DXOMARK AUTOMOTIVE IMAGE SENSOR EVALUATION REPORT

--Sample report--

Raw image sensor and lens evaluation

corp.dxomark.com

Table of content

Measurement description

1. 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.

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

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

2. 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 is the contrast to noise ratio.

$$CNR_{tot,2:1}(m,n,c) = \frac{\mu(m,c) - \mu(n,c)}{\sqrt{\sigma_{tot}(m,c)^2 + \sigma_{tot}(n,c)^2}}$$

$$\mathrm{CNR}_{N:1}(A,B) = \frac{s_A - s_B}{\sqrt{\sigma_A^2 + \sigma_B^2}}$$

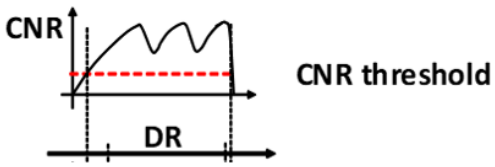
The TCG (Tonal Contast Gain) is the transfer function between the scene contrast and the image contrast.

$$TCG_{2:1}(m,n,c) = \frac{log_{10}\,\mu(m,c) - log_{10}\,\mu(n,c)}{\{L(m)\}_{dB}/20 - \{L(n)\}_{dB}/20}$$

$$\mathrm{TCG}_{N:1}(A,B) = \frac{\log_2\left(L_{A,\mathrm{target}}/L_{B,\mathrm{target}}\right)}{\log_2\left(L_{A,\mathrm{ref}}/L_{B,\mathrm{ref}}\right)}$$

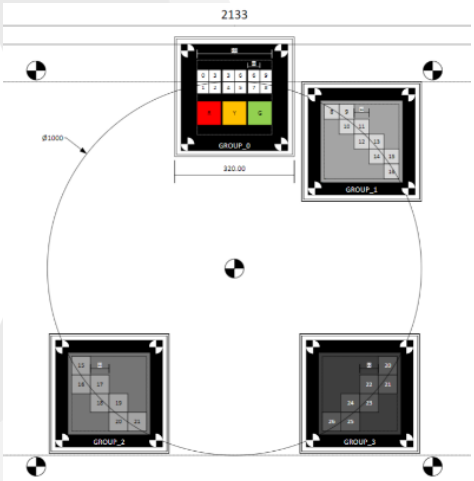
Dynamic Range is measured as Contrast Detection Ratio (CDR)

$$\mathrm{CDR}_{\mathrm{dB}} = 20 \cdot \log_{10}\left(\frac{L_{\max}[\mathrm{CNR} > 1]}{L_{\min}[\mathrm{CNR} > 1]}\right)$$



Measurement setup specifications

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



Measurement description

3. 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 is

$$FMI = 100\frac{l_{\max(t)} - l_{\min(t)}}{l_{\max(t)} + l_{\min(t)}}$$

The Flicker Detection Index is

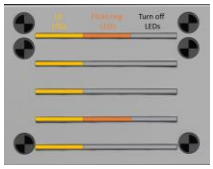
$$FDI = P\left[\frac{l(t) - l_{off}}{l_{off}} \geq \text{threshold}\right]$$

The Modulation Mitigation Probability is

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

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 2000Hz], adjustable duty cycle, phase and intensity.

4. Resolution

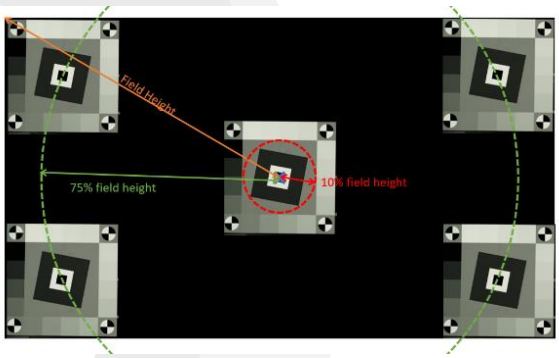
Standard compliance

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

5. 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

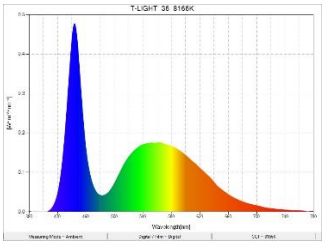
$$\text{Flare Attenuation} = 10 \cdot \log_{10}\left(\frac{E_{source}}{E_{flare}}\right)$$

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:

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

Measurement setup specifications

Spectrum of the LED light source:



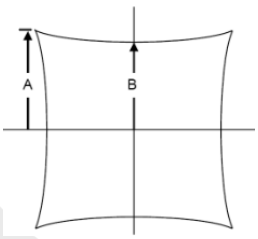
6. Distortion and lateral chromatic aberration

Standard compliance

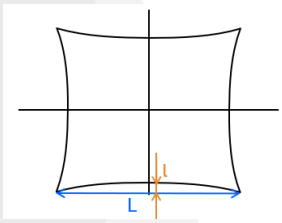
The lens distortion measurement is fully compliant with the standard ISO 17850, and the chromatic aberration measurement is fully compliant with the ISO 19084 standard.

Metrics details

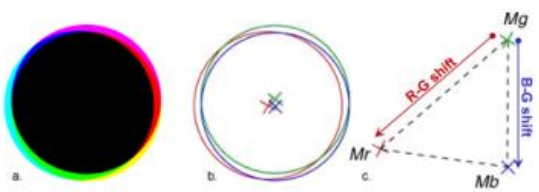
TV distortion: $100 \cdot \frac{A-B}{B}$, with A and B defined on the following figure:



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

Measurement description

7. 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	

Testing Conditions

Lens design	
Lens aperture	
Lens FOV (diagonal)	
Mode sensor	---
Frame Grabber	
SW version	

Output	
Framerate	
image resolution	
Exposure time (ms)	
gain	

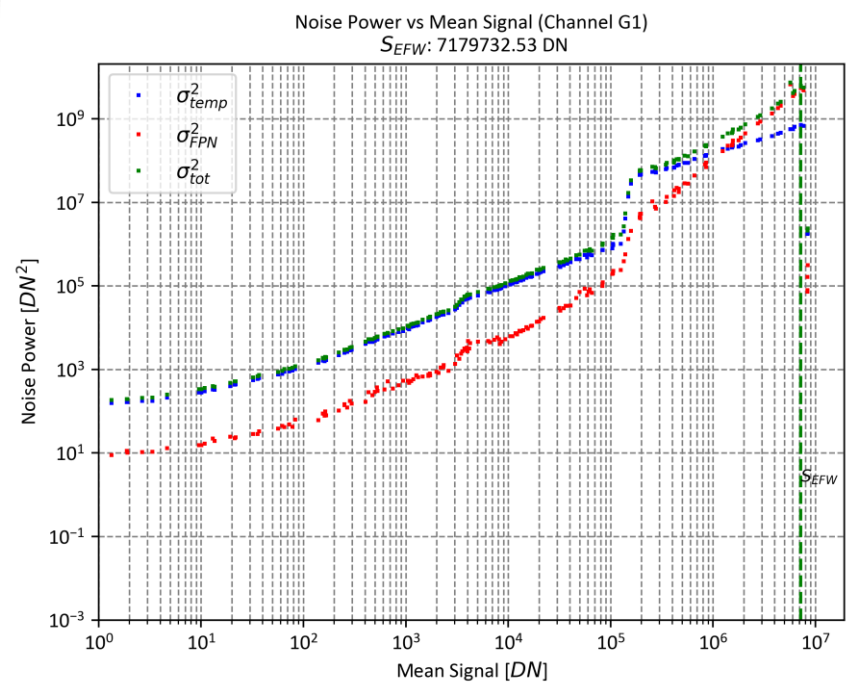
Overall Performance

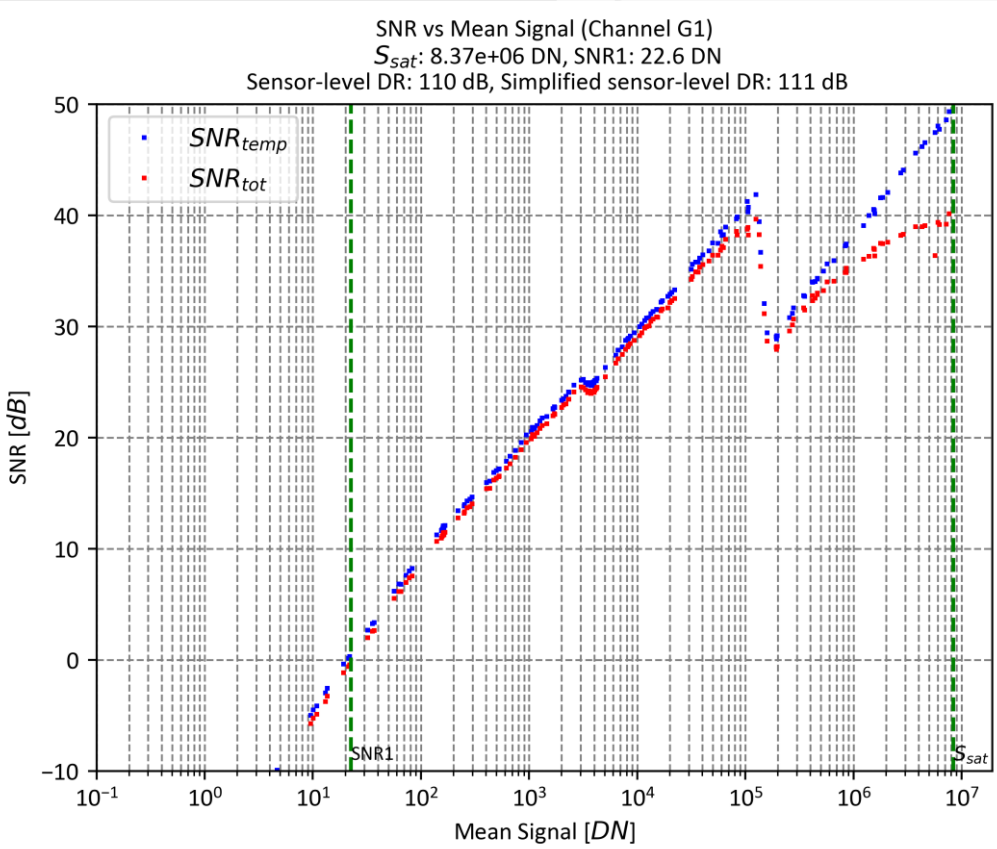
DR (SNR1 40°C)	
Saturation (D65)	
Dark (40°C)	
Full Well Capacity	
Dark flatness	

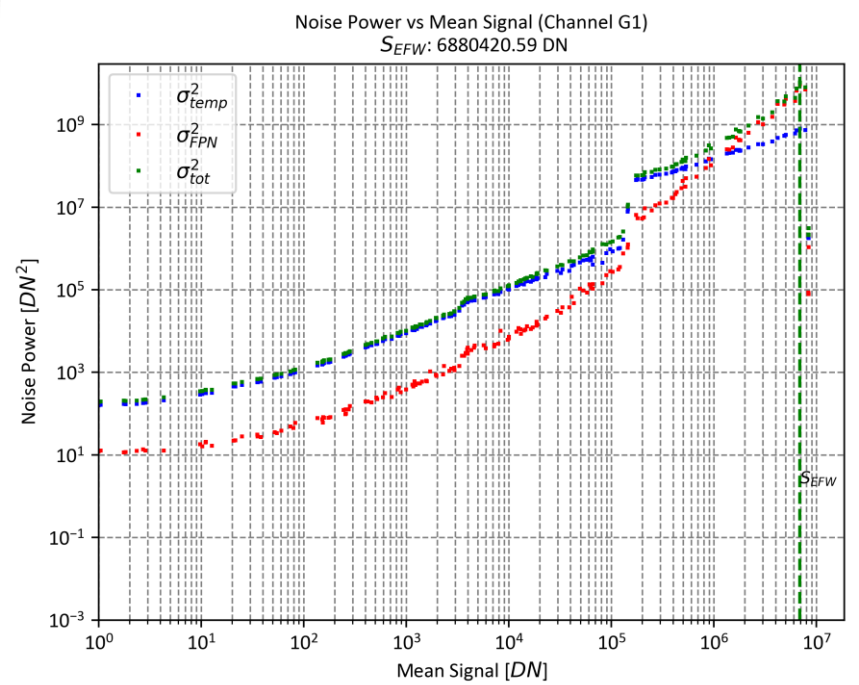
DR P2020	
Noise Autocorrelation	

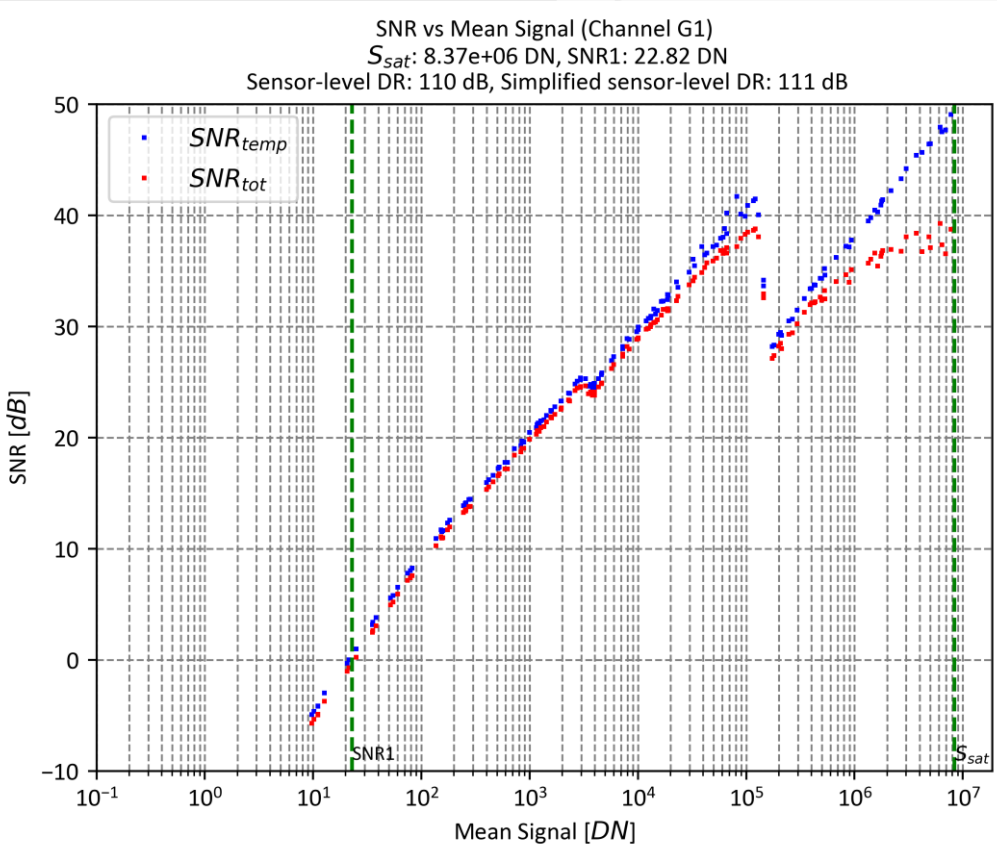
- **Measurement conditions**
  - 6 exposures from 100 to 70 000 cd/m2
  - 30 images per exposure
  - Illuminant D65
  - 5 temperatures from 20°C to 115°C (sensor temperature)

