This Module includes essential hardware and software to execute a suite of optical performance tests for digital cameras. Users can analyze sharpness, distortion, luminance and color shading, chromatic aberrations, color fringing, and effective focal length on single photos. Multiple measurements can be done using the same image on one chart.

The Module's configuration is very flexible to address a wide range of customer needs. It ranges from the simplest software + chart package to a comprehensive package including our lab system and automated lighting system.

## Key features

- **Delivers the relevant metrics of lens quality :** optical distortion, sharpness, luminance and color shading, and chromatic aberrations. Perform several measurements in one image of the chart.
- **Includes high-quality test chart(s), recommended lab equipment, in-depth documentation, and the analysis software in one package**
- **Automatically detects relevant test chart patterns and reports results** with no operator intervention
- **Performs measurements on RGB (.jpeg, .tiff, etc.) or RAW images**
- **Analyzes image quality under dynamic lighting conditions,** with a large range of color temperatures and light in-tensities
- **Can measure cameras with resolutions from VGA to 50Mpix,** and fields of view up to 160° (Fish-eye lenses support requires another module)

## Application across many markets

The Optics Module is compatible with cameras designed for many applications and markets :

- Photography (DSC and DSLRs)
- Mobile (smartphone camera module)
- Automotive (camera for ADAS system)
- Surveillance (IP Camera, CCTV)
- Medical
- Drones
- Wearables
  Etc.

## Available Optics Module measurements

Optics Module measurements are performed on several charts adapted to the measured phenomena. The respective measurements are listed in the following table :
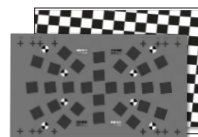
### DOT CHART
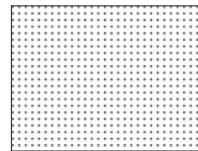


- Distortion
- Lateral chromatic aberrations
- Blur/Sharpness (BxU)
- Luminance and color shading
- Flash
- Effective focal length

### UNIFORM CHART



- Luminance and color shading

### MTF CHARTS OR ISO12233 CHART



- Modulation Transfer Function (MTF)
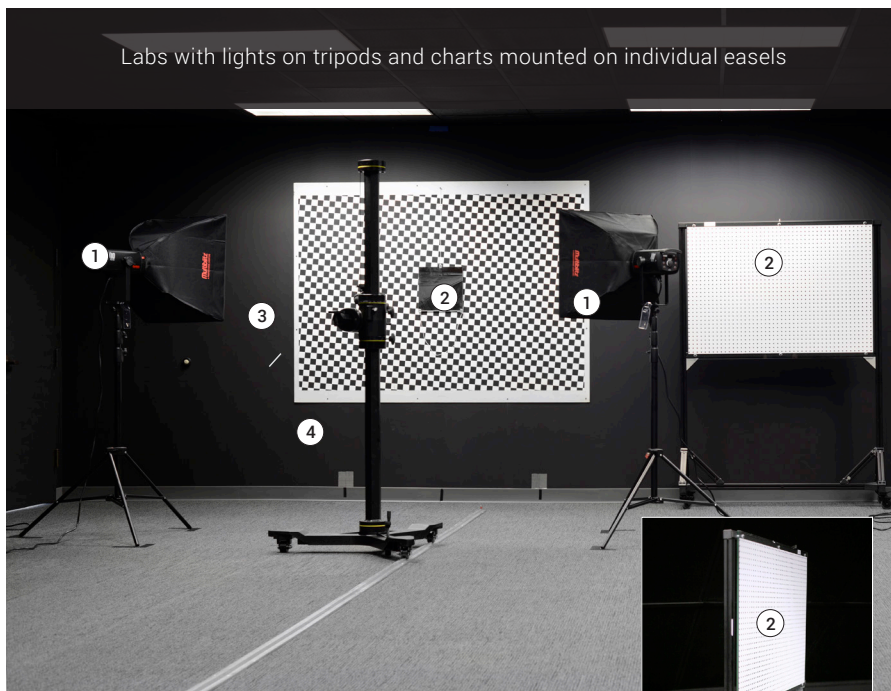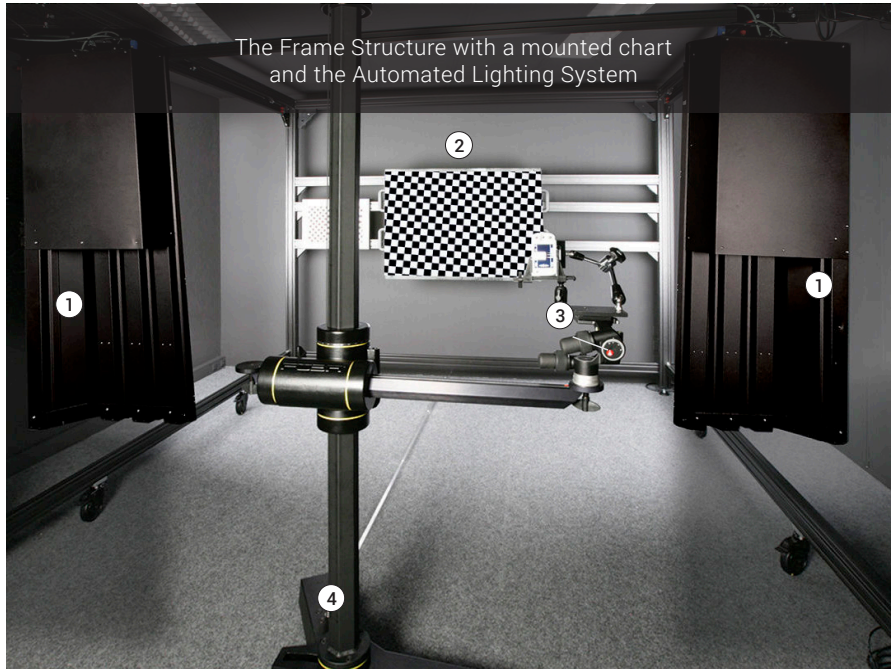- Longitudinal chromatic aberation
- Fringing
- Astigmatism

### COLOR FRINGING CHART



- Color fringing
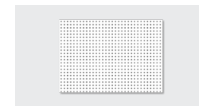
## OPTICS MODULE MEASUREMENTS HARDWARE

# Recommended lab environment : two configurations



The Frame Structure with a mounted chart and the Automated Lighting System



Labs with lights on tripods and charts mounted on individual easels

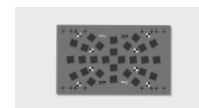① Lightboxes  ② Chart  ③ Camera  ④ Tripod

