TEST RESULTS

for

Mobile Phone Camera Test

of

test device

Date 01st June 2015

1 INTRODUCTION

The in this report presented test procedure is generally used to determine the image quality of mobile phone cameras. Among others it is used for the estimation of the so called VCX score of Vodafone. All test methods are based on ISO standards and other well accepted standards wherever possible. Some of which were already on their way at the time Image Engineering started to measure image quality in 1997. For example:

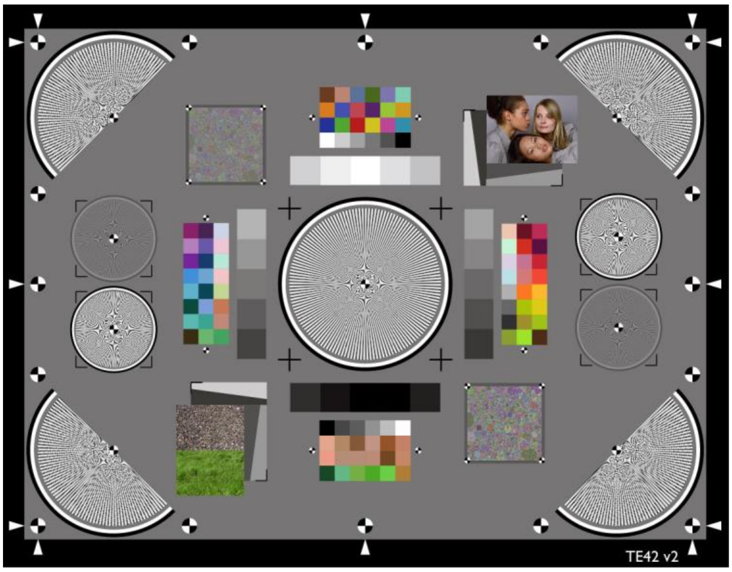
- ISO 7589: Photography - Illuminants for sensitometry - Specifications for daylight, incandescent tungsten and printer
- ISO 14524: Photography - Electronic Still Picture Cameras - Methods for measuring opto-electronic conversion functions (OECFs)
- ISO 12231: Photography - Electronic still-picture imaging - Terminology
- ISO 12232: Photography - Digital still cameras - Determination of exposure index, ISO speed ratings, standard output sensitivity and recommended exposure index
- ISO 12233: Photography - Electronic still-picture cameras - Resolution measurements
- ISO 15739, Photography - Electronic still-picture imaging - Noise measurements
- ISO 15781, Photography - Digital cameras — Measuring shooting time lag, shutter release time lag, shooting rate, and start-up time
- CIE 15.2 Colorimetry

1.1 TEST CONDITIONS

In opposite to most camera tests it was decided to use the default settings of the mobile phone even though this might not deliver the best possible results. So the device is probably measured with the adjusted 16:9 format although it has a 4:3 sensor, whereat latter theoretical results in better resolution values. The default settings of the mobile phone are just influenced if the test requires (for example image stabilization test). The test conditions are set up in a way that they represent the typical conditions present in the real world use of the mobile phone camera. If the camera is tested in a mode unusual for the specific application or under unusual conditions, the result may not represent the real image quality achievable for this application.

II MEASURING CHARACTERISTICS IN DETAIL

With the new version of the Test Chart “Forty Two” (TE42v2) Image Engineering improved the multi-functional chart for testing digital cameras and lenses: With one single chart OECF (Opto Electronic Conversion Function), dynamic range, resolution, texture loss, shading, distortion, lateral chromatic aberration, sharpening, distortion, shading and color reproduction can be measured.



The test was executed with following settings and illuminations:

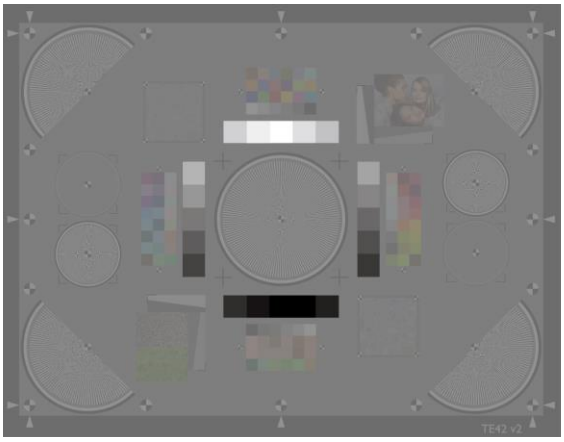
- Default settings of camera — 1000 lux
- Default settings of camera, 4x-Zoom — 1000 lux
- Default settings of camera — -2 EV (equates 250 lux)
- Default settings of camera — -4 EV (equates 63 lux)
- Default settings of camera, flash activated — -4 EV (equates 63 lux)

The following in detail described measuring characteristic are respectively gained for every setting/illumination. For smartphones using a 16:9-format a TE42v2 16:9 is used. This ensures the comparability of the resolution in the corners

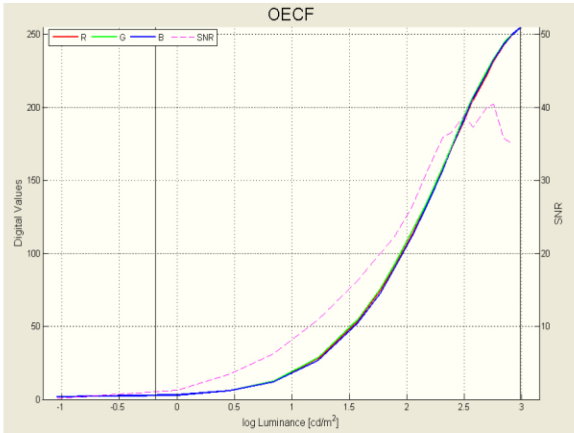
2.1 OECF AND NOISE

A circular gray scale is used to determine the opto electronic conversion function (OECF). It describes how the digital camera transfers luminance into digital values. The curve is specified for all three color channels red, green and blue in color images.

To calculate the OECF the TE42v2 test chart is used. It consists of patches of different gray levels aligned in a circle around the center.

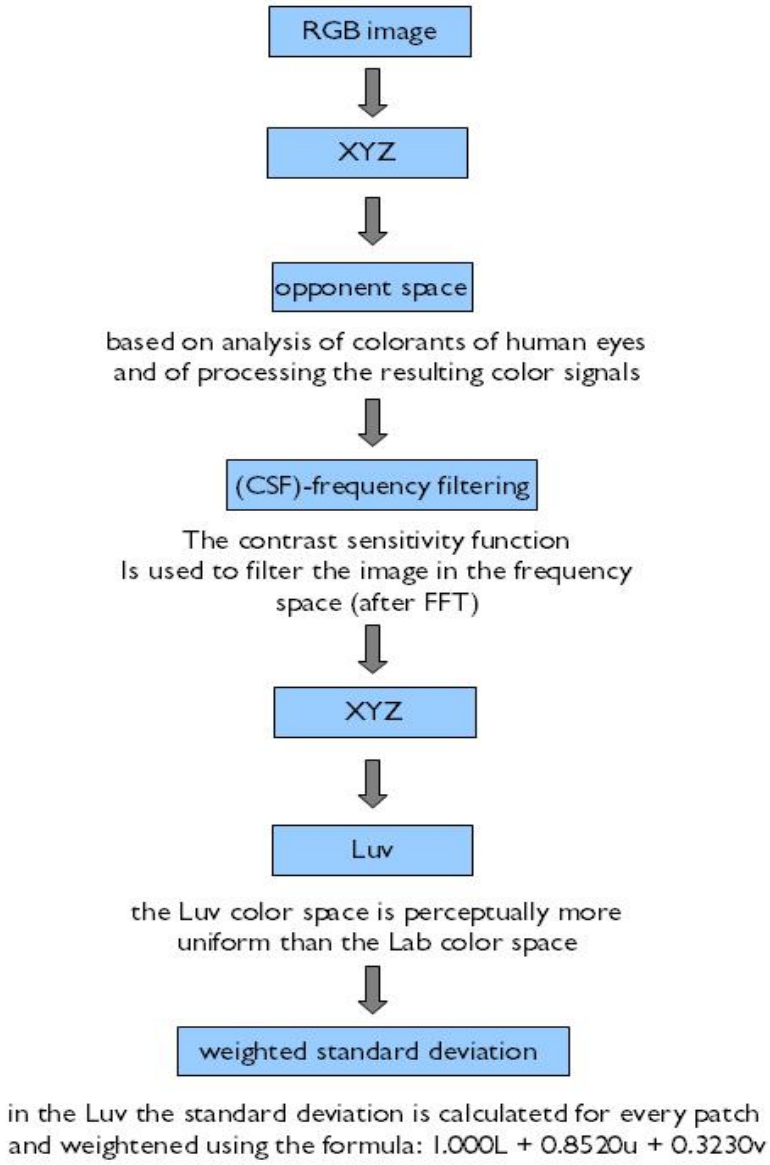


TE42v2 Chart with 20 gray patches



OECF and SNR curves after calculation

The ISO standard 14524 defines how to plot the digital output level versus the luminance on a linear or logarithmic scale. Also the **signal to noise ratio (SNR)** and the **visual noise (VN)** are calculated according to ISO 15739. The SNR describes the relationship between the signal and noise. Unlike the ISO 15739 camera signal to noise ratio the visual noise is evaluated as an output referred noise. Visual noise takes into account that the visual perception of noise can be different for human observers compared to a mere SNR approach. It quantifies how well a human observer can recognize noise. Six transformation steps model the human perception and lead to a single noise value for a defined viewing condition.



The visual perception of noise depends on the viewing conditions. Examples for viewing conditions:

VN1: 100% view on a monitor, 0.5 m distance, 96 ppi monitor resolution

VN2: Print with 10 cm height, viewing distance set to 25 cm

VN3: Print with 40 cm height, viewing distance equals the diagonal on the print

Both prints are supposed to be observed at a viewing distance of the diagonal of the print. The minimum is 25 cm.

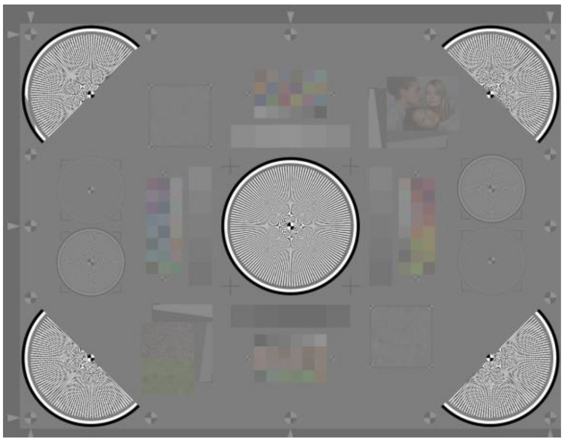
The **dynamic range** (DR) is calculated from the OECF as well. It describes the maximum scene contrast the digital camera is able to reproduce. The lightest point is chosen at the illumination level where the camera reaches its maximum output value. The darkest point is the illumination level where the SNR level passes the value of 1 according to ISO 15739. The dynamic range is the contrast between the lightest and the darkest point and it can be expressed in f-stops, densities or a contrast ratio. ISO 15739 defines the dynamic range on the basis of a SNR of 1. According to our experiences, a very flat curve of a black level clipping can cause problems with some cameras. Therefore a value of 3 was selected by Color Foto and since we often provide Color Foto results of some cameras together with the camera under test we often use this value for our tests as well.

Used digital values can be determined by analyzing the OECF. The OECF curve should start at a digital value of 0 and go up to 255 to utilize the complete contrast available at 8 bit. For 16 Bit data the range is 0 to 65535.

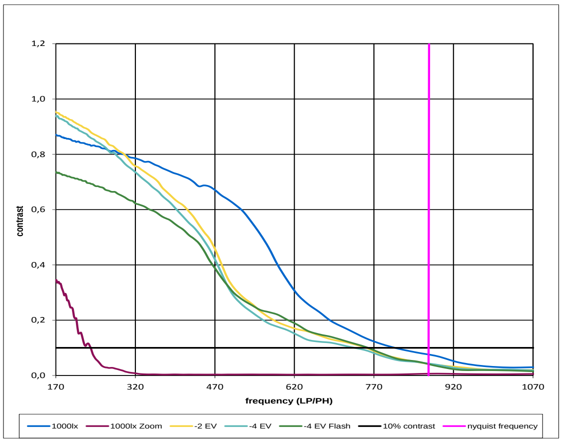
If the automatic **white balancing** works well, the curves for the three channels should lie on top of each other. If the average difference is greater than five digital values, the images show a visible color cast.

2.2 RESOLUTION SIEMENS

Resolution is measured in the center and the image corners using sinusoidal Siemens stars. There are 5 stars, one in the center and four half stars in the corners of the target.