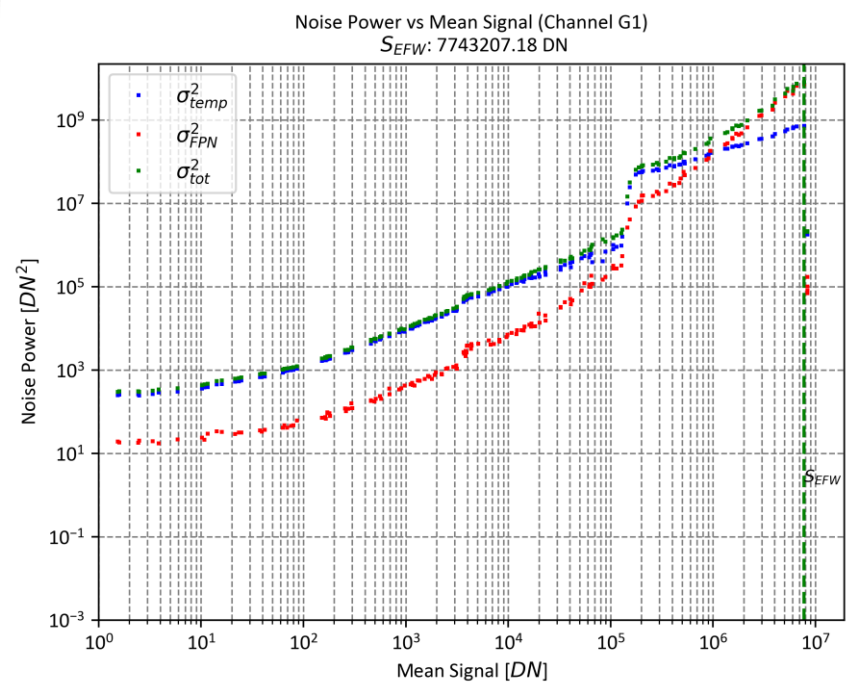
- **Results:**
  - Sensor level dynamic range: 110dB for sensor temperature 40°C
  - With the current lens, the sensor saturates for objects with luminance equal or higher than 17 000 cd/m²
  - The sensor has 3 exposures. The system gain of the first two exposures is the same
  - Autocorrelation graphs 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

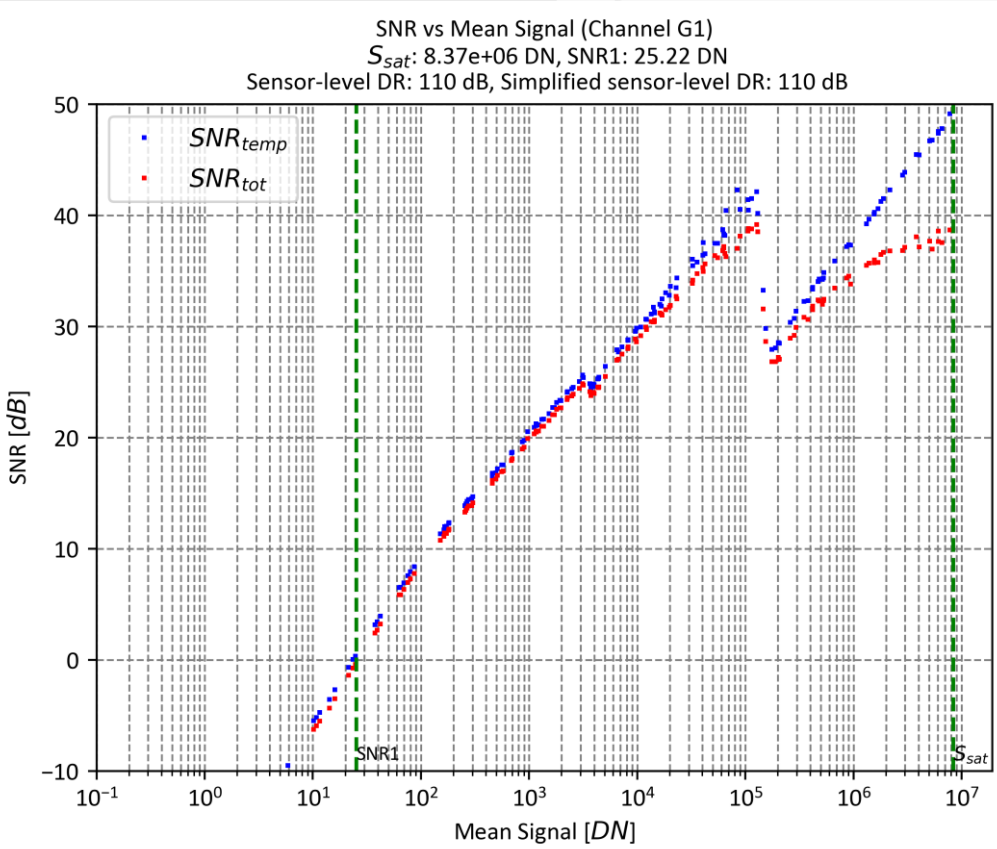

Noise Power vs Mean Signal (Channel G1)
S_{EFW}: 7179732.53 DN
σ^2_{temp}
σ^2_{FPN}
σ^2_{tot}
Noise Power [DN^2]
Mean Signal [DN]
S_{EFW}

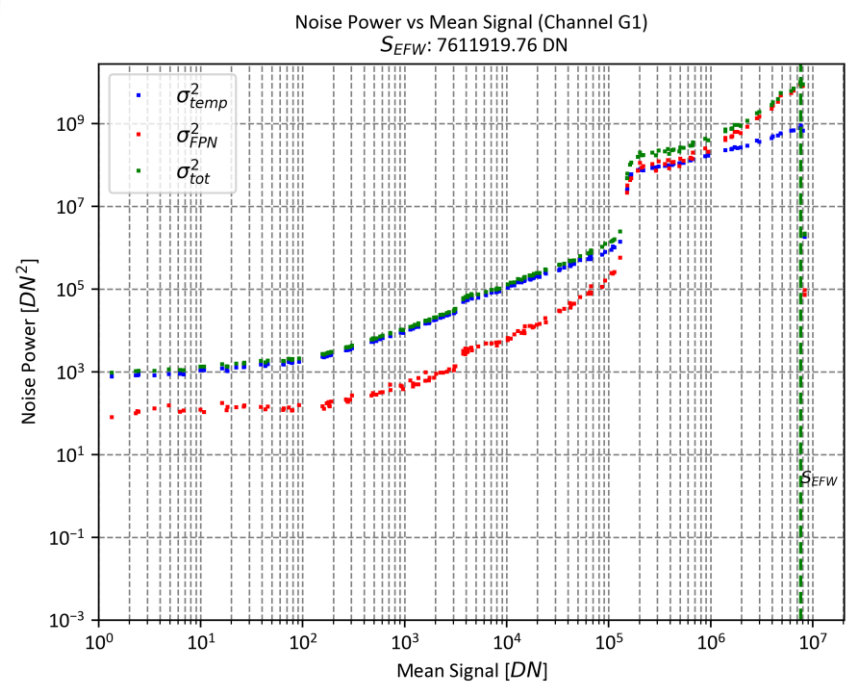

SNR vs Mean Signal (Channel G1)
S_{sat}: 8.37e+06 DN, SNR1: 22.6 DN
Sensor-level DR: 110 dB, Simplified sensor-level DR: 111 dB
SNR_{temp}
SNR_{tot}
SNR [dB]
Mean Signal [DN]
SNR1
S_{sat}

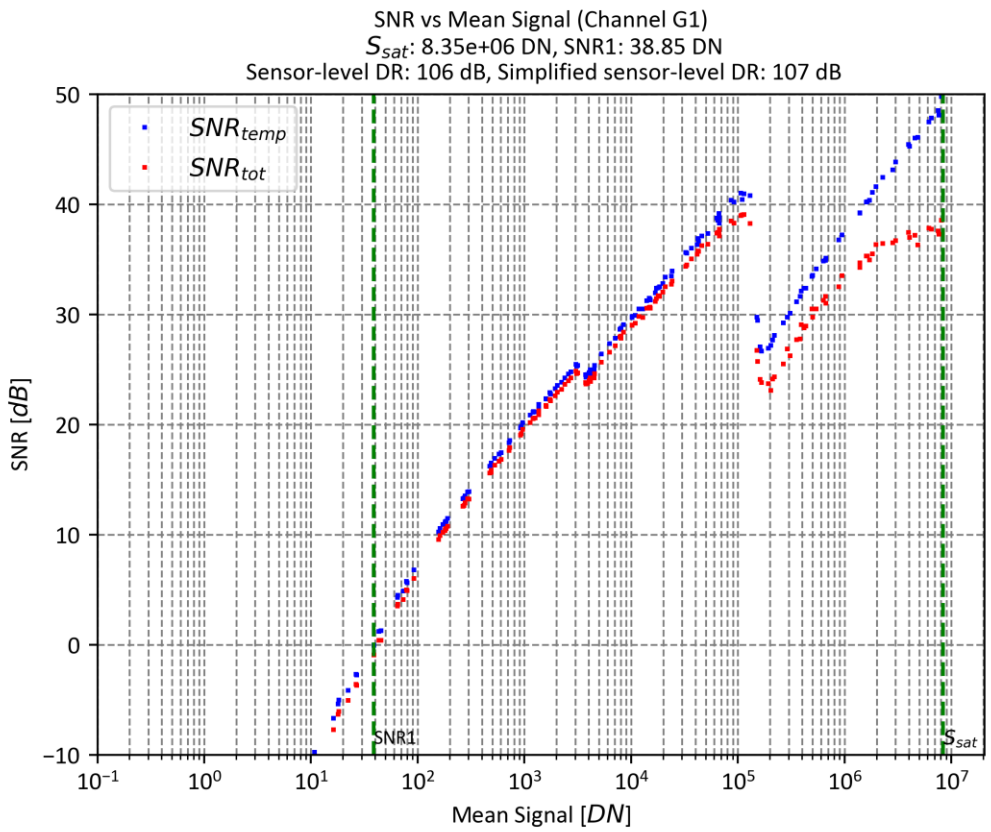

Noise Power vs Mean Signal (Channel G1)
S_{EFW}: 6880420.59 DN
σ^2_{temp}
σ^2_{FPN}
σ^2_{tot}
Noise Power [DN^2]
Mean Signal [DN]
S_{EFW}

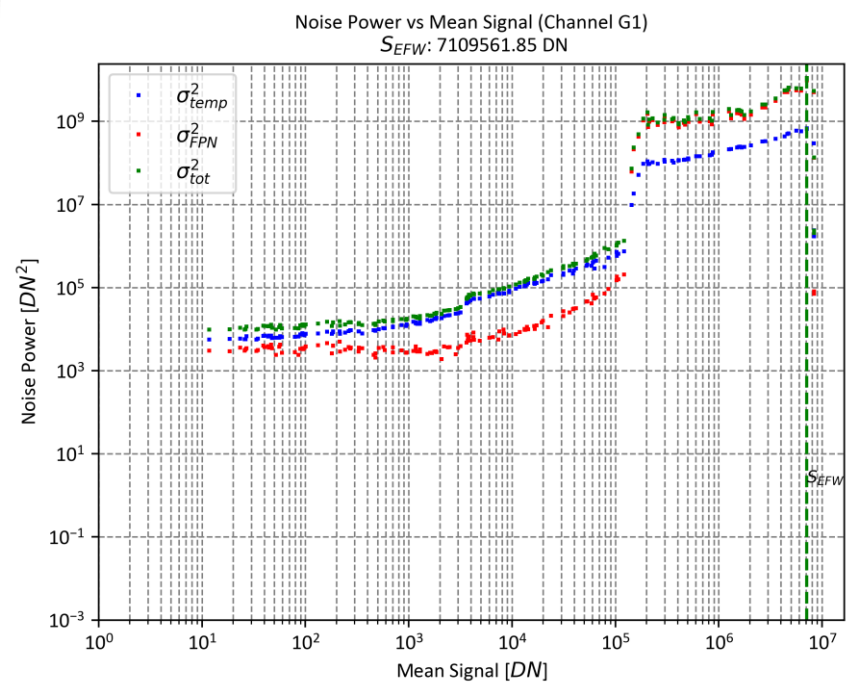

SNR vs Mean Signal (Channel G1)
S_{sat}: 8.37e+06 DN, SNR1: 22.82 DN
Sensor-level DR: 110 dB, Simplified sensor-level DR: 111 dB
SNR_{temp}
SNR_{tot}
SNR [dB]
Mean Signal [DN]
SNR1
S_{sat}

