Colorimetric and Resolution requirements of cameras

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ADDENDUM 67: Comparison of lenses for HDTV

This document is a report of the results of tests that are the precursor of those described in the EBU technical document Tech3335. It is not an endorsement of the product.

Tests were made of several HDTV zoom lenses, all B4 mounted ⅔" format. All the lenses were new and unused. No attempt was made to assess their ergonomic suitability to use in programme-making, the intent was only to assess the optical performance without having to resort to formal optical test-bench measurements. Measurement techniques were devised such that they can all be used in a conventional television studio using no specialised equipment. All the lenses were tested on a single camera, a Sony PMW350.

1 Measurement to be made

Only those aspects of lens performance which can be assessed on real images recorded by a real camera were considered.

- **Resolution**, a subjective assessment using a circular zone-plate test chart. Numerical analysis was used as a cross-check, but found to be unnecessary.
- **Chromatic aberration**, any difference of image sizes in the RGB components of the output picture.
- **Image geometry**, any deviation from strict rectilinearity, e.g. pincushion and barrel distortion.
- **Focus breath**, the change of magnification as focus is adjusted.
- **Exposure ramping**, the loss of light when the lens is used at its longest focal length.

2 Measurement methods

All measurements were made by capturing images from the Sony PMW350 camcorder via HDSDI into a nanoFlash video recorder as MXF files, then importing the captured files into video editing software for further export as bitmap image files for analysis. No specialist software was required, although initial tests for resolution using specialist software showed that sensible results could be got through simpler (and quicker) means. All images were illuminated by a single Redhead, placed to get uniform illumination levels wherever possible. This often meant that the luminaire had to be place behind the camera, which potentially threw shadows onto the test charts. Occasionally, it had to be moved much closer, and then it was angled specifically to get uniform illumination, checked using a digital waveform monitor.

2.1 Resolution

A circular zone-plate test chart was used with six identically sized patterns, for P_r Y P_b across the top half, and *RGB* across the bottom. The chart also has 'Siemens stars' in the corners, intentionally for focus checking, but they also have other uses, see below. The chart is designed to be used with camera gamma-correction switched on, and has modulation which appears sinusoidal in the gamma-corrected video signal. Thus, harmonic distortion is avoided.

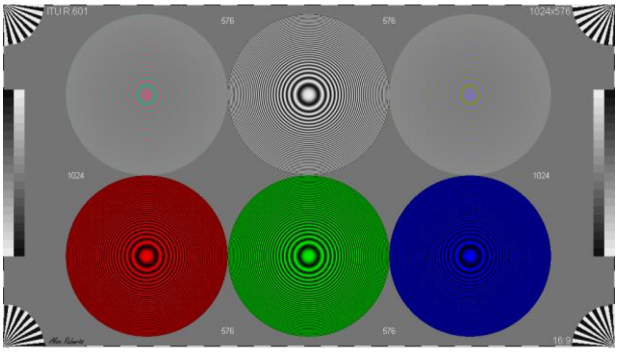

Figure 1 Zone plate test chart

Figure 1 shows the arrangement for a low-resolution chart, the chart used was computed for 1920x1080, and printed 21⅓" x 12" (541.877 x 304.8mm). The frequency calibration is correct when the entire chart

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exactly fills the 1920x1080 image.

Only one of the circular patterns was used, the one for luminance (Y). It represents dc in the middle, and extends to exactly 960 cycles/picture width and 540 cycles per picture height at its extremes, and the distribution of frequencies is linear with distance from the centre of the pattern. Thus the frequency response can be read off simply by measuring from the centre, scaled to the pattern size.

Since the pattern has circular self-similarity, only one quadrant is ever needed. Horizontal resolution is explored horizontally, vertical resolution vertically. Fig. 2 shows one quadrant, from a test on one of the lenses (file FA269), when the camera had been set to place this pattern in the top-left corner of the image, and the horizontal frequency response is judged to be limited to about 86% of 1920. The upper-left hand quadrant has been used such that the highest frequencies are near the edge of the television picture, but the image in Fig.2 has been flipped horizontally to show it more conventionally.

