EBU - Tech 3335 : Methods of measuring the imaging performance of television cameras for the purposes of characterisation and setting

Alan Roberts, July 2015

SUPPLEMENT 17: Assessment of a Canon XC10 camera

Tests have been conducted in line with EBU R.118. This document is a report of the results of the tests defined in Tech3335 and is not an endorsement of the product.

This is a report on tests carried out on a Canon XC10 camera, serial number 953054000076, a European version. It closely resembles a small DSLR rather than a conventional television camera, but has an integral lens and no monocular viewfinder. However, a monocular viewfinder can be simulated by using an accessory mirror-box adaptor on the LCD touch-screen display, but this prevents access to some control functions which are operated only on the touch-screen.

According to the specification, the sensor is a single large-format CMOS with the Bayer pattern of photo-sites; 8.29Meg for video (3840x2160), 12Meg for stills (4,000x3,000), and nominally 1" size. Further information from Canon reveals that the full sensor is 4224x3164, actually 16.8mm diagonal. Thus the full sensor dimensions are 13.48x10.10mm and the photo-sites are spaced at 3.192 microns, giving a photo-site area of 10.19 square microns, about 40% of that of a conventional ⅔" camera. The video image (both 4k and HD) is made from a central 3840x2160 part which must be 12.26x6.89mm and 14.1mm diagonal. The effective photo-site size for HD is 6.38 microns square, similar to that of a conventional ⅔" camera.

The lens is fixed (not inter-changeable) with a 10:1 zoom range from 27.3 to 273mm (35mm equivalent). Maximum aperture is F/2.8 and ramps to about F/5.6 at the long end of the zoom. It has a manual zoom ring and a focus ring which is disabled in 'auto-focus' mode, so is not calibrated.

All recording is 8-bit MPEG4 AVC/H.264 4:2:2. HDTV recording is onto SDHC card (long-GoP, at 50Mb/s for 50P, 35mB/s for 25P or 25I), 4k recording is onto CFast card (3840x2160 intra-frame at 305Mb/s for 50P, 205Mb/s for 25P). Recording can also be done 'off-speed' between 4 and 1/1200 times normal, and there's a 5-second cache for pre-recording (only in HD).

The camera weighs 1kg with the internal battery (7.2v) and consumes 6.2W when recording 4k, 5.4W when recording HD. The removable battery is 1.865Ah (14Wh) so should last at about 2.5 hours in normal video use. The battery can be charged in the camera or in an external charger.

There are connectors for HDMI output (disabled when Wi-Fi is enabled), USB for file transfer, 3.5mm microphone, 3.5mm headphone.

Controls include three assignable buttons. The right-hand side hand-grip can be swivelled up to ±90°.

Monitoring is done on a 3" LCD panel of 'approximately 1,030,000 pixels' (about 64x43mm, implying about 1240x830 pixels). It can be swivelled up or down nearly 90° and the image can be enlarged 2:1 for focusing. Most of the camera control is via this display as a touch-screen, although the system controls are via a menu system driven by buttons on the hand-grip. Since the touch-screen is capacitative, it responds only to fingers, not finger-nails or styli. Also, the accessory mirror-box prevents access to the screen.

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Many of the menu items have little or no effect on image quality. Those that have significant effect are highlighted. Control of the camera is split between 'proper' menus and item-by-item control from the touch screen. In boxes with a range of numeric settings, the values indicate the range, and no scales are given. Default settings, where known, are underlined. Only settings relevant for video shooting are listed here, although many operate for video shooting, replaying and photo modes. All measurements were made using Manual mode.

The tested camera was an E version which has items related to 50Hz, the U version (NTSC) has items related to 59.94Hz and drop-frame timecode. Only the E version is covered here.

In the tables, items that have an important effect on picture appearance are highlighted with grey background. Rather than making recommendations for settings, I have included measurement results from which the user can make his own decisions.

This is not intended as a replacement for reading the manual.

1. Switches, Connectors and Menu settings

Switches and connectors

Left side	Focus	Manual/auto switch
	Disp. (Assign 1)	Cycles screen info
	Push AF (Assign 2)	Find auto focus
	Mic	3.5mm stereo input
	HDMI out	Video, disabled if WiFi enabled
	USB	Computer connection
Handle top	Start/Stop	Traditional red button
	Photo/Video	Mode switch
	Wheel	Asignable rotary control
	On/Off	Power button
	Play	Playback start/stop
	Shooting mode dial	Manual, Av (aperture priority), Tv (shutter priority), P (program AE), Auto, Scn (special scene)
Handle back	Magnify (Assign 3)	LCD enlarger, x2
	Menu button	
	Menu joystick	
Handle right	Headphone	3.5mm stereo output
Bottom back	Memory card slots	
	Battery compartment	

Menu settings

Access by menu button or touch screen. Select/set via joystick or touch or drag relevant part of the screen. Submenus are indented.

Camera setup

Item	Mode	Range	Description
Face detection & tracking	MAvTvPScn	<u>On</u>, Off	Not tested
Auto slow shutter	PAv	On, <u>Off</u>	Blurs in low light
ND filter	All	On, <u>Off</u>	3 stops, x1/8
Flicker reduction	All	Auto, <u>Off</u>	Reduce lighting flicker
Auto ISO limit or AGC limit	AvTvP	Auto, ISO or Auto, dB	Set max ISO160~4000 or Gain 0dB ~ 28.5dB

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Shockless WB	All	On, Off	
Onscreen markers	All	Off, Level (white), Level (grey), Grid (white), Grid (grey)	Level is mid-high horizontal, Grid is 3x3
Focus ring direction	All	Normal, Reverse	
Focus ring response	All	Fast, Normal, Slow	
ISO/Gain	All	ISO, Gain	Changes some menu items
Gain increment	All	Normal, Fine	

Recording setup

Item	Mode		Range	Description
4k/HD	All		4k clips, HD clips	Also on screen, bottom left
4k recording	All		25p/305Mb/s, 25p/206Mb/s	
HD recording	All		50p/50Mb/s, 50i/35Mb/s, 25p/35Mb/s	
Slow & Fast motion[1]	All	4k	Off, x2, x4, x10, x20, x60, x120, x1200	Also on screen, bottom right
		HD	Off, x1/4, x1/4, x2, x4, x10, x20, x60, x120, x1200	
Available space in memory	All		Reports on cards	
Initialize	All		CF, SD	Format memory cards
Timecode mode	All		Preset, Regen	
Timecode running mode	All		Recrun, Freerun	
Initial timecode	All		hh:mm:ss:ff	Set the timecode
User bit type	All		Setting, Time, Date	
Color bars	All		Off, EBU, SMPTE	Swap EBU for ARIB in the U version
1kHz tone	All		-12dB, -18dB, -20dB, Off	Tone with bars
File numbering	All		Reset, Continuous	