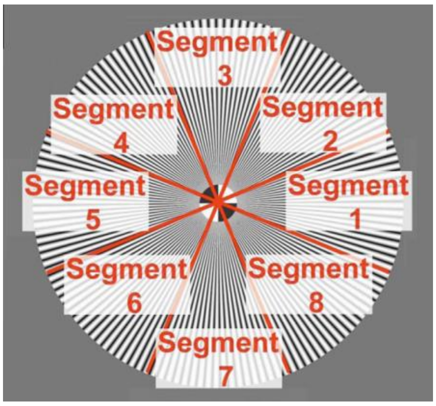


TE42v2 Chart with sinusoidal stars



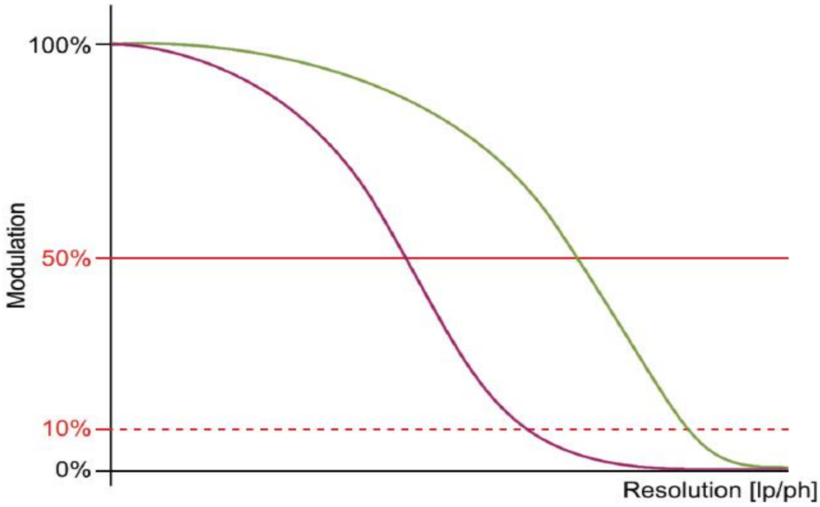
MTF curves after calculation

The stars are divided into segments and the resolution is measured for each of them. There are eight segments for the center star and three for the corner stars. Finally the mean-value of the segments for each star and additionally for the corners will be reported. These curves contain a lot of information about sharpness and resolution at the various positions and orientations. They can be used to check the optical centering of the system, to analyze optical errors like astigmatism, to verify orientation-specific or frequency-specific image processing and to determine the limiting resolution.



one star with marked segments

The MTF gives the imaging system response as a function of spatial frequency and its values represents the relative decrease of modulation for a given spatial frequency normalized to one at 0 line pairs per picture height.



The figure above shows an example for a good (green) and a poor camera system (magenta)

The value for the frequency, where the limiting resolution (dashed red line) is reached, is called **MTF10**. Accordingly, **MTF50** is the highest spatial frequency that results in a spatial frequency response of ≤50% (red line). The report also states the limiting resolution at 25% and 50%.

Another way to reduce the MTF to a single value is to calculate the **acutance**. Therefore a contrast sensitivity function (CSF) is used to weigh the different spatial frequencies.

$$Acutance = \frac{A}{A_r}$$

$$A = \int_0^\infty SFR_L(v)x\, CSF(v)dv$$

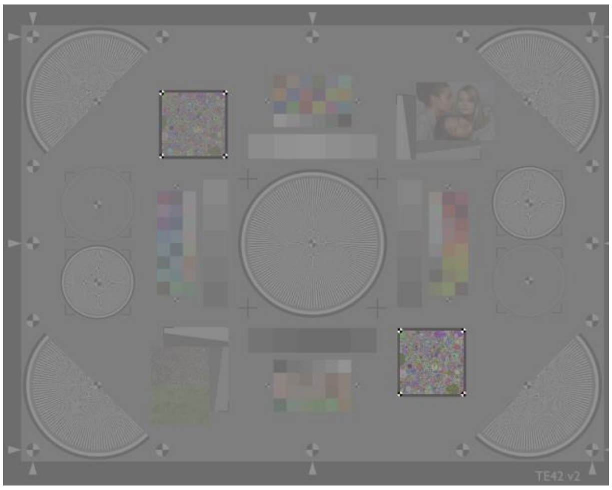
$$A_r = \int_0^\infty CSF(v)dv$$

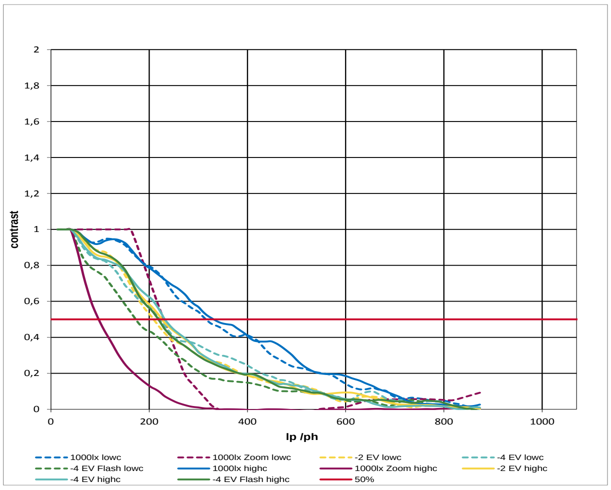
Concerning the CSF, viewing conditions used for calculating the acutance values **vMTF1**, **vMTF2** and **vMTF3** are the same as for visual noise:

- Set 1: 100% view on a monitor, viewing distance 50 cm, 96 ppi monitor resolution
- Set 2: 10 x15 cm print, viewing distance 25 cm
- Set 3: Print with 40 cm height, viewing distance equals the diagonal of the print

2.3 DEAD LEAVES

The so-called texture loss is a critical parameter in the objective image quality assessment of today's cameras. Especially cameras build in mobile phones show significant loss of low contrast and fine details which are hard to describe using standard resolution measurement procedures. The combination of very small form factor and high pixel count leads to a high demand of noise reduction in the signal-processing pipeline of these cameras. The so called DeadLeaves-pattern is used for quite a while in this context. For an extensive assessment the TE42v2 has two DeadLeaves-patches, one high contrast and one with a low contrast.





The dead leaves pattern is created by placing circles at a random position with a random size and a random gray value. If the probability function is known, the power density spectrum of the target can be well estimated. The spatial content of the target $X(f)$ is transferred by the camera into the spatial image content $Y(f)$. The transfer function of the camera $H(f)$ is the wished information, as it represents the SFR of the camera system. In this assumption, the image content $Y(f)$ equals the product of $X(f)$ and $H(f)$.

$$Y(f) = X(f)\,H(f)$$

2.3.1 Dead Leaves$_{direct}$

Based on assumption from the previous page, the easiest approach is to divide the power spectrum of the image $PS_{image}(f)$ by the power spectrum of the target $PS_{target}(f)$. This provides the amplitude response of the system which can be seen as the **SFR** of the camera. The camera does not only transfer spatial frequencies, but also adds spatial information such as noise, artifacts, etc. This fact takes the **SFR$_{DeadLeavesdirect}$** method into account by measuring a grey reference from the same image. The noise power spectrum $PS_{noise}(f)$ measured on this reference patch is used as a correcting factor:

$$SFR(f) = \sqrt{\frac{PS_{image}(f) - PS_{noise}(f)}{PS_{target}(f)}}$$

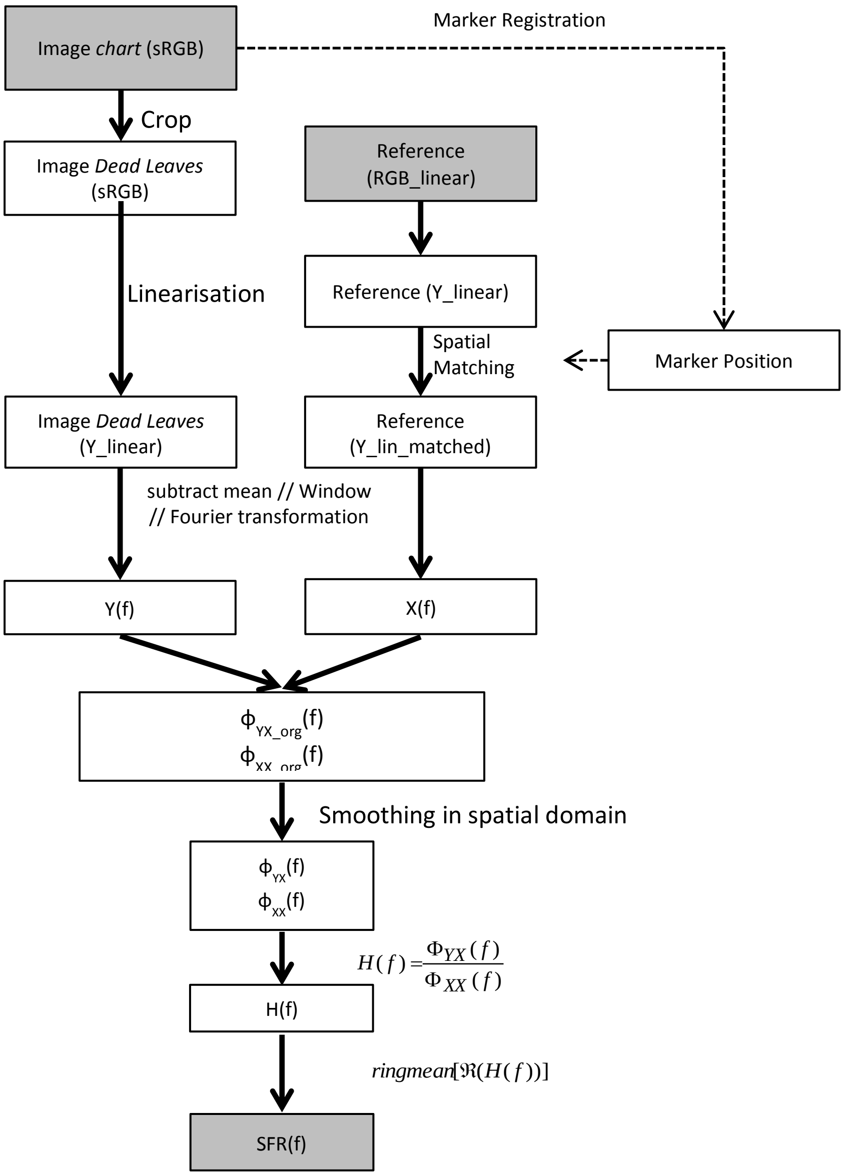
The calculation is done in these steps, assuming the camera under test has reproduced the dead leaves target and a reference patch which is the mean value of the dead leaves structure and is homogenous. The OECF patches of the TE42v2 are used to obtain an opto electronic conversion function (OECF) for linearization, as cameras do not deliver linear OECF.

- Calculate *PStarget(f)* using the meta information from chart production process.
- Read ROI of dead leaves patch, reference patch and gray patches.
- Calculate OECF with image data from gray patches and the known reflectance of these patches. The OECF here is a function of reflectance vs. Y (Y is a weighted sum of R, G, B)
- Calculate Y image from the RGB image of dead leaves patch and reference patch.
- Linearize using the inverse of the OECF.
- Calculate *PSimage(f)* (from dead leaves patch) and *PSnoise(f)* (from the reference patch).
- Calculate SFR(f) using Equation 1.

The calculation of the power spectrum includes a reduction process from the 2D spectrum to 1D data and the calculation of the SFR includes a normalization process for presentation purposes.

2.3.2 Dead Leaves$_{cross}$

While the ***direct***-method follows the concept of a semi-reference method where known properties of the test target are compared to properties of the image content, the **SFR$_{DeadLeavescross}$** follows the concept of a full reference method, which means the target and the image are compared pixel by pixel (often used for evaluation of compression algorithm performance).



The flow chart illustrates the algorithm

The SFR is calculated as well from the obtained transfer function H (f). The biggest difference to the ***direct***-approach is that in this case a calculation with the complex transfer function is possible, as the phase information is still available. The ***cross***-approach uses the cross power density Φ_{YX} (f) of target and imager and the auto power density Φ_{XX} (f) of the target to obtain H (f).

$$H(f) = \frac{\emptyset_{YX}(f)}{\emptyset_{XX}(f)}$$

With the spatial matching, the cross power density of target and image can be calculated and leads to H (f). A smoothing step on Φ_{YX} (f) and Φ_{XX} (f) is performed by applying a narrow window in the spatial domain. The SFR is finally calculated as a 1D representation of the real part of the 2D H (f). The transformation from 2D to 1D is performed as a so called ringmean, which uses the average of all coefficients belonging to the same spatial frequency, regardless their orientation (a circle in the 2D spectrum).

