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

Alan Roberts, March 2018

SUPPLEMENT 27: Assessment of a Canon XF-400/405

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.

Tests were made on a Canon XF405E, supplied by Canon and labelled CANXF405-04, serial number 423519000114. The lens is integral; 15:1 zoom (8.3 to 124.5mm, equivalent to 25.5 to 382.5mm in a 35mm camera), with maximum aperture 2.8 but ramping to F/4.5 at the long end. The specification describes the (single) sensor as 3840x2160 and '1.0 type' but does not give image dimensions. Using the claims for the lens as a guide, the photo-sites must be between 3μm and 3.5 μm square, giving an area of between 9 and 13 square microns, between ⅓ and ½ that of a conventional ⅔" HDTV camera. This calculation cannot be exact since the sensor aspect ratio is 16:9 and 35mm is 3:2, but this answer should be in the right ball-park.

It records MPEG4-compressed video (AVC/H.264) 8-bit depth with 4:2:0 colour sampling onto two cards (SD, SDHC, SDXC). Since the sensor has the only one photo-site (red, green or blue) per pixel at UHD resolution, there would be little point in recording UHD at 4:2:2. Recording rates are 150Mb/s for UHD, down to 35/17/8/4 Mb/s for HD in 1920x1080 or 1280x720. Recording to external devices is more flexible: 10-bit 4:2:2 is possible at 1920x1080.

The camera has HDSDI output (3G for UHD), but has no gen-lock or timecode connection. The model tested produced video signals at 50 and 25Hz.

There is a conventional viewfinder (approximately 1664x936 pixels, the same as the XF305), plus a separate LCD screen (approximately 1664x936 pixels) front mounted. Both displays are adequate for focusing HDTV, focus assistance is helpful for UHDTV. The LCD screen is touch-sensitive and can be used for navigating the control system without using the menus.

The camera weighs only 1.5kg and consumes up to 8.4 Watts from the 7.4V battery pack, which is charged on the camera. Capacity is 19Wh, so the camera should run for over 2 hours on one charge.

There are neutral filters for exposure control, and manual control of the lens. Four of the control buttons are assignable, and one LCD menu item is assignable as well. Sensitivity is specified in an obscure way, and is quite low. There is a 2:1 image magnifier as a focus aid, but no exposure guides other than zebras.

There is a built-in stereo microphone, 3.5mm jack for an external stereo mic, and twin XLR audio sockets on the removable top handle.

There are some surprises in the performance, see the test results in Section 5.

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Many of the menu items have little or no effect on image quality. Those that have significant effect are highlighted. The full set of menu items is given for completeness. In boxes with a range of numeric settings, e.g. -99~+99, the values indicate the range, and zero means no alteration to factory setting, not zero effect, and no scales are given in the manuals. For each item, the factory setting is underlined. "Pref" (preferred) settings are in the last column, where appropriate, for normal video shooting and for film-look shooting. Where no preferred value is given, either the factory setting is best, or the setting does not have great effect on image quality. In some instances, it is possible to alter the menus such that they produce more meaningful numbers. Menus are nested: items in bold-face in the listing are headings leading to a further nested menu.

Camera settings which affect picture quality directly, such as gamma, detail and matrix are held as Look settings. These are available via the FUNC button on-screen.

Settings are only starting points, recommendations. They should not be used rigidly, they are starting points for further exploration. However, they do return acceptable image performance.

Measurement results are given in section 5, after the menus.

This listing of the menus and contents is complete, but this should not be used as an excuse for not reading the manuals.

1. Controls and connections

Left side body		
ND Filter +	push	Off, ¼ (2 stops), 1/16 (4 stops),
ND Filter -	push	1/64 (6 stops)
Focus/Zoom	slide	Select function of the lens ring
Custom button	push	
Custom dial	rotate	Customisable dial
Left side, inside LCD		
Infrared	slide	
Pre Rec / Assign 3	push	
Review / Assign 4	push	
Disp/Batt Info	push	
Left side, on LCD		
AF/MF / Assign 1	push	
Powered IS / Assign 2	push	
Right side body, under covers		
SD card slots	slide	2 card slots
USB	miniature socket	
HDMI socket	miniature socket	
Ethernet	socket	
Mic	3.5mm stereo jack	
SDI/HDSDI	BNC	
Back of body		
Menu joystick	push	up/down, left/right, push
Menu	push	menus on/off