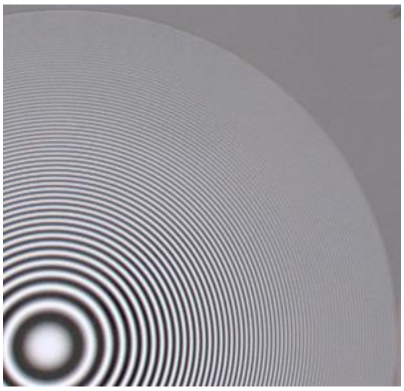

Figure 2 Zone plate luminance quadrant

Fig.3 shows a mathematical analysis of the video signal from a line-scan through the centre of the pattern. This time, the data values are as recorded from the image and have not been horizontally flipped.

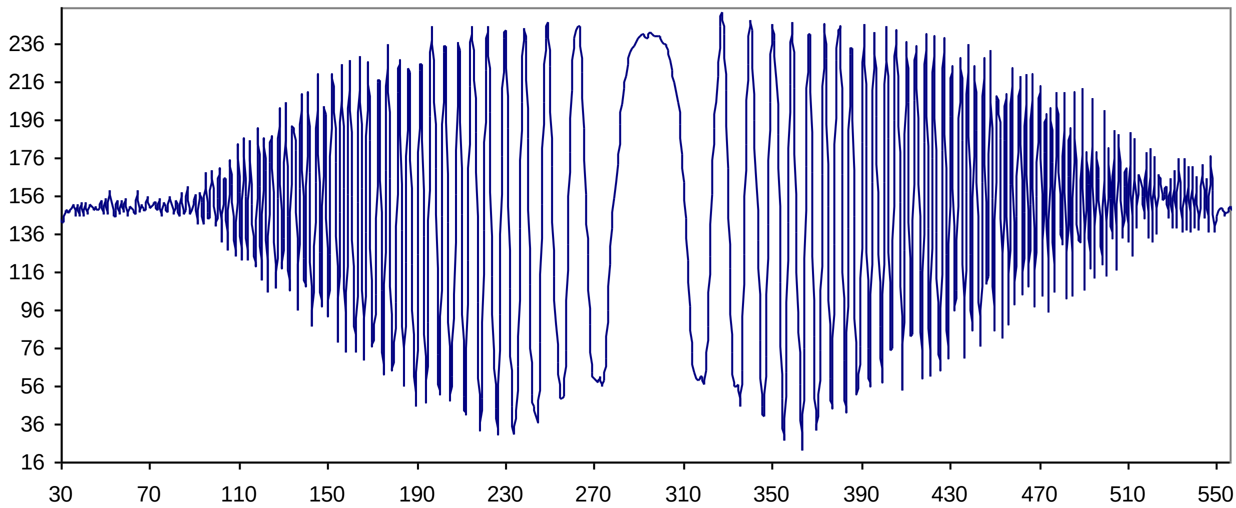

Figure 3 Zone plate line scan

Clearly, the resolution in the right half is higher than the left half, thus the resolution is dropping significantly towards the edge of the lens. Since DC is in the middle, we can measure, in pixel positions, from the centre (pixel 296) to the edge (pixel 34) and derive an equation relating horizontal image frequency to pixel position. Doing so, shows that the lowest meaningful amplitude of the pattern, the extinction frequency, occurs at about pixel 71, or 86%.

In practice, it is easier to use the eye's extremely good pattern-recognition facilities simply to look at the image and decide where the extinction limit is, and to measure it with a ruler (in CorelDraw). Accordingly, all resolution assessment was done by eye.

Measurements were made at a distance of 2m, aperture F/4, focal length 30mm. This was possible on all the lenses. More measurements were made at a closer distance, intending to get as close as possible to the chart. In some cases it was possible to achieve correct framing at the shortest focal length and/or closest focus of the lens, in other cases it was not and compromises were needed, these are noted in the results. More measurements were made, placing the luminance pattern in the corners of the image, without changing zoom or focus setting, and the lowest resolution observed is recorded. In all cases, the measurements are only of horizontal resolution, and are expressed as a percentage of the maximum achievable resolution (1920, 960 cycles per picture width).