The report states numerical results of the **MTF10** and **MTF50** (*cross*-approach) for both DeadLeaves-patches (high – and low contrast). Also the acutance **vMTF1**, **vMTF2** and **vMTF3,** with the same viewing conditions as for visual noise and sinusoidal stars is reported.

Concerning the CSF, viewing conditions used for calculating the acutance values **vMTF1**, **vMTF2** and **vMTF3** are the following:

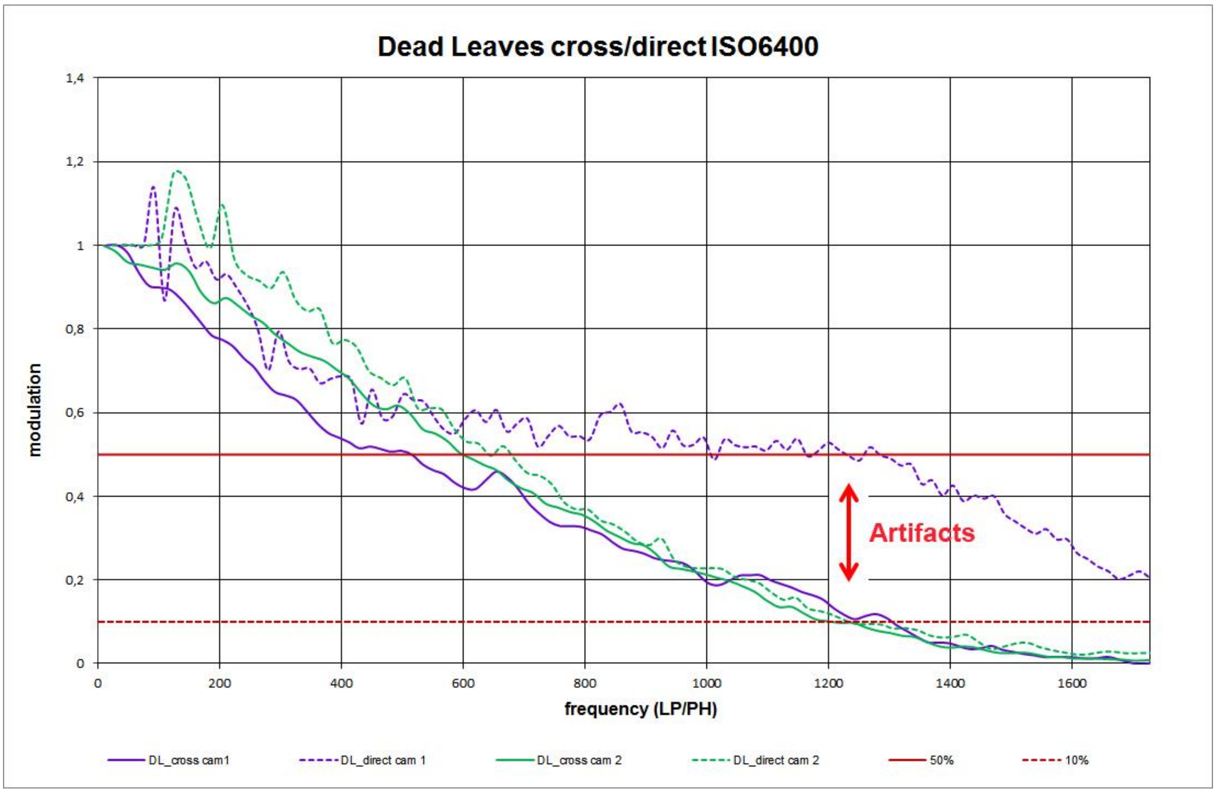
- Set 1: 100% view on a monitor, viewing distance 50 cm, 96 ppi monitor resolution
- Set 2: 10x15 cm print, viewing distance 25 cm
- Set 3: Print with 40 cm height, viewing distance equals the diagonal of the print

More information

2.3.2 ARTIFACTS

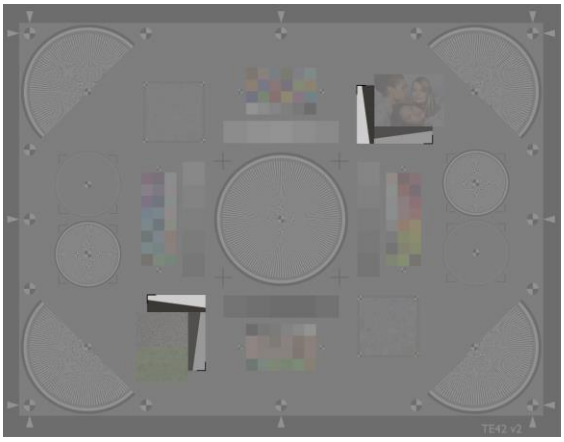
As described before any kind of artifacts influences the SFR resulting from the $\mathbf{SFR_{DeadLeavesdirect}}$ method, while the $\mathbf{SFR_{DeadLeavescross}}$ method does not show this behavior. From the difference of the calculated SFRs using the two different methods, a metric can be derived that describes the artifacts. As numerical value, simply the differences in the acutance of the two different methods are calculated. This occurs based on a 100% view on a 96ppi screen in half meter distance.

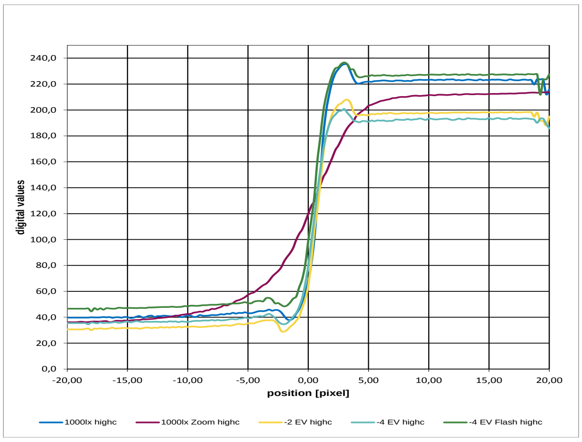
$$Artifacts = \frac{Acutance_{direct} - Acutance_{cross}}{Acutance_{cross}}$$



2.4 SLANTED EDGES

The **SFR$_{Edge}$** algorithm is described in ISO12233 and is based on the reproduction of a slanted edge in the image field. The over-sampled description of the edge is called the edge spread function *ESF*. The first derivative of the ESF is the line spread function LSF, which can be imagined as an1-D representative of the point-spread function PSF. The SFR$_{Edge}$ is the Fourier transform of the LSF. Before the transformation, the data is windowed to avoid leakage.

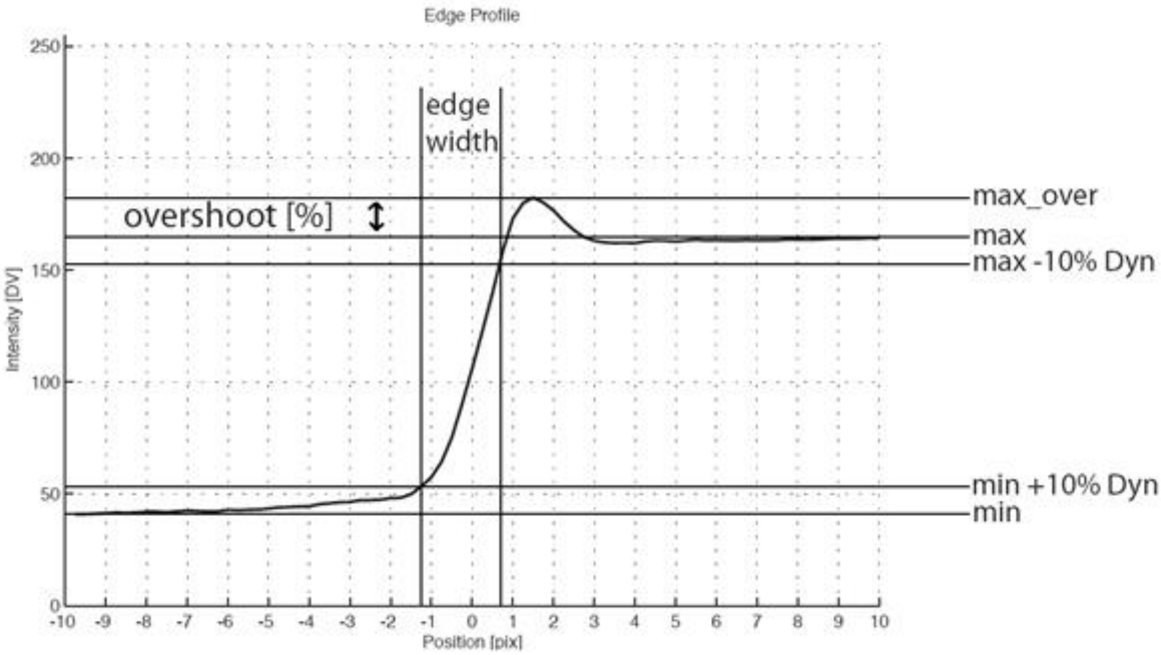




The TE42v2 contains four edges, whereby two different contrasts are used and each is available in horizontal and vertical orientation. If not otherwise stated, the reported **MTF50**, **vMTF1**, **vMTF2**, **vMTF3** respectively are the average of horizontal and vertical edge. The different contrasts of the edges are a low contrast edge (60% edge modulation contrast as defined in ISO12233:2014 Annex C) and a high contrast edge (80% edge modulation contrast). Different contrasts are used as the sharpening algorithms in the image signal processor of today's cameras may detect the edge contrast and adjust the sharpening according to this. The report also states the deviation of the modulation contrast for the two different contrasts.

2.4.1 SHARPENING / OVER & UNDERSHOOT

In the analysis process of the slanted edge, the ESF can also be extracted and used for further analysis. Digital sharpening mostly appears in the image as undershoot and overshoot along edges. Just around the edge the values get increased on the high level side and decreased on the low level side.



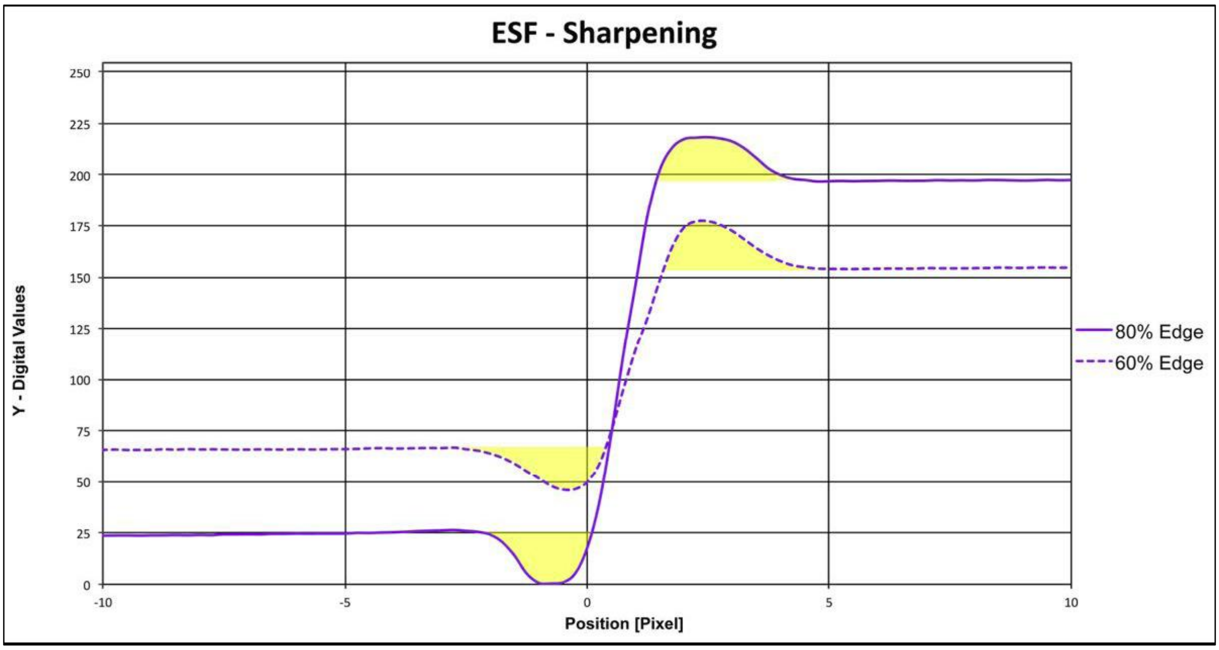
Overshoot describes the increase of the intensity values close to the edge *max_over* related to the intensity value at the outer right position in the graph, the high level value *max* (see above). Undershoot describes the ratio of the lowest value close to the edge related to the mean value of the low intensity side *min*. The reported value printed at the lower right side is the 10% edge width. The edge width is the distance in pixels between two points in the edge profile. First point is reached by an increase of the intensity by $10\%_{Dyn}$, second point is reached at

$$max - 10\%Dyn,$$

with

$$10\%Dyn = 0.1 \cdot (max - min)$$

The former described approach is reported as percentage. Additionally the area of the over- and undershoot (yellow marked region) is stated for two different visual perceptions. The so called ***area set 1*** takes into account how a viewer will see under- and overshoot at a view on a monitor with 100% magnification, viewing distance 50 cm and 96 ppi monitor resolution.