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Magn	push	v/f and lcd magnifier
REC	push	stop/start
Remote	2.5mm jack	remote control
Headphones	3.5mm stereo jack	monitoring
DC IN	coax	power socket
Top of body		
Power	slide	camera/off/media
Zoom	rocker	
Mode	slide	auto/manual
Handle unit		
Zoom	rocker	
Rec	push	start/stop
Audio	dials 1/2	volume levels
Audio level	slide 1/2	auto/manual
Audio input	slide 1/2	internal mic/input XLR
Audio input	slide 1/2	XLR line/mic/mic+48v
XLR	sockets 1/2	mic or line input

2. Controls via the touch-screen

Top left corner, mode		Dial controls selection
P		Full auto
Tv		shutter
Av		iris
M	cycled by custom button	Shutter, iris, gain
etc	cycled by custom dial	Tv/Av/M, Gain, Bracket, Off
Bottom row, Func		
Iris	F/2.8 ~ F/11.0	
Zebra on-screen	Off, 70%, 100%	
Shutter	1/6 ~ 1/2000	Drag the slider across the bottom
Zebra on-screen	Off, 70%,100%	
Gain	0dB ~ 39dB	
Zebra on-screen	Off, 70%,100%	
Auto White Balance	Auto, Sunlight, Tungsten, Kelvin, Preset 1, Preset 2	
Backlight compensation	Off, On	
Focus	Auto, Manual	
Manual	Infinity, Preset	
Magnification	Off, On	Drag magnified bit around the screen
Zoom	Wide, Tele	Drag the slider
Photo		Takes a still
Rec/Stop		Video recording
Tracking	On, Off	Face tracking
2.0x	On, Off	Digital magnifier, not a good idea
Looks	1 Standard, 2 Wide DR, 3 Mono	Custom Looks
Adjustments		All sorts
Audio	Auto, Manual	Only monitoring in Auto
Manual	Levels	
Bottom row, Photo		Take a photo
Bottom row, frame		LCD and vf frame

3. Assignable buttons; press and hold Menu, press the relevant button

Back light compensation On/Off, Face-only AF On/Off, Focus guide On/Off, WB priority Current/Priority,

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IR light On/Off, Monitor channels (headphones), AF/MF, Powered IS, Pre Rec, Rec review, Magnification, Photo, Off

4. Menus and settings (press the menu button)

Setup menu

Camera Setup 1

Item	Range	description	Pref
Digital Zoom	Off, 30x Advanced, 300x, 2.0x Digital Tele-conv	30x only at low-res	
Zoom Speed Level	Fast, Normal, Slow		
Zoom Rocker Speed	Variable, Constant		
Normal (Constant)	1 ~ 8 ~ 16		
Handle Rocker Zoom Speed	Off, Constant		
Constant	1 ~ 8 ~ 16		
Wireless Ctrlr Zoom Speed	1 ~ 8 ~ 16		
High-Speed Zoom	On, Off		

Camera Setup 2

Item	Range	description	Pref
AF Mode	Boost, Continuous		
AF Frame Size	Auto, Large, Small		
AF Speed	Fast, Normal, Slow		
AF Response	Fast, Normal, Slow		
Face Detection & Tracking	On, Off		
Focus Guide	On, Off		

Camera Setup 3

Item	Range	description	Pref
Focus Preset Speed	Fast, Normal, Slow		
Auto backlight Compensation	On, Off		
Auto Slow Shutter	On, Off	Only in P shooting mode	
Conversion Lens	Tele TL-U58, Wide WA-U58, Off	For 1.5 x and 0.8x lenses	
Image Stabilizer	Off, Standard, Dynamic		
Powered IS button	Press and Hold, Toggle On/Off		

Camera Setup 4

Item	Range	description	Pref
Set WB Priority	Automatic, Daylight, Tungsten, Color Temperature, Set 1,Set 2		
Focus Ring Direction	Normal, Reverse	Applies to the single lens ring when used in zoom or focus	
Focus Ring Response	Fast, Normal, Slow		
Zoom Ring Direction	Normal, Reverse		
IR Light	On, Off		
IR Rec Color	White, Green	IR Rec is mono as usual	

