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

Alan Roberts, March 2018

SUPPLEMENT 29: Assessment of a Panasonic GH5s 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 production model of the Panasonic DC-GH5s camera, serial number WH8AB005834. It resembles a medium-sized SLR camera, but without the mirror and pentaprism. The manual gives no specifications, therefore some of the content here is from the specification given on-line.

It is a Micro Four Thirds format (sensor size 17.3x13mm, 4:3 aspect ratio) with a "total of 11.93 Mega pixels". This implies that the resolution is about 4000x3000, however, the specification also says that only "10.28 Megapixels are active, making the resolution about 3704x2778 if it's 4:3. So the individual photo-sites must be about 4.7µm square, about the same as a conventional 3-sensor HDTV camera. Neither of these sets of dimensions is enough for 4096x2160 recording unless my assumptions are over-simplifications – which seems likely. If the sensor is 4096 photo-sites wide, then it must be about 2510 photo-sites high giving enough for 4096x2160, but the aspect ratio would be 1.632:1, neither 4:3 nor 16:9 nor 17:9. Either way, the pixel size is about 22 square microns, enough for good sensitivity and noise.

It records stills in many sizes, including burst-recording for action-freezing and post-production focus control. More significantly for television, there is a huge variety of video recording formats (63 in all), from 4096x2160 to 1920x1080, in four different compression systems, at frame rates from 59.94Hz to 23.98Hz. It records 2 or 4 audio channels 16/24-bit.

There is a monocular OLED viewfinder (approximately 3.68 Mpixels, not enough for critical-focusing without image magnification) and a fold-out 8cm LCD panel (1.62 Mpixel) which can be used to control most of the menu system.

Connectivity is rather good: HDMI output at up to 4096x2160, timecode input/output (to set the start-time), mini USB, headphone and stereo microphone via 3.5 mm jack sockets.

Power consumption is not specified; the battery is 7.2 volts 1.86Ah and are charged outside the camera. Optional add-ons allow for external power and XLR audio inputs. The bare camera weighs 660g. There are many Fn (assignable) buttons and two assignable control wheels.

The camera performed rather well under test. Tests were made according to EBU Tech.3335, and the results establish that the camera belongs in HD Tier 1 and could arguably belong in UHD Tier 2.

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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. Menus are nested: items in italics in the listing are headings leading to a further nested menu. Only items avialbel in Video mode are listed..

Camera settings which affect picture quality directly, such as gamma, detail and matrix are held in scene files. These are available via the Custom Picture facility (2nd category in the menus). Other functions such as gain and iris are also controlled by dial/button.

Measurement results are given in section 3, after the menus. Measurements were made according to the procedures set out in EBU Tech.3335.

This listing of the menus and contents is complete, but this should not be used as an excuse for not reading the manuals. Not all menu items are available in both Camera and Media mode.

1. Controls and connectors

Main camera body

Front	Lamp	Self-timer indicator/AF Assist Lamp
	Preview/Fn6 button	Below/left of the lens
	Timing socket	Flash sync/TC in/out, top/right of the lens
Left	Mic 3.6mm jack	All under rubber covers
	Headphones 3.5mm jack	
	HDMI socket	
	USB socket	
Back, clockwise from left	Playback button	
	LVF/Fn5 button	Select monocular/LCD panel
	Joystick/Function button	Press=Fn12, up=Fn13, right=Fn14, down=Fn15, left=Fn16
	AF/AE lock button	
	Focus mode rotary	
	Rear dial	assignable
	Disp button	
	Q menu/Fn2 button	
	Auto focus/Fn3 button	
	Cursor buttons in control dial	Up=Fn17, right=Fn18, down=Fn19, left=Fn20
	Control dial	
	Menu/Set button in control dial	
	Delete/Cancel/Fn4 button	
Top from left	Drive mode dial	
	On/Off lever	
	Mode dial	
	Mode dial lock button	
	Fn1 button	
	WB button	
	ISO sensitivity button	
	Exposure compensation button	

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	Shutter button	
	Motion picture record button	
Right	SD card slots	Under rigid cover
Bottom	Battery grip connector	Under rubber cover
	Battery compartment	

2. Menu contents

Creative Video Menu

Access by menu button, select/set via joystick or control dial. Submenus are indented.