# Recommended equipment

### CHARTS AND FRAMING

**DOT Chart**
*(Four sizes available)*

**MTF Chart***
*(Three sizes available)*

**MTF Chart***
*(IEEE-CPIQ compliant Two sizes available)*

**Color Fringing Chart**
*(to be used with a Kyoritsu pattern box)*

*\* Charts are provided with calibrated MTF (compensation for paper chart resolution)*

**Kyoritsu Pattern Box**
*(fluorescent or tungsten)*

**ITEM Framing Structure**
*(3mx3mx2.5m)*

**ITEM Easel for charts**

### REFLECTION LIGHTING

**Automated Lighting System (2 units) :** *+ with control software and auto-regulation setup*

**Kino Flo LED Celeb 250** *(2 units)*

### ACCESSORIES

**Delkin Gator Clamp holding clamp**

**LEICA Laser Telemeter**

**Foba DSS Gamma camera stand**
*+ modified wheels + 4m guiding rail*

**Gossen Luxmeter - Mavolux 5032B**
*+ luminance attachment + certificate*

# Optics Measurements

## Analyzer software processes the image files

Measurements provided by all purchased modules are available in this interface, and can be accessed from their respective charts. The results are displayed in the interface after processing, and can be exported in html, spreadsheet, or pdf formats.

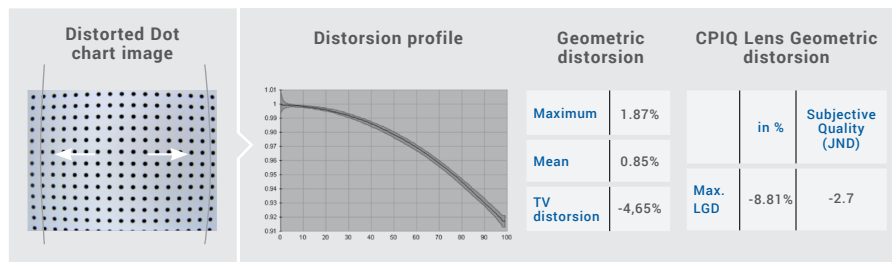Here are examples of Analyzer results for all the available Optics Module measurements

**The Analyzer interface**
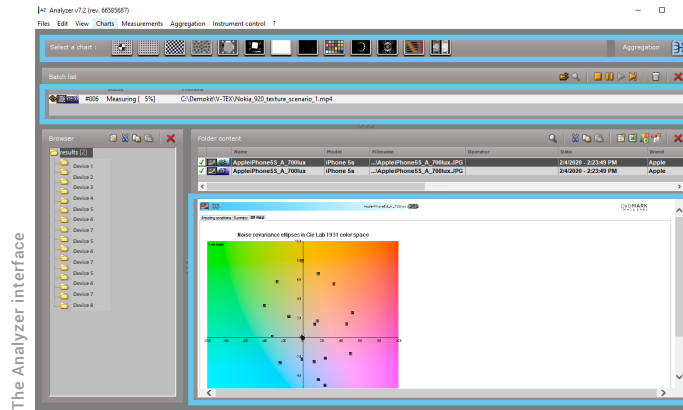


Select chart to launch a new measurement

Batch processing of photos and videos

Results are available in comprehensive graphiecs

## Distortion

Distortion from DOT chart analysis – including CPIQ metrics



| Distorted Dot chart image | Distorsion profile | Geometric distorsion | | CPIQ Lens Geometric distorsion | |
|---|---|---|---|---|---|
| | | | | in % | Subjective Quality (JND) |
| | | Maximum | 1.87% | | |
| | | Mean | 0.85% | | |
| | | TV distorsion | -4,65% | Max. LGD | -8.81% | -2.7 |

## Lateral chromatic aberrations

LCA from DOT chart analysis – including CPIQ metrics



| Dot image with lateral chromatic aberration | Max LCA map | CA 2D Map (LGD) | | | CPIQ Lens Geometric distorsion (LCA) | | |
|---|---|---|---|---|---|---|---|
| | | | Pixels | /1000 | in µm (20x30 cm eq.) | in % | Pixels | Subjective Quality (JND) |
| | | Max. | 1.7 | 2.1 | 745.728 | Max. LCA | -0.17% | -0.8 | -0.0 |
| | | Mean | 0.7 | 0,9 | 313.391 | | | | |

## Blur/Sharpness (BxU, "Blur eXperience Unit")

Sharpness - BxU Measurement from DOT chart



**25 BxU values across the image frame**

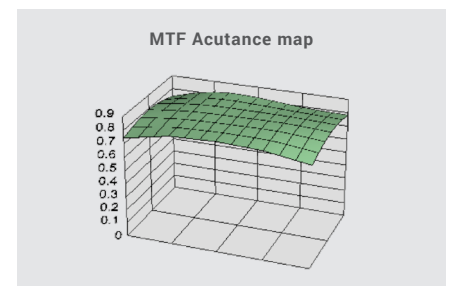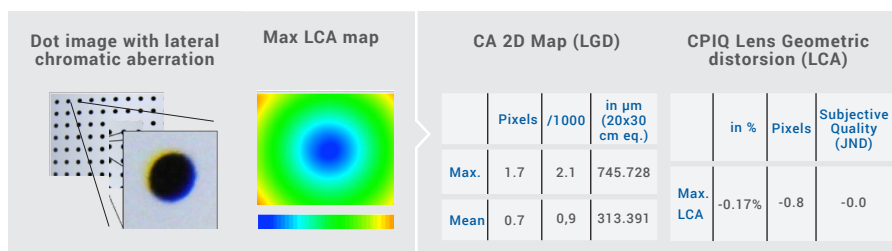| 1.55 | 1.46 | 1.45 | 1.41 | 1.42 |
|---|---|---|---|---|
| 1.47 | 1.40 | 1.33 | 1.36 | 1.35 |
| 1.51 | 1.26 | 1.25 / 1.25 / 1.33 / 1.55 | 1.32 | 1.29 |
| 1.36 | 1.36 | 1.31 | 1.27 | 1.25 |
| 1.34 | 1.27 | 1.27 | 1.28 | 1.26 |

**BxU map**

## Modulation Transfer Function (MTF)

Multi-point MTF measurements from MTF chart :