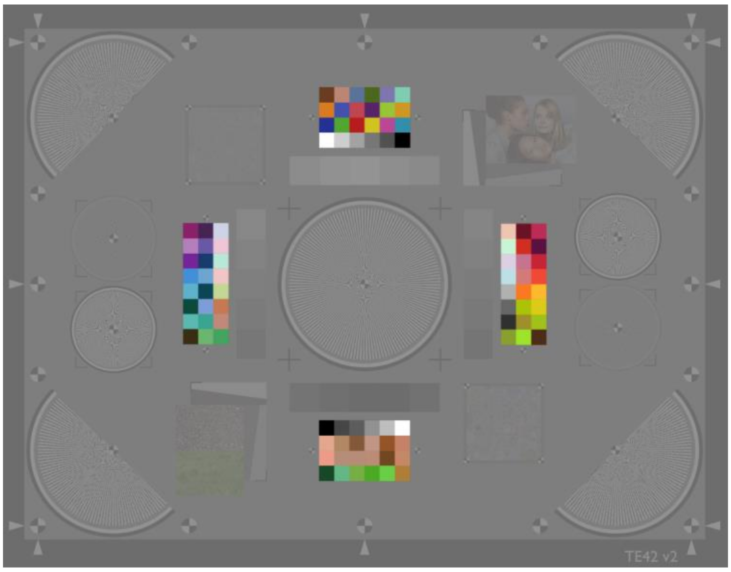


The value for ***area set 3*** takes the perception at a view of a 40x60 cm print, viewing distance 72 cm (print diagonal) into account. All edge results are stated for for all measured settings and illuminations, which are following:

- Default settings of camera — 1000 lux
- Default settings of camera, 4x-Zoom — 1000 lux
- Default settings of camera — -2 EV (equates 250 lux)
- Default settings of camera — -4 EV (equates 63 lux)
- Default settings of camera, flash activated — -4 EV (equates 63 lux)

2.5 COLOR

The color patches around the OECF patches base on the Xrite ColorChecker SG and are used for evaluation of color reproduction.



The image is captured, the patches are located and converted into color coordinates in the CIE L*a*b* color space that represents the color reception of the human visual system. From these values the color distance ΔE (Delta E) that describes the color reproduction quality is calculated. The lower the ΔE values the better the color reproduction of the original scene. ΔE is calculated by the formula:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

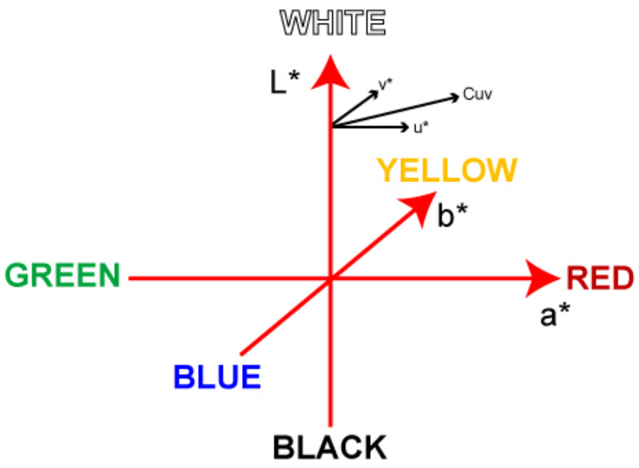
with

$$\Delta L = L_{reference} - L_{sample}$$

$$\Delta a = a_{reference} - a_{sample}$$

$$\Delta b = b_{reference} - b_{sample}$$

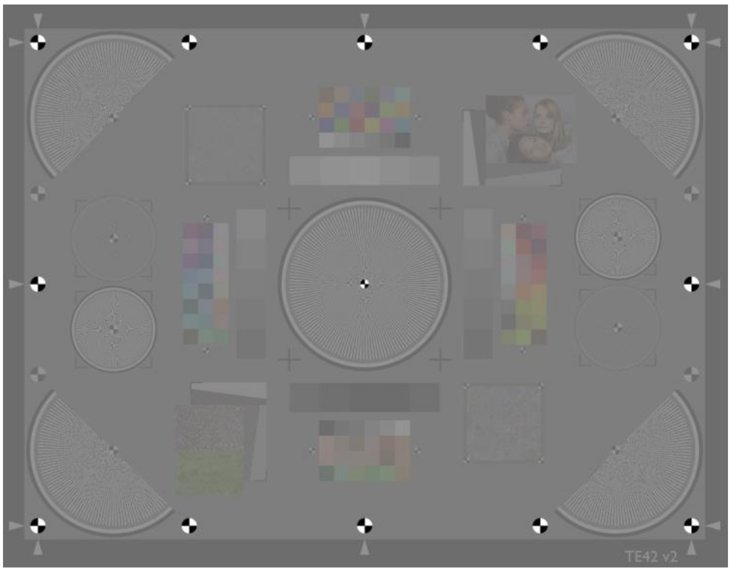
L*a*b* color space



The report states ΔE, ΔL (luminance), ΔC (chroma), ΔH (hue) for all measured settings and illuminations, which are following:

○ Default settings of camera	1000 lux
○ Default settings of camera, 4x-Zoom	1000 lux
○ Default settings of camera	-2 EV (equates 250 lux)
○ Default settings of camera	-4 EV (equates 63 lux)
○ Default settings of camera, flash activated	-4 EV (equates 63 lux)

2.6 DISTORTION



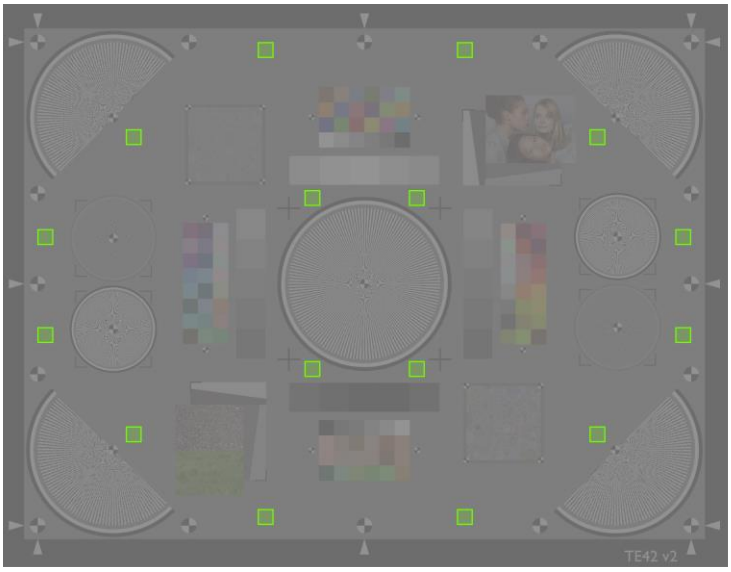
- comparison of measured and ideal position of marks in Y
- for each mark the distance between the center of R to G and B to G (chromatic aberration) is calculated
- concentrate on horizontal direction (TV-distortion, picture high distortion, EBU Tech 3249)

The TV-Distortion for following settings and illuminations are reported:

- Default settings of camera 1000 lux

2.7 SHADING

All kinds of effects that change the intensity or color over the field in the image are measured as ***shading***. For the measurement 24 ROIs evenly distributed over the images of the TE42v2 are evaluated.



Reported values are:

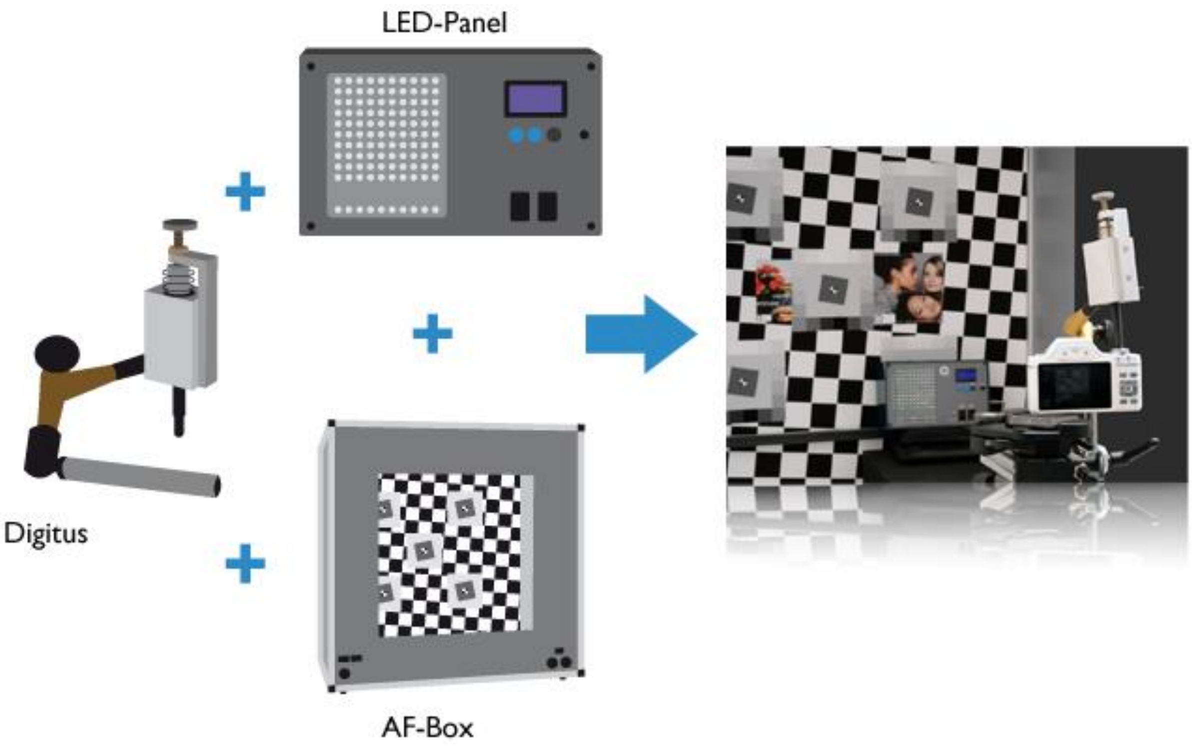
- Intensity Shading in f-stops
- Color Shading in ΔEab

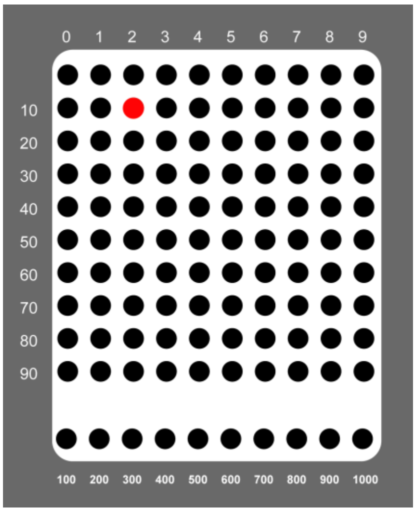
These values are respectively gained for all illuminations and settings, which are following:

Default settings of camera	1000 lux
Default settings of camera, 4x-Zoom	1000 lux
Default settings of camera	-2 EV (equates 250 lux)
Default settings of camera	-4 EV (equates 63 lux)
Default settings of camera, flash activated	-4 EV (equates 63 lux)

2.8 TIME MEASUREMENT

Time measurements are performed according to ISO 15781 using a LED-Panel in the so called AF-Box. It consists of 10 rows with ten LEDs that light up at a selectable frequency. Shutter lag and frame sequence can be measured.





10x10 LEDs ordered in a square field with 100 LEDs altogether. Each LED is switched on separately one after the other.
An additional row with ten more LEDs is switched forward each time the 100 LEDs of the main panel are through.

To measure ***shooting time lag***, the LED-Panel is started with a microswitch connected with a cable. The microswitch is mounted on display and both "switches" are pressed and released simultaneously. Beforehand the device is defocused so the focustime is included. In the pictures the elapsed time can be determined by counting the LEDs that have already been lit up.
For the determination of the ***shutter time lag*** device is prefocused on the target and then released. The difference between shooting time lag and shutter time lag is the time the device needs to focus (***focustime***).
These measurements are executed with two illuminations:

- 800 lux
- 30 lux

Additionally the time the camera of the smartphone needs to take 10 images is measured. Therefore the continuous-mode is activated if possible. This test is only executed with an illumination of 800 lux.