Audio setup

Item	Mode	Range	Description
Headphone volume	All	0~8~15	
Notification sounds	All	0~8~15	Beeps for self-timer etc
Built-in mic wind screen	All	Auto (high), Auto (low), Off	Custom audio only
Built-in mic att	All	Auto, On, Off	
Built-in mic freq response	All	Normal, Boost LF, Low cut, Boost MF, Boost HF+LF	
Built-in mic directionality	All	Mono, Normal, Wide	
Mic Att	All	Auto, On, Off	Only when external audio is plugged in
Mic low cut	All	On, Off	
Mic terminal input	All	Line, Mic	
Audio limiter	All	On, Off	
Audio compressor	All	High, Low, Off	

Wi-Fi setup

Item	Mode	Range	Description
Browser remote	All	Off, On	Must be Off to enable HDMI
Browser connection settings	All	Set camera ID and port	
Smartphone connection	All		
Access point connection	All		
Display MAC address	All		

[1] Slow & Fast recording is not quite what it seems, e.g. x1/4 means recording 4 times over-speed, and setting 50p at 50Mb/s the camera will run at 25p and recording is at 18Mb/s. Beware, check other settings such as shutter speed to make sure that recordings will be sensible.

System setup

Item	Mode	Range	Description
Language	All	For the menus (English)	Lots of languages
Time zone/DST	All	Lots of cities (Paris)	Also Summer time On, Off
Date/Time	All		
Date/Time	All		Enter date and time
Date format	All	YMD, MDY, DMY	MDY in U version
24 hour	All	Select	Changes time to am/pm or 24h
LCD brightness	All	Horizontal scale	Shows greyscale to help
LCD backlight	All	H, M, L	
Fan	All	Auto, On	The fan is very quiet
Wireless remote control	All	On, Off	
Tally lamp	All	On, Off	
Auto power off	All	On, Off	5 minutes to auto power-off
Assign button 1 Assign button 2 Assign button 3	All	Disp, Push AF, Magnification, Zebra, Peaking, Digital tele-conv, Powered IS, ND filter,Start/stop, Photo	Default is 1=Disp, 2=Push AF, 3=Magnifcation
Control Dial	All	Iris, Shutter, ISO/Gain	Rotary control near Start/Stop
Customize FUNC menu	All	Aperture, Shutter, Gain/ISO, White balance, Mic level, Exposure lock, AE shift, Zebra, Peaking, Powered IS, Digital tele-conv, Focus, Magnification	Add/remove items from the FUNC menu, display top right
Batt info	All	Display battery info	
HDMI timecode	All	On, Off	
HDMI rec command	All	On, Off	
HDMI status	All	Display only	
Distance units	All	Metres, Feet	
Backup menu settings	All	Save, Load	Saves menu to SD card
GPS auto time setting	All	Off, Auto update	
GPS information display	All	Display	
Certification logo display	All	Display	
Firmware	All	Display	
Reset all	All	No, Yes	Full reset

Touch screen controls Submenus are indented.

Item	Mode			Range	Description
FUNC					Vertical list, right-hand side
Iris	MAv			F/2.8~F/11	In ¼ stop steps. Max aperture reduces with zoom
Shtr	MTv			½~1/50~1/2000	Shutter, 4 steps per factor of 2
ISO/GAIN[2]	M	Look 1,2,4	ISO	160~20000ISO	ISO stops 3 steps per factor of 2, GAIN in 1.5dB steps
			GAIN	0~42dB	
		Look 3,5	ISO	500~20000ISO	
			GAIN	9~42dB	
WB	MAvTvPScn			Automatic, Daylight, Shade, Cloudy, Flourescent, Fluorescent H, Tungsten, K, User 1, User 2	White balance. K can be set 2000 to 15000. User setting are auto
Mic level	MAvTvPScn			Auto, Manual	Manual can be set 0~100
Exposure lock	AvTvPScn			Manual, Off	Manual can be set -3~+3 stops in ¼ steps

[2] Noise is good up to 6400ISO (31.5dB) but the picture softens significantly above 1600ISO (19.5dB)

AE shift	AvTvP	-2~0~+2	Stops in ¼ steps
Zebra	All	Off, 70,100	70%/100%
Peaking	All	Peak, Peak off	Make sharp edges red in LCD
Powered IS	All	On, Off	Image stabiliser
Digital tele-conv[3]	All	On, Off	X2 lens magnification
Focus[3]	All		Touch spot to focus
Magnification[3]	All	Off, On	Touch to select area
FUNC			Vertical list, left-hand side
Look/Scn[4]	MAvTvP	1 Standard, 2 EOS Std, 3 Wide DR, 4 Cinema EOS Std, 5 Canon log, User 1, User 2	2 is too vivid, 5 needs post
	Scn	Portrait, Sports, Night, Snow, Beach, sunset, lowlight, Spotlight, Fireworks	
Audio scene	All	Standard, Music, Festival, Speech, Meeting, Forest & birds, Noise suppression, Custom	
Metering mode	AvTvP	Standard, Spotlight, Backlight	
Self-timer[5]	All	Off, 2 sec, 10 sec	
Image stabilizer	All	Off, Standard, Dynamic	
Pre Rec[6]	All	On, Off	5 second pre-rec

Other FUNC controls

Item	Mode		Range	Description
HD/4k	All		4k clips, HD clips	Bottom left of screen
Slow & Fast motion[1]	All	4k	Off, x2, x4, x10, x20, x60, x120, x1200	Bottom right of screen
		HD	Off, x1/4, x1/4, x2, x4, x10, x20, x60, x120, x1200	

[3] Item not available unless specifically added via 'Customize FUNC menu'
[4] Standard has good knee for general purpose shooting, EOS Std is too vivid, 3 4 and 5 have a more gentle knee for a film-type look
[5] Self-timer appears in the menu list but could not be enabled in the tested camera.
[6] Pre-recording is available only in HD recording.

2. Measurements

All measurements were made on frames captured onto a SDHC card for HD, CFast card for 4k. Images for this document were extracted as BMP files or LZW-compressed TIF files using Edius 7.31 and Edius 8. I shall use the EBU system of designating scanning standards. Live viewing was done on a 42" consumer grade plasma Panasonic display with 'studio' settings. In this section,

2.1. Colour performance

A standard Colorchecker chart was exposed, using daylight. The camera was allowed to auto-white balance and to auto-expose. Fig 1 shows the performance for the five standard 'Looks'.

(a) Look 1 **(b) Look 2** **(c) Look 3** **(d) Look 4** **(e) Look 5**

Figure 1 Colorchecker p/50

Look 1 (standard) is good for normal television, Look 2 (EOS vivid sharp and crisp) is quite vivid and over-saturated, Look 3 (wide dynamic range) is desaturated and nice for a film look, Look 4 (EOS camera) is less saturated but possibly a little too much, Look 5 (Canon Log, wide dynamic range for post-processing) is under-exposed and under-saturated.