- 15 MTF curves across the image field
- Ability to define ROI for custom MTF measurement
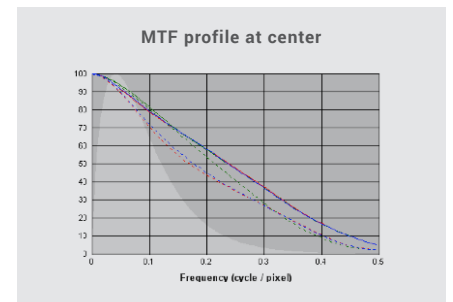- Edge acutance (computed from human CSF) for different viewing conditions
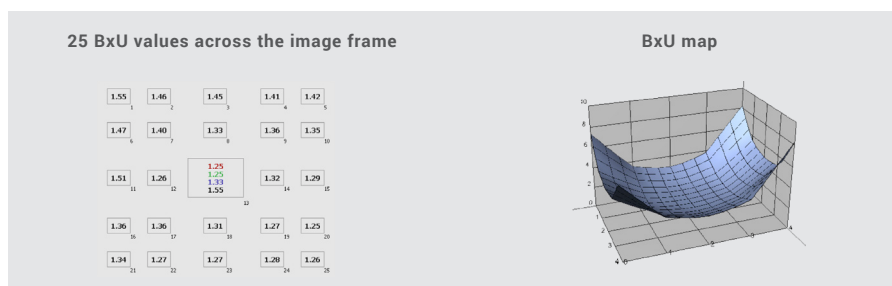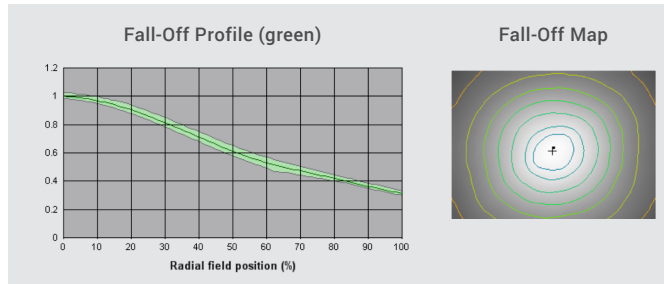

**MTF Acutance map**


**MTF profile at center**

- : red channel (horizontal)
- : red channel (vertical)
- : green channel (horizontal)
- : green channel (vertical)
- : blue channel (horizontal)
- : blue channel (vertical)

## Luminance and color shading
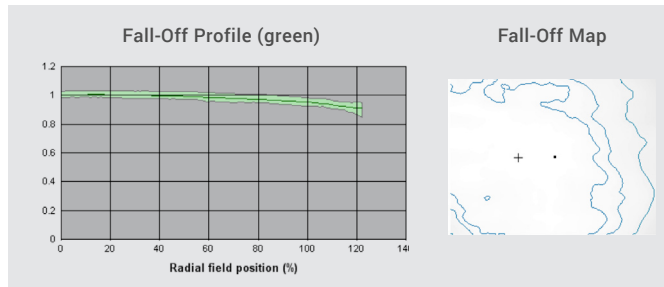
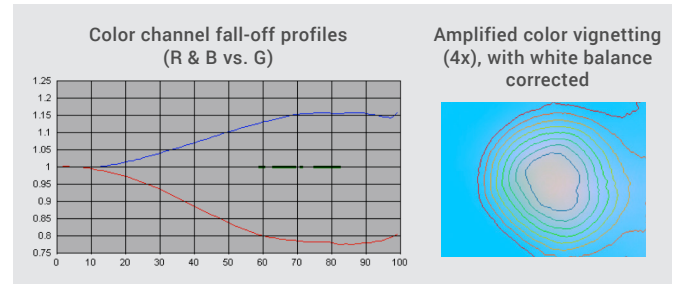Luminance shading from DOT or uniform chart - RAW and JPEG

*> Measurement from RAW*



Fall-Off Profile (green)     Fall-Off Map
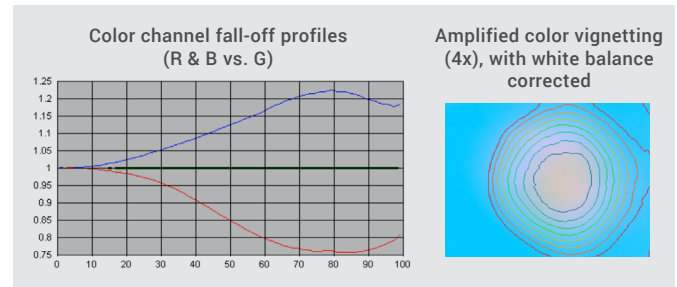
*> Measurement from RGB*



Fall-Off Profile (green)     Fall-Off Map

Color shading from DOT or uniform chart

*> Daylight illumination - RAW*



Color channel fall-off profiles (R & B vs. G)     Amplified color vignetting (4x), with white balance corrected

*> TL84 illumination - RAW*



Color channel fall-off profiles (R & B vs. G)     Amplified color vignetting (4x), with white balance corrected

## Effective focal length

Effective focal length and field of view with DOT chart, measured in the field.



Effective focal length profile (24x36mm equivalent)

Field of view profile
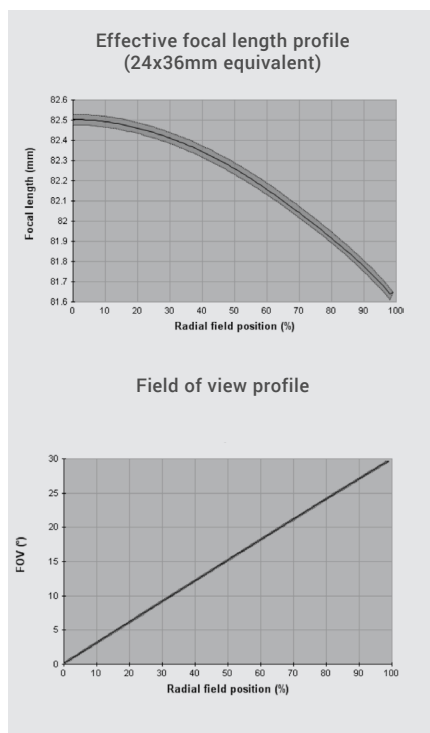
## Flash

Flash uniformity and white balance, from DOT or uniform chart.



Fall-Off Profile     Fall-Off Map

| | Chromatic deviation | Off-centering |
|---|---|---|
| | 1.61 | 15.03 |

| | In EV | in % | in density |
|---|---|---|---|
| Max. atténua-tion | 0.18 | 11.08 | 0.05 |
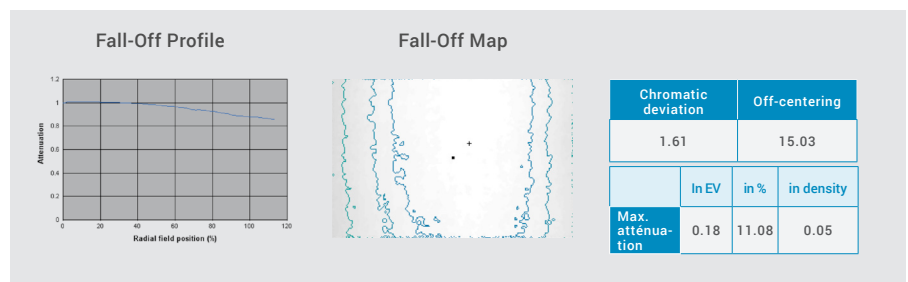
## Color fringing

Color fringing is due to longitudinal chromatic aberration, and is highly visible when the sensor is saturated. It is computed using a Color Fringing chart.