The time needed to get ready to shoot after the camera-app was started (***start-up time***) is an important value and is determined by using the LED panel. So the start-up time includes the shooting time lag.

2.9 IMAGE STABILIZATION (STEVE)

To measure the quality of the stabilization system an AF box (16:9) and the so called STEVE (***St***abilization ***Ev***aluation ***E***quipment) is used. The TE261-chart within the AF-box is positioned in front of STEVE so that always the whole chart height is captured. First of all reference images are generated, which means that STEVE isn't moving and if possible the image stabilization of the mobile phone is switched off. After this STEVE is switched on and a test series without enabled image stabilization (if selectable) is done. If the device doesn't offer an arbitrary image-stabilization the measurement is finished. Otherwise an additional test series is generated with a moving STEVE and enabled image stabilization.

This procedure is done for two illuminations:

- 800 lux
- 40 lux

The generated images are analyzed with the iQ Analyzer 6 to gain information about the slanted edge in the middle of the chart. The report states contrast, edge width and visual noise for all images. Also the Δedge and Δcontrast are stated.

2.10 LIGHTSTUDIO

For a visual evaluation images of the lightSTUDIO are made with D50 with 100% and 10 %. Only visible flaws are reported.

III GRAPHICAL AND NUMERICAL RESULTS

3.1 OECF AND NOISE

OECF20	VN1	VN2	VN3	DR	SNR
1000lx	2,2	1,2	1,5	7,3	31
1000lx Zoom	2,4	2,3	2,4	7,3	38
-2 EV	2,2	1,4	1,6	7,3	33
-4 EV	2,9	1,7	2,0	7,0	21
-4 EV Flash	2,3	1,3	1,6	7,3	27

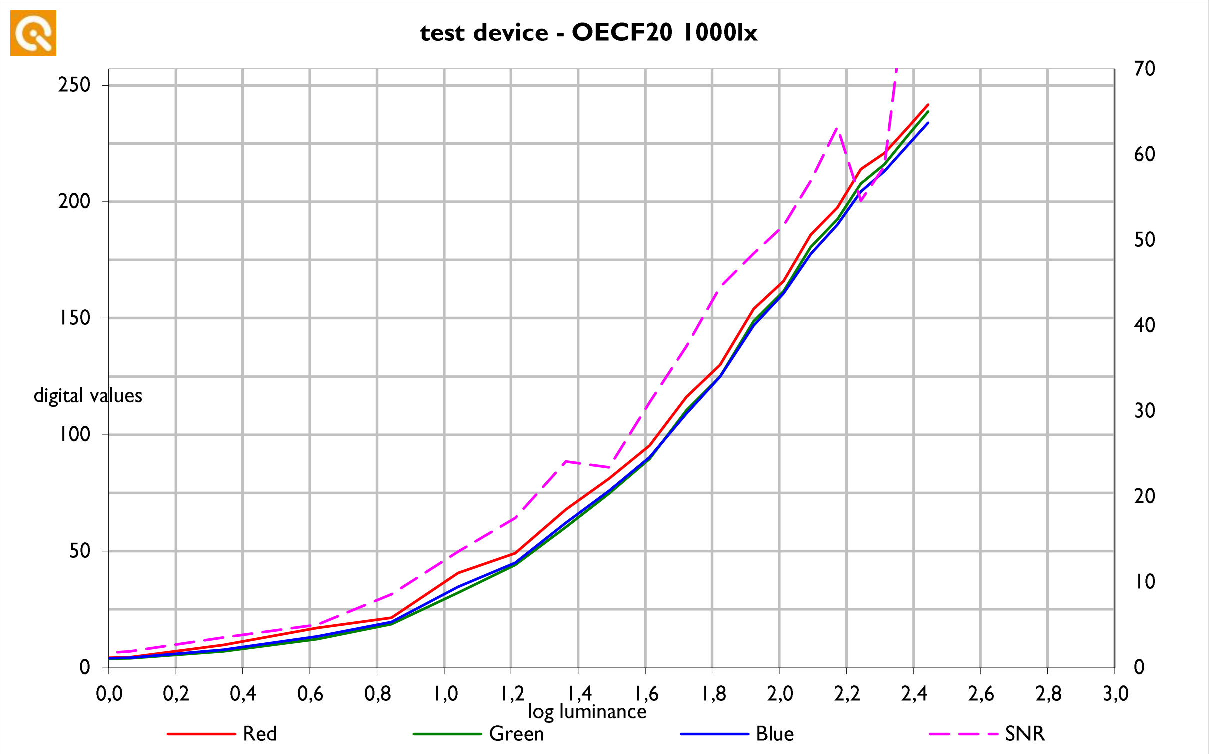
VN1: 100% view on monitor, 0.5m distance, 96 ppi monitor resolution - no unit; the smaller the number the better the result (less noise)

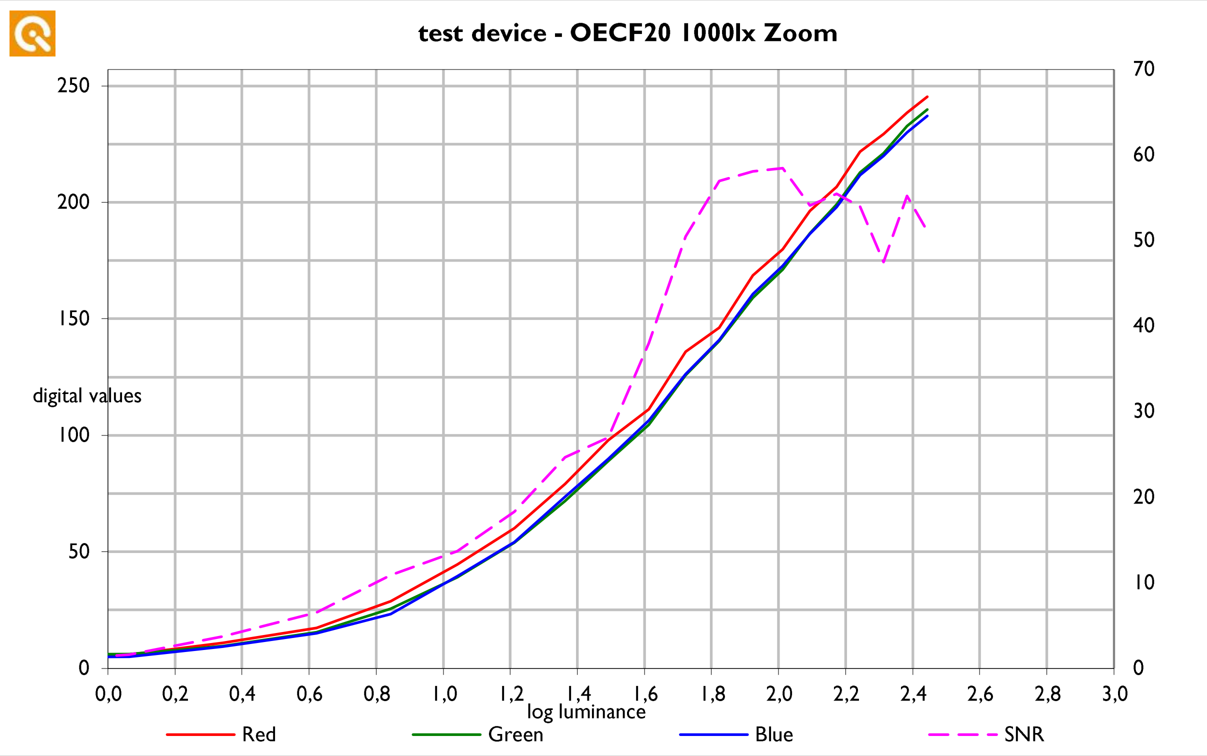
VN2: Print with 10 cm height, viewing distance set to 25 cm - no unit; the smaller the number the better the result (less noise)

VN3: Print with 40 cm height, viewing distance equals the diagonal of the print - no unit; the smaller the number the better the result (less noise)