2.2 Chromatic aberration (colour fringing)

The zone-plate test chart was used, although this may not, at first sight, appear to be the best choice.

Chromatic aberration is best thought of as differential magnification of the red green and blue images formed at the camera sensor, although the effect is continuous across the visible light band from 380 to 760nm. It always appears worst in the corners of the image, furthest from the optical axis. Since the HDTV image has a 16:9 aspect ratio, the effect always appears to be more horizontal rather than vertical, since the horizontal edges are further away from the optical axis than are the vertical edges. Thus, it should be necessary only to establish the magnitude of the difference between red and blue images, and the blue image is always bigger than the red.

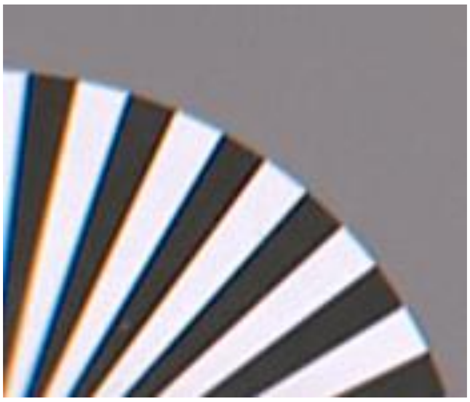

Figure 4 Chromatic aberration

Fig.4 shows the effect from the bottom left corner of an image (file FA196). Clearly, the blue image is bigger than the red, because there are blue-green fringes to the left of white/black transitions, and red fringes to the left of black/white transitions.

Bitmap files were imported into CorelDraw, and the width of the colour fringe measured in pixels. Thus this measurement is related directly to the video image dimensions rather than to the absolute values which lens measurements would normally be expected to deliver. This measurement is difficult to make accurately, since the effect is compounded by the loss of sharpness in the corners. Nevertheless, the results are reasonably consistent and represent the appearance of the effect in all the lenses tested.

Measurements were made at a distance of 2m, aperture F/4, focal length 30mm. This was possible on all the lenses. More measurements were made at the closer distance at which the test chart could be framed and focused.

2.3 Image geometry (differential magnification)

The zone-plate chart was used, although it is not ideally suited to these tests. Two forms of geometric distortion were expected, pincushion and barrel. In the event, only pincushion distortion was observed. This is best thought of as differential magnification of the image, where the outer parts are more magnified than the central, and the change of magnification is proportional to the distance from the lens optical axis.

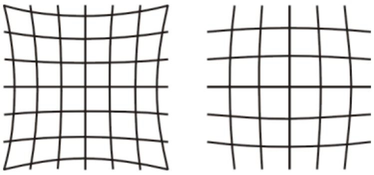

Figure 5 Pincushion and Barrell

Ideally, the measure of distortion should be the magnitude of the deviation of a straight line in the scene from a straight line in the image, as a percentage of height or width of the image, but a simpler method was adopted.

The image bitmap file was imported into CorelDraw, and the size of the image noted. The images had all been exported from the video editing software as Windows bitmap files, for which the default scale factor is 72 dots (pixels) per inch. Thus the image files are all exactly 26⅔ x 15”, or 667⅓ x 381mm.

To measure the differential magnification, a reference measure was taken of the lower half-height of the luminance pattern (i.e. from the centre to the lower limit) in the zone plate. Then measures were taken of the outer half-height and half-width of the *R*, *B*, P_b and P_r patterns, as representing the edges of the picture. Taking the ratio of the centre reference value to the largest of these sizes gives a measure of the geometric distortion, as a percentage. Clearly, this does not explore the full limits of the image, but by taking consistent measurements with the chart always framed to fill the image (but only vertically, at the centre) delivers consistent values with which lenses can be compared.

Measurements were made at a distance of 2m, aperture F/4, focal length 30mm. More measurements were made at F/1.8 and F/8 to examine the effects of aperture setting, and at the lens’ widest focal length setting.

2.4 Focus breath (magnification change with focus setting)

The checkerboard chart was used, Fig.6.