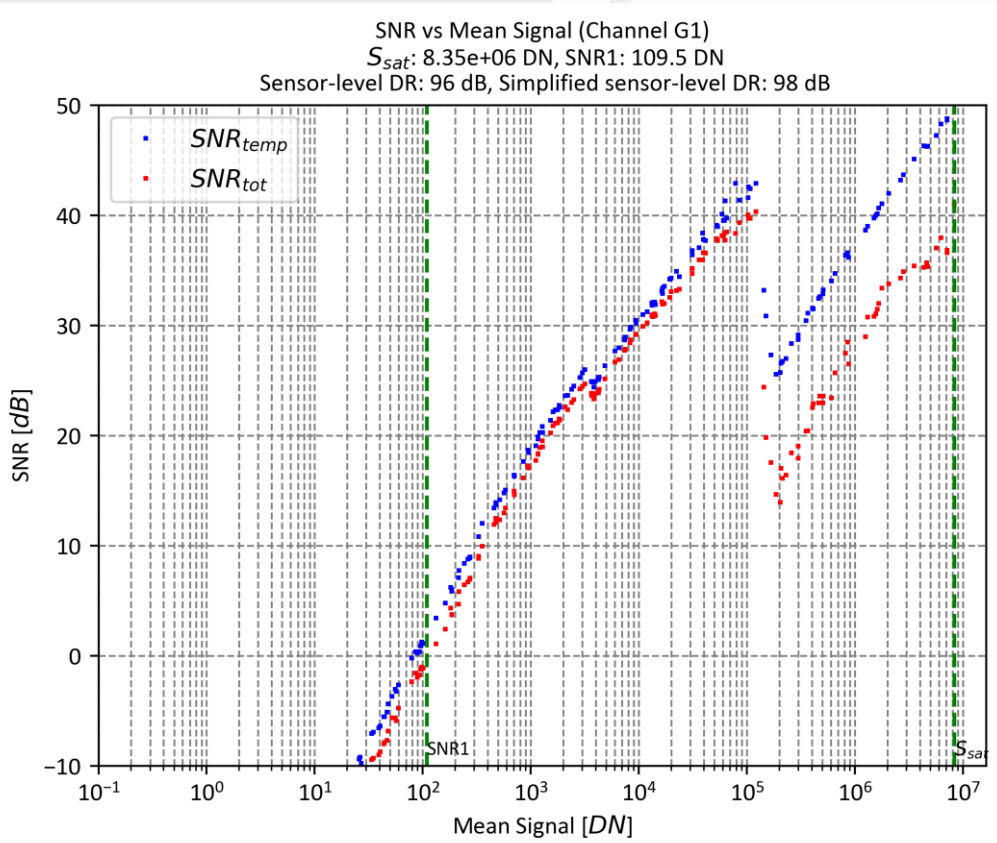

Noise Power vs Mean Signal (Channel G1)
S_{EFW}: 7743207.18 DN
σ^2_{temp}
σ^2_{FPN}
σ^2_{tot}
Noise Power [DN^2]
Mean Signal [DN]
S_{EFW}


SNR vs Mean Signal (Channel G1)
S_{sat}: 8.37e+06 DN, SNR1: 25.22 DN
Sensor-level DR: 110 dB, Simplified sensor-level DR: 110 dB
SNR_{temp}
SNR_{tot}
SNR [dB]
Mean Signal [DN]
SNR1
S_{sat}

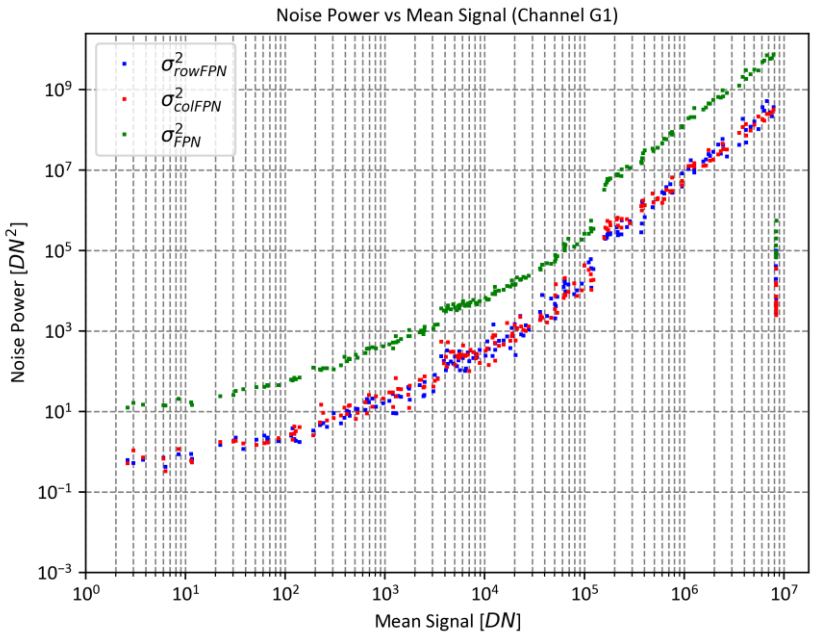

Noise Power vs Mean Signal (Channel G1)
S_{EFW}: 7611919.76 DN
σ^2_{temp}
σ^2_{FPN}
σ^2_{tot}
Noise Power [DN^2]
Mean Signal [DN]
S_{EFW}

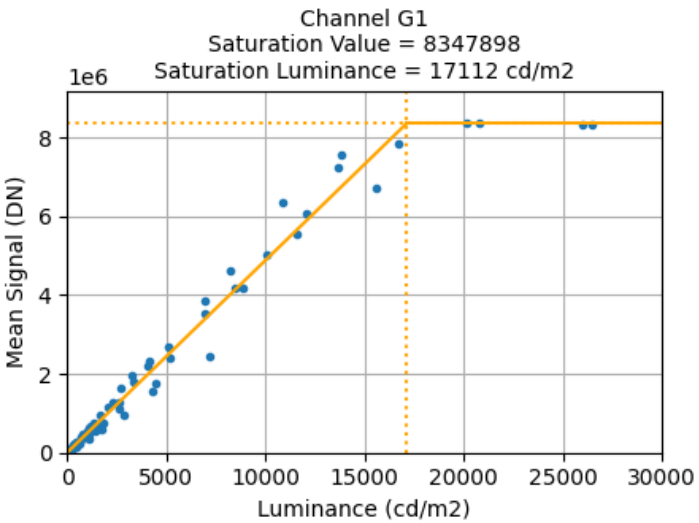

SNR vs Mean Signal (Channel G1)
S_{sat}: 8.35e+06 DN, SNR1: 38.85 DN
Sensor-level DR: 106 dB, Simplified sensor-level DR: 107 dB
SNR_{temp}
SNR_{tot}
SNR [dB]
Mean Signal [DN]
SNR1
S_{sat}

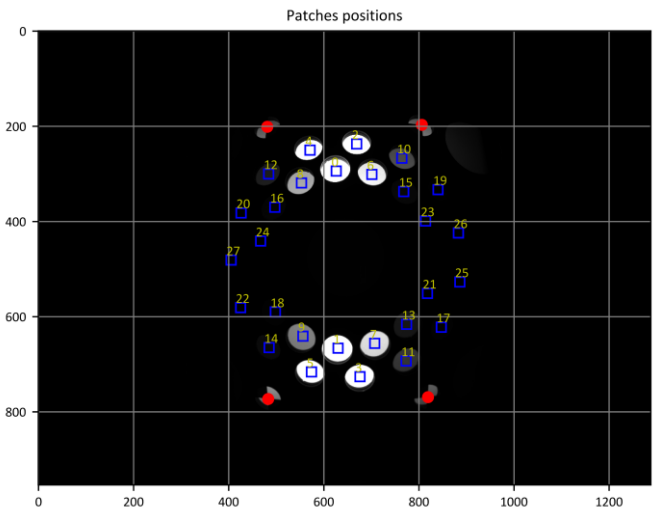

Noise Power vs Mean Signal (Channel G1)
S_{EFW}: 7109561.85 DN
σ^2_{temp}
σ^2_{FPN}
σ^2_{tot}
Noise Power [DN^2]
Mean Signal [DN]
S_{EFW}

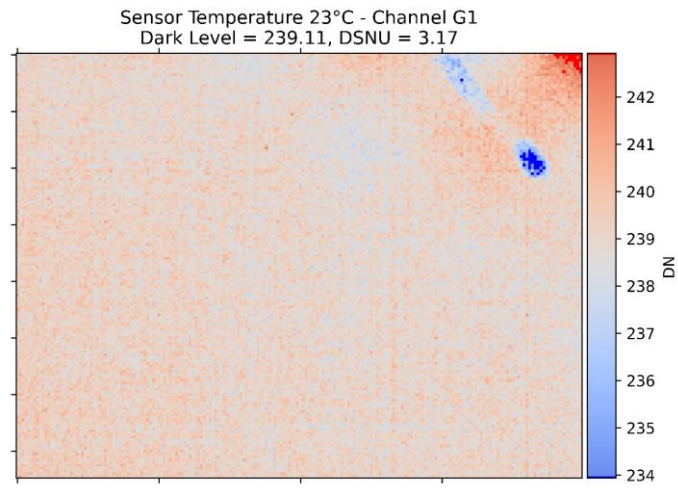

SNR vs Mean Signal (Channel G1)
S_{sat}: 8.35e+06 DN, SNR1: 109.5 DN
Sensor-level DR: 96 dB, Simplified sensor-level DR: 98 dB
SNR_{temp}
SNR_{tot}
SNR [dB]
Mean Signal [DN]
SNR1
S_{sat}

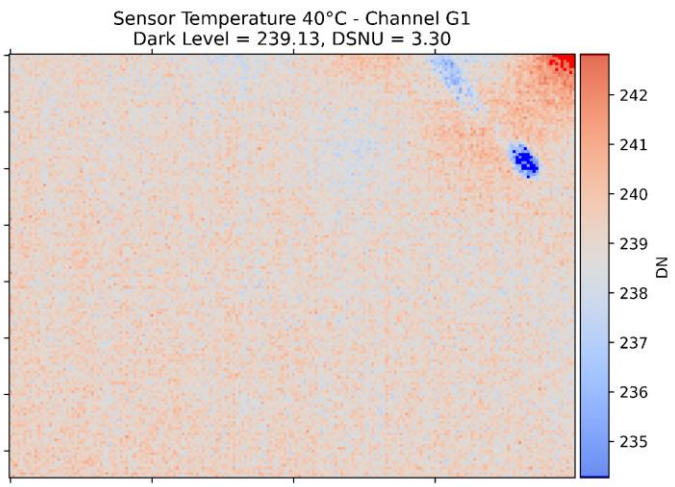
Row and Column fixed pattern noise

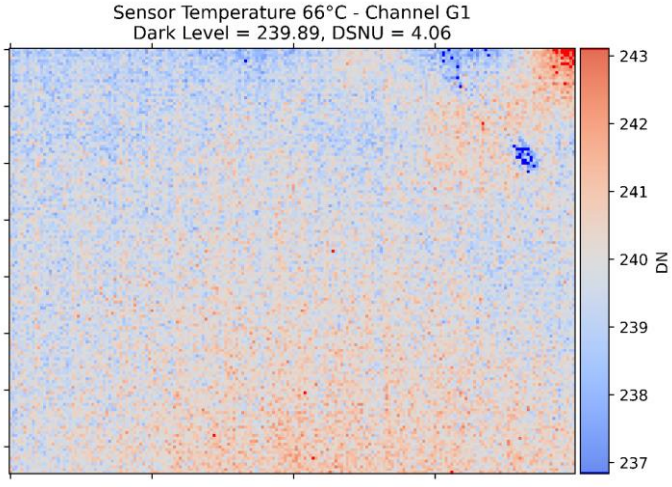


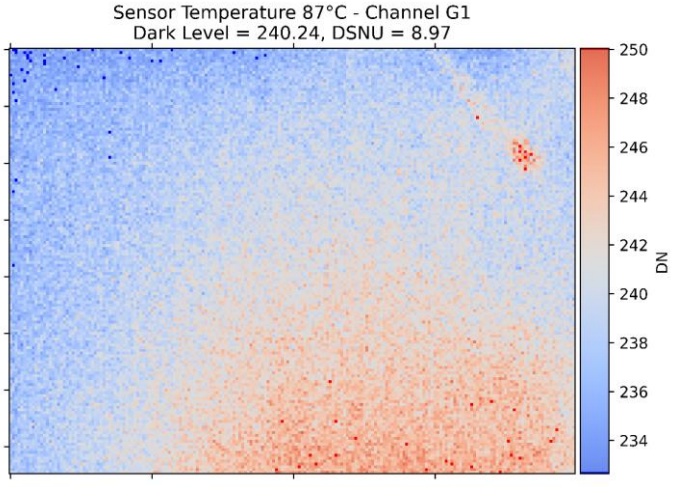


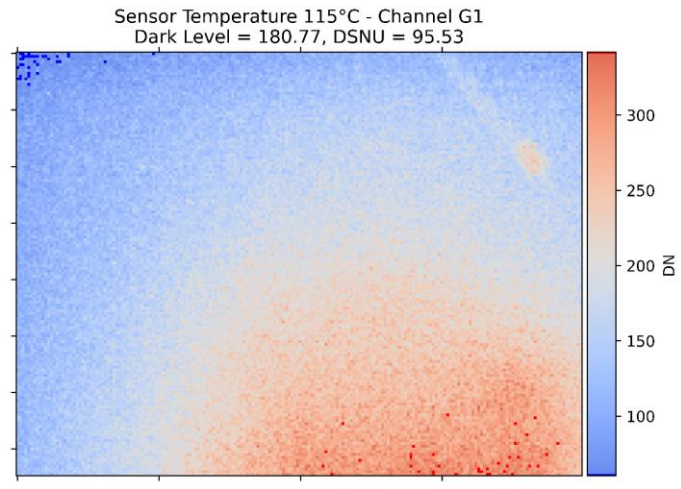












Notice that map scales are different for each temperature.
2 phenomena can be noted:

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

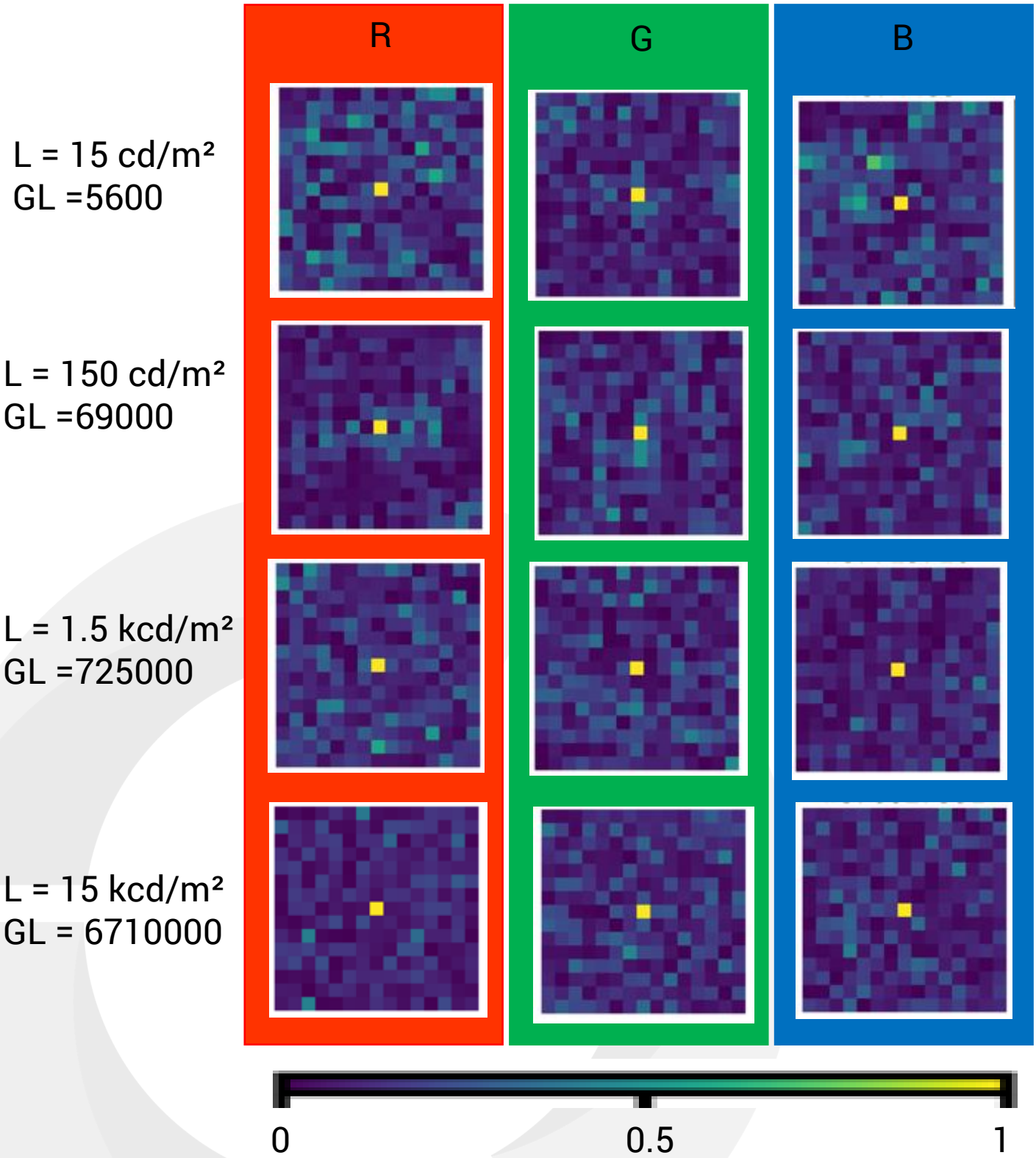
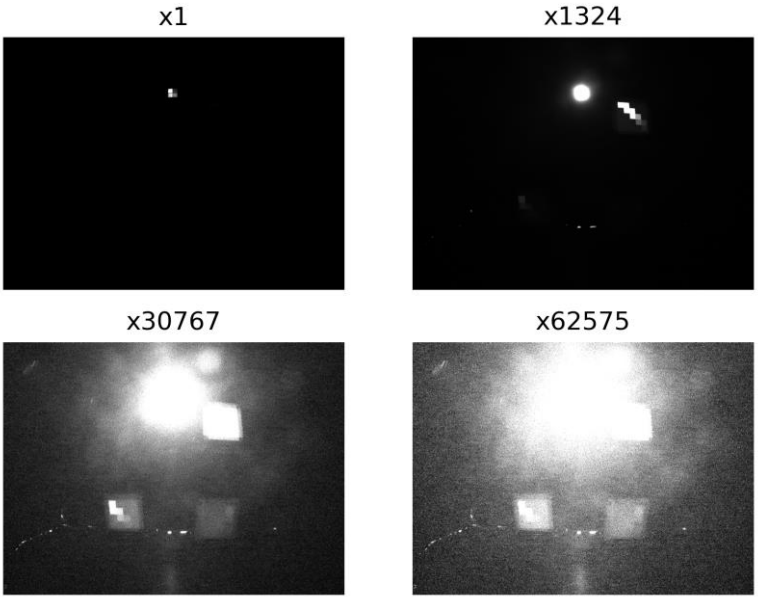
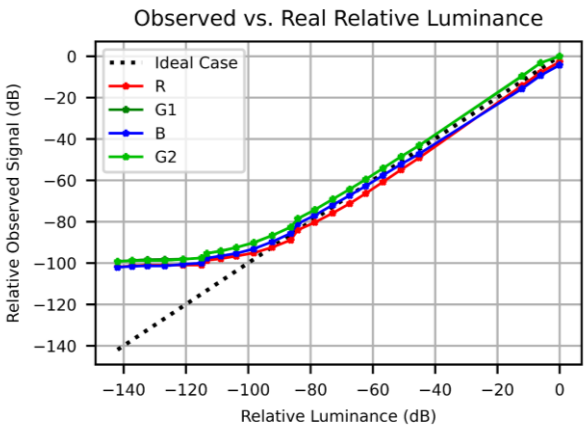
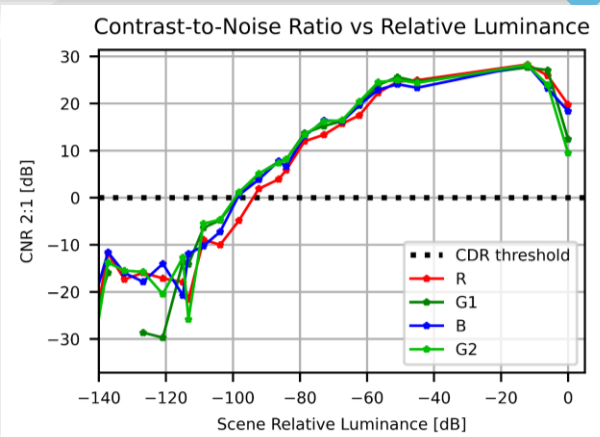


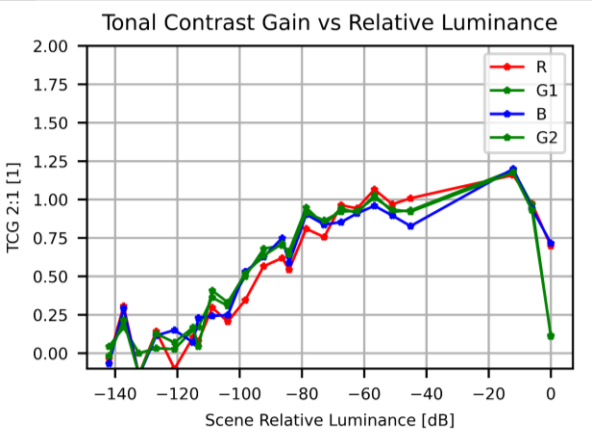
Image preview with different amplification factors



150dB setup with maximum scene luminance 37000 cd/m²







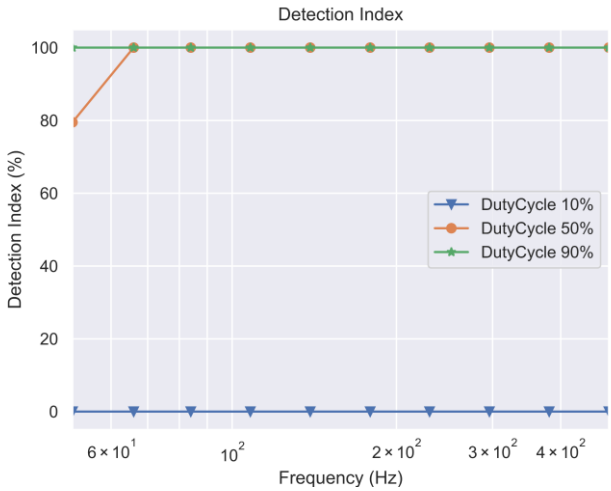
	R	G1	B	G2
CDR (dB)	94 dB	99 dB	99 dB	100 dB

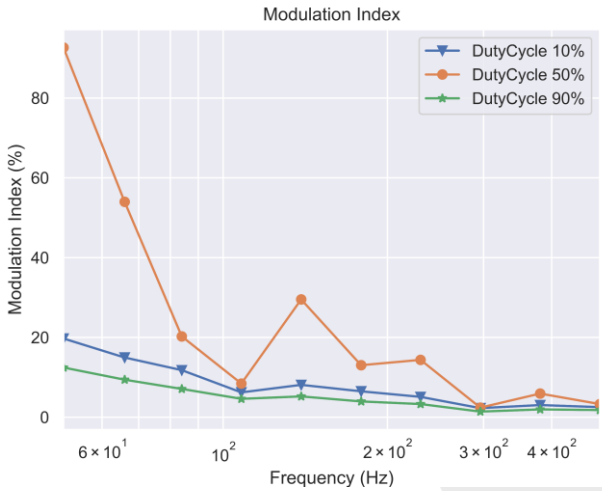
The P2020 dynamic range (CDR) value is only 10dB lower than the sensor level dynamic range, which means that the lens is well fitted to the sensor.

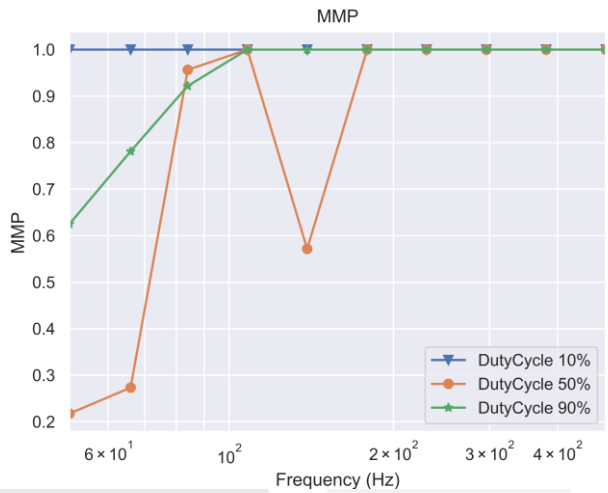
- **Measurement conditions:**
  - 10 LED PWM frequencies in Hz: 51, 66, 84, 108, 139, 179, 230, 296, 381, 490
  - 3 LED PWM duty cycles: 10%, 50%, 90%
  - 3 test conditions:
    - Background at 10000 lux, LED light intensity at 3000 cd/m²
    - Background at 180 lux, LED light intensity at 90 cd/m²
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

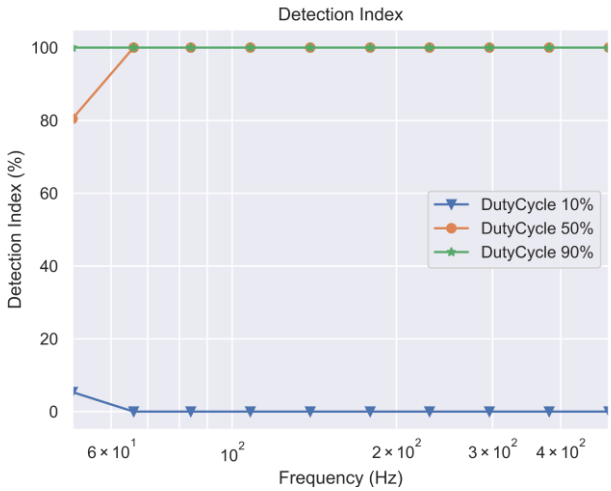
Background at 10000 lux, LED light at 3000 cd/m²

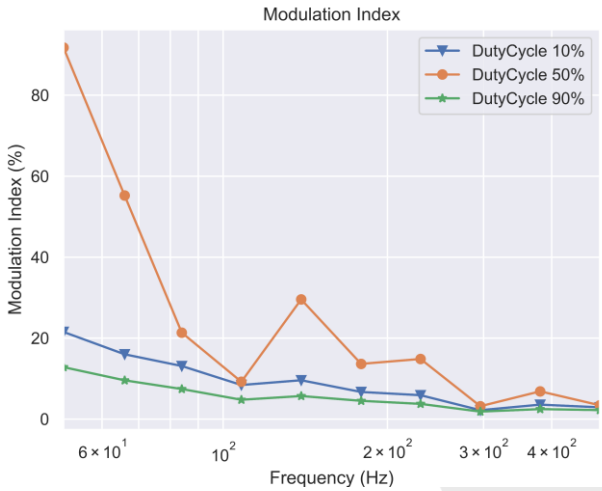


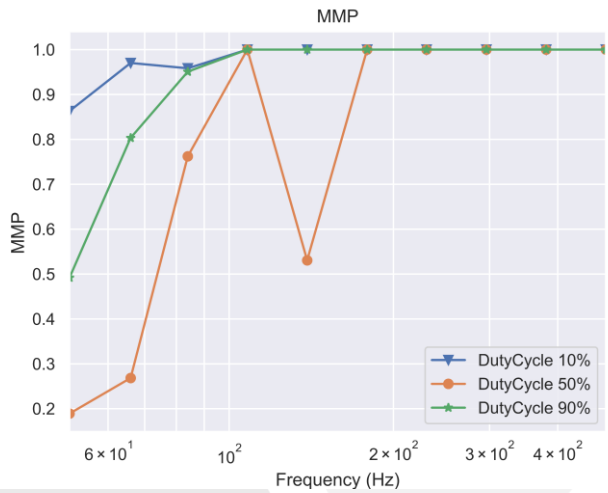




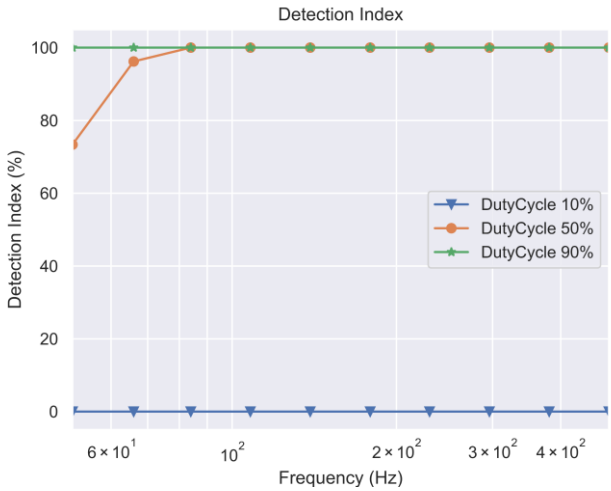
Background at 180 lux, LED light at 90 cd/m²