Item	Range	Description
Exposure Mode	P, A, S, M	Program, Aperture priority, Shutter priority, Manual
Variable Frame rate		Available only 8-bit: AVCHD 1080 24Mb/s and MP4 [MOV] 100Mb/s
Anamorphic (4:3)	On <u>Off</u>	For use with 2:1 anamorph. Records 3328x2496
Loop Recording	On, <u>Off</u>	Only in MP4 (LPCM or MOV, fills the card
Synchro Scan	On, <u>Off</u>	Adjust to minimise lighting flicker
Master Pedestal Level	-15 ~ <u>0</u> ~+15	
SS/Gain Operation	Sec/ISO, Angle/ISO, Sec/dB	Set the display
WFM/Vectorscope	Wave, Vector. <u>Off</u>	Monitoring display
Anamorphic Squeeze Display	On, <u>Off</u>	Only when using an anamorphc lens
HLG View Assist	Mode2, Mode1, <u>Off</u>	Mode2 to prioritises low levels, Mode1 for high
V-LogL View Assist		Select LUT from card
Focus Transition		See the manual
4K Live Cropping		See the manual, makes HD from 4k with pan/scan

Motion Picture Menu

Item	Range					Description					
Rec Format	AVCHD, MP4, MP4 HEVC, MP4 (LPCM), MOV					HEVC does HLG					
	Coder	Resolution	Compression			Mb/s	59.94	50	29.97	25	24	23.98
Rec Quality	AVCHD	1920x1080	4:2:0	8	LongGOP	28	P	P				
						24	I¹	I¹				P
						17	I	I				
	MP4	3840x2160	4:2:0	8	LongGOP	100			P	P		P
		1920x1080	4:2:0	8	LongGOP	28	P	P				
						24						P
						20			P	P	P	
	MP4 HEVC	3840x2160	4:2:0	10	LongGOP	72			P	P		P
	MP4 (LPCM), MOV	4096x2160	4:2:2	10	All-Intra	400					P	P
			4:2:2	10	LongGOP	150			P	P		P
			4:2:0	8	LongGOP	150	P	P			P	
						100			P	P	P	P
		3840x2160	4:2:2	10	All-Intra	400			P	P	P	P
			4:2:2	10	LongGOP	150			P	P	P	P
			4:2:0	8	LongGOP	150	P	P				
						100			P	P	P	P
		1920x1080	4:2:2	10	All-Intra	200	P	P	P	P	P	P
			4:2:2	10	LongGOP	100	P	P	P	P	P	P
			4:2:0	8	LongGOP	100	P	P	P	P	P	P
Time Code Display	On, Off										
Count Up	Rec Run, Free Run										
Tine Code Value	Reset, Manual Input, Current Time										

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¹ Strictly PsF (Progressive with Segmented Frames i.e. film-motion) rather than properly Interlaced.