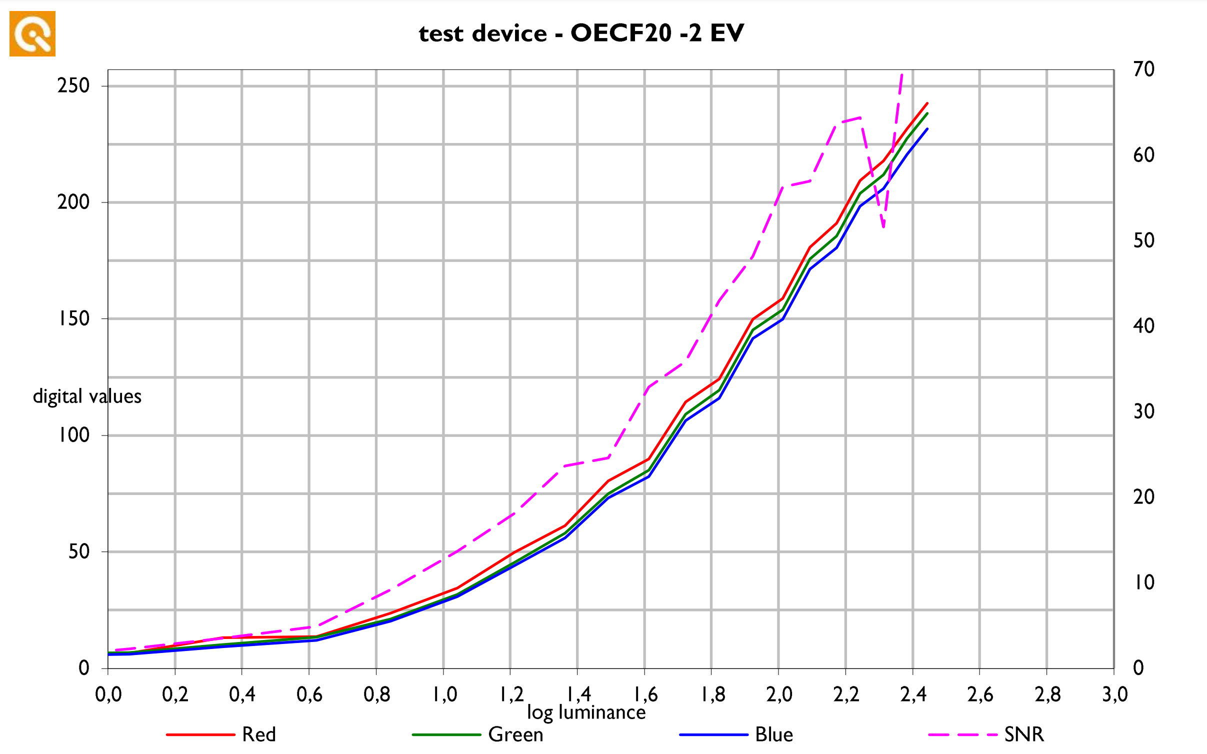
DR: Dynamic range in f-stops

SNR: Signal to noise ratio

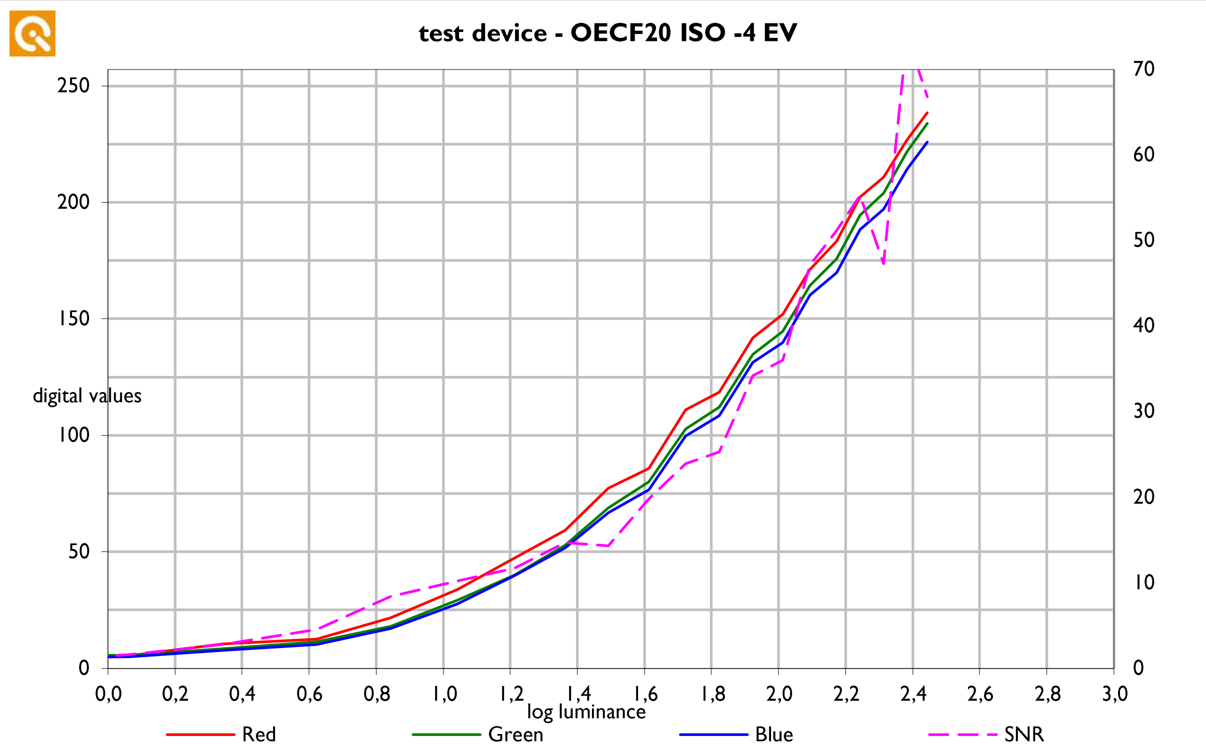


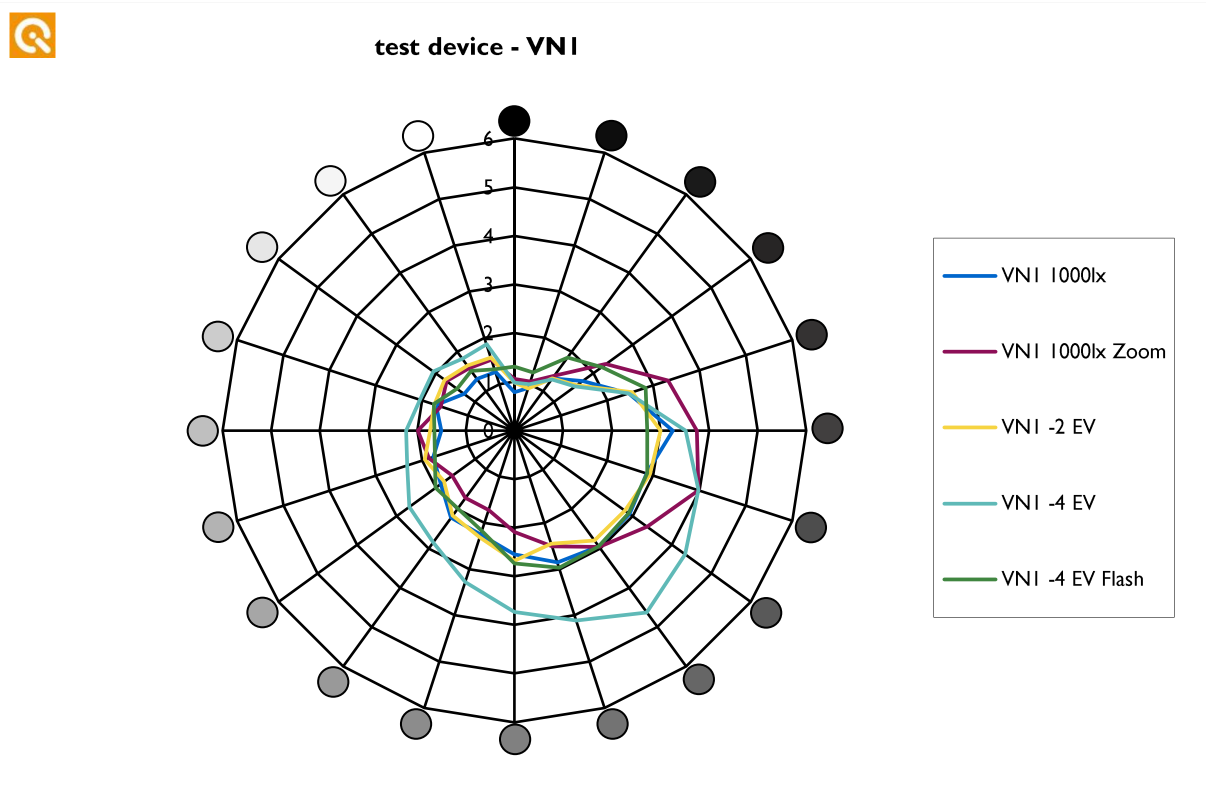


test device - OECF20 1000lx Zoom
digital values
log luminance
Red
Green
Blue
SNR



test device - OECF20 -2 EV
digital values
log luminance
Red
Green
Blue
SNR


test device - OECF20 ISO -4 EV
250
200
150
digital values
100
50
0
70
60
50
40
30
20
10
0
0,0
0,2
0,4
0,6
0,8
1,0
1,2
1,4
1,6
1,8
2,0
2,2
2,4
2,6
2,8
3,0
log luminance
Red
Green
Blue
SNR

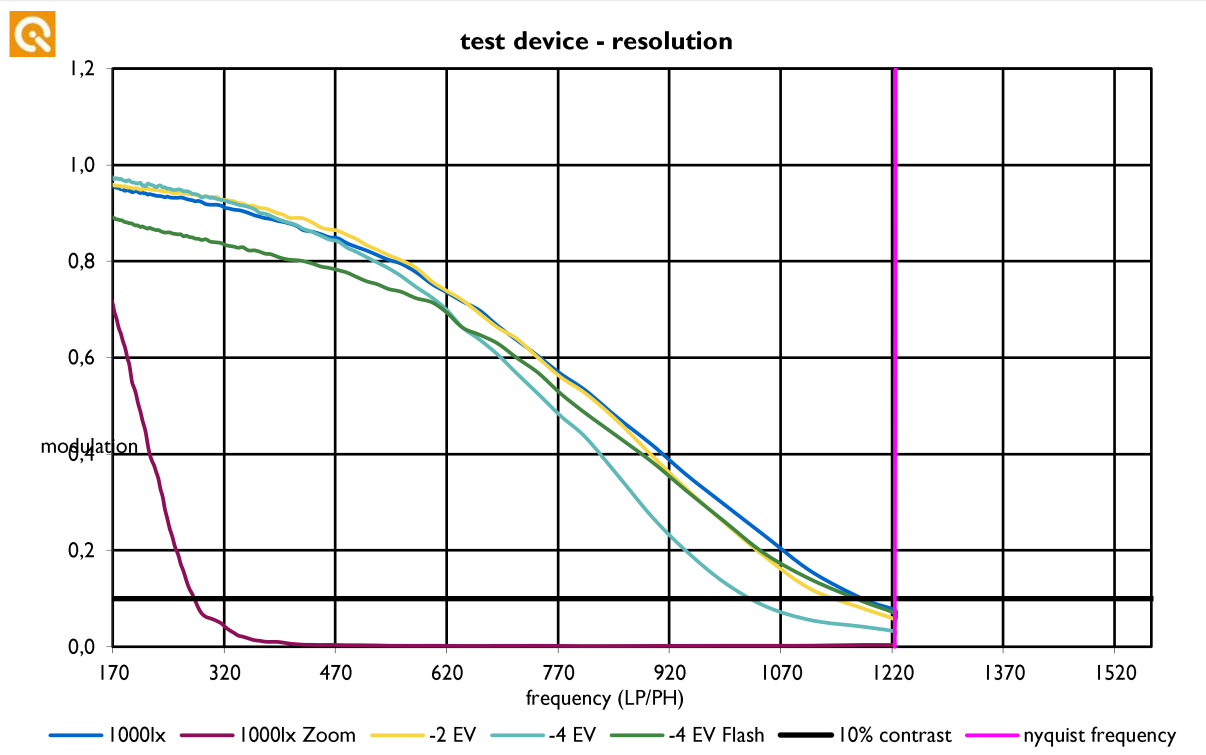

test device - VN1
6
5
4
3
2
0
VN1 1000lx
VN1 1000lx Zoom
VN1 -2 EV
VN1 -4 EV
VN1 -4 EV Flash

3.1.1 Short assessment of OECF data

The OECF data doesn't show any critical flaws of the camera. The visual noise is stable over the different illuminations but slightly visible. Altogether in comparison to the latest competitors (16 models) the test device shows around 22% more noise. Also the dynamic range is pretty uniform but it tends to be a bit low. The average of the measured smartphones reaches a dynamic range of 7.6 (at 1000lx) with the highest result of 8.8 f-stops. As the graphs show, the automatic white balance of the camera tends to be slightly red (the R-curve is a bit higher than the G- and B-curve).

3.2 RESOLUTION SIEMENS

resolution Siemens	center [LP/PH]	%	corners [LP/PH]	MTF 25 [LP/PH]	MTF 50 [LP/PH]	centering
1000lx	1180	96%	1037	1032	832	8
1000lx Zoom	280	23%	279	246	204	4
-2 EV	1145	94%	994	1000	826	9
-4 EV	1032	84%	894	909	760	12
-4 EV Flash	1172	96%	989	1003	794	9



contrast Siemens	vMTF1		vMTF2		vMTF3	
	center	corners	center	corners	center	corners
1000lx	0,73	0,61	0,90	0,82	0,85	0,75
1000lx Zoom	0,08	0,08	0,23	0,24	0,16	0,16
-2 EV	0,74	0,60	0,91	0,82	0,86	0,75
-4 EV	0,70	0,54	0,91	0,80	0,85	0,72
-4 EV Flash	0,68	0,65	0,83	0,90	0,79	0,82

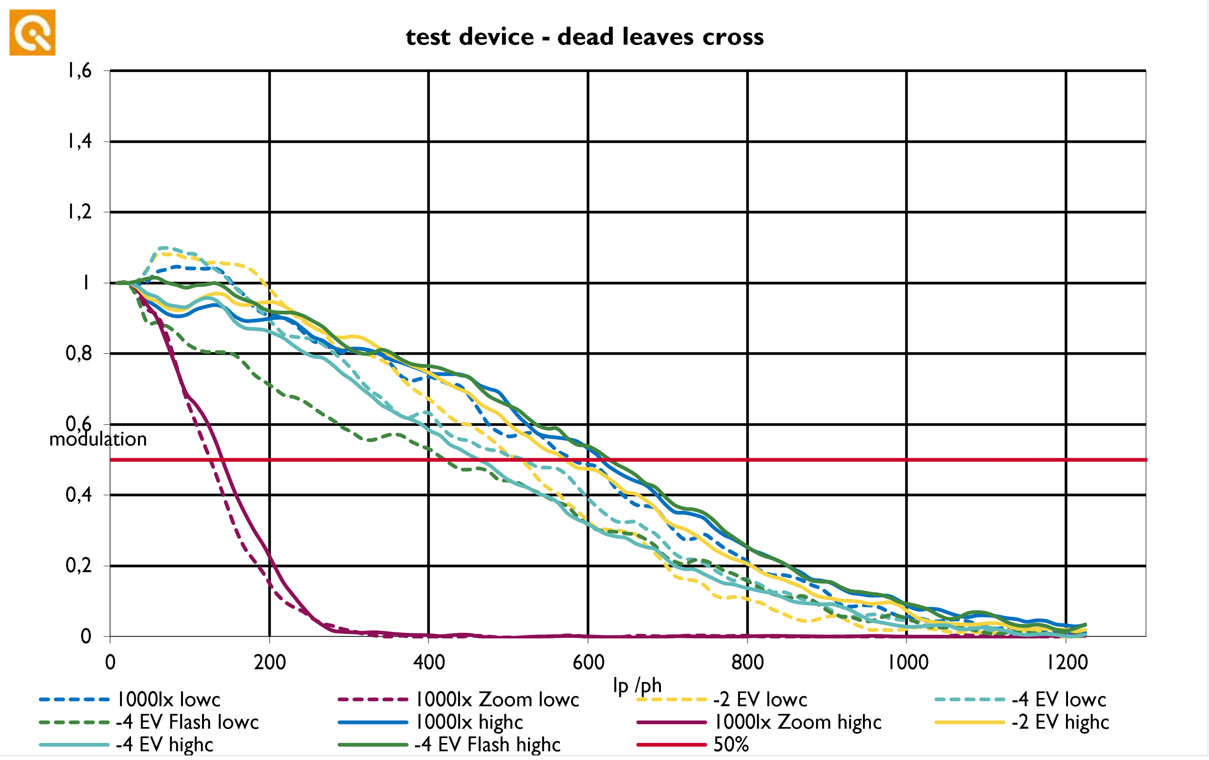
3.2.1 Short assessment of RESOLUTION SIEMENS data