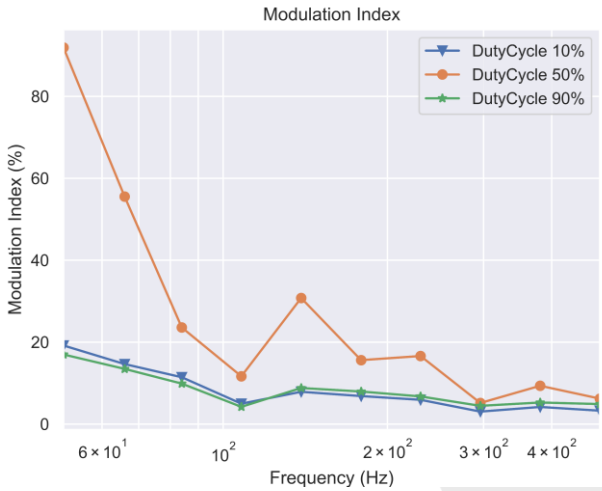


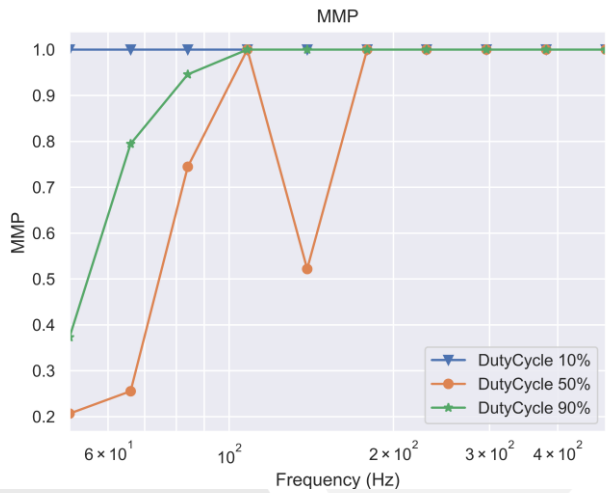




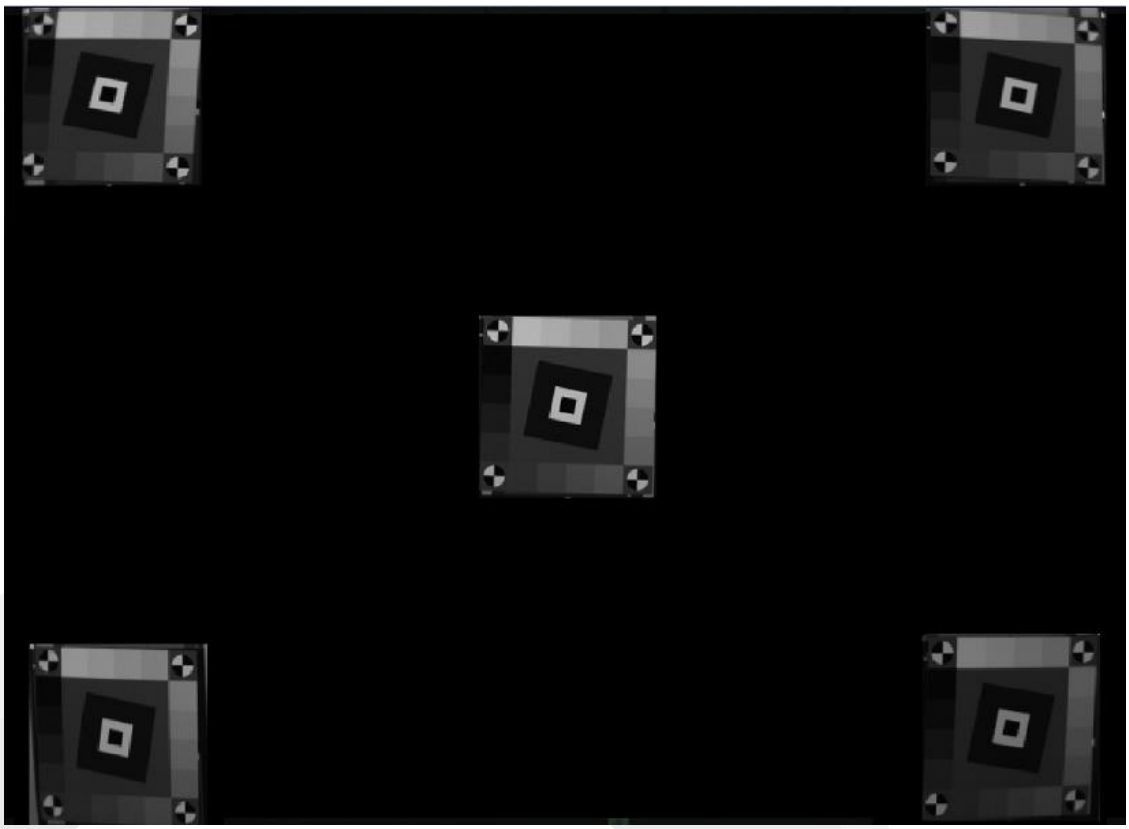
Background at 0.5 lux, LED light at 6 cd/m²







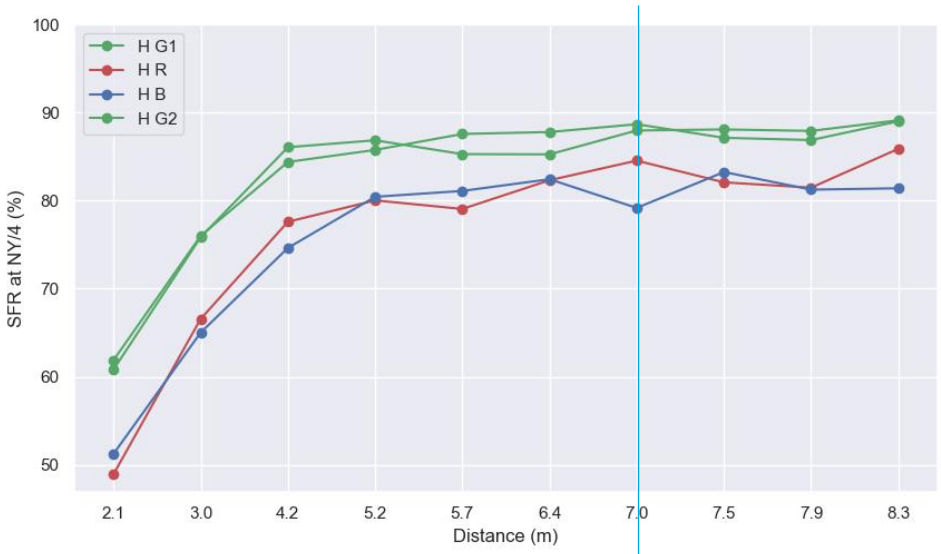
The measurement is performed for different positions in the field of view of the device.

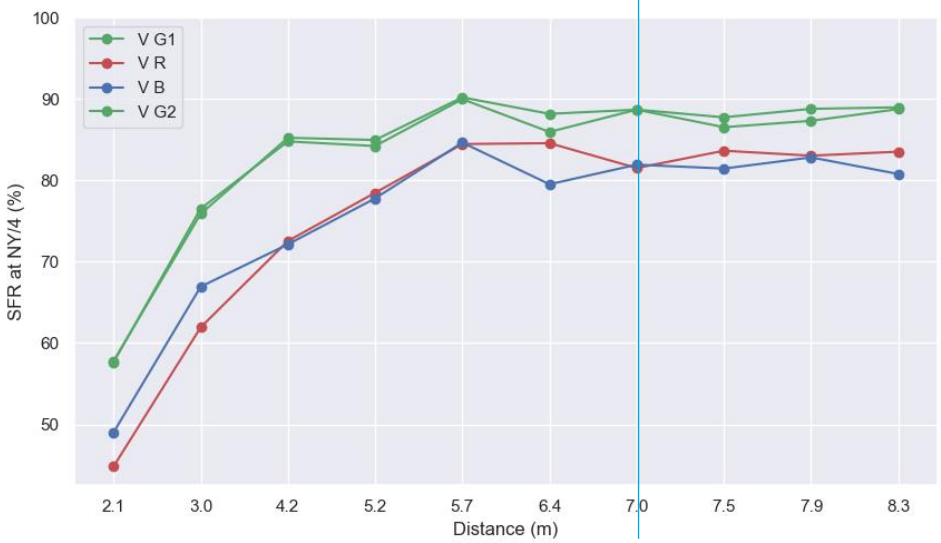


- **Measurement conditions:**
  - Illumination: D65 360lux
  - Through focus to find the best sharpness in the center
  - DUT to chart distance: 7m
  - Number of images averaged: 30
  - Viewing condition for acutance computation:
    - Distance: 600mm
    - pixel pitch: 0.254mm

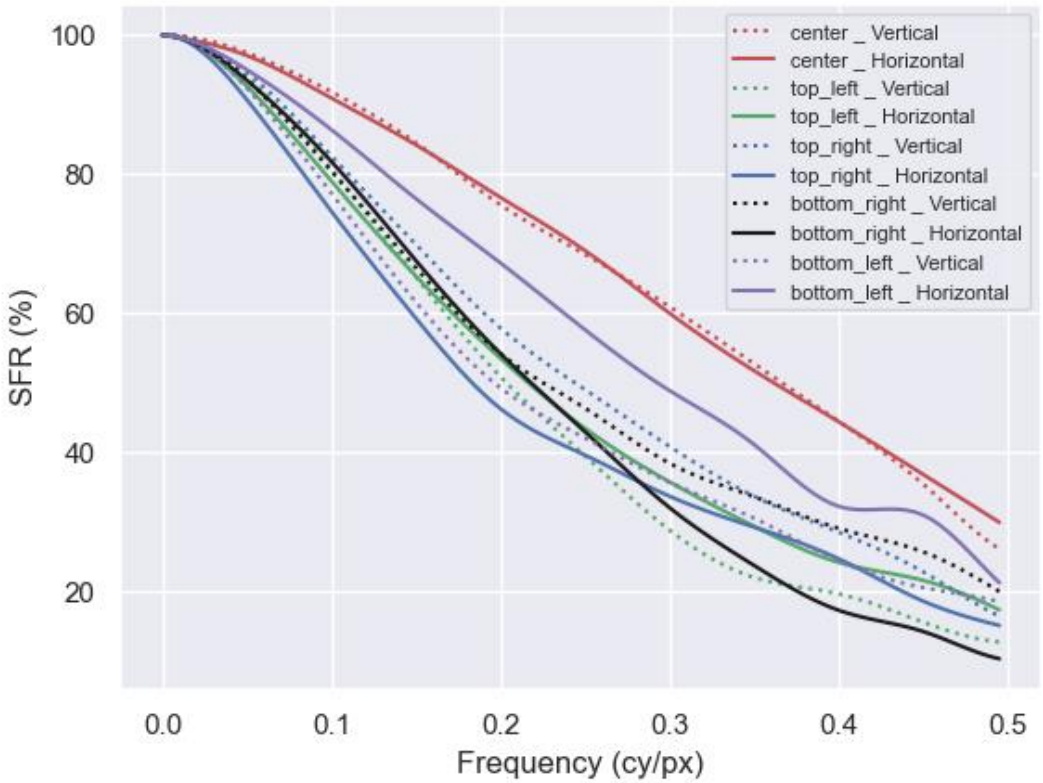
- Through Focus

- Chosen position for best focus is 7m.



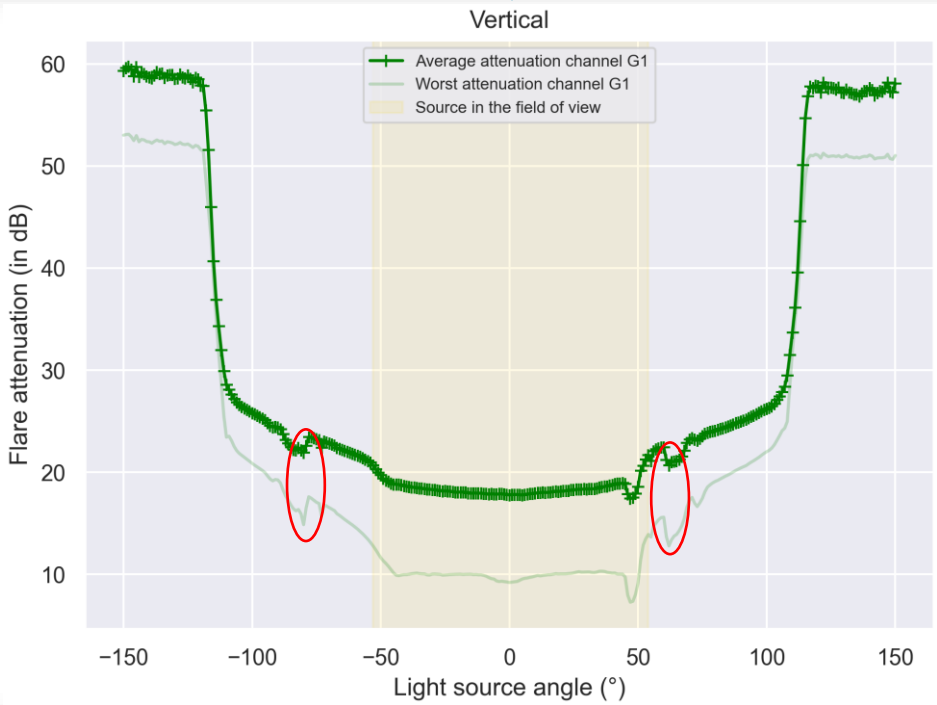


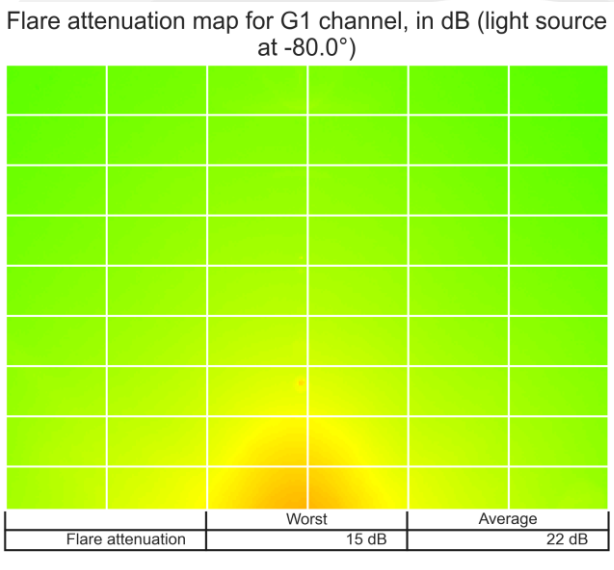
- MTF at 7m, chart illumination : D65 360 lux