Choosing the right Look is a personal matter, but Look 1 is fine for normal TV, Look 3 is good for a film look. The others are all acceptable but may bring problems with noise and/or saturation levels.

There was no response to infra-red, clearly there must be an IR-stop filter in the optical path. This augurs well.

2.2. Resolution and aliasing

2.2.1. Resolution for 4K (UHD-1)

Tests were made at F/5.6. The usual zone plate test chart was framed to fill exactly half the width and height of the image. Thus the calibrated dimensions should all be doubled.

Fig.2 shows one quadrant of the luma pattern which now reaches the 3840x2160 limits of UHD-1, plus one quadrant of the smaller pattern which now reaches the 7680x4320 of UHD-2. The recording was intra-frame at 305Mb/s, using Look 1.

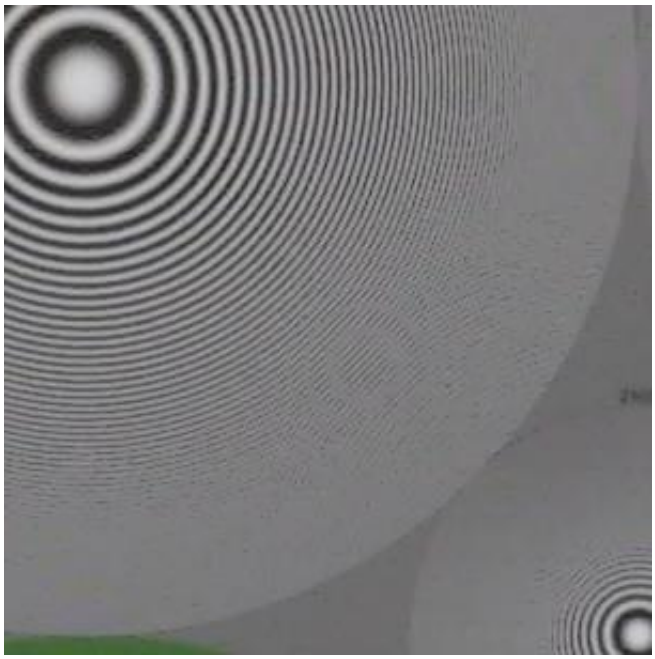


Figure 2 4k luma p/50

The modulation is extinguished above 3000 horizontally, and 1700 vertically. There is fairly strong diagonal aliasing which is inevitable with a Bayer-patterned sensor. There is no evidence of any aliasing above the limits of UHD-1, therefore either the lens cannot resolve it or there is an optical low-pass filter tailored to the limits of UHD-1.

Interestingly, the diagonal resolution exceeds both horizontal and vertical extinction limits. This implies that the Bayer-decoding is the limit, rather than the optics, which in turn suggests that there is probably no optical low-pass filter and it is the lens which is providing the spatial filtering.

Fig. 3 shows quadrants of red and green. The red pattern resolution is little different from the green, which confirms that resolution is limited by the lens.

The resolution performance is acceptable for Tier 2, UHD-1, although 10-bit output is required for full compliance and so this camera should strictly not be accepted for 4k broadcast. Aliasing levels are acceptably low.

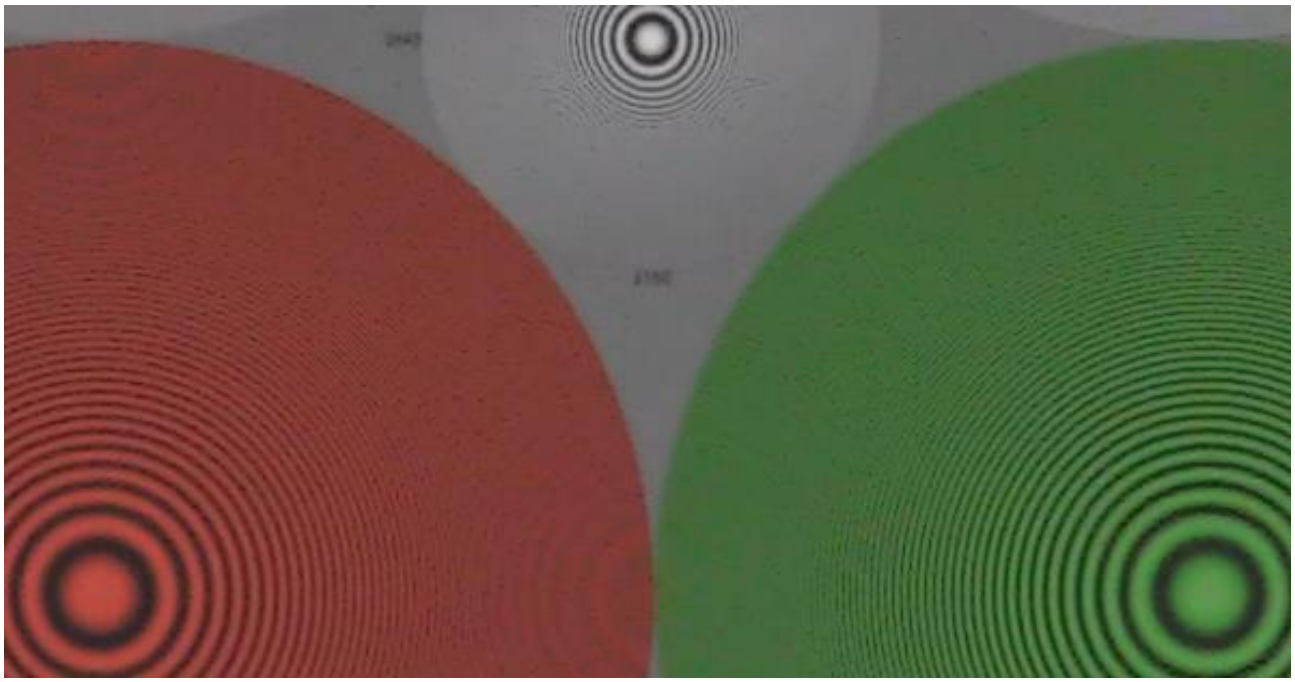
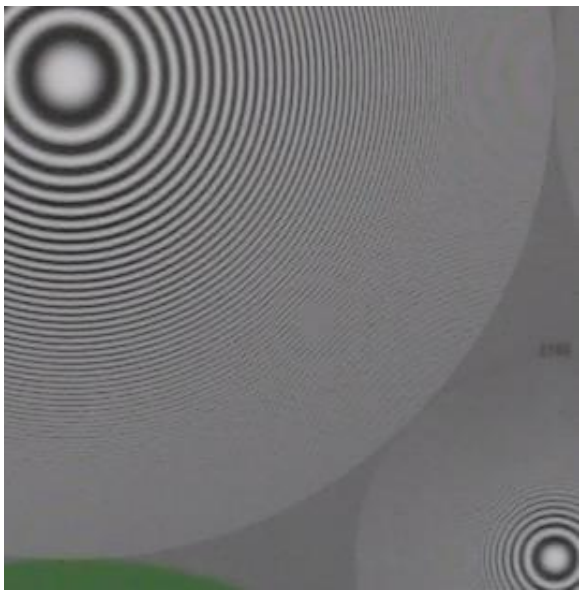
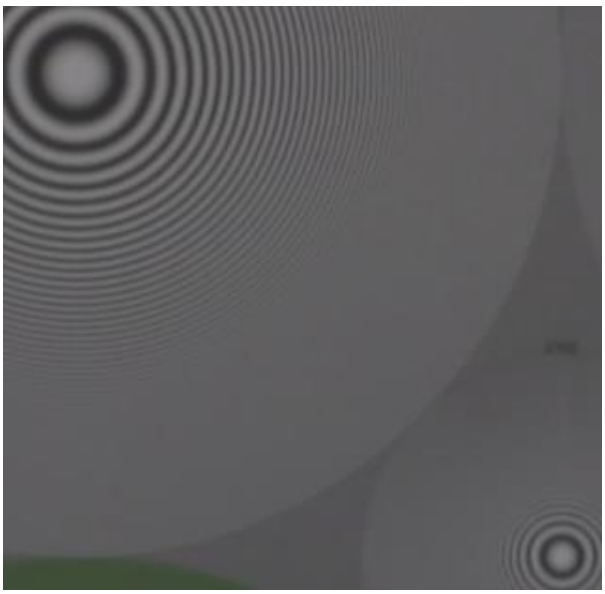