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Time Code Mode	DF, NDF		Automatically NDF for 24.25.50Hz
HDMI Time Code Output			
External Time Code Setting			Ext sync via BNC adaptor
AFS/AFF	AFS, AFF		Auto Focus Single for scenic, AFFlexible for motion
Continuous AF	On, Off		Off locks AF while recording
Photo Style	Standard, Vivid, Natural, Monochrome, L.Monochrome, Scenery, Portrait, Custom1, Custom2, Custom3, Custom4, CineLike D, CineLike V, Like709, Hybrid Log Gamma, V-Log L		See the measurement section below for comments
Contrast	-5 ~ 0 ~ +5		Not all controls available in all modes
Sharpness	-5 ~ 0 ~ +5		
Noise Reduction	-5 ~ 0 ~ +5		
Saturation	-5 ~ 0 ~ +5		
Hue	-5 ~ 0 ~ +5		
Fn2: Knee Setting	Auto, Manual, Off		Only in Like709 mode
Point	80% ~ 107%		
Slope	0 ~ 99		
Filter Settings	On, Off, Set		
Luminance Level	8-bit	0-255, 16-235, 16-255	0-255 for photos, 16-235 or 64-940 for video.
	10-bit	0-1023, 64-940, 64-1023	
Metering Mode	Multiple, Centre weighted, Spot		
Highlight Shadow	Standard, Raise the contrast, Lower the contrast, Brighten dark areas, Custom		
i.Dynamic	Auto, High, Standard, Low, Off		Dynamic range stretch/squeeze, not available in 709 HLG V-Log L
i.Resolution	High, Standard, Low, Off		Seems to be auto sharpness control
ISO Sensitivity			Set limits for auto exposure sensitivity range
ISO Auto Lower Limit	160 ~ 25600		
ISO Auto Upper Limit	Auto, 200 ~51200		
Shading Comp	On Off		Fixed vignetting compensation
Diffraction Compensation	Auto, Off		Compensate for softening as iris closes
Stabilizer	Normal, Panning, Off		Optical image stabiliser, needs lens with OIS
Flkr Decrease	1/50, 1/60, 1/100, 1/120, Off		Shutter to reduce lighting flicker
Ex Tele Conv	On, Off		Electronic zoom, not available in all modes
Digital Zoom	Off, x2, x4		
Picture Mode in Rec			Shoot stills while recording video
Time Stamp Rec	On, Off		Record date in the image
Sound Rec Level Disp	On, Off		
Sound Rec Level Adj	-12dB ~ +6dB		
Sound Rec Limiter	On, Off		
Wind Noise Canceller	High, Standard, Off		Only for built-in mic
Wind Cut	High, Standard, Low, Off		Only for external mic
Lens Noise Cut	On, Off		Reduces lens motor noise
Special Mic	Stereo, Lens Auto, Shotgun, S.Shotgun, Manual		Set polar diagram for DMW-MS2 external mic
Sound Output 208	Real Time, Rec Sound		Rec Sound allows for coder delay
XLR Mic Adaptor Setting	96kHz/24bit, 48kHz/24bit, 49kHz/16bit, Off		For DMW-XLR1 adaptor. 24bit only in MOV recording format
HDMI Rec Output			
Info Display	On Off		
Down Convert	Auto, 4k/25p, 1080p, 1080i, Off		
HDMI Recording Control	On, Off		
HLG View Assist (HDMI)	Auto, Mode2, Mode1, Off		HLG LUT on the output
LUT HDMI Display	On, Off		For V-LogL LUT
Sound Down Convert	Auto, Off		For external XLR module
Color Bars	SMPTE, EBU, ARIB		Bars turn off automatically