Crop of an edge shot     Profile differences

| | Average amount |
|---|---|
| R | 54.6 (7.48) |
| B | 0.4 (0.06) |
| P | 0.4 (0.06) |

*unit = size in pixel * intensity in % (and size in 20x30cm eq. * intensity in %)*

# Measurement accuracy

### DISTORTION AND LATERAL CHROMATIC ABERRATIONS

These calculations are accurate to about 0.5 pixel (the usual observed accuracy for the positions of the dot centers). Thus the accuracy of lateral chromatic aberration is ± 0.5 pixel. The accuracy of the geometric distortion measurement is directly proportional to the image resolution, according to the formula (± 0.5 pixel x 100) / (image height in pixels). Example: For a 4064x2704-pixel image, the accuracy of the positional error measurement is ± 0.02 %.

### EFFECTIVE FOCAL LENGTH

The measurement accuracy depends on the accuracy of the measured distances and on the orthofrontality of the chart during shooting. With an orthofrontality angle of less than 0.5 degree, and a distance error of less than 1% on the measured distance, the measurement accuracy is ± 1%.

### MODULATION TRANSFER FUNCTION (MTF)

For MTF curves, the measurement repeatability is ± 4% on average, with higher accuracy at lower frequencies, as shown in the table:

Frequency (cy/pixel) Repeatability of acutance measurements is ± 0.04. However, this depends on the measured camera characteristics (autofocus accuracy and repeatability, mechanical vibrations).

| Frequency (cy/pixel) | Accuracy (RGB) | Accuracy (RAW) |
|---|---|---|
| [0;0.1] | ± 2% | ± 3% |
| [0.1;0.3] | ± 4% | ± 6% |
| [0.3;0.5] | ± 7% | ± 10% |

### BLUR/SHARPNESS (BXU)

Measurement accuracy is ± 5 %. For example, if a perceptual blur measures 4 BxU, its accuracy is ± 0.2 BxU.

### LUMINANCE AND COLOR SHADING

Measurement accuracy strongly depends on the uniformity of the lighting on the chart. Usually, the best possible lighting uniformity (1 − luminosity min / luminosity max) is 7%, leading to a 7% error for RAW measurements. The error for RGB measurements then depends on the tone curve applied by the camera.The repeatability of the color shading ratio is ± 0.5%.

### FLASH

The flash measurement is the equivalent of a shading measurement that evaluates the flash and optics. Optics shading cannot be separated from flash shading. The power of the light emitted by the flash unit is dependent on the level of the battery charge and the time between two consecutive shots. There is currently no way to retrieve these parameters accurately.

### COLOR FRINGING

This measurement estimates the saturation level in the image. The accuracy of the saturation measurement is related to the quantization of the step wedge. As each step is 0.05 density, a saturation factor  is known with a precision of 12%. For example, if the measured saturation is 11.22, it means that saturation is between 10 and 11.22. The accuracy of the fringing measurement is ±8 pixels.

# Specifications

## Camera testing specifications

**Min resolution :** VGA
**Max resolution :** up to 50Mpix
**FOV :** up to 160°
**Focal length :** Min.: 12 mm in 35 mm format (no fish-eye lenses) Max.: limited by lab depth, 500mm for a 10m shooting distance
**Spectral sensitivity :** measurements have been designed for visible spectrum cameras
**Sensor :** Bayer filter sensor
**File formats :** Images: .jpeg, .bmp, .png, .tif, and many RAW formats (latest release notes provides a list of supported RAW formats)

## Platform requirements

PC-type computer with the following minimum configuration :

**Windows 10**
**2 GB of RAM** or more
**At least 3 Go of free disk** space to operate the software
**A video card with 3D driver**, compatible with DirectX 9c
**1024 x 768 more** for Screen display resolution

**At least one USB port**
It is possible to run Analyzer on a virtual computer (to run on a Mac platform, for instance), or to control it remotely. Depending on the selected remote OS, some graphics may not be generated.

## Laboratory requirements

**Laboratory minimum size :** 4.5 x 5m
**RAL9005 mat paint** for walls and ceiling
**Dark gray antistatic carpet** on the floor
**Temperature :** 23°C ± 2°C (ISO 554:1976)
**Humidity :** 50% ± 20% (ISO 554:1976)

**ANALYZER** *by* **DXOMARK**

This Module includes essential hardware and software to perform a suite of photo quality performance tests for digital cameras. User can analyze ISO sensitivity, tone curve, dynamic and tonal range, contrast, noise, color, texture preservation and defective photosites.

The Module configuration is very flexible to address a wide range of customer needs. It ranges from the simplest software + chart package to a comprehensive package including our complete lab system including our computer controlled Automated Lighting System.

## Key features

- Delivers the relevant metrics of photo quality : ISO sensitivity, tone curve (OECF), dynamic and tonal range (up to 120dB), noise, texture, dark signal analysis, color, texture preservation and defective photosites

- Includes high quality test charts, recommended lab equipment, in-depth documentation and the analysis software in one package

- Automatically detects relevant test chart patterns and reports results with no operator intervention

- Performs measurements on RGB (jpeg, .tiff, etc.) and RAW images

- Can measure cameras with resolutions from VGA to 50Mpix, and fields of view up to 160°

## Application across many markets

The Photo Module is compatible with cameras designed for many applications and markets : photography (DSCs and DSLRs), mobile (smartphone camera modules), automotive (camera for ADAS system), surveillance (IP Camera, CCTV), medical, drones, wearables, etc.

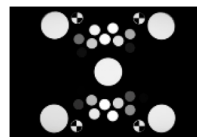## Available Photo Module measurements

Photo Module measurements are performed on several charts adapted to the measured phenomena. The respective measurements are listed in the following table :

### X-RITE COLOR CHECKER® CHART



- Noise (SNR, dynamic range, tonal range)
- Color fidelity
- Color sensitivity
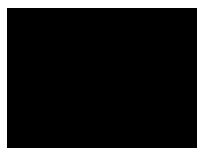- White balance accuracy

### HDR NOISE CHART



- Noise
- ISO sensitivity
- Dark signal
- Tone curve

### DEAD LEAVES CHART
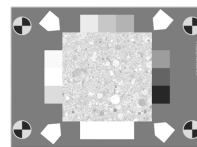


- Texture preservation (MTF and acutance on deadleaves pattern)
- Visual noise on grey level patches
- CPIQ texture for different viewing conditions