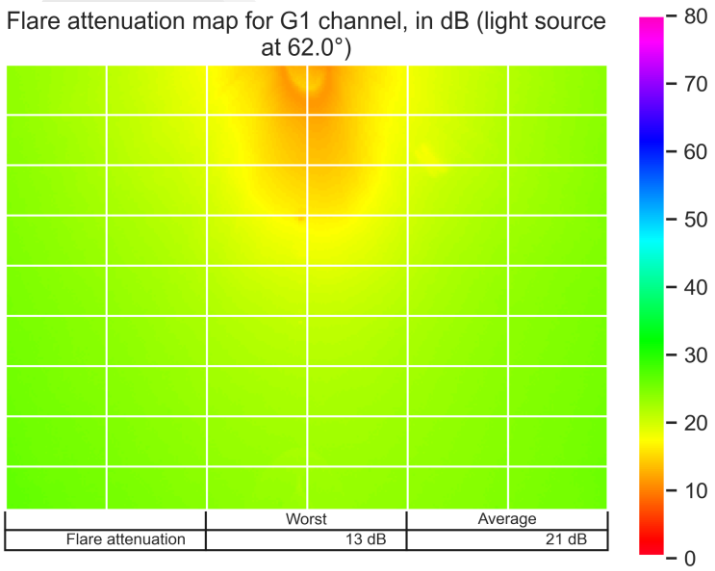


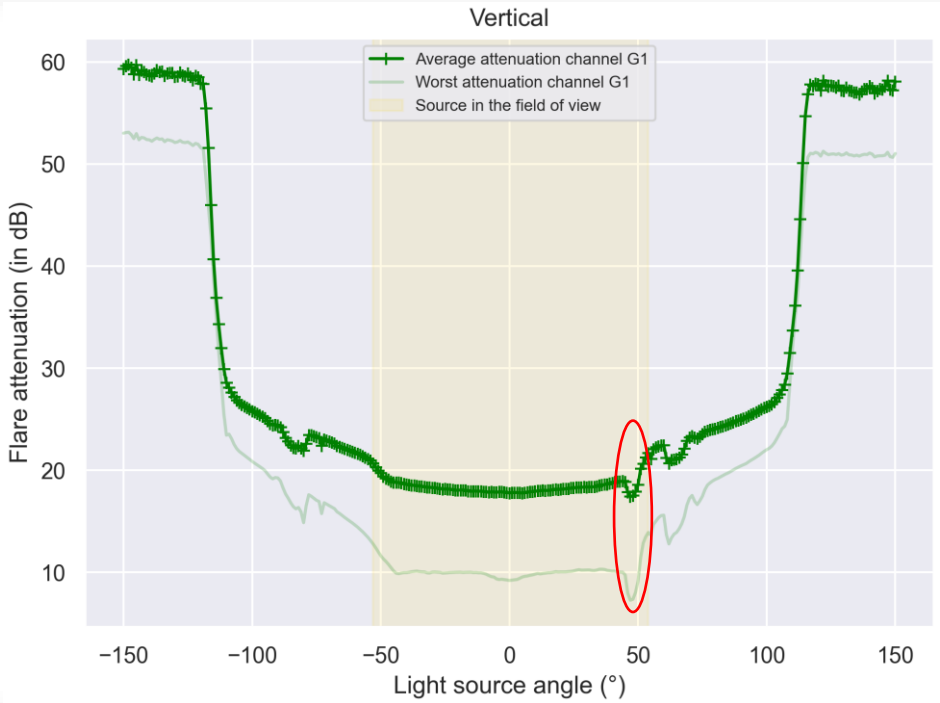
	center Vertical	center Horizontal	top_left Vertical	top_left Horizontal	top_right Vertical	top_right Horizontal	bottom_right Vertical	bottom_right Horizontal	bottom_left Vertical	bottom_left Horizontal
SFR10 in cy/px	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
SFR50 in cy/px	0.37	0.36	0.2	0.22	0.24	0.18	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

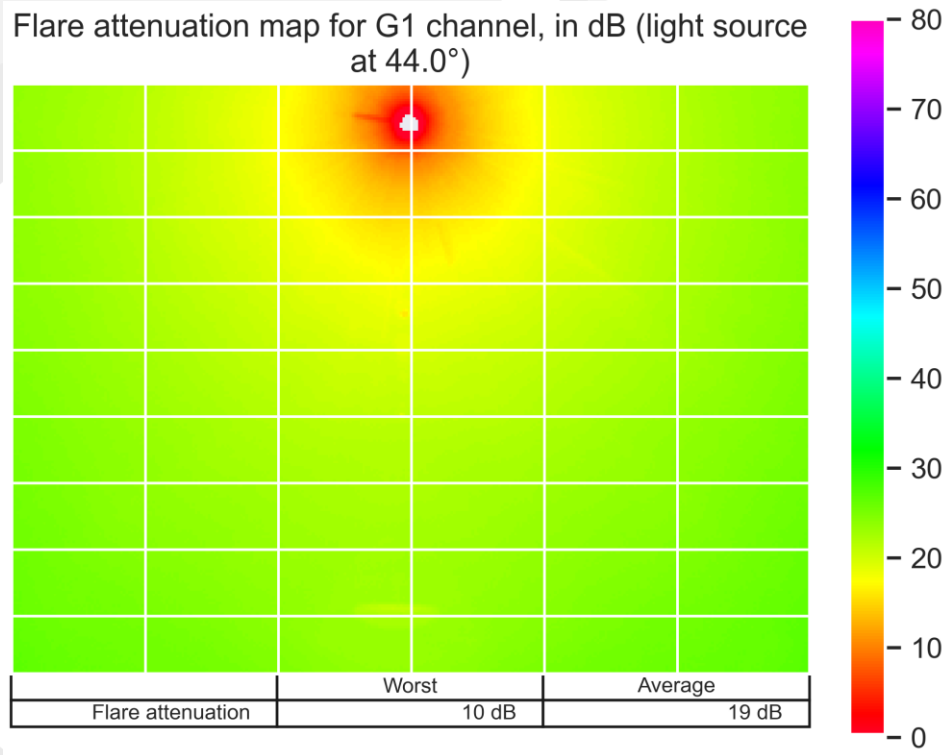
	Vertical	Horizontal
Corner Variance SFR50 in %	19.54	37.43
Corner Variance Acutance in %	8.36	18.2

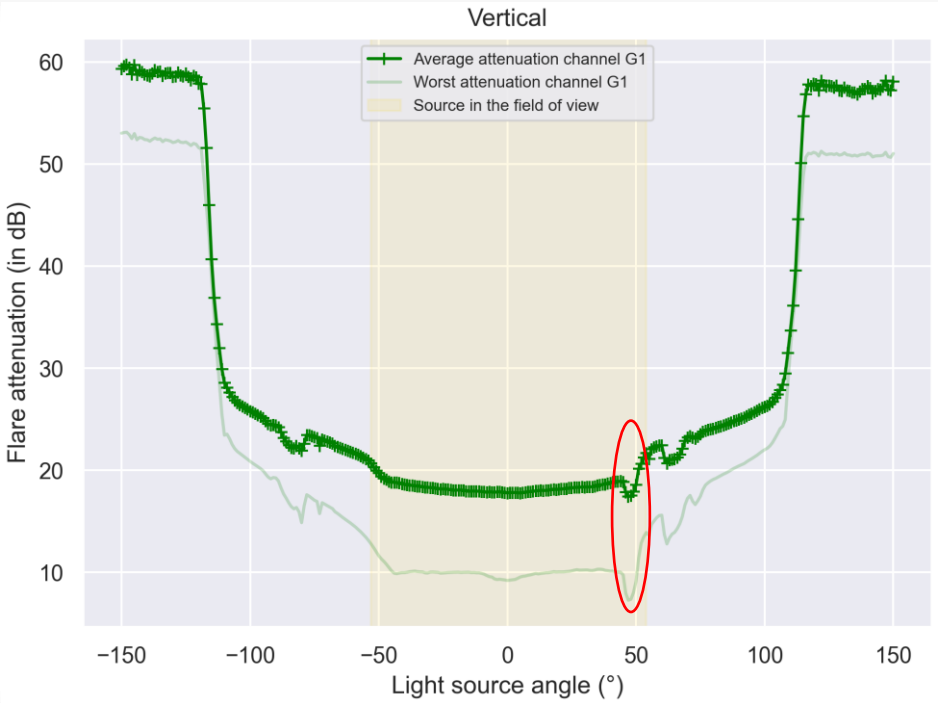

Vertical
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

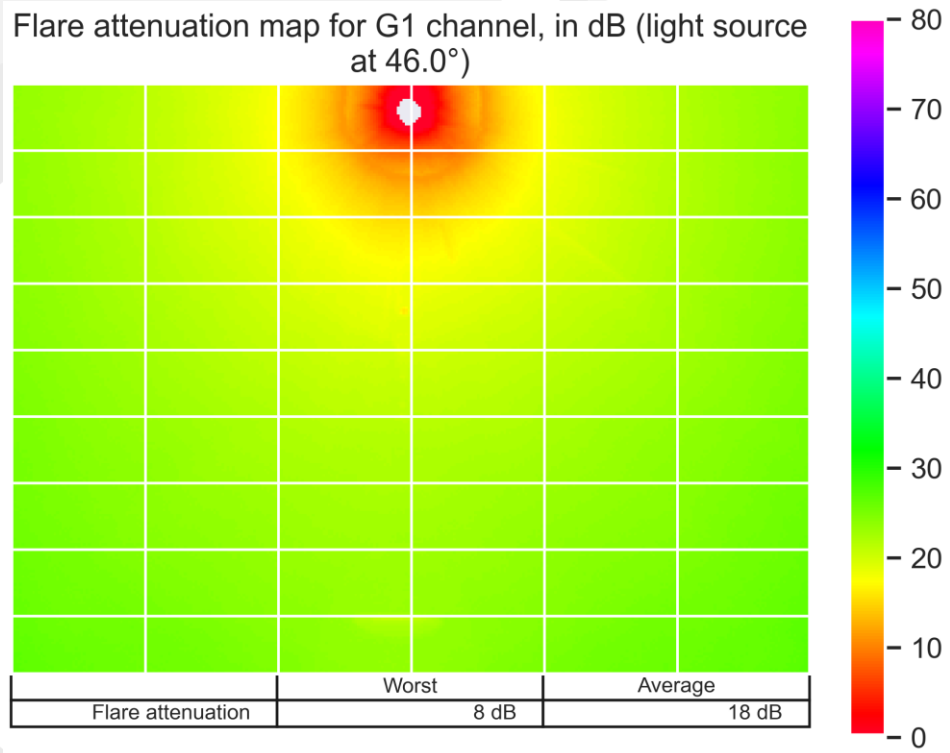

Flare attenuation map for G1 channel, in dB (light source at -80.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
15 dB
22 dB

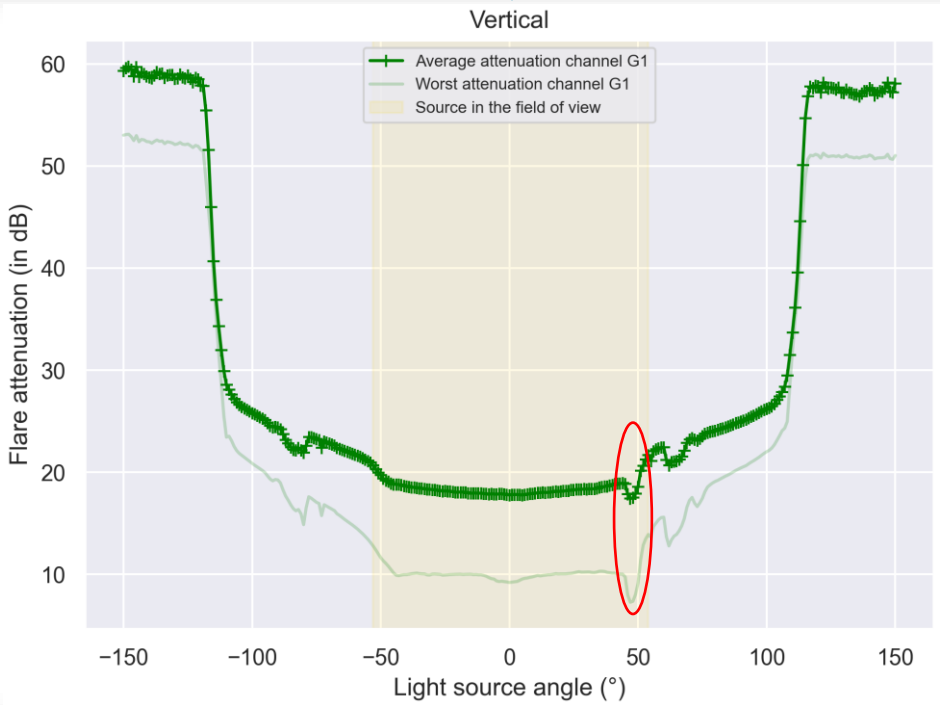

Flare attenuation map for G1 channel, in dB (light source at 62.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
13 dB
21 dB

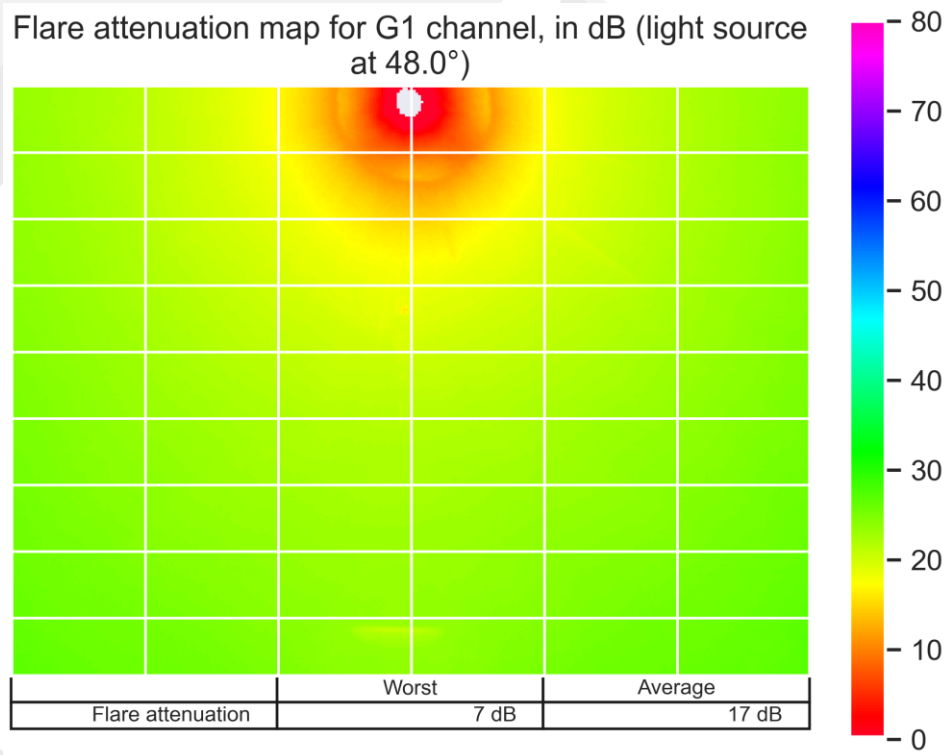

Vertical
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

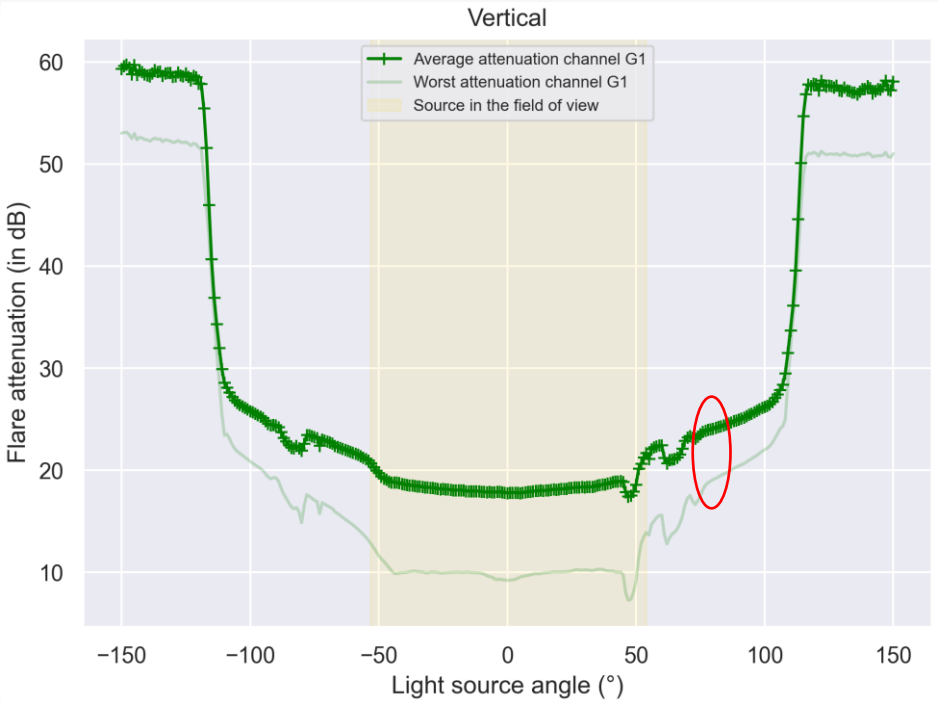

Flare attenuation map for G1 channel, in dB (light source at 44.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
10 dB
19 dB