The image files were imported into CorelDraw, and the width of a group or patches (usually 4 or more) in the chart was measured. The effects of any geometric distortion were generally ignored, but care was taken to use only central parts of the image to minimise any such effects. Occasionally, it was not possible to be consistent in the number of patches measured when, for example, the magnification changed dramatically, in this case the width of a reduced number of patches was measured, and the results scaled to correct for the change.

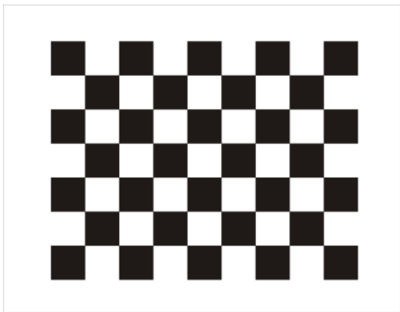

Figure 6 Checkerboard

It was always found that the magnification change was inversely proportional to the focus distance (magnification is biggest at close focus, least at infinity), thus the effect could be measured simply by expressing the size at infinity relative to that close-up. In some cases it was not possible to get meaningful measurements at the focus extremes, in those cases the results were taken at the largest measureable extremes, and this limitation noted.

Measurements were made at a distance of 2m, aperture F/4, focal length 30mm. More measurements were made at the lens' widest and longest focal length setting.

2.5 Exposure ramping

A checker-board pattern of black squares on white was used.

For this test, gamma-correction was turned off, and the camera used as a light meter. Captured bitmap files were imported into Paint Shop Pro, and the 'eye-dropper' used to measure the *RGB* signal levels at signification points. Since all the lenses performed as expected, only a limited number of measurement points were needed.

Exposure ramping occurs when the internal elements of a lens are not big enough for the passage of light at all focal-length settings of the lens. This is done for reasons of economy (both financial and weight/size considerations are important). The loss of light is not evenly distributed over the image, light is lost initially at the edges, and the amount lost is directly related to the distance from the optical axis, while none is ever lost at the centre. The slope of this light loss is constant for all the lenses tested, and appears to be a standard property of ramping.

Fig.7 shows this, the result of two separate line scans across a tight shot of the chart, in which one line has black at both edges, the other having white. The sloping edges of the transitions are dues to defocusing the lens in order to minimise the effect of any dirt or blemishes on the printed chart.

Thus, it is only necessary to measure in the middle of the image to get a 'normal' white level, and then at the extreme edges. Taking the average of the two edges eliminates any residual lighting unevenness, and expressing this mean value as a percentage of that of the centre value gives a measure for ramping.

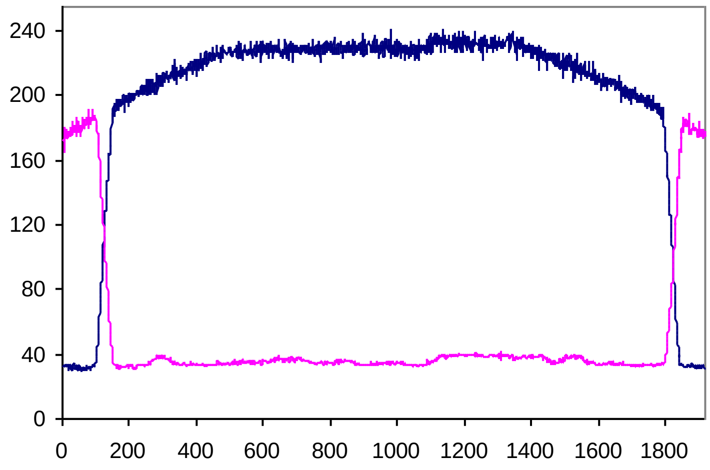

Figure 7 Ramping, line scans

The onset of this light loss usually occurs within the last 2:1 range of focal lengths, going in the long direction. It is rare for a zoom lens not to exhibit ramping at all.

Measurements were made at a distance of 2m, aperture F/4, focal length 30mm. More measurements were made at 60mm focal length (where possible), and at the lens' longest focal length setting (if greater than 60mm).