Figure 2 4k red and green, p/50

Fig. 4 shows how the resolution changes with the 'Look' setting. Clearly, there is a considerable drop with Look 5, and the alias levels have dropped dramatically as well. However, the resolution in Look 5 only just exceeds the limits of HD, and while it is likely that post-processing would restore much of the resolution loss the alias level would probably also rise.



(a) Look 4



(b) Look 5

Figure 4 4k luma

2.2.2. Resolution for HDTV

Exposures were made at F/5.2. The zone plate chart was framed to exactly fill the image. The image for 1920x1080 HD comes from a 3840x2160 part of the sensor, thus there seems to be no need to decode the Bayer pattern since each of the red and blue sub-patterns are 1920x1080, and the green sub-pattern has two, spatially offset, patterns of 1920x1080. However, this would cause serious aliasing since the optical low-pass filter (if there is one) must be tailored to the 4k performance of the camera. Therefore we should expect to see the effects of down-scaling in the HD performance, i.e. some aliasing.

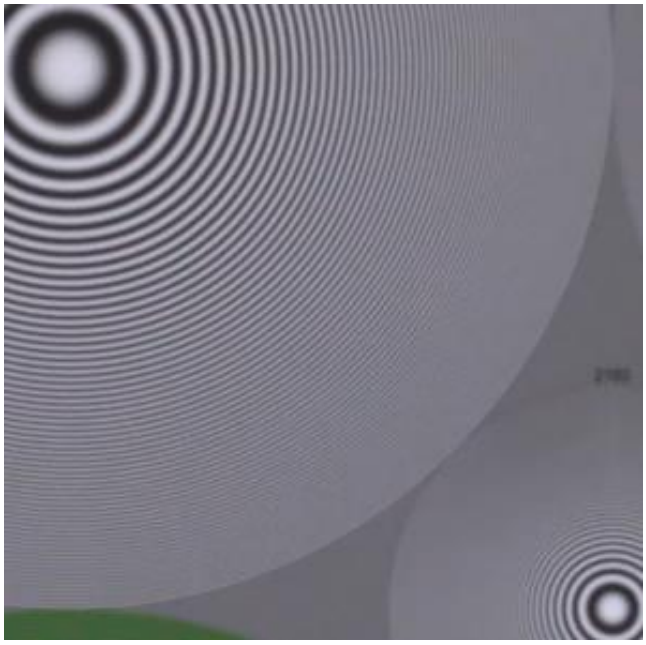


Figure 5 HD luma p/50, sharp=0

Fig. 5 shows luma quadrants in p/50 with sharpness set to minimum, zero, and using 'Look 1', described as 'Standard image for shooting clips'. The main quadrant reaches 1920x1080, 3840x2160 in the smaller pattern. There is little or no aliasing. Vertical resolution is significantly better than horizontal, the extinctions appear to be at about 1700x1080. Since the photo-sites are square, there seems to be no reason why resolution should not also be square, i.e. horizontal and vertical should be the same.

Fig. 6 shows red and green quadrants. Since the image is from the compressed video the red pattern should not have the same resolution as the green. However, the difference is quite small but appears to be symmetrical. Nevertheless, it is quite acceptable.