Recording Setup 1

Item	Range	description	Pref
Internal/External Rec.	Internal Rec Priority, SDI External only, HDMI External only		
Resolution	3840x2160 (150Mb/s), 1920x1080 (35Mb/s), 1920x1080 (17Mb/s), 1280x720 (8Mb/s), 1280x720 (4Mb/s)		
Frame Rate	50P, 25P		
MP4 Audio Format	2CH AAC 16-bit, 4CH LPCM 16-bit		
Recording Media			
For Movies	Mem Card A, Mem Card B		
For Photos	Mem Card A, Mem Card B		
Dual/Relay Recording	Standard, Dual, Relay	Dual to clone cards, relay to span cards	

Recording Setup 2

Item	Range	description	Pref
Slow & Fast Motion	Off, x0.2, x0.25, x0.5, x2, x4, x10, x20, x60, x120, x600, x1200	Inverse of actual motion speed	

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Available Space in Memory		Report on card usage	
Initialize	Mem Card A, Mem Card B	Format the cards	
External Rec Video Config	3840x2160 50P YCC420 8bit, 1920x1080 50P YCC 422 10bit, 3840x2160 25P YCC422 8bit, 1920x1080 25P YCC422 10bit	UHD only via HDMI	
Rec Command	On, Off		
HDMI Timecode	On Off	Add TC to HDMI output	

Recording Setup 3

Item	Range	description	Pref
Time Code Mode	Preset, Regen		
Time Code Running Mode	Rec Run, Free Run		
Initial Time Code	Set time code		
User Bit Type	Setting, Time, Date		
Color Bars	Off, EBU, SMPTE		SMPTE
1kHz Tone	-12dB, -18dB, -20dB, Off		

Recording Setup 4

Item	Range	description	Pref
File Numbering	Reset, Continuous		

Audio Setup 1

Item	Range	description	Pref
CH2 Input	Input2, Input1		
CH3/CH4 Input	Input Terminal, Int/Mic		
Input 1 Mic Trimming	+12dB, +6dB, 0dB, -6dB, -12dB		
Input 1 Mic Att	On, Off		
Input 2 Mic Trimming	+12dB, +6dB, 0dB, -6dB, -12dB		
Input 2 Mic Att	On, Off		

Audio Setup 2

Item	Range	description	Pref
Input 1/2 Limiter	On, Off		
Input 1/2 ALC Link	Linked, Separate		
Built-in Mic Sensitivity	Normal, High		
Built-in Mic Att	On, Off		
Built-in Mic Low Cut	On, Off		
Mic Att	On, Off		

Audio Setup 3

Item	Range	description	Pref
Mic Low Cut	On, Off		
Mic ALC Link	Linked, Separate		
Headphone Volume	0 ~ 8 ~ 15		
Speaker Volume	0 ~ 8 ~ 15	Only in Media Mode	
Monitor Channels	CH1/2, CH1/CH1, CH2,CH2, CH1+2/CH1+2, CH3/4, CH3/3, CH4/4, CH3+4/CH3+4, CH1+3/CH2+4		
HDMI Channels	CH1/2, CH3/4		
Notification Sounds	High Volume, Low Volume, Off		

Display Setup 1

Item	Range	description	Pref
Output Terminal	Off, SDI, HDMI	No SDI on the XF400	
HDMI Max Resolution	3840x2160, 1920x1080, 1280x720		
Output Status	Reports		
LCD Brightness	Up/Down	Shows grey scale	
LCD Backlight	Bright, Normal, Dim		
Viewfinder Backlight	Bright, Normal		

Display Setup 2

Item	Range	description	Pref
LCD Mirror Image	On, Off	Flips when LCD is rotated	
Output Onscreen Displays	On, Off	Show menus on output	
Onscreen Markers	Off, Level (Gray), Level (White), Grid Gray), Grid (White)		

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Distance Units	Meters, Feet		

System Setup 1

Item	Range	description	Pref
Language	Several		
Time Zone	Paris, Select by city and DST		
Date/Time	Enter date, time, year and format		
Network Settings			
Connection Settings	1 ~ 4		
Activate	Browser Remote, Off		
Browser Remote Settings			
Port No.	1 ~ 80 ~ 65535		
Camcorder ID	Camera name, up to 8 characters		
FTP Transfer Settings			
FTP Server	Up to 32 characters		
FTP User Name	Up to 32 characters		
FTP Password	Up to 32 characters		
Destination Folder	Path, up to 152 characters		
Port No.	1 ~ 21 ~ 65535		
Passive Mode	On, Off		
New Folder by Date	On, Off		
Save Named Files	Skip, Overwrite		
View Information			
Fan	Automatic, On		
Wireless Remote Control	On, Off		

