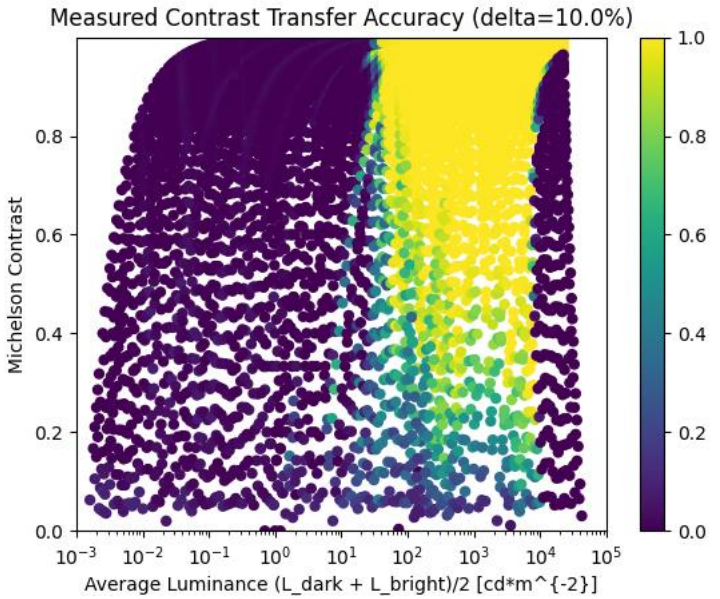


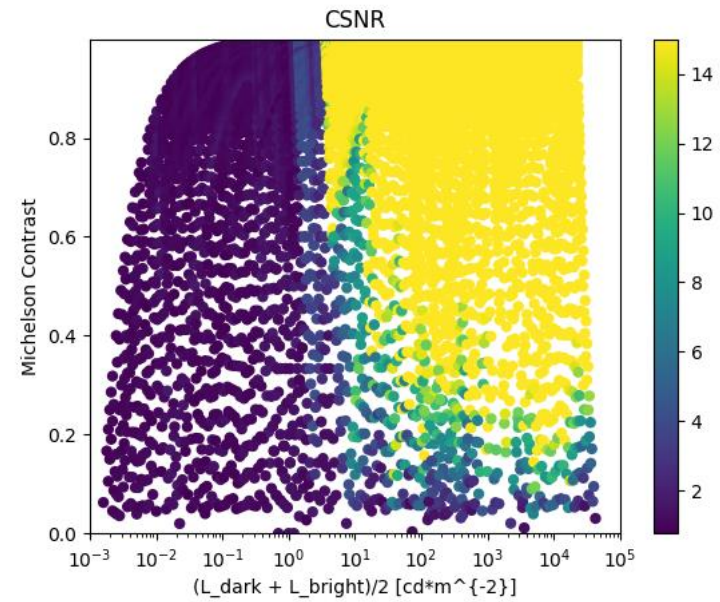
Background at 0.5 lux, LED light at 6 cd/m²

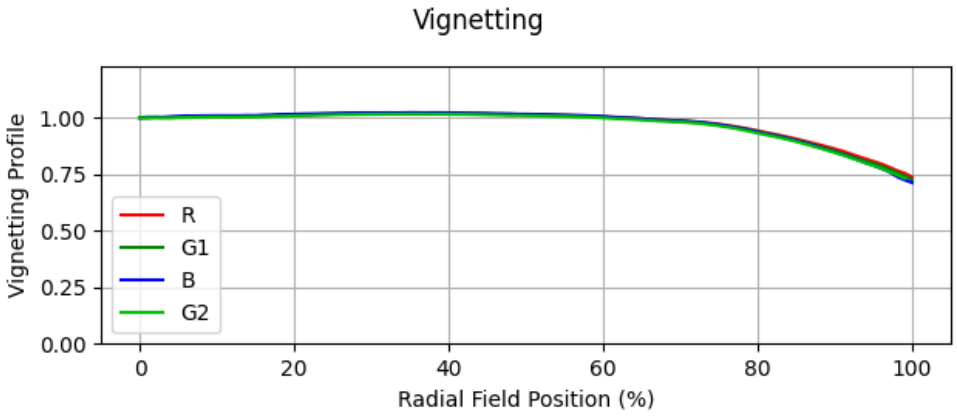




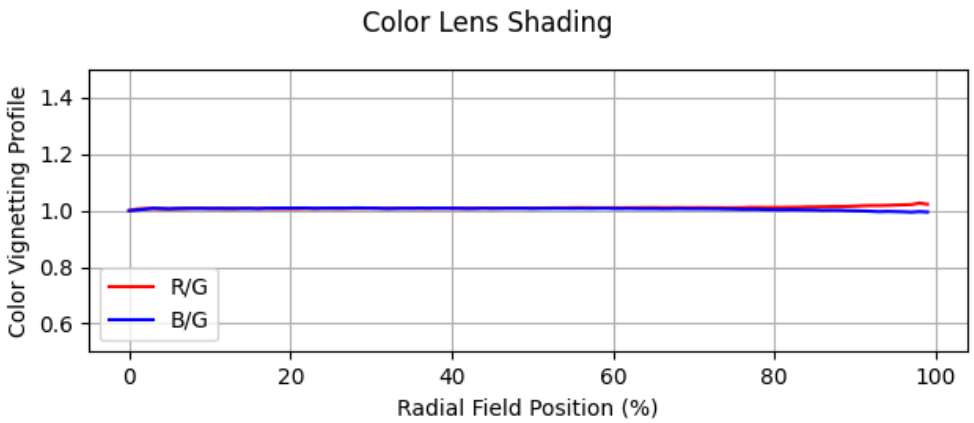








	R	G1	B	G2
Max Attenuation	24.5 %	25.6 %	27.5 %	26.8 %
Max Amplification	2.0 %	2.0 %	2.3 %	1.6 %



	R	B
Max Attenuation	0.8 %	2.3 %
Max Amplification	3.5 %	2.4 %

Green Imbalance	1.2 %

Vignetting Measurement done with an integrating sphere with illuminant D50

Results: Good vignetting and color lens shading performance

24-26, quai Alphonse le Gallo
92100 Boulogne-Billancourt - France

corp.dxomark.com