### BLACK PICTURE
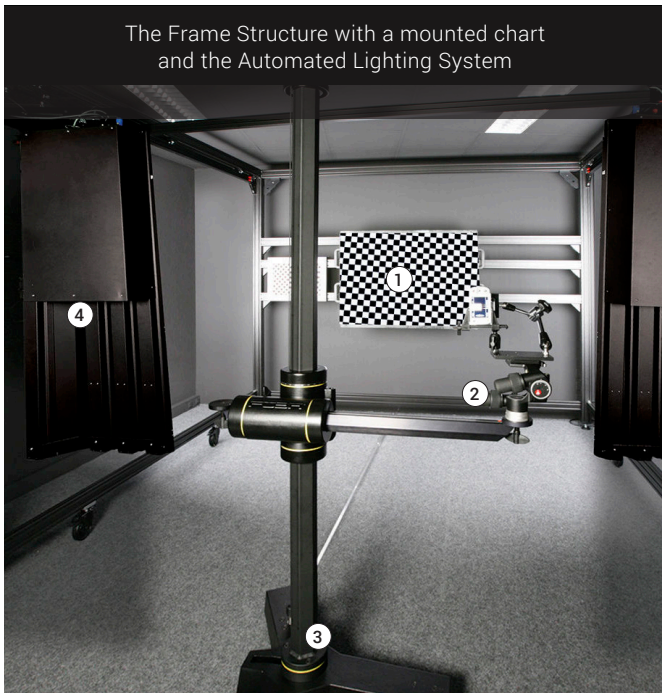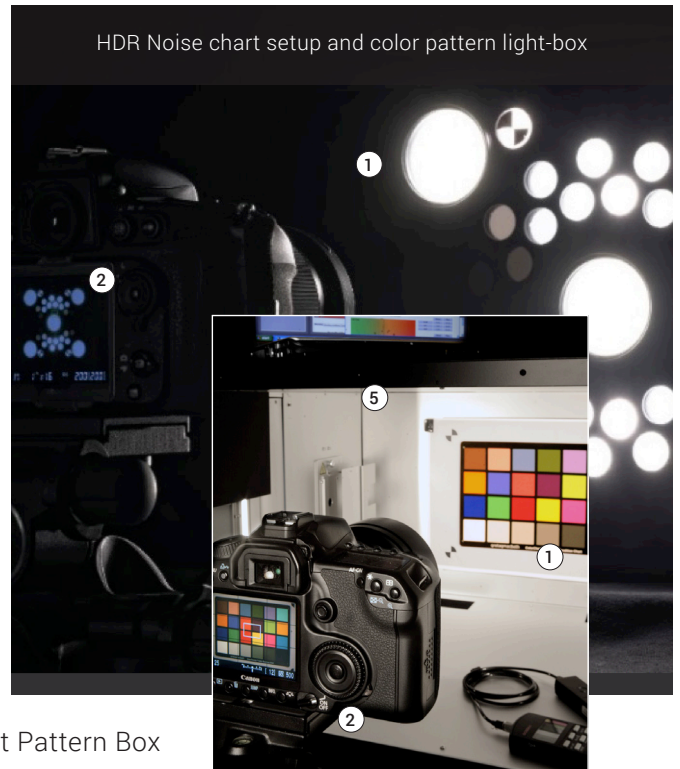


- Hot pixels
- Row/Column noise

### GREY CHART



- Dead pixels

ANALYZER *by* DXOMARK

## Recommended lab environment



The Frame Structure with a mounted chart and the Automated Lighting System



HDR Noise chart setup and color pattern light-box



① Chart , ② Camera, ③ Tripod, ④ Lightboxes, ⑤ Light Pattern Box

## Required equipment

| | |
|---|---|
|  **X-Rite Color Checker® Chart** |  **HDR Noise Chart** *(120dB luminance range)* |
|  **Dead Leaves Chart** *(785mm x603mm)* |  **Grey Chart** *(1400mm x 970mm)* |

## Recommended equipment

### REFLECTION LIGHTING

| | |
|---|---|
|  **X-Rite SpectraLight QC** |  **Kino Flo Celeb 250 LED DMX (2 units)** |
|  **Automated Lighting System (2 units):** *+ with control software and auto-regulation setup* |  **Kyoritsu Reflected Light Pattern Box** |

### FRAMING & ACCESSOIRES

| | |
|---|---|
|  **Foba DSS Gamma camera stand** *+ modified wheels* *+ 4m guiding rail* |  **Gossen Luxmeter - Mavolux 5032B** *+ luminance attachment* *+ certificate* |
|  **ITEM Framing Structure** *(3mx3mx2.5m)* |  **ITEM Easel for charts** |

**ANALYZER** by DXOMARK
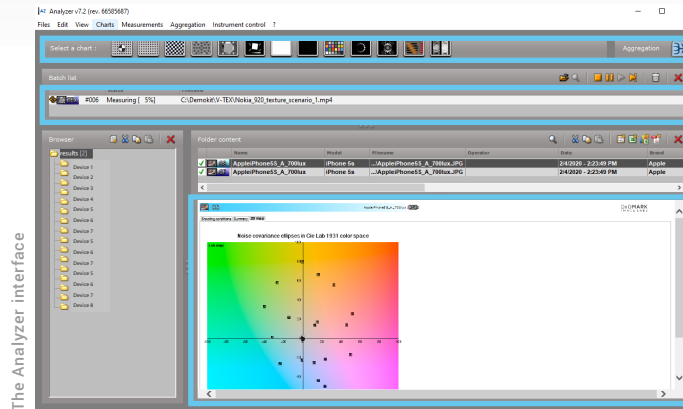
## Analyzer software processes the image files

Measurements provided by all purchased modules are available in this interface, and can be accessed from their respective charts. The results are displayed in the interface after processing, and can be exported in html, spreadsheet, or pdf formats.

The Analyzer interface



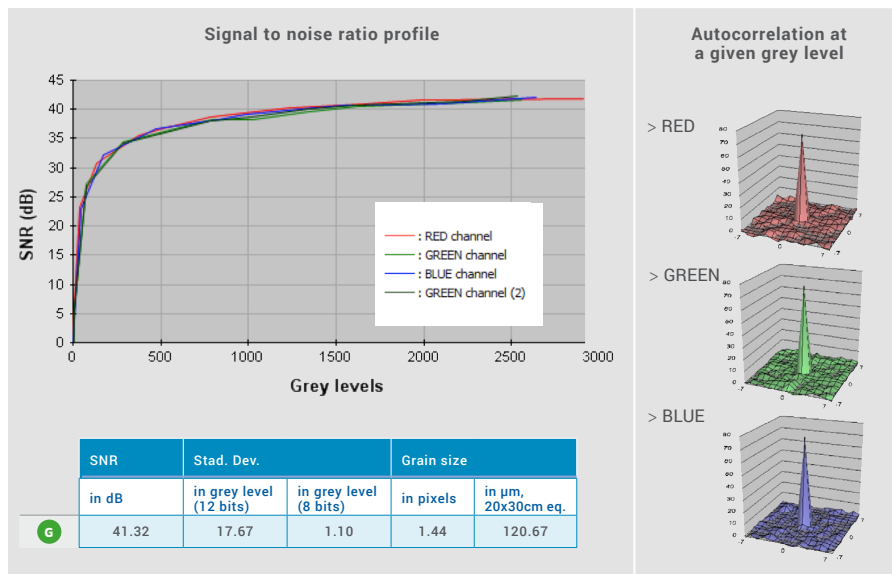Select chart to launch a new measurement

Batch processing of photos and videos

Results displayed in comprehensive graphics

⬇ Here are examples of Analyzer results for all the available Photo Module measurements

## Noise

SNR, grain size, grain coloration and autocorrelation function.