System Setup 2

Item	Range	description	Pref
POWER LED	On, Off	Shows external power	
Tally Lamp	On, Off	When recording, wireless control, battery low, SD card full	
Access LED	On, Off	Shows SD card activity	
Network LED	On, Off	Shows network activity	
Remote Terminal	IRC-V100, Standard		
Assignable Button 1	AF/MF	See list in Section 3	

System Setup 2

Item	Range	description	Pref
Assignable Button 2	Powered IS		
Assignable Button 3	Pre Rec		
Assignable Button 4	Rec Review	See list in Section 3	
Assignable Button 5	Magnification		
Onscreen Assignable Button	Photo		
Custom Dial and Button	Tv/Av/M, AGC Limit, Exposure Comp, Off		

System Setup 2

Item	Range	description	Pref
Battery Info	Shows remaining time		
Backup Menu Settings	Save, Load		
GPS Auto Time Setting	On, Disable		
GPS Info	Display		
Certification Logo Display	Display		
Firmware	Display		

System Setup 2

Item	Range	description	Pref
Reset All	No, Yes	Factory reset	

'Looks' menu (press FUNC then 1, 2 or 3, then the icon to make adjustments)

Item	Range	description	Pref
Look 1, Standard			
Sharpness	0 ~ 3 ~ 7	Normal shooting	0
Contrast	-4 ~ 0 ~ 4		0

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Color Depth	-4 ~ <u>0</u> ~ 4		0
Look 2, Wide DR		Wide dynamic range, minimum gain=9dB	
Sharpness	0 ~ <u>2</u> ~ 7		1
Color Depth	-4 ~-<u>0</u> ~ 4		2
Look 3, Monochrome			
Sharpness	0 ~ <u>3</u> ~ 7		
Contrast	-4 ~ <u>0</u> ~ 4		

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5. Measurement results

All measurements were made on frames captured in the camera onto SDHC card. Live viewing was done on a 50" UHD LCD television via HDMI. Clips were ingested into Edius 8.52 and images for this document were extracted as BMP files. In all cases, the project resolution was set to match the clip resolution thus avoiding any scaling.

5.1   Colour performance

A standard 'Colorchecker' chart was exposed, using tungsten. The camera was allowed to auto-white balance and to auto- expose.

Fig. 1 shows the performance for the two colour 'Looks'. 'Look1' is quite conventional and looks fine on a normal display, no colours gave any cause for concern. Look2 is clearly aimed at wide dynamic range shooting, and looked normal when the display was switched HLG (Hybrid Log Gamma).

Figure 1 Colour performance
a)   Look 1, normal   b) Look2, Wide DR

However, the use of HLG in an 8-bit recording can give rise to colour contouring when the slope of the gamma curve is very low – at high brightness. This mode should perform much better using an external recorder with 10-bit depth.

There was no difference between HD and UHD performance.

5.2.   Gamma curves

The Colorchecker chart was recorded at 0dB gain: exposure was adjusted with the iris and aperture to cover a large range of light levels. Clips were captured in the camera, 8-bit, and measurements made of the signal levels in the grey scale.
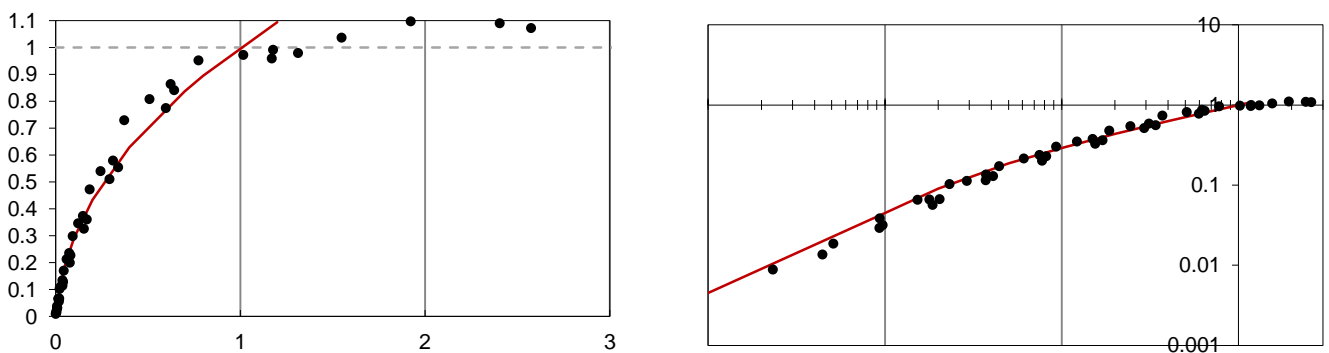