3 Results

		Fujinon					
		HA18x7.6 BERM M58B	ZA12x4.5 BERM M58	HA23x7.6 BERM S58	HA14x4.5 BERM M58	ZA12x4.5 BERM M58H	ZA22x7.6 BERM M58
Resolution	30mm	100%	100%	100%	100%[1]	100%	100%[2]
	wide	100%[3]	98%[4]	88%[5]	100%	91%	100%
	corner	87%[6]	89%[7]	87%	95%	70%	88%
Chromatic aberration	30mm	4.3	2.8	3.0	3.0	2.4	4.4
	wide	3.7[8]	4.3	4.0	2.4	3.7	2.6
Geometry	30mm	93%	100%	100%	95%	94%	95%
	F/1.8	93%	100%	92%	94%	94%	95%
	F/8	93%	100%	93%	94%	95%	95%
	wide	90%[9]	60%[10]	89%[11]	89%	95%[12]	93%
Focus breath	30mm	86%[13]	86%[14]	73%	87%[15]	70%[16]	73%
	wide	84%[17]	100%[18]	84%	99%[19]	84%[20]	85%
	long	88%[21]	96%[22]	80%[23]	90%[24]	74%[25]	87%[26]
Exposure ramping	30mm	88%	91%	94%	90%	94%	98%[27]
	long	97%[28]	78%[29]	98%[30]	78%	96%	97%[31]
	longer	83%[32]	n/a	80%[33]	n/a	81%[34]	85%

[1] Fujinon HA14x4.5 : resolution 30mm : 94% at F/1.8, 100% at F/4, 97% at F/8
[2] Fujinon ZA22x7.6 : resolution 30mm : 100% at F/1.8, 98% at F/8
[3] Fujinon HA18x7.6 : resolution wide : 7.6mm focal length, 2m distance
[4] Fujinon ZA12x4.5 : resolution wide : 96% at F/1.8
[5] Fujinon HA23x7.6 : resolution wide : 7.6mm focal length, 0.8m distance, 96% at F/4, 79% at F/1.8
[6] Fujinon HA18x7.6 : resolution corner : 7.6mm focal length, 0.6m distance
[7] Fujinon ZA12x4.5 : resolution corner : 4.5mm focal length, 0.6m distance
[8] Fujinon HA18x7.6 : chromatic aberration wide : F/4, 0.6m distance
[9] Fujinon HA18x7.6 : geometry wide : 7.6mm focal length, 2m distance
[10] Fujinon ZA12x4.5 : geometry wide : 5mm focal length, 0.45m distance
[11] Fujinon HA23x7.6 : geometry wide : 7.6mm focal length
[12] Fujinon ZA12x4.5 : geometry wide : 7.6mm focal length
[13] Fujinon HA18x7.6 : focus breath 30mm : 0.6m to ∞ focus
[14] Fujinon ZA14x4.5 : focus breath 30mm : 0.3m to ∞ focus
[15] Fujinon HA14x4.5 : focus breath 30mm : 2m distance, focus 0.3m to ∞ focus
[16] Fujinon ZA12x4.5 : focus breath 30mm : 0.6m to ∞ focus distance
[17] Fujion HA18x7.6 :focus breath wide : 7.6mm focal length
[18] Fujion ZA12x4.5 : focus breath wide : 7.6mm focal length
[19] Fujinon HA14x4.5 : focus breath wide : 4.5mm focal length, 2m distance, focus 0.3m to ∞ focus
[20] Fujinon ZA12x4.5 : focus breath wide : 0.6m to ∞ focus
[21] Fujion HA18x7.6 : focus breath long : 137mm focal length, 2m to 5m distance
[22] Fujion ZA12x4.5 : focus breath long : 54mm focal length, 5m to ∞ focus
[23] Fujinon HA23x7.6 : focus breath long : 175mm focal length, 1.5m to 5m focus
[24] Fujinon HA14x4.5 : focus breath long : 63mm focal length, 2m distance, focus 0.6m to ∞ focus
[25] Fujinon ZA12x4.5 : focus breath long : 54mm focal length, 1.5m to ∞ focus
[26] Fujinon ZA22x7.6 : focus breath long : 167mm focal length, 2m to 5m focus
[27] Fujinon ZA22x7.6 : ramping long : 80mm focal length
[28] Fujion HA18x7.6 : ramping long : 60mm focal length
[29] Fujion ZA12x4.5 : ramping long : 54mm focal length
[30] Fujinon HA23x7.6 : ramping long : 60mm focal length
[31] Fujinon ZA22x7.6 : ramping longer : 167mm focal length
[32] Fujion HA18x7.6 : ramping longer : 137mm focal length
[33] Fujinon HA23x7.6 : ramping longer : 175mm focal length, 99% at 80mm