**Signal to noise ratio profile**

: RED channel
: GREEN channel
: BLUE channel
: GREEN channel (2)

| SNR | Stad. Dev. | | Grain size | |
|---|---|---|---|---|
| in dB | in grey level (12 bits) | in grey level (8 bits) | in pixels | in µm, 20x30cm eq. |
| G 41.32 | 17.67 | 1.10 | 1.44 | 120.67 |

**Autocorrelation at a given grey level**

> RED

> GREEN

> BLUE

## Tone curve (OECF)

The tone curve, also called OECF, is a non-linear function applied to the input luminance values to convert them into grey levels. It can vary with the selected mode of the camera.



**Autocorrelation at a given grey level**

: RED channel
: GREEN channel
: BLUE channel
: Luminance

Relative exposure (0 to 100%)

## Dynamic range / Tonal range

Dynamic range is the ratio between the largest luminance and the lowest luminance that a camera can capture. Tonal range is the effective number of grey levels of the camera, and takes noise into account. Here are the results for the same camera, with HDR mode activated or not:
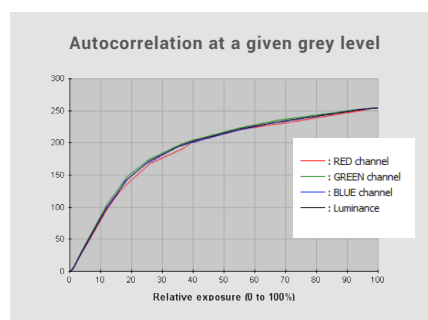
**HDR mode not activated**

| | Dynamic range | Dynamic range (Ev, stop) | Tonal range (steps) | Tonal range (bits) |
|---|---|---|---|---|
| R | 702.37 | 9.46 | 220.87 | 7.79 |
| G | 462.02 | 8.85 | 223.66 | 7.81 |
| B | 320.66 | 8.32 | 219.05 | 7.78 |
| Y | 412.08 | 8.69 | 224.80 | 7.81 |

| Contrast dynamic range | 65.01 | 6.02 EV |
|---|---|---|

> Scale of grey levels

**HDR mode activated**

| | Dynamic range | Dynamic range (Ev, stop) | Tonal range (steps) | Tonal range (bits) |
|---|---|---|---|---|
| R | 26913.75 | 14.72 | 213.38 | 7.74 |
| G | 17089.29 | 14.06 | 226.25 | 7.82 |
| B | 10338.62 | 13.34 | 220.01 | 7.78 |
| Y | 22738.62 | 14.47 | 228.36 | 7.84 |

| Contrast dynamic range | 1875.58 | 10.87 EV |
|---|---|---|

> Scale of grey levels

## Color fidelity and white balance

Ability of the camera to accurately reproduce colors in comparison with an objective reference.



As shot



Zoom on grey patches

| | Mean | Max. |
|---|---|---|
| Δ ab | 14.45 | 28.63 |
| Δ C | 12.18 | 27.31 |
| Δ H | 5.77 | 19.10 |

| | Mean | Max. |
|---|---|---|
| White Balance | 9.73 | 11.31 |
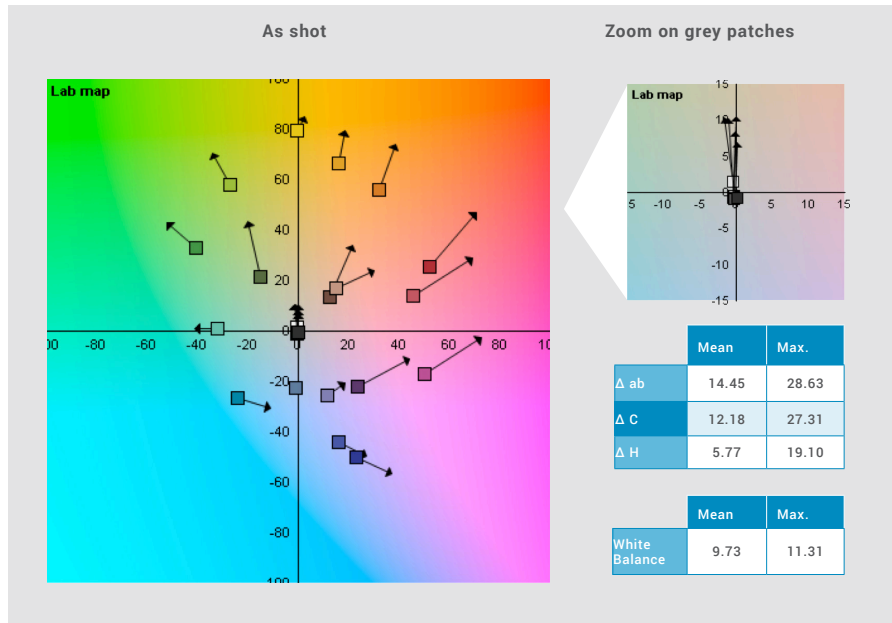
## ISO sensitivity