Figure 2 Gamma curve, Look 1: linear and log scales

Fig.2 shows the data for Look 1.

The horizontal scales have been adjusted such that the lower parts of the curve match the standard IT.709 curve (the red line) reasonably well. This shows that there is a progressive knee function which bends the curve to accommodate about 2.5 times overexposure, about 1.3 stops. The exposure range runs from about 2.5 times that for peak white, down to about 0.003 (at which point a one-stop change in exposure results in a change of only one quantum video level), thus the exposure range must be about 2.5/0.003=850:1, about 9.7 stops.

Fig. 3 shows the results for Look 2.

Again, the exposure scales are adjusted to make a reasonable match to the 709 curve at low levels. As a result, the maximum exposure is now about 8.5 times that for peak white, about 3.1 stops. The exposure range runs down to about 0.005, at which point a one-stop change results in a single quantum video level change. Thus the exposure range must be about 8.5/0.005, 1700:1, about 10.7 stops.

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From this it is seems that Look 2 (Wide DR) does deliver slightly higher dynamic range, by remapping the available range to the HLG gamma curve (Hybrid Log Gamma). Of course, it is likely that better performance can be had if an external recorder is used, when the benefits of 4:2:2 sampling and 10-bit coding could improve things by at least a stop.
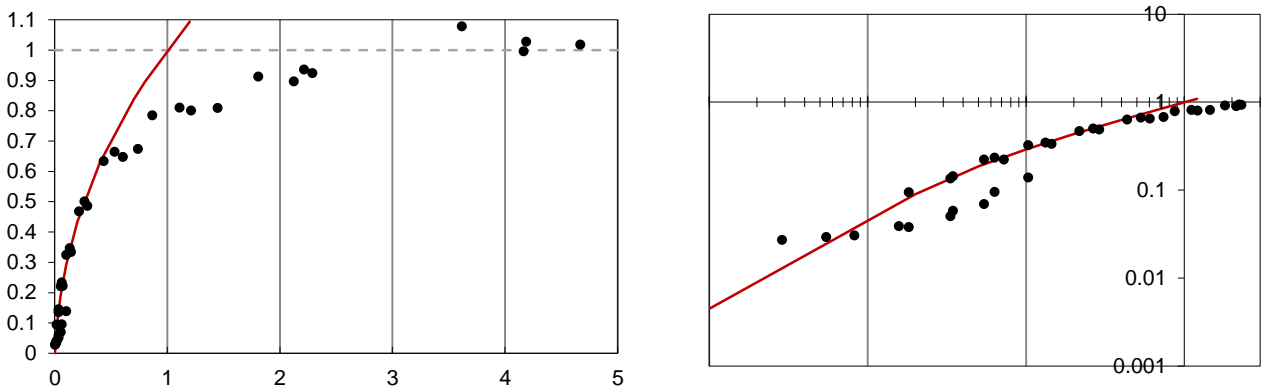

Figure 3 Gamma curve, Look2: linear and log scales

5.3. Resolution

Tests were made at about F/5.6. The usual zone plate test chart was framed to exactly fill the frame for HD (1080 and 720 formats) and to exactly fill only half the width of the frame for UHD (2160).

Fig. 4 shows one quadrant of the luma pattern which reaches the resolution limit of the format.