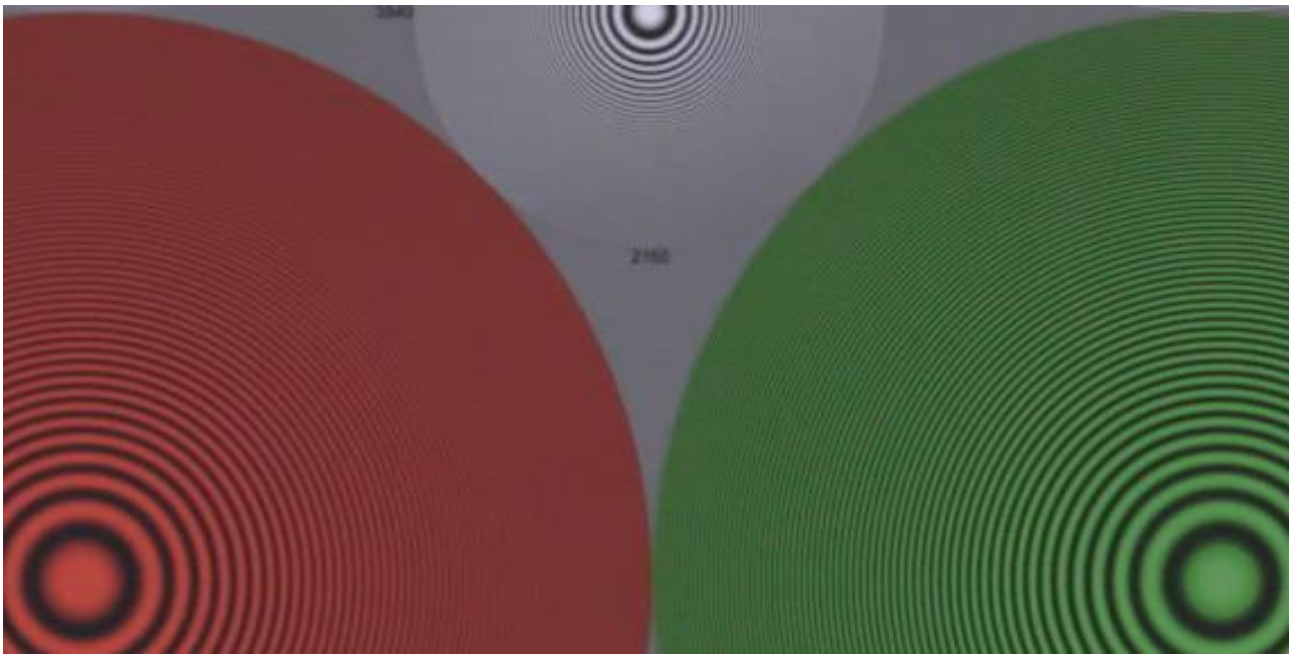
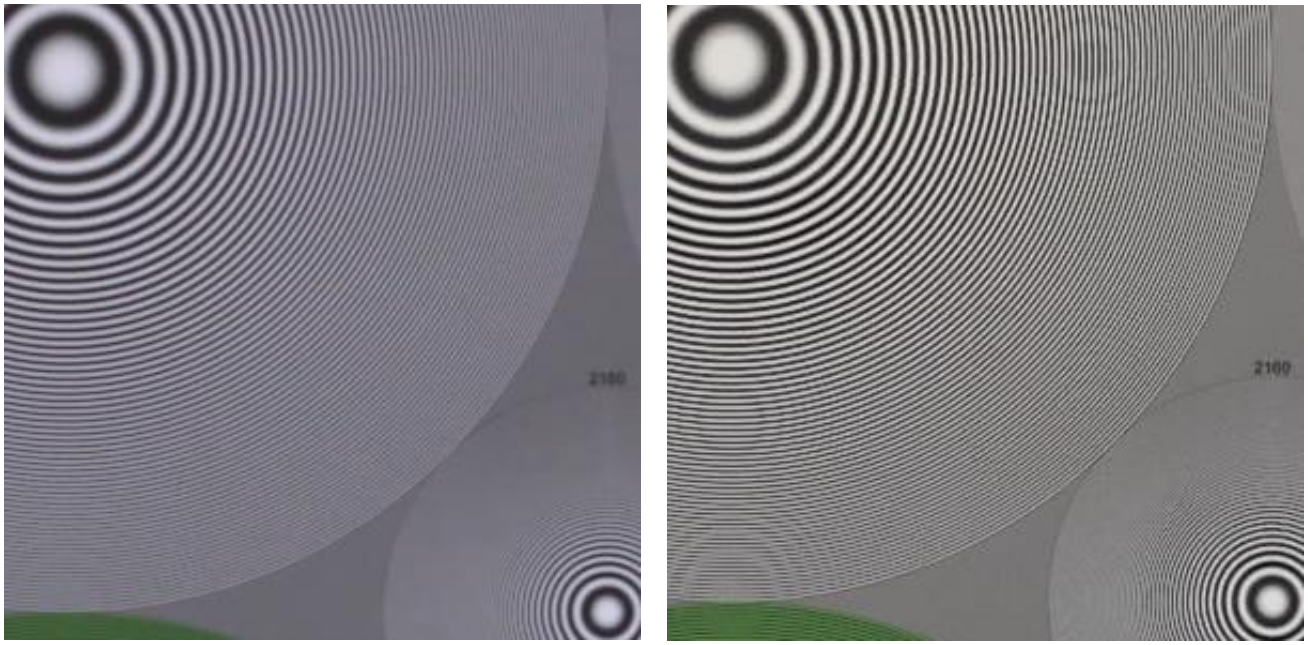


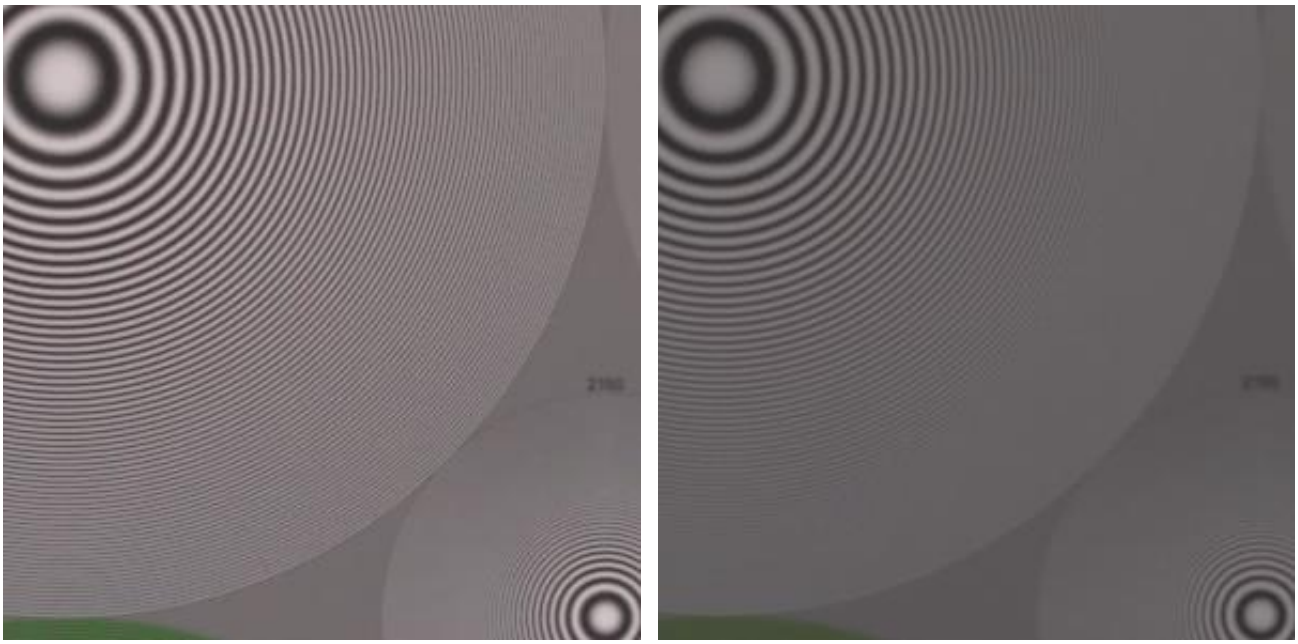
Figure 6 HD red and green p/50, sharp=0

Fig 7 shows the luma part of the chart with detail set to the default value 3, and to maximum 7. The default value seems a good compromise between aliasing and resolution, while the maximum setting is clearly not acceptable for good HD. Note that the maximum setting also brings up aliasing beyond the limits of HD, which will cause problems with motion in MPEG coding. This also shows that the optics do not block frequencies beyond HD.

Ass for 4k shooting, the 'Look' setting affects the resolution. Fig.8 shows the same part of the chart with the 'Look' set to 4 (similar to Canon EOS cameras) and 5 (wide dynamic range and colours for post-processing). The resolutions are clearly very different, Look 4 appears to be much sharper although there is an associated risk of some aliasing.