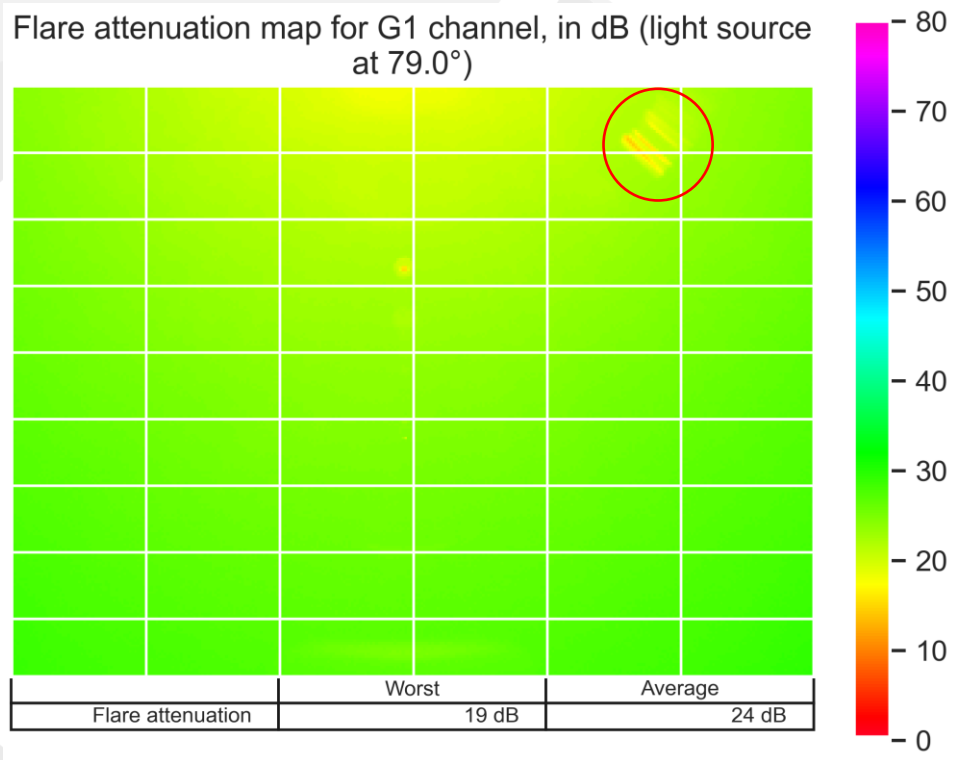

Vertical
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

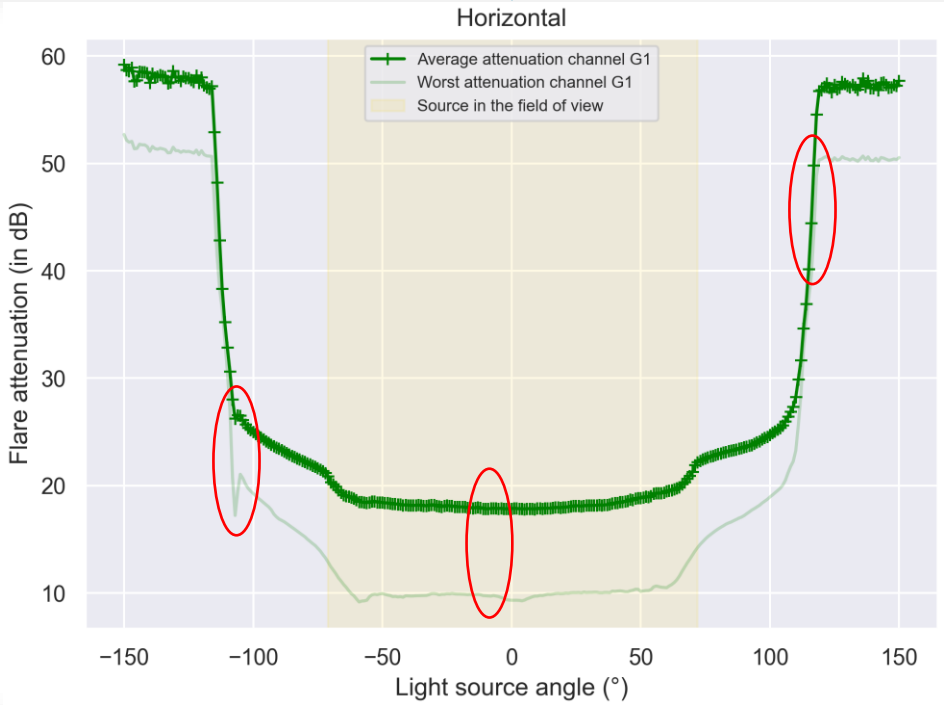

Flare attenuation map for G1 channel, in dB (light source at 46.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
8 dB
18 dB

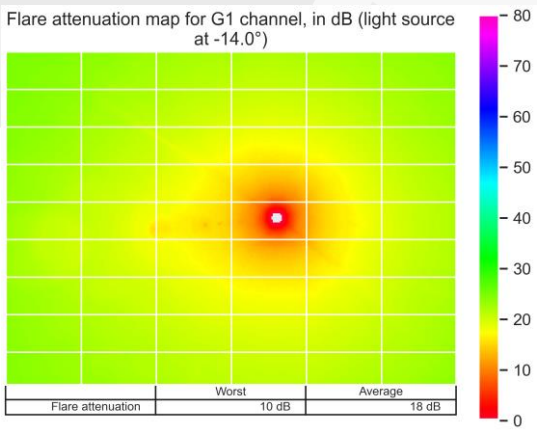

Vertical
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

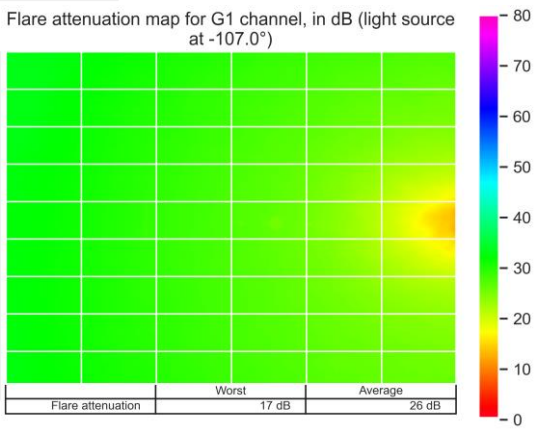

Flare attenuation map for G1 channel, in dB (light source at 48.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
7 dB
17 dB

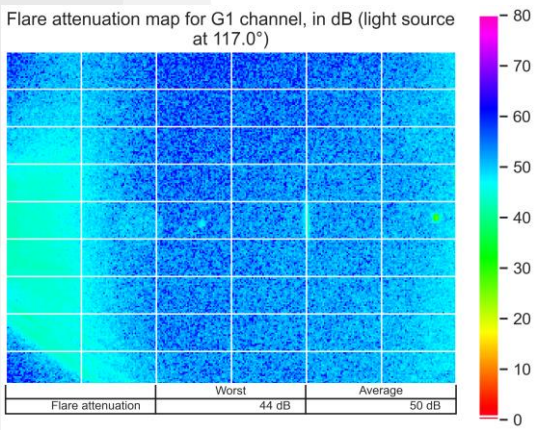

Vertical
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

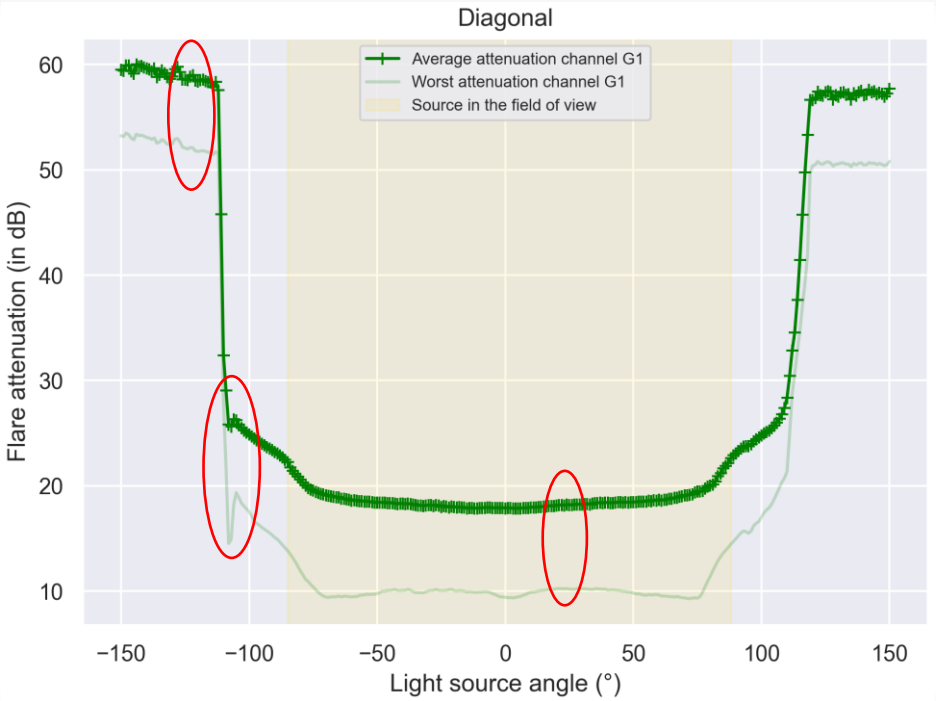

Flare attenuation map for G1 channel, in dB (light source at 79.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
19 dB
24 dB

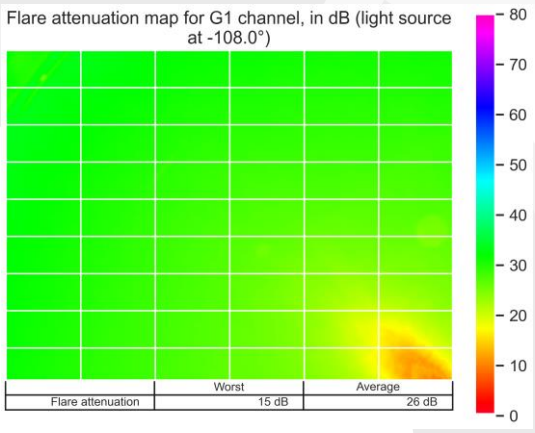

Horizontal
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

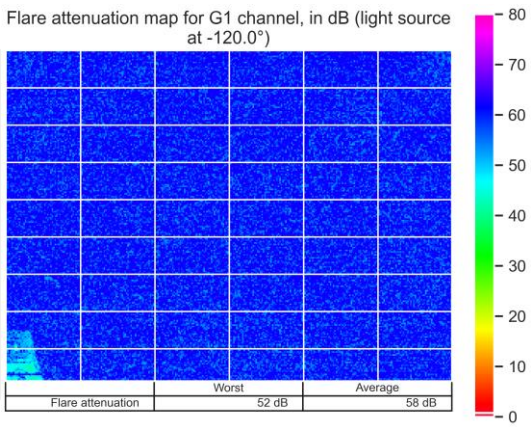

Flare attenuation map for G1 channel, in dB (light source at -14.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
10 dB
18 dB

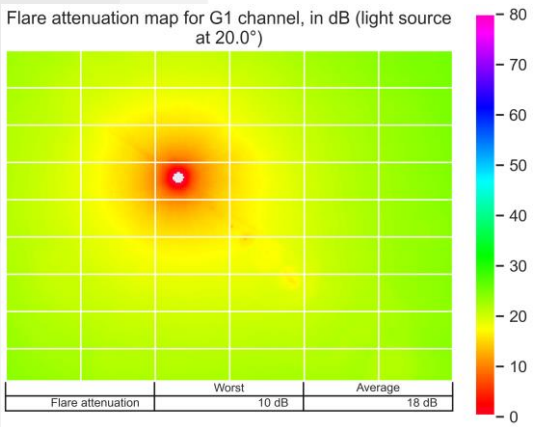

Flare attenuation map for G1 channel, in dB (light source at -107.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
17 dB
26 dB

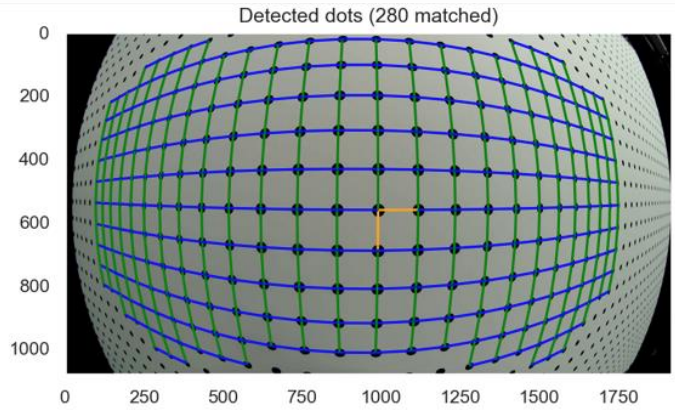

Flare attenuation map for G1 channel, in dB (light source at 117.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
44 dB
50 dB