In both cases, the Sharpness control was set to 3 (the range is 0 to 7). Clearly, the HD performance is rather good (implying that the 2:1 down-scaling is good) but the UHD pattern shows considerably coloured aliasing vertically and horizontally, and luma aliasing diagonally. This is to be expected when using a Bayer-patterned sensor with exactly UHD photo-site counts, and it hints at the camera being acceptable for HD broadcast but not for UHD. However, the UHD performance also shows that there is significant image detail about the limits for
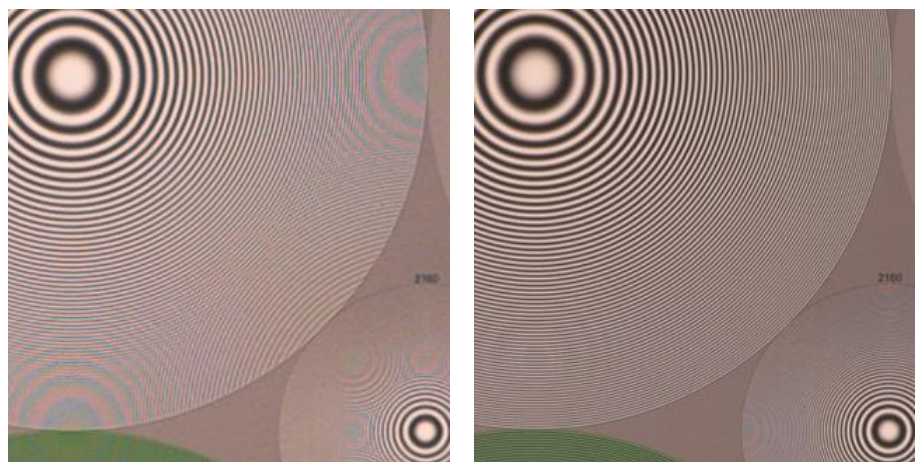

Figure 4 Resolution
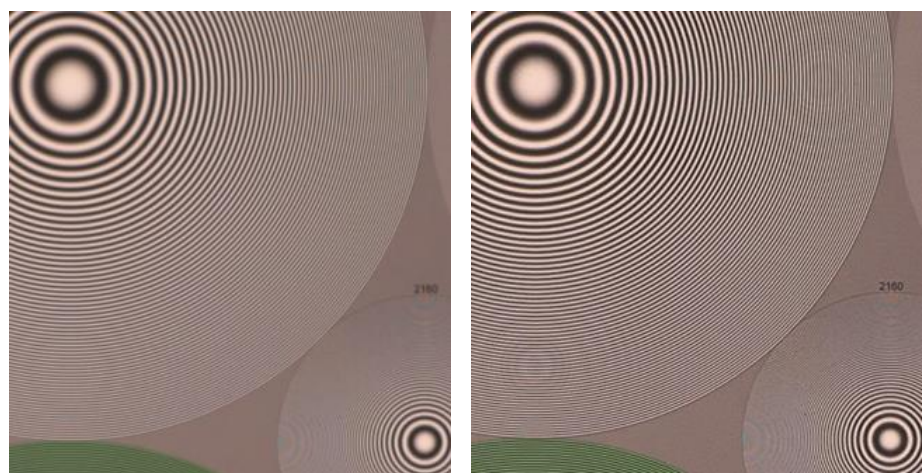 a)   UHD 3840x2160   b) HD 1920x1080

Figure 5 Resolution at HD
  a) Sharpness = 0   b) Sharpness = 7

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UHD (c.f. the smaller pattern which goes up to 7680x4320 for UHD), implying that there is probably no optical low-pass filter in the lens.

The Sharpness control is not too powerful. Fig.5 shows the extremes for HD. Set to zero reveals the base-level camera performance, while set to maximum it emphasises aliasing quite badly. The default setting is acceptable for HD, although a lower setting is advisable for UHD since the higher settings increase the visibility of aliasing without actual sharpening the picture.

Fig.6 shows the resolution at HD 720-line. There is significant horizontal and vertical aliasing, implying that the down-scaling from the UHD sensor (3:1) is not as good as that for the much simpler HD operation.

Figure 6 Resolution at 720-line

Before measuring the noise levels, exposures were made of the zone plate chart at various gain levels, to see how much resolution is lost as the gain increases. Fig. 7 shows the results.

Figure 7 Resolution (HD 1920x1080): the effects of gain setting

   a) 0dB   b) 20dB   c) 39dB

Evidently, there is little loss as the gain changes, only more noise at 39dB. This is encouraging.