		Canon				
		HJ22ex7.6 B IASE A	HJ17ex7.6 B IRSE	HJ14ex4.3 IRSE	KJ17ex7.6 B IRSE	KJ10ex4.3 B ~ISRE
Resolution	30mm	100%[35]	100%	100%	100%	100%[36]
	wide	98%	100%	100%[37]	100%[38]	89%[39]
	corner	92%	90%	79%	86%[40]	92%[41]
Chromatic aberration	30mm	2.0	3.4	0.9	2.7	2.7
	wide	2.2	5.2	1.7	3.4	3.3
Geometry	30mm	95%	94%	95%	95%	93%
	F/1.8	95%	95%	95%	94%	92%
	F/8	94%	95%	94%	96%	94%
	wide	91%	88%[42]	na[43]	92%	88%
Focus breath	30mm	76%[44]	69%[45]	87%	69%	89%[46]
	wide	88%[47]	84%[48]	100%[49]	83%[50]	99%
	long	80%[51]	78%[52]	98%[53]	81%[54]	92%[55]
Exposure ramping	30mm	95%	100%	92%	95%	95%
	long	98%[56]	100%[57]	79%[58]	100%[59]	84%[60]
	longer	76%[61]	82%[62]	n/a	87%[63]	n/a

[34] Fujinon ZA12x4.5 : ramping longer : 130mm focal length
[35] Canon HJ22x7.6 : resolution wide : 18mm focal length, 0.85mm distance
[36] Canon KJ10x4.5 : resolution 30mm : 100% at F/4 to F/8, 82% at F/1.8
[37] Canon HJ14x4.3 : resolution wide : 8mm focal length, 0.45m distance
[38] Canon KJ17x7.6 : resolution wide : 100% at F/8 and F/4, 88% at F/1.8
[39] Canon KJ10x4.5 : resolution wide : 7.5mm focal length
[40] Canon KJ17x7.6 : resolution corner : 86% at 30mm focal length, 74% at 8.5mm focal length
[41] Canon KJ10x4.5 : resolution corner : 92% at 30mm focal length, 89% at 7.5mm focal length
[42] Canon HJ17x7.6 : geometry wide : about 10mm focal length, 0.65m distance
[43] Canon HJ14x4.3 : geometry wide : measurement not made at this setting
[44] Canon HJ22x7.6 : focus breath 30mm : 0.85m to ∞ focus
[45] Canon HJ17x7.6 : focus breath 30mm : 0.56m to ∞ focus
[46] Canon KJ10x4.5 : focus breath 30mm : 0.3m to ∞ focus
[47] Canon HJ22x7.6 : focus breath wide : 7.6mm focal length, 0.85m to ∞ focus
[48] Canon HJ17x7.6 : focus breath wide : 0.56m to ∞ focus
[49] Canon HJ14x4.3 : focus breath wide : 4.3mm focal length, 0.3m to ∞ focus
[50] Canon KJ17x7.6 : focus breath wide : 7.7mm focal length, 0.6m to ∞ focus
[51] Canon HJ22x7.6 : focus breath long : 168mm focal length, 1.3m to 4m focus
[52] Canon HJ17x7.6 : focus breath long : 130mm focal length, 1.3m to 5m focus
[53] Canon HJ14x4.3 : focus breath long : 60mm focal length
[54] Canon KJ17x7.6 : focus breath long : 131mm focal length, 1.3m to 4m focus
[55] Canon KJ10x4.5 : focus breath long : 45mm focal length
[56] Canon HJ22x7.6 : ramping long : 60mm focal length
[57] Canon HJ17x7.6 : ramping long : 60mm focal length
[58] Canon HJ14x4.3 : ramping long : 60mm focal length
[59] Canon KJ17x7.6 : ramping long : 60mm focal length
[60] Canon KJ10x4.5 : ramping long : 45mm focal length
[61] Canon HJ22x7.6 : ramping longer : 168mm focal length
[62] Canon HJ17x7.6 : ramping longer : 130mm focal length
[63] Canon KJ17x7.6 : ramping longer : 131mm focal length