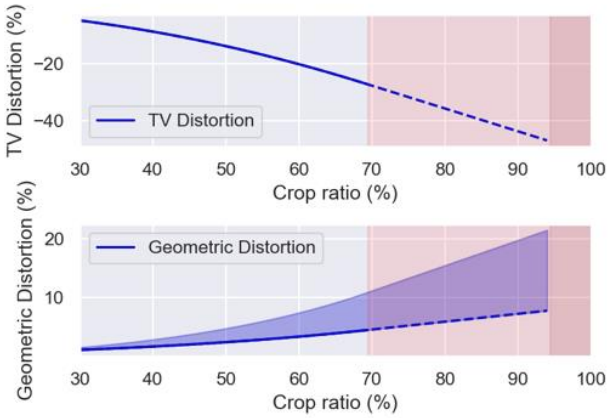

Diagonal
Average attenuation channel G1
Worst attenuation channel G1
Source in the field of view
Flare attenuation (in dB)
60
50
40
30
20
10
−150
−100
−50
0
50
100
150
Light source angle (°)

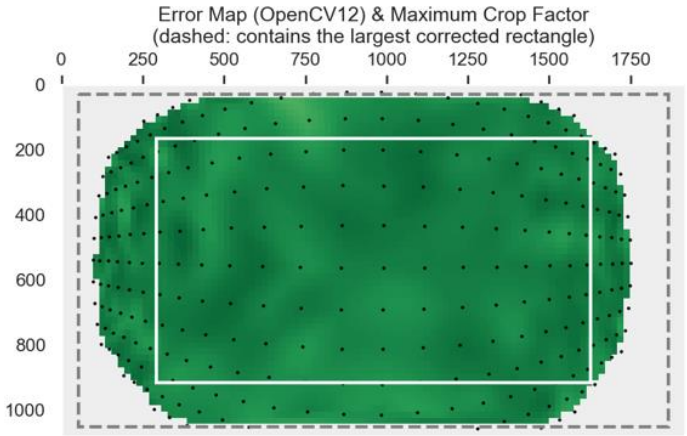

Flare attenuation map for G1 channel, in dB (light source at -108.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
15 dB
26 dB

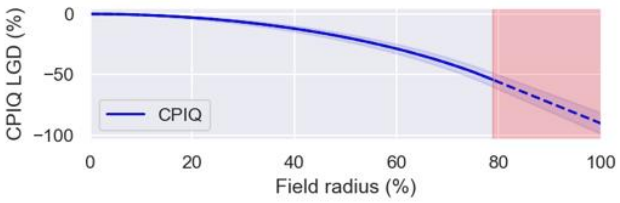

Flare attenuation map for G1 channel, in dB (light source at -120.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
52 dB
58 dB

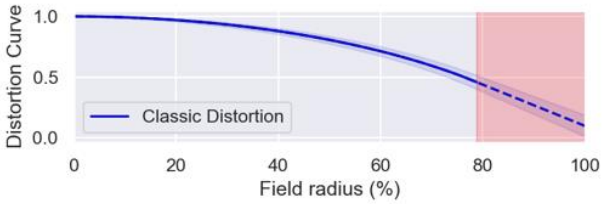

Flare attenuation map for G1 channel, in dB (light source at 20.0°)
80
70
60
50
40
30
20
10
0
Worst
Average
Flare attenuation
10 dB
18 dB

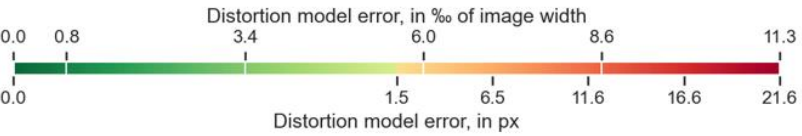






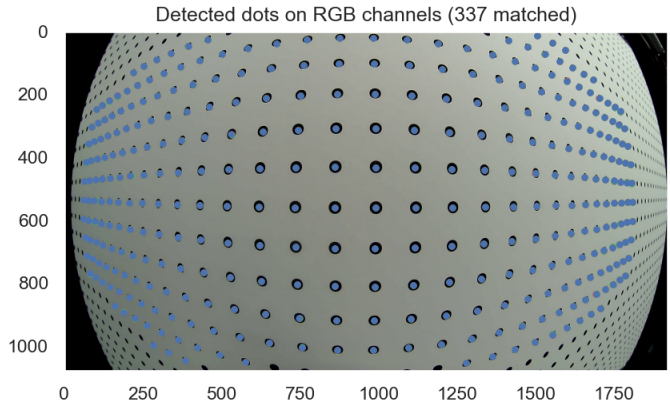


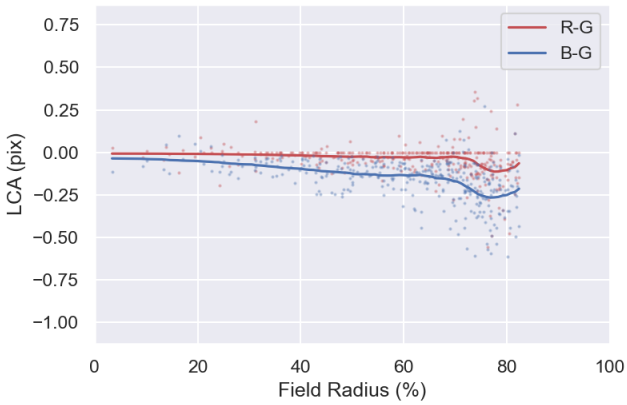


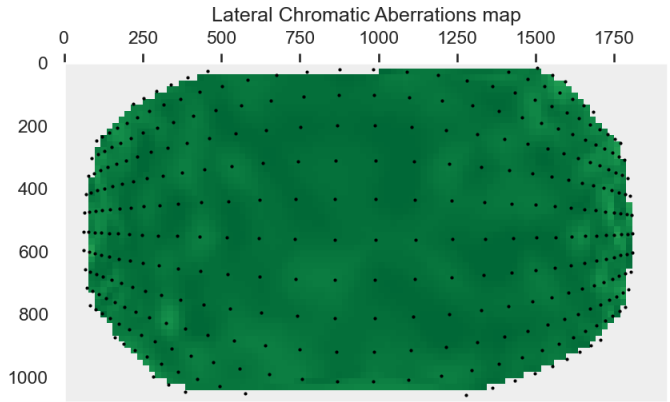


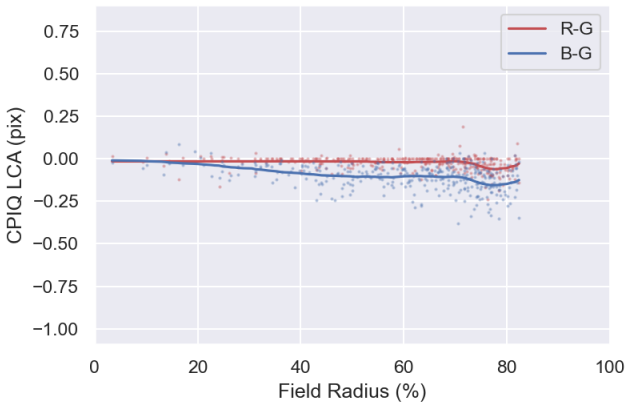
	Results	Results (extrapolated)
TV Distortion	-46.83%	-27.27%
Geometric Distortion (avg)	+7.81%	+4.55%
Geometric Distortion (Max)	+21.48%	+11.00%
CPIQ LGD (Max)	-98.73%	-59.81%
CPIQ LGD (JND)	-15.17%	-15.17%

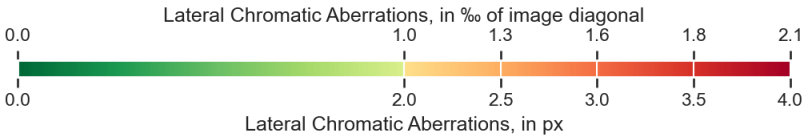
Good fitting of the distortion model (small reprojection error)





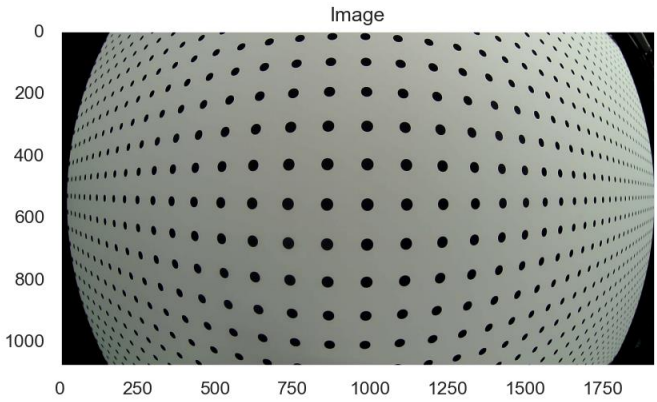


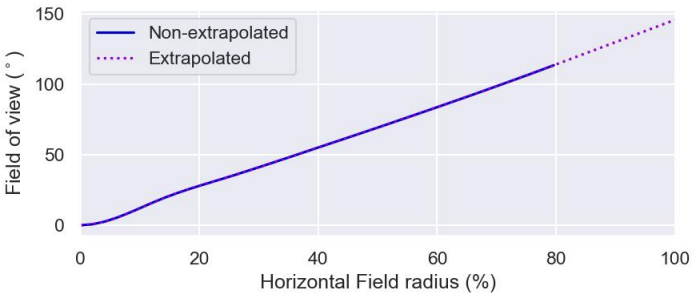


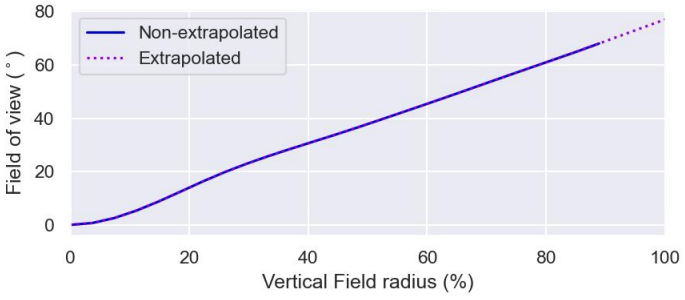


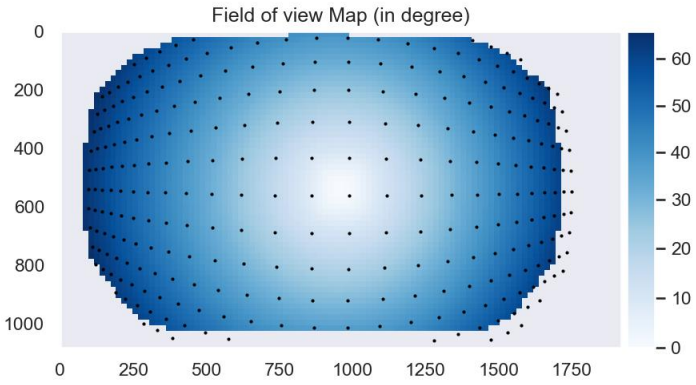
CPIQ Max LCA (Pixels)	-0.15 px
CPIQ Max LCA (Percent)	-0.01 %
CPIQ Max LCA (JND)	0.00

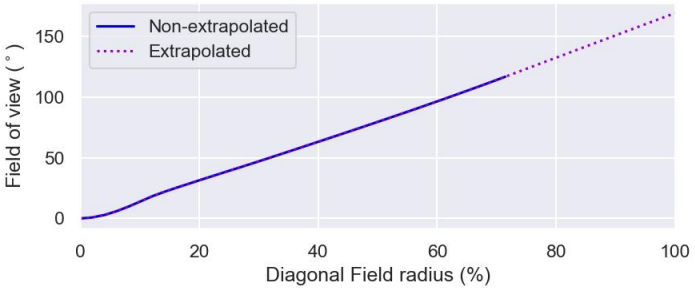
Chromatic Aberrations are negligible (less than 1 pixel in the full measurement area)







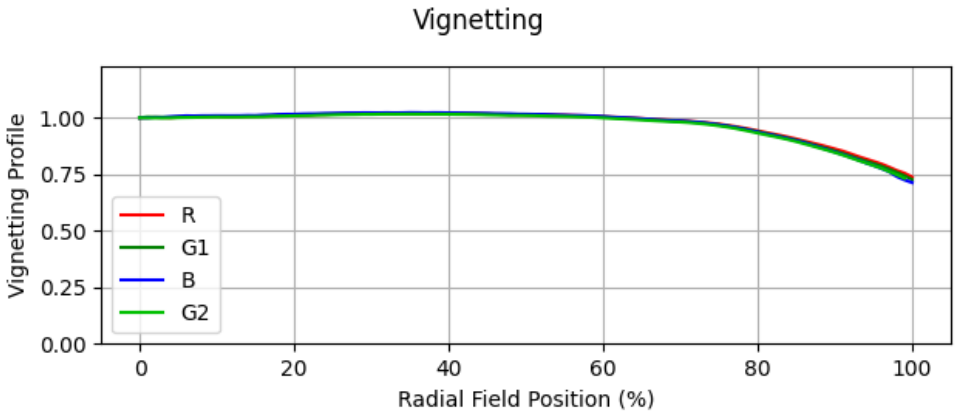




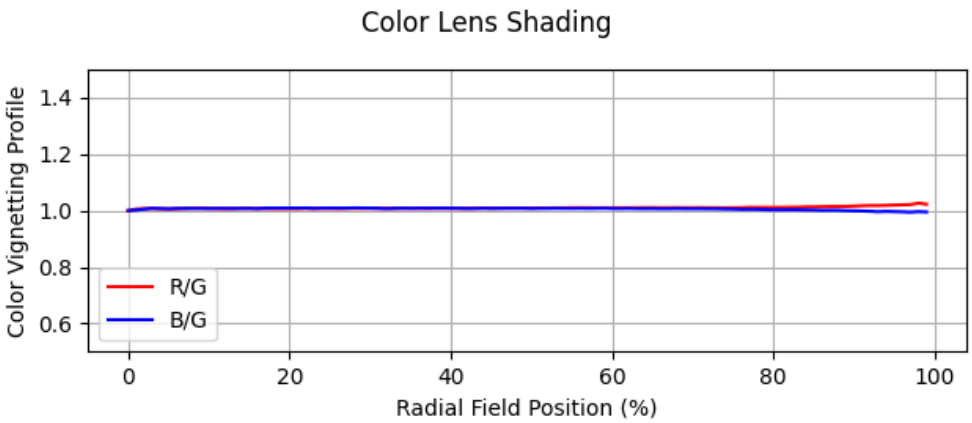
	H. FoV	V. FoV	D. FoV
Non-extrapolated	113.41 °	67.98 °	116.96 °
Extrapolated	145.64 °	77.01 °	169.55 °
	Tilt	Pan	
Orthofrontality	2.5 °	0.68 °	

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

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



	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

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