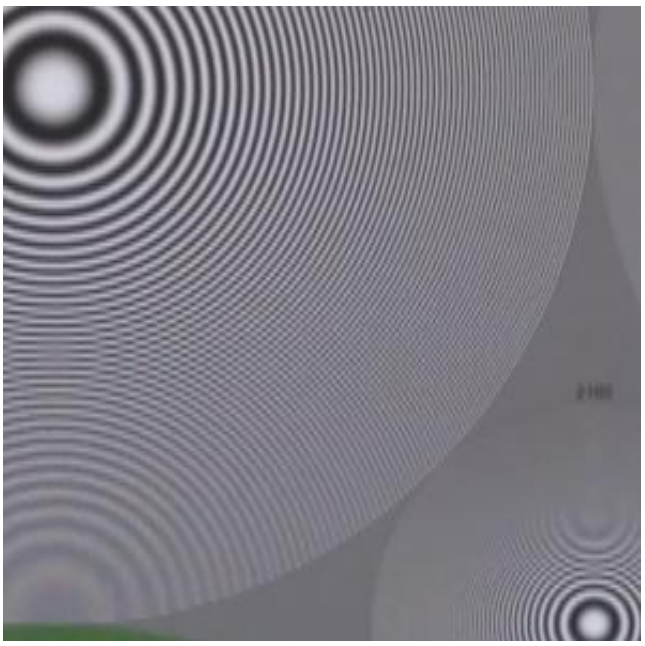


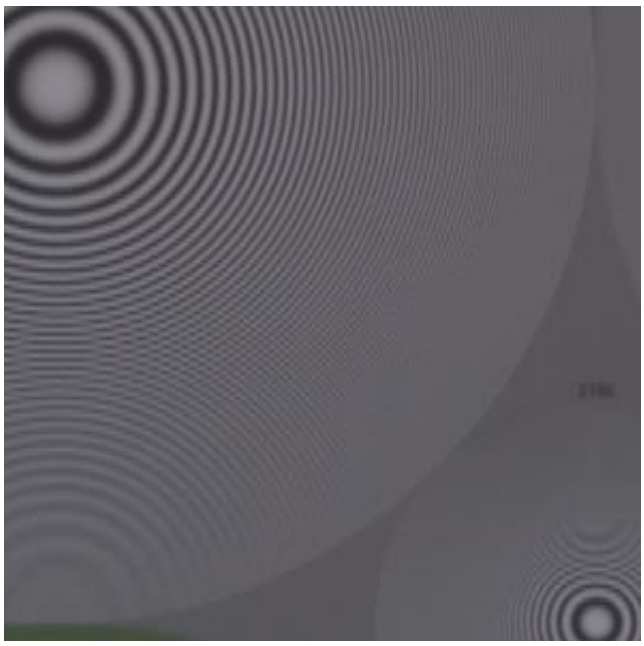
(a) sharp=3 **(b) sharp=7**
Figure 7 HD luma p/50,



(a) Look 4 **(b) Look 5**
Figure 8 HD luma p/50, sharp=3

Fig. 9 shows the resolution for interlaced HD, with standard sharpness and Looks 1 and 5. The re-sampling process which generates the interlaced output does not filter out the vertical components sufficiently to avoid serious aliasing.





(a) Look 1 **(b) Look 5**

Figure 9 HD luma i/25, sharp=3

2.3. Noise, Dynamic Range and Sensitivity

2.3.1. Noise, Dynamic Range and Sensitivity for HDTV

The camera was exposed to a 6-step grey scale, tungsten illuminated. Multiple exposures were taken to explore the dynamic range at ISO800 (13.5dB Gain), shooting HD using Look1. Fig. 10 shows the result, noise levels plotted vertically versus signal level. The solid line is a trend line through (or nearly through) the luma points.

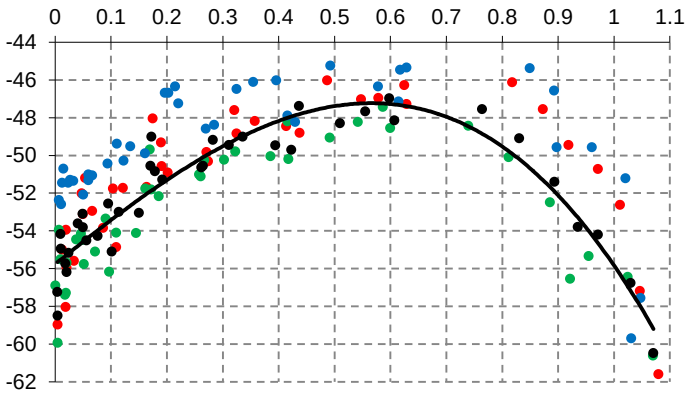


Figure 10 HD noise profile, p/50 Look 1, ISO 800

Conventionally, the noise level would be expected to rise near black since the differential gain applied by gamma correction affects the noise level, but here it drops consistently. There are several possible reasons, but it is hardly worth exploring these since the user has no control over the noise performance. The level at 50% video is about -48dB which is the qualifying level for EBU R.118 HD Tier 1. However, since the noise level falls from this level towards black, the pictures look rather less noisy than these figures imply.

Next, the camera was exposed to achieve 50% luma level over the full range of ISO settings. Exposure was controlled using the shutter and iris. Fig. 11 shows the result, plotting the noise level versus the ISO setting expressed in dB, with 0 being ISO 160. The 'normal' curve for this test would be a linear slope, rising by 3dB in noise level with each 6dB in gain. The deviation from this ideal indicates that there is some signal processing, probably noise reduction, going on which is one of the