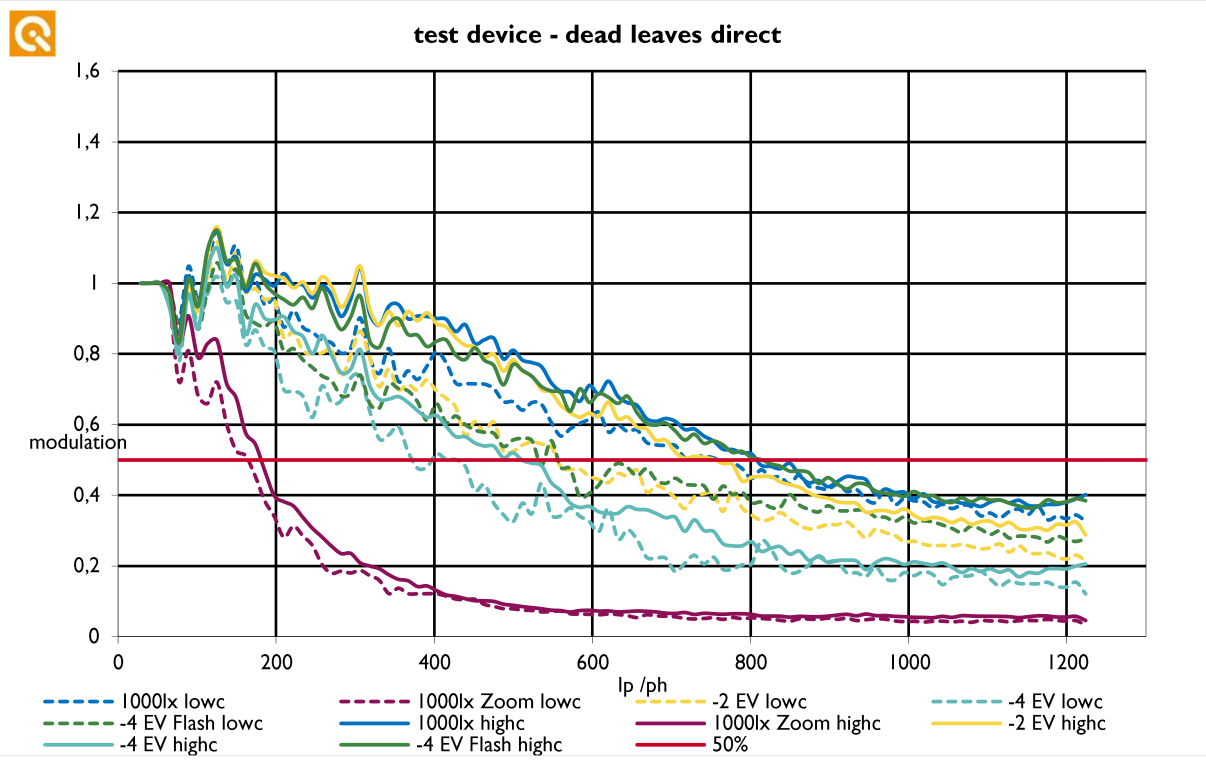
The test device reaches a resolution of 96% of the theoretical possible, the so called nyquist frequency (at 1000lx), which correlates exactly to the average of the comparison field. Nevertheless the camera shows some issues with the contrast which is below average at all light conditions. Also it shows some resolution-issues with the zoom. The resolution drops to just 23 percent of the theoretical possible, which leads to pretty blurry images. Also this is a common problem of all smartphone cameras (except Nokia-devices), the reached resolution with zoom is 25% worse than the average of the comparison field. The resolution in the corners just slightly drops compared to the center. Over all illuminations the device just loses 11% resolution in the corners, while the average loses 16%.

3.3 DEAD LEAVES

Dead Leaves Highcontrast	MTF10 [LP/PH]	MTF50 [LP/PH]	vMTF1	vMTF2	vMTF3	Artifacts [%]
1000lx	992	617	0,62	0,87	0,79	28,7
1000lx Zoom	236	141	0,13	0,41	0,28	43,9
-2 EV	935	571	0,61	0,88	0,80	27,4
-4 EV	857	463	0,52	0,83	0,72	16,7
-4 EV Flash	989	628	0,64	0,91	0,82	24,7

Dead Leaves Lowcontrast	MTF10 [LP/PH]	MTF50 [LP/PH]	vMTF1	vMTF2	vMTF3	Artifacts [%]
1000lx	912	581	0,61	0,91	0,81	24,0
1000lx Zoom	219	126	0,12	0,38	0,25	40,0
-2 EV	809	514	0,57	0,93	0,81	19,7
-4 EV	882	518	0,56	0,89	0,78	0,0
-4 EV Flash	883	420	0,46	0,73	0,63	33,0





3.3.1 Short assessment of DEAD LEAVES data

Relating to texture loss the device shows a good behaviour. It has a good compromise between texture loss and adding of artifacts. But again the performance is not good at the zoom position and tends to be around 30% worse than the average.

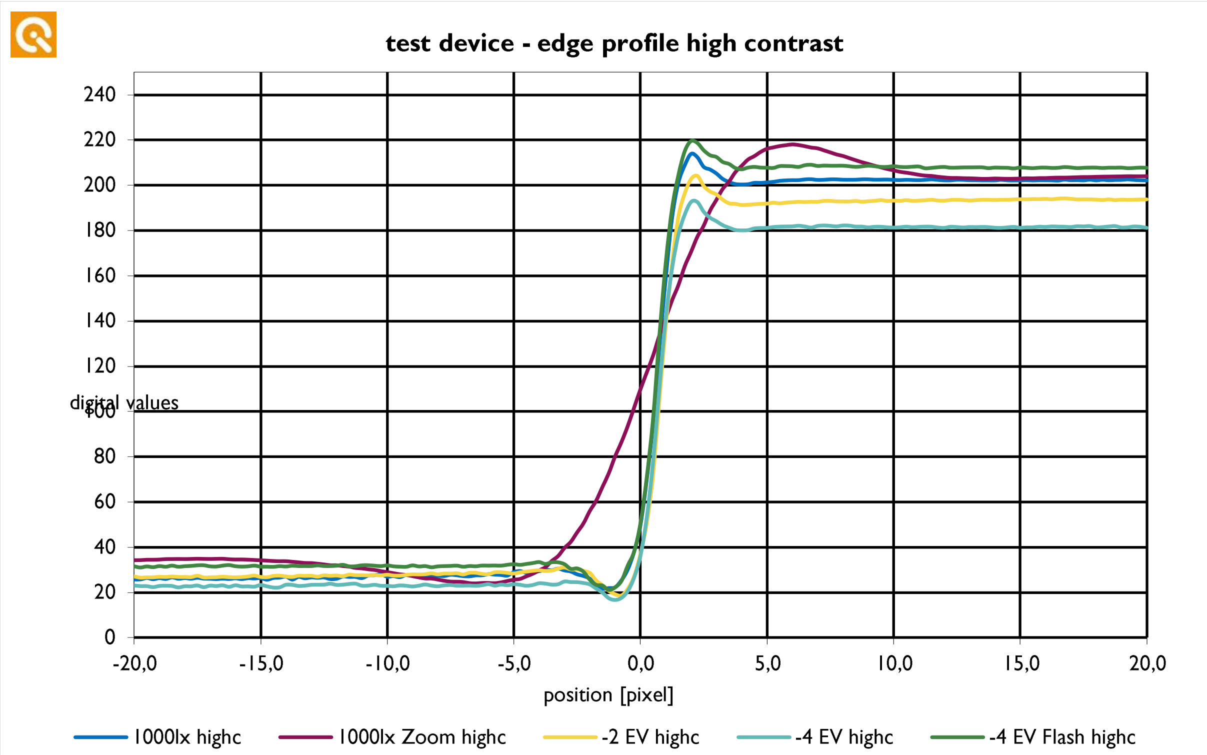
3.4 SLANTED EDGES

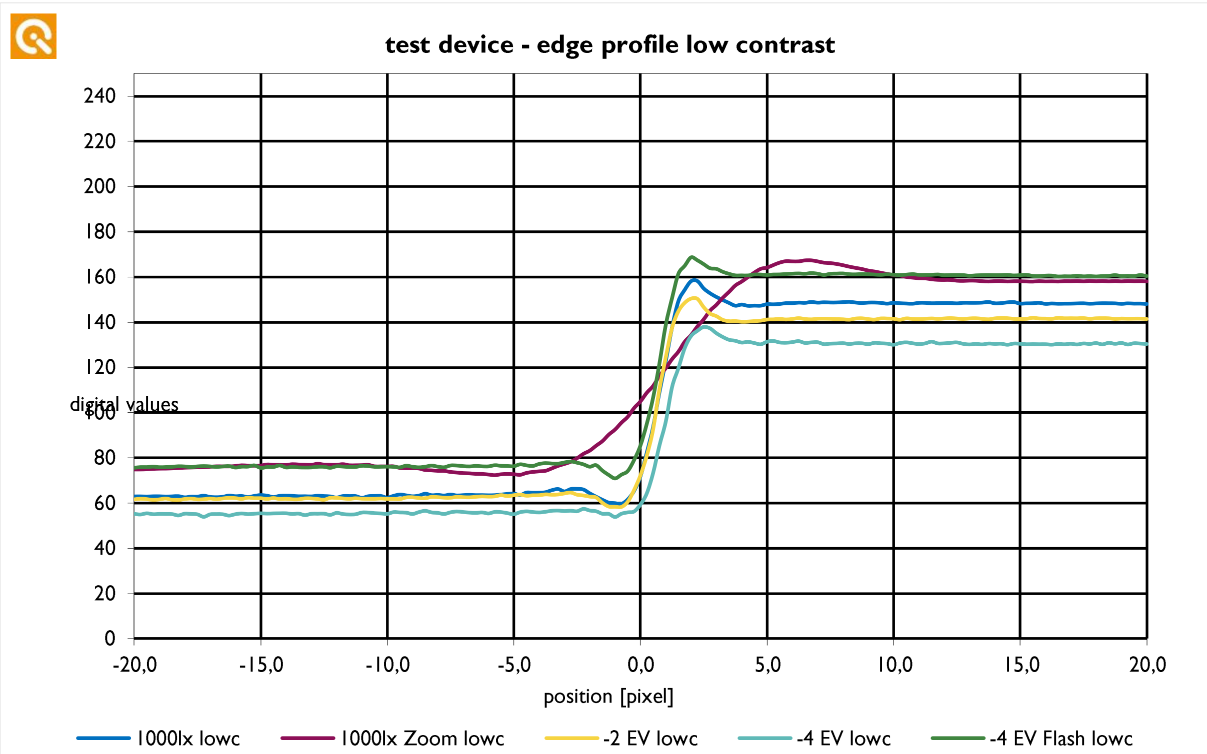
Edge High contrast	Overshoot %	Overshoot area set 1	Overshoot area set 3	Undershoot %	Undershoot area set 1	Undershoot area set 3
1000lx	8,7	524	86	6,6	503	82
1000lx Zoom	10,8	0	0	6,8	0	0
-2 EV	8,1	454	74	8,3	594	97
-4 EV	8,8	475	78	6,0	337	55
-4 EV Flash	7,3	484	79	7,4	689	113

Edge High contrast	MTF50 [LP/PH]	vMTF1	vMTF2	vMTF3	modulation [%]
1000lx	1059	0,85	1,02	0,98	6,2
1000lx Zoom	286	0,09	0,23	0,17	-0,7
-2 EV	1085	0,87	1,02	0,99	4,8
-4 EV	1052	0,86	1,03	0,99	7,5
-4 EV Flash	1028	0,84	1,02	0,97	1,4

Edge Low contrast	Overshoot %	Overshoot area set 1	Overshoot area set 3	Undershoot %	Undershoot area set 1	Undershoot area set 3
1000lx	15,7	475	78	9,5	327	53
1000lx Zoom	12,5	0	0	6,9	0	0
-2 EV	14,3	444	73	9,0	247	40
-4 EV	11,7	309	51	3,5	115	19
-4 EV Flash	11,0	304	50	9,2	275	45

Edge Low contrast	MTF50 [LP/PH]	vMTF1	vMTF2	vMTF3	modulation [%]
1000lx	955	0,86	1,05	1,02	14,3
1000lx Zoom	267	0,07	0,09	0,13	4,3
-2 EV	998	0,89	1,09	1,04	12,9
-4 EV	879	0,77	0,95	0,94	15,7
-4 EV Flash	916	0,80	0,99	0,96	2,9


test device - edge profile high contrast
240
220
200
180
160
140
120
digital values
100
80
60
40
20
0
-20,0
-15,0
-10,0
-5,0
0,0
5,0
10,0
15,0
20,0
position [pixel]
1000lx highc
1000lx Zoom highc
-2 EV highc
-4 EV highc
-4 EV Flash highc


test device - edge profile low contrast
240
220
200
180
160
140
120
digital values
100
80
60
40
20
0
-20,0
-15,0
-10,0
-5,0
0,0
5,0
10,0
15,0
20,0
position [pixel]
1000lx lowc
1000lx Zoom lowc
-2 EV lowc
-4 EV lowc
-4 EV Flash lowc

3.4.1 Short assessment of SLANTED EDGES data

In general the camera works with a moderate over- and undershoot. While some competitors tend to increase over- and undershoot differently, the test device uses an equal over- and undershoot. Thereby the edges are enhanced but don't show to strong sharpening artifacts.