5.4.   Noise performance

Next, more exposures were made of the Colorchecker chart, using the grey scale for measurement. Fig. 8 shows the HD (1920x1080) noise distribution with video level at 0dB gain.
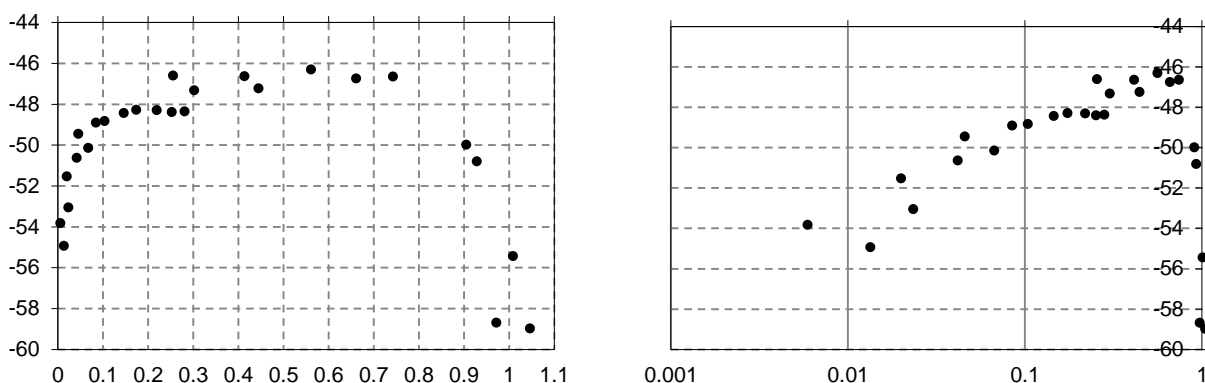

Figure 8 Noise distribution vs signal level, HD (1920x1080)

Noise level at mid-grey is slightly better than -46dB, which meets the -44dB threshold to qualify for EBU R.118 HDTV Tier 2. Tier 1 demands noise at -48dB or better.

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Fig. 9 shows the results for UHD (3840x2160). The story is much the same, but mid-grey6 noise level only just meets the -44dB threshold for HD Tier 1, and there is no UHD Tier 2 for which it might qualify. The camera is too noisy for UHD broadcasting.
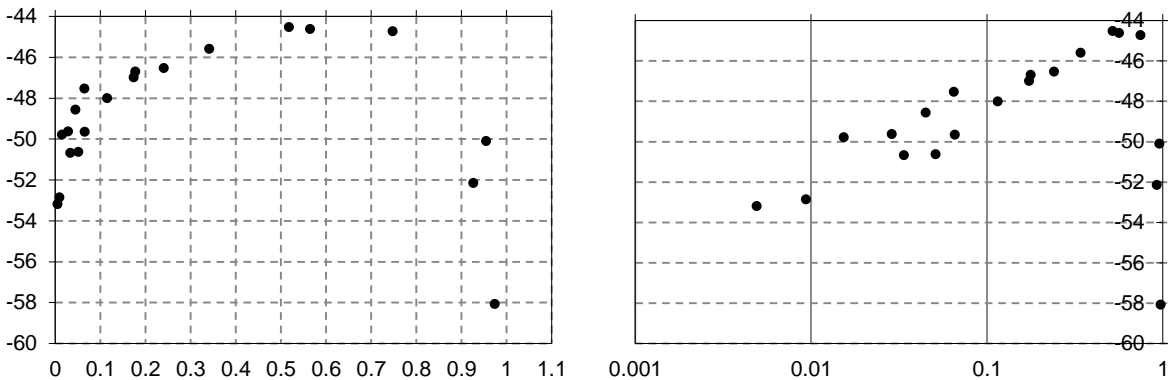

Figure 9 Noise profile: distribution vs signal level, UHD (3840x2160)

HD performance is better than UHD probably because of the filtering action of the down-scaling operation.

Next, the relationship between camera gain and noise level was explored. More measurements of the Colorchecker chart grey scale, adjusting the exposure over the range of gain settings to keep the middle patches near mid-grey. Fig. 10 shows how the noise levels vary in HD (1920x1080).