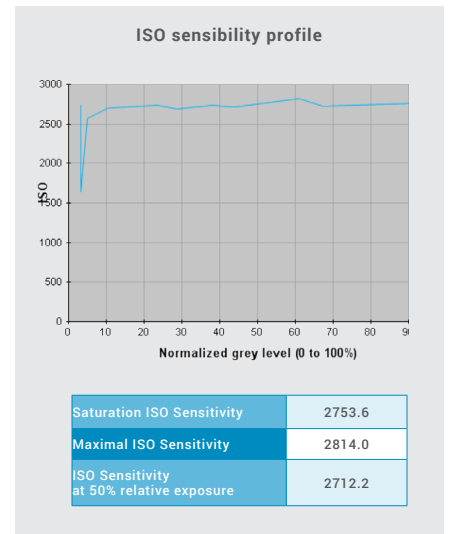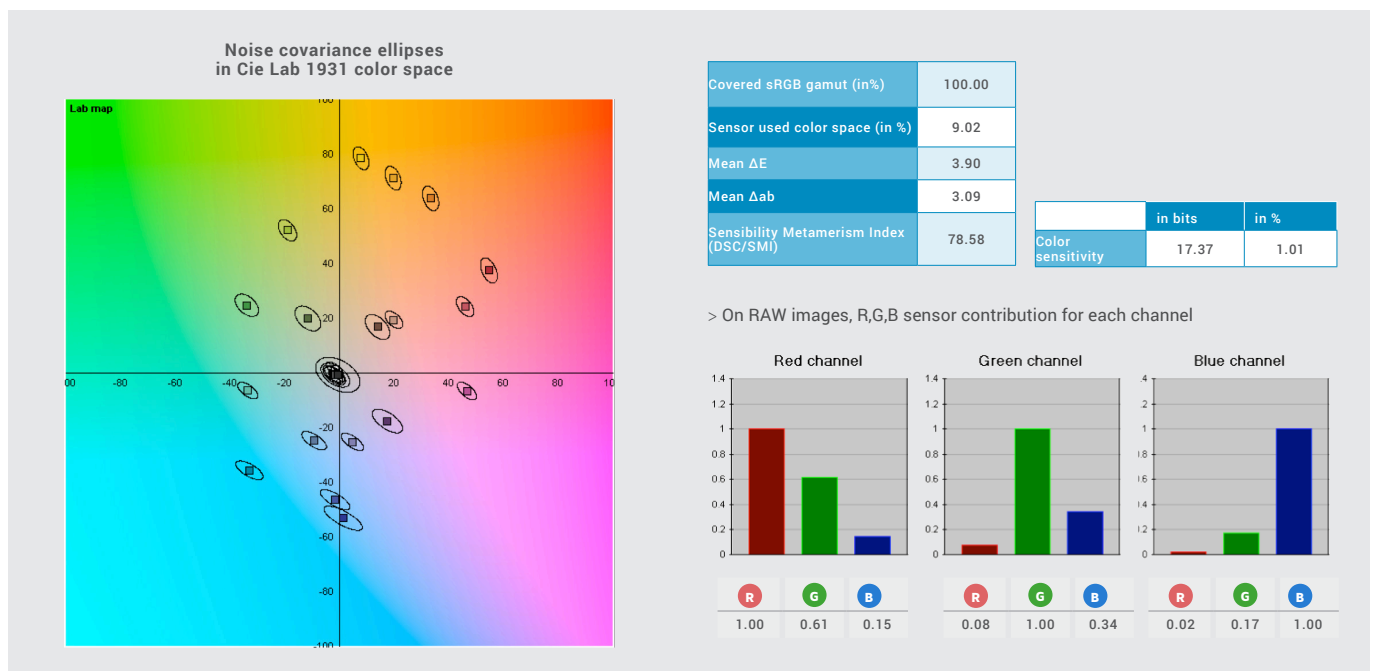ISO Sensitivity (#12232). Analyzer implements the ISO saturation method: more reliable than the noise threshold method with high noise.



ISO sensibility profile

| | |
|---|---|
| Saturation ISO Sensitivity | 2753.6 |
| Maximal ISO Sensitivity | 2814.0 |
| ISO Sensitivity at 50% relative exposure | 2712.2 |

## Color sensitivity

Number of reliably distinguishable colors, up to noise.



Noise covariance ellipses in Cie Lab 1931 color space

| | |
|---|---|
| Covered sRGB gamut (in%) | 100.00 |
| Sensor used color space (in %) | 9.02 |
| Mean ΔE | 3.90 |
| Mean Δab | 3.09 |
| Sensibility Metamerism Index (DSC/SMI) | 78.58 |

| | in bits | in % |
|---|---|---|
| Color sensitivity | 17.37 | 1.01 |

> On RAW images, R,G,B sensor contribution for each channel



Red channel

| R | G | B |
|---|---|---|
| 1.00 | 0.61 | 0.15 |

Green channel

| R | G | B |
|---|---|---|
| 0.08 | 1.00 | 0.34 |

Blue channel

| R | G | B |
|---|---|---|
| 0.02 | 0.17 | 1.00 |

## Row/Column noise

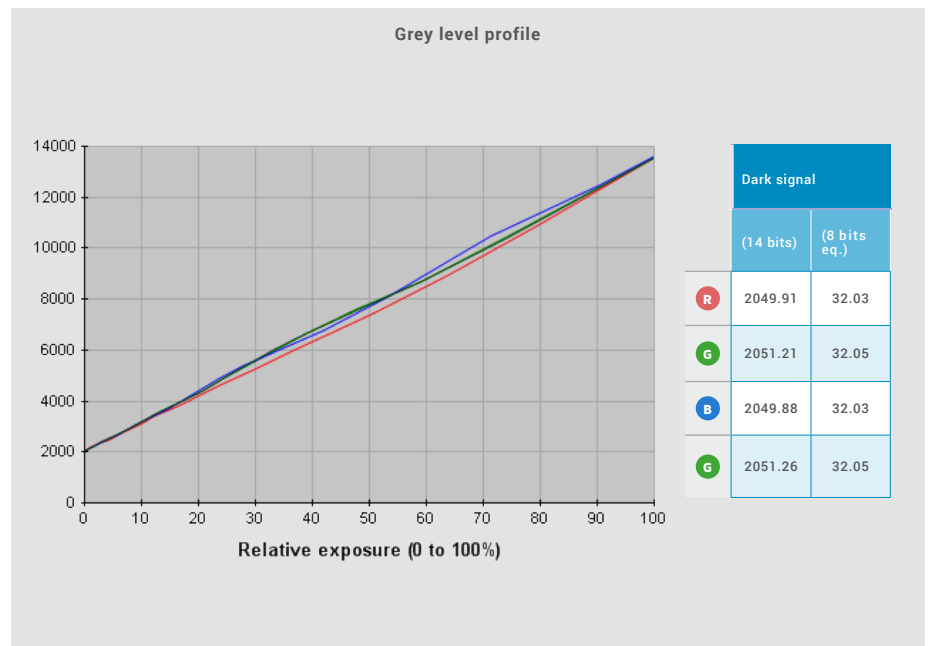Analysis of the spatial frequencies of RAW images provides data on row and column noise, also known as fixed pattern noise.