		Angenieux		
		T26x7.8 BESSD HD	T19x7.3 BESMO HD	T14x4.5 BESMD HD
Resolution	30mm	94%[64]	100%[65]	95%[66]
	wide	87%[67]	92%[68]	89%[69]
	corner	72%[70]	86%	80%[71]
Chromatic aberration	30mm	3.6	4.9	2.6
	wide	4.2	3.7	5.5
Geometry	30mm	95%	93%	95%
	F/1.8	95%[72]	93%	95%
	F/8	95%	93%	94%
	wide	93%[73]	90%	91%[74]
Focus breath	30mm	92%[75]	62%[76]	87%[77]
	wide	84%[78]	86%[79]	88%[80]
	long	66%[81]	77%[82]	87%[83]
Exposure ramping	30mm	98%	94%	95%
	long	100%[84]	99%	-[85]
	longer	74%[86]	86%[87]	n/a

[64] Angenieux T26x7.8 : resolution : 94% at F/4; 89% at F/8; 86% at F/2.2
[65] Angenieux T19x7.3 : resolution : 100% at F/4 30mm focal length, 93% at F/8, 83% at F/1.8
[66] Angenieux T14x4.5 : resolution : 95% at F/4; 88% at F/8; 78% at F/1.8
[67] Angenieux T26x7.8 : resolution wide : 18mm focal length, can’t focus on the chart any closer
[68] Angenieux T19x7.3 : resolution wide : 95% at F/4, 88% at F/1.8, 81% at F/8
[69] Angenieux T14x4.5 : resolution wide : 8mm focal length, 0.3m focus distance; 89% at F/4, 86% at F/8, 84% at F/1.8
[70] Angenieux T26x7.8 : resolution corner : 72% at 18mm focal length; 76% at 30mm focal length
[71] Angenieux T14x4.5 : resolution corner : 30mm focal length, F/4, 2m focus distance
[72] Angenieux T26x7.6 : geometry F/1.8 : lens opens up only to F/2.2
[73] Angenieux T26x7.8 : geometry wide : at 18mm focal length, can’t focus closer to the chart
[74] Angenieux T14x4.5 : geometry wide : at 8mm focal length, couldn’t focus closer
[75] Angenieux T26x7.8 : focus breath : 0.9m to ∞ focus distance
[76] Angenieux T19x7.3 : focus breath : 0.6m to ∞ focus distance
[77] Angenieux T14x4.5 : focus breath : 0.3m to ∞ focus distance
[78] Angenieux T26x7.8 : focus breath wide : 7.8mm focal length, 0.9m to ∞ focus distance
[79] Angenieux T19x7.3 : focus breath wide : 0.6m to ∞ focus distance
[80] Angenieux T14x4.5 : focus breath wide : 4.5mm focal length, 0.3m to ∞ focus distance
[81] Angenieux T26x7.8 : focus breath long : 61% at 60mm focal length, 0.9m ∞ focus distance; 66% at 203mm focal length, 1.2m to ∞ focus distance
[82] Angenieux T19x7.3 :focus breath long : 62% at 60mm focal length, 0.6m to ∞ focus distance; 77% at 139m focal length, 1.5m to ∞ focus distance, too soft to measure any closer
[83] Angenieux T14x4.5 : focus breath long : 63mm focal length, 0.6m to ∞ focus distance
[84] Angenieux T26x7.8 : exposure ramping long : 60mm focal length
[85] Angenieux T14x4.5 : exposure ramping long : 63mm focal length accidentally not measured, but should be near 100%
[86] Angenieux T26x7.8 : exposure ramping longer : 74% at 203mm focal length; 90% at 100mm focal length
[87] Angenieux T19x7.3 : exposure ramping longer : 86% at 139mm focal length, 98% at 80mm focal length