This result is unusual. Normally, the noise level should rise by 3dB for each gain change of 6dB. However, the curve shows two points of inflection which suggests that the down-scaling filter is not constant with gain. Oddly, the performance between 16dB and 26dB gain is much better than that at 0dB, which means that the camera can qualify for EBU R.118 Tier 2 at up to 30dB gain, a truly surprising result.
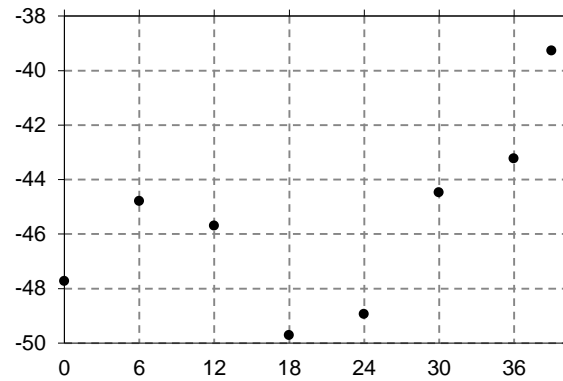

Figure 10 Noise profile: noise vs gain, HDTV

5.5. Sensitivity

The specification claims '1.4 lux minimum illumination', but with auto-slow-shutter enabled and 1/25 shutter. This is confusing, and does not help much. The conventional way of defining sensitivity is to specify the lens aperture at which the camera makes 100% video signal level with 2000 lux illumination of a 90% reflectance chart, but that doesn't help either because the camera does not have a standard gamma curve, and so the inevitable knee compresses highlights well before reaching peak white level.

Therefore, I have adopted my usual procedure for such cases: a Kodak Gray card (90%/18% reflectance) was illuminated at 2000 lux, and the aperture found at which the grey reached 50% video level when using Look 1. I also used a 1/50 shutter, since this is more representative of normal usage.

The 18% patch reached 50% video level at about F/4.1 where the white reached 95%. So the sensitivity is about F/4.1. Note that in Look 2, the minimum gain is 9dB, reserving 1.5 stops of exposure range for the highlight part of the HLG curve, thus making the camera appear to be 1.5 stops more sensitive (about F/7) at the expense of higher noise levels.

5.6. Motion performance

The specification makes no reference to the type of read-out process from the sensor, but the evidence is firmly that the sensor is scanned, the so-called 'rolling shutter'. A small desk fan was recorded, set to the speed where the blades strobe and appear to be almost stationary. Recordings at UHD and both HD standards show the same thing: in each case, the fan blades were made to almost fill the image vertically, and the shutter was set to 1/1000 to illustrate the effect.

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Fig. 11 shows still frames. In each case, the fan is rotating clockwise as seen, so the right-hand blade is descending and extended by the scanning process, while the other blade is shortened. This is typical of normal sensor scanning. The effect is less visible when the rotation occupies less of the frame, and when the shutter duration is longer.

Figure 4 Motion portrayal
a)   UHD 3840x2160   b)   HD 1920x1080   c) HD   1280x720

5.7.   Conclusions

The camera has many of the features of a broadcast camera, but is missing some crucial ones. It has no gen-locking facility and no time-code input or output. It has only zebras for exposure setting (there is no waveform or vector-scope monitoring). The battery can be charged only when attached to the camera.

There is little real control over picture performance, only the limited controls in the Look settings, see the end of Section 4.

In HD mode (1920x1080) the performance is quite good, noise levels and resolution performance allow it to pass both EBU R.118 Tier 2 levels, but at UHD the noise and resolution are inadequate. This is inevitable with a Bayer-patterned sensor of only 3840x2160.

Noise performance at HD is surprising. Although it only just makes the grade for Tier 2J at 0dB gain, the noise levels actually improve as gain is increased, up to about 26dB gain, and there is no discernible resolution loss with increased gain – perhaps there is active noise reduction in the middle-gain region, but there is no mention of it in the specification. Performance at 1280x720 is not as good as at 1920x1080, there is visible aliasing due to the use of a simple down-scaler.

Sensitivity is low when using Look 1, about F/4 for 2000 lux, and the achieved dynamic range is about 9.7 stops. Sensitivity is better when using Look 2, about F/7, and the noise levels are higher but the dynamic range is better, at about 10.7 stops. With an external recorder (HDMI connected) HD recordings can be made at 10-bit 4:2:2 rather than the internal 8-bit 4:2:0, which has the potential to increase the dynamic range by two stops, perhaps a little more.

Motion performance is typical of single-sensor cameras using the so-called 'rolling shutter', but could be acceptable unless short shutter durations are used.

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