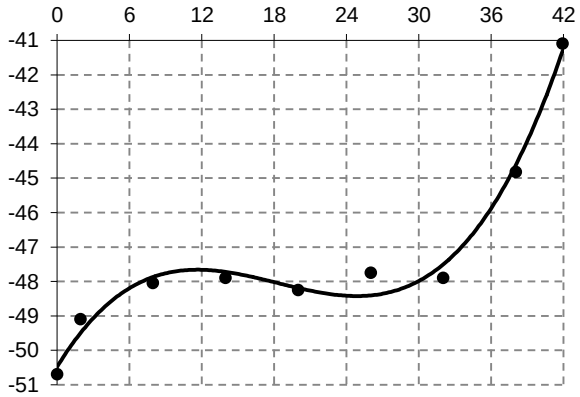
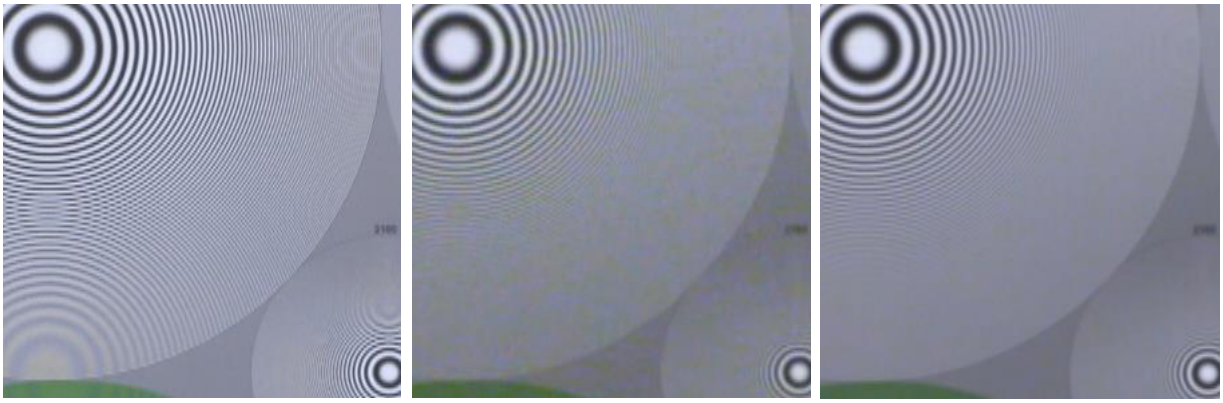


Figure 11 HD noise vs gain setting at 50% video

possible reasons for the unconventional shape in Fig. 9. Nevertheless, the noise level of -48dB is held up to 32dB gain, which is the equivalent of ISO 6400.

A more likely reason for the unusual noise levels is a change in resolution with ISO setting. Fig. 12 shows this clearly. Resolution drops considerably at the higher speed settings, so speeds higher than about ISO1600 (19.5dB) gain) ought not to be regarded as full HD even though the noise level is acceptable.

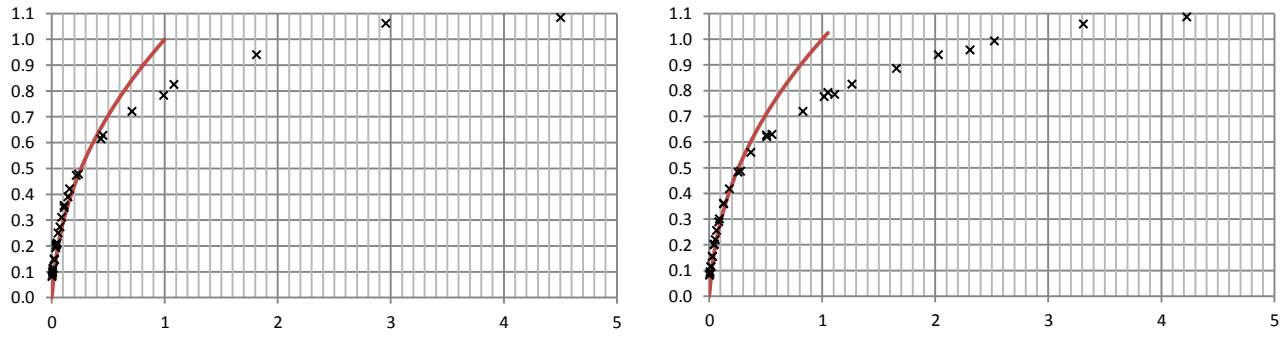


(a) ISO 400 (7.5dB) **(b) ISO6400 (32.5dB)** **(c) ISO 20000 (42dB)**

Figure 12 HD zone plate softening with ISO setting, i/25 Look 1

For dynamic-range measurements, multiple exposures were made of a Colorchecker chart at ISO 400 (7.5dB) using Look1, aiming to record exposures at which the white patch was just clipped, and the black patch only just discriminable. These extremes were met with exposure difference of 80:1. The reflectances of the white and black patches are 90.01% and 3.13% respectively, a ratio of 28.76:1. Thus the total dynamic range must be about 2,300:1 about 11¼ stops. The same data was used to explore the opto-electronic (gamma) curve, which appears to be the standard ITU.709 curve up to about 50% output level then curving gently through a knee into a lower slope and reaching clipping level at about 450% exposure level. Thus this curve appears to be able to cope with about 2.12 stops of headroom.

For comparison, the same test was done using Look5 and ISO500 (10.5dB) which was expected to have a much wider range. The exposure difference was again 80:1, again making a total dynamic range of about 2,300:1. This is a surprise, since it implies that the only advantage in using the Looks is in the distribution of this, apparently fixed, dynamic range. Again, the same data can be used to explore the gamma curve, and again the curve is very like the ITU.709 curve up to about 40% output, then curving through a knee to reach about 450% exposure level, about 2.12 stops of headroom, the same as for Look 1. Fig.13shows the curves.



(a) Look 1 **(b) Look 5**

Figure 13 gamma curves

For sensitivity calculations, more multiple exposures were used to find the aperture setting at which the peak white patch reached 100%, when illuminated at 2000 lux. The camera was set to ISO800 (13.5dB gain) and Look1, 1/25 second exposure. The signal levels are not clipped at 100% video level and it was simple to find an exposure which reached exactly 100%, at between F/6.7 and F/7.3. So the sensitivity must be about F/5 at

ISO800 and 1/50 exposure. However, since the gamma curve of Look1 reaches 100% video at 2.4 times the exposure at which a genuine ITU.709 gamma curve would reach 100% video, the aperture which would cause 100% signal without this knee must be a factor of 1/2.4 less than measured, i.e. 1.55 stops less light, so the lens aperture at which 100% video would be recorded without the knee must be about F/6.7 at ISO800.

2.3.2 Noise, Dynamic Range and Sensitivity for 4k

The camera was exposed twice to the 6-step grey scale, at F/4 and F/11. This gives 12 points in a plot of noise versus signal level, Fig.14.

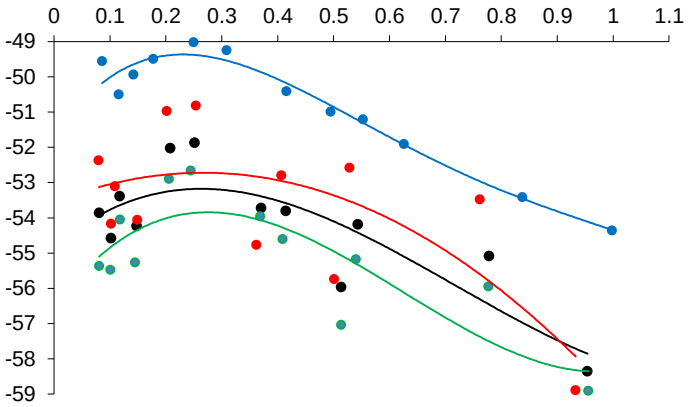


Figure 14 4k noise profile, Look 5, ISO 800

The plot lines are trend lines through the relevant points and thus are only approximate. However, it is clear that the shapes are different from those at HD, these curves are much more like the conventional shape where the noise level is roughly proportional to the slope of the gamma curve. This implies that the down-conversion process for deriving HD pictures is acting as a filter rather than an interpolator, which is highly desirable.