3.5 COLOR

Color	ΔE	ΔL	ΔC	ΔH	WB
1000lx	10,2	0,8	2,8	1,1	3,2
1000lx Zoom	10,8	4,1	4,1	1,8	3,7
-2 EV	9,3	-1,0	0,9	0,9	3,5
-4 EV	9,6	-3,1	-0,4	1,1	4,4
-4 EV Flash	7,1	0,4	-1,5	1,3	3,7

Delta E

	A	B	C	D	E	F	G	H	I	J	K	L
1	19,7	11,0	7,5	10,5	12,7	8,4	12,4	8,3	11,6	4,6	7,8	25,6
2	15,0	14,5	6,3	14,2	14,8	20,8	13,4	9,6	12,0	6,0	15,0	12,6
3	6,8	10,4	7,4	12,6	5,8	15,8	10,0	14,0	7,8	5,1	15,7	19,7
4	11,2	7,1	6,1	0,0	5,1	2,1	6,1	10,3	3,1	5,9	15,6	19,5
5	8,3	10,8	9,1	3,6	10,6	10,1	3,3	4,6	1,8	4,9	14,8	11,4
6	11,8	6,6	17,8	8,4	10,0	11,0	9,2	12,8	14,3	7,0	10,7	10,2
7	9,6	9,5	15,8	10,4	9,8	8,7	9,5	12,4	12,3	7,4	8,8	10,9
8	9,3	12,6	5,6	15,1	7,5	7,9	7,3	6,8	11,3	6,9	11,6	10,5

Delta L

	A	B	C	D	E	F	G	H	I	J	K	L
1	4,4	-5,9	7,5	-7,3	0,5	-6,4	-9,4	-2,6	6,2	3,7	-3,1	8,2
2	7,5	-2,4	5,8	3,3	-8,1	3,6	-4,2	6,0	4,1	3,9	7,1	-4,5
3	2,9	-7,7	5,9	-8,4	0,9	5,9	5,9	2,7	-2,0	5,0	2,7	8,4
4	2,4	5,1	5,3	0,0	5,1	1,9	-5,8	-10,1	-2,9	4,8	3,1	8,9
5	6,5	-7,4	9,1	-3,3	-10,2	-10,0	-3,2	4,6	-0,4	4,7	3,7	9,0
6	-6,9	4,6	4,3	3,2	0,3	-7,4	1,5	-5,5	0,8	-6,9	8,7	7,1
7	8,5	5,9	5,8	1,8	0,0	-0,2	0,4	-8,7	0,9	-7,2	0,8	8,7
8	-7,5	7,1	4,9	-9,3	4,1	-0,3	-2,2	1,9	-1,6	2,1	8,5	-7,8

Delta C

	A	B	C	D	E	F	G	H	I	J	K	L
1	-0,7	-8,7	-0,4	-1,1	12,6	4,8	-7,6	7,7	9,6	2,6	-1,2	12,5
2	12,1	13,7	2,3	3,7	11,6	17,6	-11,4	-4,0	-3,3	1,3	13,2	-5,7
3	0,0	3,1	4,2	8,6	-1,2	13,2	-6,9	7,5	-2,1	0,0	14,7	14,9
4	7,9	4,9	2,8	0,0	0,3	0,3	0,8	0,8	-0,9	3,2	15,2	17,4
5	4,9	-6,0	-0,6	-1,2	1,8	0,1	0,2	0,4	1,7	0,7	5,0	-3,5
6	-9,6	4,7	16,5	7,7	8,9	3,4	9,0	0,7	14,2	0,4	-6,1	-6,7
7	4,6	-7,4	14,6	10,2	9,7	8,5	9,4	-3,0	12,0	-1,4	-4,4	-6,0
8	-5,4	9,9	-0,4	-11,8	6,2	-0,3	-3,8	-0,1	2,1	-5,2	-4,3	-6,0

Delta H

	A	B	C	D	E	F	G	H	I	J	K	L
1	19,2	3,1	-0,6	-7,5	-1,2	2,5	2,7	2,0	1,6	-1,2	7,0	20,8
2	4,9	4,2	0,7	-13,3	4,4	10,4	5,6	6,4	-10,7	4,3	1,2	10,3
3	6,2	6,2	1,1	3,9	5,6	6,4	-4,0	11,5	7,3	-0,9	4,5	9,8
4	7,5	0,9	0,9	0,0	-0,4	-0,8	1,5	1,8	0,2	0,9	2,3	0,1
5	1,4	5,0	0,6	0,8	2,3	1,0	0,4	0,4	0,2	1,0	-13,4	-6,0
6	-0,1	0,7	-4,9	-0,6	-4,7	-7,5	-1,5	-11,6	-2,0	1,0	-1,9	-2,6
7	0,4	0,9	0,0	-0,3	-1,6	-1,9	-1,3	-8,3	-2,4	0,6	-7,6	2,5
8	-1,5	3,5	-2,6	-1,3	1,0	7,9	5,9	6,6	-11,0	4,1	6,7	-3,7

Classification of the Δ values

ΔE < 10	good color reproduction	
10 < ΔE < 20	visible color differences, but acceptable	
ΔE > 20	visible color differences	

Left side: color reproduction of the camera, right side: reference colors

Colors at 1000 lux

3.5.1 Short assessment of COLOR data

The device shows no issues with the color reproduction.

3.6 DISTORTION AND SHADING

Distortion	TV-Distortion
1000lx	0,1
1000lx Zoom	0,1
-2 EV	0,1
-4 EV	0,2
-4 EV Flash	0,1

Shading	Intensity Shading [f-stop]	Color Shading [ΔE_ab]
1000lx	0,7	2,9
1000lx Zoom	0,6	2,0
-2 EV	0,8	2,4
-4 EV	0,9	3,1
-4 EV Flash	1,3	3,4

3.6.1 Short assessment of DISTORTION and SHADING data

The lens of the test device shows no distortion issues. While the device is one of the best in course of color shading it shows a tesslightly higher intensity shading than the average. But latter one still doesn't affect the images negatively.

3.7 TIME-MEASUREMENT AND IMAGE STABILIZATION

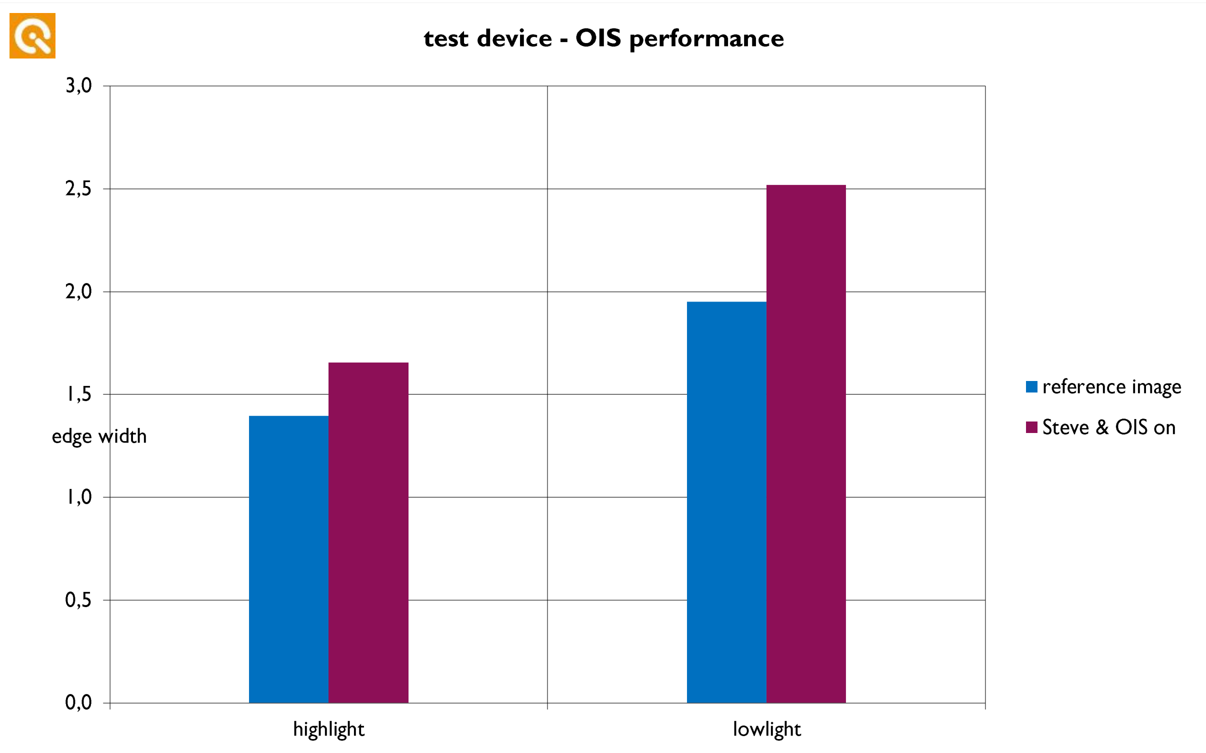
shutter	AF (800lx)	AF (30lx)	non-AF
lens 1	0,73	1,14	0,03

startup time [s]	0,9

JPG best	frames per second	10

STEVE highlight	reference image	Steve & OIS on	Delta (ref - Steve&OIS on)
Visual Noise	2,15	2,09	//
Contrast	0,88	0,78	-12,0%
Edge Width	1,40	1,66	15,6%

STEVE lowlight	reference image	Steve & OIS on	Delta (ref - Steve&OIS on)
Visual Noise	3,10	3,05	//
Contrast	0,62	0,45	-27,8%
Edge Width	1,95	2,52	22,6%



3.7.1 Short assessment of TIME and IMAGE STABILIZATION

The test device is one of the fastest to start the camera app and take an image. The average of the compared smartphones needs 2 seconds until a picture is taken. Also the time the device needs to take 10 images in a row is pretty fast. It is around 47% faster than the average of the competitors.

The image stabilization shows no issues, the camera is pretty able to compensate movements without increasing the noise too much.

V ASSESSMENT OF RESULTS

The OECF data doesn't show any critical flaws of the camera. The visual noise is stable over the different illuminations but slightly visible. Altogether in comparison to the latest competitors (16 models) the test device shows around 22% more noise. Also the dynamic range is pretty uniform but it tends to be a bit low. The average of the measured smartphones reaches a dynamic range of 7.6 (at 1000lx) with the highest result of 8.8 f-stops. As the graphs show, the automatic white balance of the camera tends to be slightly red (the R-curve is a bit higher than the G- and B-curve).

The test device reaches a resolution of 96% of the theoretical possible, the so called nyquist frequency (at 1000lx), which correlates exactly to the average of the comparison field. Nevertheless the camera shows some issues with the contrast which is below average at all light conditions. Also it shows some resolution-issues with the zoom. The resolution drops to just 23 percent of the theoretical possible, which leads to pretty blurry images. Also this is a common problem of all smartphone cameras (except Nokia-devices), the reached resolution with zoom is 25% worse than the average of the comparison field. The resolution in the corners just slightly drops compared to the center. Over all illuminations the device just loses 11% resolution in the corners, while the average loses 16%.

Relating to texture loss the device shows a good behaviour. It has a good compromise between texture loss and adding of artifacts. But again the performance is not good at the zoom position and tends to be around 30% worse than the average.

The lens of the test device shows no distortion issues. While the device is one of the best in course of color shading it shows a slightly higher intensity shading than the average. But latter one still doesn't affect the images negatively.

The test device is one of the fastest to start the camera app and take an image. The average of the compared smartphones needs 2 seconds until a picture is taken. Also the time the device needs to take 10 images in a row is pretty fast. It is around 47% faster than the average of the competitors.
The image stabilization shows no issues, the camera is pretty able to compensate movements without increasing the noise too much.

In general the camera works with a moderate over- and undershoot. While some competitors tend to increase over- and undershoot differently, the test device uses an equal over- and undershoot. Thereby the edges are enhanced but don't show too strong sharpening artifacts.

Altogether the test device has a good image quality, except the performance with the digital zoom could be improved.