**Mean Row Spectrum**

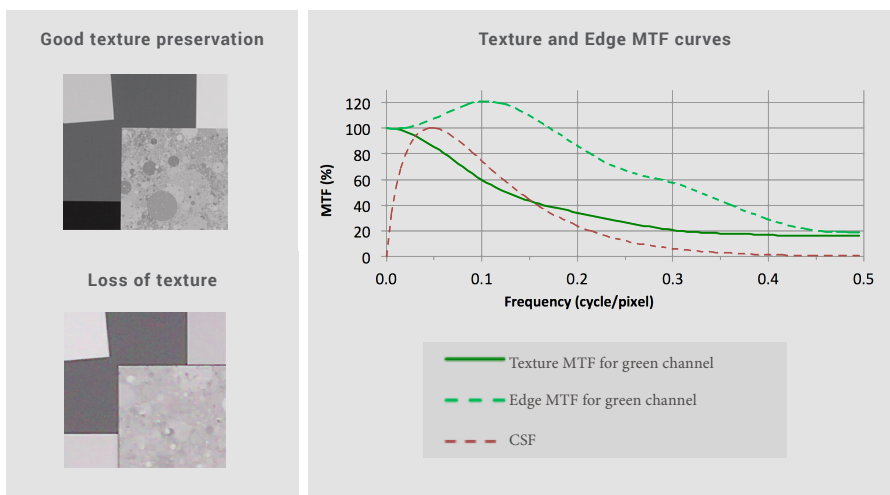

**Mean Column Spectrum**
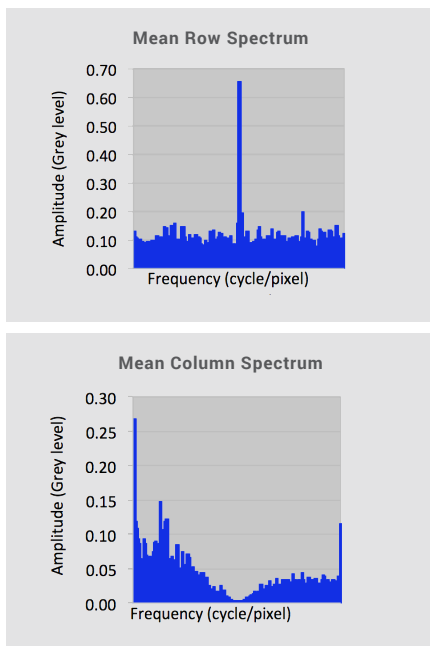
## Dark signal

It computes first the response of the sensor as a function of luminance on a HDR Noise chart. The dark signal is then defined as the value for an interpolated luminance value equal to 0. The luminance is normalized so that 100% corresponds to the saturation value.



**Grey level profile**

| | Dark signal | |
|---|---|---|
| | (14 bits) | (8 bits eq.) |
| R | 2049.91 | 32.03 |
| G | 2051.21 | 32.05 |
| B | 2049.88 | 32.03 |
| G | 2051.26 | 32.05 |

## Texture preservation

Texture preservation measurement analyzes sharpness on a dead leaves pattern, and compares it to sharpness measured on edges. This is used to understand the trade-off between details, noise and sharpness.



**Good texture preservation**

**Loss of texture**



**Texture and Edge MTF curves**

Texture MTF for green channel

Edge MTF for green channel

CSF

## Defective photosites (for RAW data)

There are two kinds of defective photosites: bright photosites (hot pixels) with a response higher than the average and dark photosites (dead pixels) with a response lower than average. The number of hot pixels by megapixel is given, as well as the mean value of the observed grey levels and the standard deviation of grey levels.

| | Mean of all channels |
|---|---|
| Analyzed photosites (%) | 100.00 |
| Defective photosites (by Mphotosite) | 0.48 |
| Mean (12 bits) | 127.97 |
| Standard deviation (12 bits) | 2.71 |

## Measurement accuracy

### NOISE

The accuracy of the noise intensity is ± 0.2 grey level on the measured standard deviation. Accuracy of the strength of noise coloration is ± 0.5 grey level. Accuracy of the grain size is ± 0.5 pixel.The accuracy of the Tonal Range is ± 0.3 bit. The accuracy of the Dynamic Range is ± 0.5 Ev.

### COLOR FIDELITY

Accuracy of the color fidelity measurement is ± 5%.Accuracy of the white balance error computed on delta ab is ± 5%.

### COLOR SENSITIVITY

Color sensitivity measurement accuracy depends on exposure and noise measurement. The total accuracy is ±0.5 bits. A good exposure increases the measurement accuracy.

### TEXTURE

Repeatability of acutance measurement is ± 0.04. For MTF curves, the measurement repeatability is ± 4% on average.

### ISO SENSITIVITY

Repeatability of the ISO sensitivity measurement is +/-2%. Notice that the ISO speed accuracy is limited by the accuracy of the aperture and exposure time values.

### TONE CURVE / DARK SIGNAL

Repeatability of the tone curve measurement, with same normalization, is ±1.5 grey levels. The dark signal measurement accuracy is ± 1%.

### DEFECTIVE PHOTOSITES

Accuracy on the percentage of defective photosites is ± 2% if influencing factors are fixed (ISO sensitivity, exposure time and room temperature).

### ROW/COLUMN NOISE

Repeatability of dark signal is 2 grey levels in the sensor dynamic. Repeatability of standard deviation is ±3%. Repeatability of proportion of variance is ±1.5.

## Specifications

### Camera-under-test specifications

**Min resolution :** VGA (noise / color / ISO) or 1Mpix with distortion < 4% (texture)
**Max resolution :** up to 50Mpix
**FOV :** up to 160°, provided it exists a 1Mpix area with distortion < 4% in image
**Focal length :** down to 12mm in 35mm format
**Spectral sensitivity :** measurements have been designed for visible spectrum cameras
**Sensor :** RGB Bayer filter sensor
**File formats :** Images: jpeg, bmp, png, tif, DNG, and many RAW formats (latest release notes provides a list of supported RAW formats), Videos: Windows Media Foundation (WMF) and DirectShow are used to open video files. Available video formats depend on the operating system and installed DirectShow codecs

### Platform requirements

PC-type computer with the following minimum configuration :
**Windows 10**
**2 GB of RAM** or more
**At least 3 Go of free disk space** to operate the software
**A video card with 3D driver,** compatible with DirectX 12 and Open GL
**1024 x 768 or more** for Screen display resolution, with Windows DPI scaling <125
**At least one USB port**
It is possible to run Analyzer on a virtual computer (to run on a Mac platform for instance), or to control it remotely. Depending on the selected remote OS, some graphics may not be generated.

### Laboratory requirements

**Laboratory minimum size :** 4.5 x 5m
**RAL9005 mat paint** for walls and ceiling
**Dark grey antistatic carpet** on the floor
**Temperature :** 23°C ± 2°C (ISO 554:1976)
**Humidity :** 50% ± 20% (ISO 554:1976)

### References

Cao, F., Guichard, F., Hornung, H., **"Dead leaves model for measuring texture quality on a digital camera",** Proceedings of SPIE 7537, Digital Photography VI, 75370E (January 18, 2010)