Next, the camera was exposed to the 6-step grey scale again, using Look 1 and p/50. The 'speed' was set to 6 values from ISO 500 to 16,000. Fig. 15 shows the results. Clearly, as the speed rises, the noise distribution rises further towards black, but there is still an eventual down-turn near black in each case.

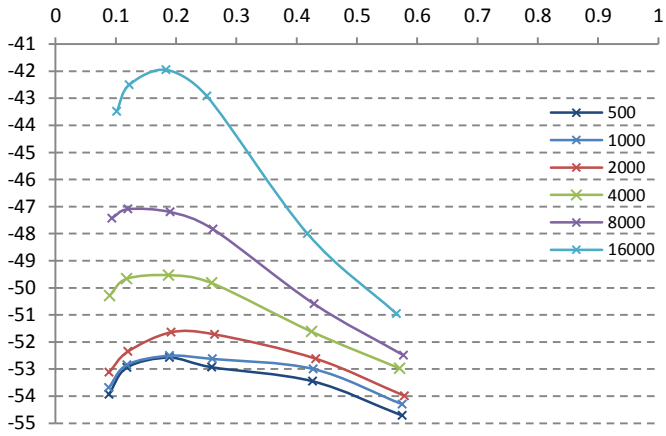


Figure 15 4k noise profiles

Noise around mid-grey, the usual signal level for categorisation of cameras, is much less affected. Even at 16,000 ISO the mid-grey noise is acceptable although the increase near black is rather steep.

Fig. 16 shows the noise level at mid-grey versus speed, expressed as gain in dB. The level is better than -50dB (the target level for EBU R.118 UHD Tiers 1 and 2) for all speeds below 36dB gain. However, the rise in level near black (see Fig. 14) makes the pictures look more noisy than this measure would suggest when the camera is set to high photographic speed. Nevertheless, the noise levels are acceptable provided the photographic speed is set not greater than about 10,000 ISO or 24dB gain.

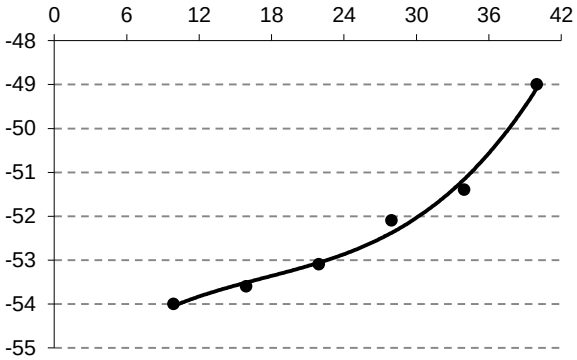
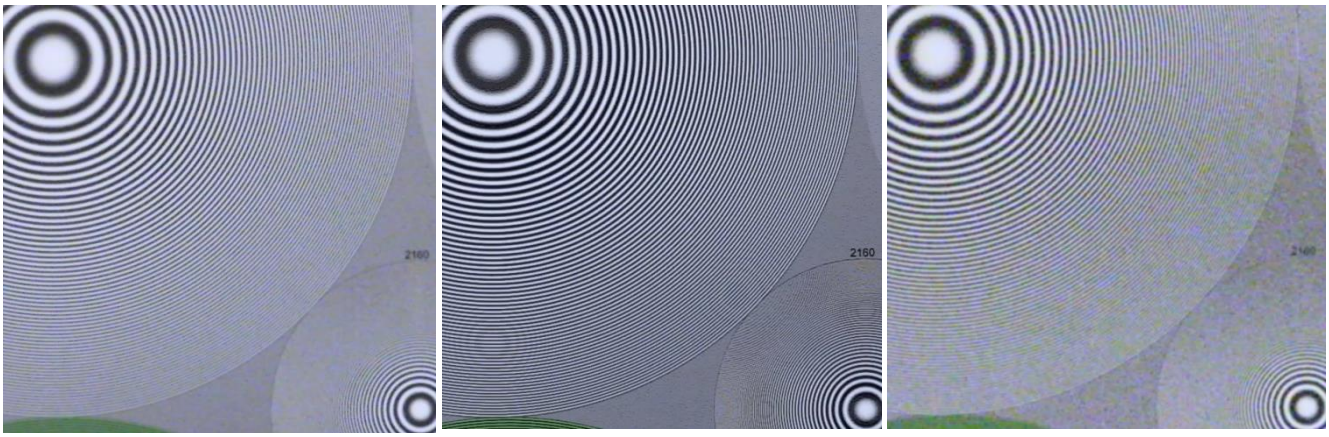


Figure 16 4k noise level at mid-grey versus camera gain in dB

Fig. 17 shows how the resolution changes with speed. For this test, the zone-plate chart was framed to fill the image, i.e. the dimensions of the larger quadrant at 1920x1080 and the smaller 3840x2160. It shows that the higher speeds cannot be properly regarded as 4k resolution, but are quite good for HD. So, shooting at up to about 10,00 in 4k is a good way to get HD performance using down-conversion from the full frame in post-processing. The noise levels at 20,000 are unacceptable.



(a) ISO 400 **(b) ISO 6,400** **(c) ISO 20,000**

Figure 17 4k resolution, Look 1, 50mm, F/5.6

2.4. Motion effects

The sensor has a conventional 'rolling shutter' process for readout, and so differentially distorts objects moving in the frame. Fig. 18 shows parts of two frames from a sequence of a small desk fan, the blades rotating such that they appear to be almost stationary. The distortion is quite obvious, and cannot be corrected. This level of distortion is not unusual in cameras with a rolling-shutter.

Figure 18 motion effects

2.5. Conclusion

The recording coder bit-rates qualify the camera for all Tiers in R.118, however, the bit-depth is problematic.

The 4k resolution is limited by the optics, and there is some diagonal aliasing. The camera cannot officially qualify for R.118 UHD-1 because the recording is 8-bit, whereas R.118 requires 10-bit or greater. Also, R.118 demands interchangeable lenses for UHD-1. Nevertheless the noise performance meets the criteria for both Tiers of UHD-1, and the 4k mode is a good way to shoot for HD production provided extreme speed settings are not used.

The HDTV resolution and aliasing is good enough for the camera to qualify for R.118 HD Tier 1, as is the noise level. It is only the monitoring and connectivity requirements which are not really met. Thus its performance meets Tier 1, and it easily meets Tier 2L. It could be used in Tier 1 situations provided the monitoring and connectivity problems can be dealt with.

There is no infra-red response, implying the presence of an IR-stop filter. Motion portrayal is affected by the sensor rolling-shutter.