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Custom Menu

Item	Range	Description
Exposure		
Dual Native ISO Setting	Auto, Low, High	Low=160~800, High=800~204800
ISO Increments	⅓EV, 1EV	
Extended ISO	On, Off	Stretches limits to ISO80~204800
Exposure Comp Reset	On, Off	
Focus/Release Shutter		
AF/AE Lock	AE Lock, AF Lock, AF/AE Lock, AF-On	Lock the auto controls
AF/AE Lock Hold	On, Off	Locks it all
Shutter AF	On, Off	Allows AF with shutter button half-press
Half Press Release	On, Off	Fires shutter at half-press
Quick AF	On, Off	Uses more battery
Eye Sensor AF	On, Off	AF happens only when you're looking
Focus/Release Priority	Focus, Balance, Release	Sets criteria for shooting out-of-focus
Focus Switching for Vert/Hor	On, Off	On can hold separate AF for horizontal and vertical camera orientation
Loop Movement Focus Frame	On, Off	Allows wrap-around for focus frame
AF Area Display	On, Off	Show the areas used for AF
AF+MF	On, Off	Allows fine manual control of AF
MF Assist	On, Off	Adds more options for selected lenses
MF Asist Display	On, Off	Enlargement can be full image or window
Operation		
Fn Button set, 1~11		Huge list, see manual p.60
Q.Menu	Preset, Custom	Add up to 15 menu items to Quick Menu
Dial Set	Assign Dial (F/SS)	F/SS=Aperture Front/Shutter Rear SS/F=Shutter Front/Aperture Rear
	Rotation (F/SS)	Rotation changes directions
	Control Dial Assignment	Headphone volume, Exposure Aperture, Exposure compensation, Focus Frame Size
	Exposure Comp	Front Dial, Rear Dial=Off
	Dial Operation Switch Setup	Set temp operations of Front/Rear Dials
Joystick Setting	D.Focus Movement, Fn, Menu, Off	Joystick operations during recording
Operation Lock Setting	Cursor, Joystick, Touch Screen, Disp. Button	Set what's locked by Operation Lock button
Video Button	On, Off	Disables motion picture button
Touch Settings	Touch Screen, Touch Tab, Touch AF, Touch Pad AF	Disable operations
Monitor/Display		
Auto Review	Duration Time, Playback Operation Priority, Hold	Reviews recording immediately
Monochrome Live View	On, Off	
Constant Preview	On, Off	See effect of aperture/shutter in manual
Live View Boost	On, Off, Set	Makes LCD brighter
V-LogL View Assist		Import LUT from card
Peaking	On, Off, Set	Set colour/brightness for MF assistance
Histogram	On, Off	Lovely
Guide Line	Grid, Star, Cross, Off	
Video Guide Line	2.39:1, 2.35:1, 16:9, 1:1, Off	Markers
Center Marker	On, Off	
Highlight	On, Off	Flashes clipped whites in playback
Zebra Pattern	Zebra1, Zebra2, Off, Set	

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Set Zebra1	50 ~ 105%	
Set Zebra2	Off, 50 ~ 105%	
Expo Meter	On, Off	Show exposure meter across screen
MF Guide	On, Off	Show focus distance bar
LVF/Monitor Disp Set	On, Off	Underscans to put data outside the image
Monitor Info Disp	On, Off	
Rec Area	Photo, Video	Show the image cropped to what's recording
Video-Priority Display	On, Off	Show only relevant data when recording
Menu Guide	On, Off	
Lens Position Resume	On, Off	Returns les to last condition on power-up
Power Zoom Lens	Disp Focal Length, Step Zoom, Zoom Speed, Zoom Ring	
Zoom Speed	H, M, L	
Lens Fn Button Setting	Focus Stop, AF/AE Lock, AF-On, Stabilizer, Focus Area Set, AF Mode/MF, Preview, Off, Restore to Default	Set which button acts as focus for an interchangeable lens
Face Recog	On Off, Memory	Store up to 3 identities, by name/age/type
Profile Setup	Baby1, Baby2, Pet, Off, Set	

Setup Menu

Item	Range	Description
Folder/File Settings	Select Folder, Create a New Folder, Fine Name Setting	Useful file-naming stuff
Double Slot Function 262	Relay Rec, Backup Rec, Allocation Rec	Relay fills both cards, Backup makes duplicates
Allocation Rec	JPEG, RAW, 4K Photo, Video	Specify card slot for each recording type
Save/Restore Camera settings	Save, Load, Delete	Save setup info to card
No. Reset	Slot1, Slot2	Reset last digits of file number to 0001
Reset	Yes, No	Reset settings to factory
Reset Network Settings	Yes, No	Default network settings
Pixel Refresh	Yes, No	Finds/conceals dead pixels
Sensor Cleaning	Yes, No	Ultrasonically shake the sensor
Level Gauge Adjust	Adjust, Level Gauge Value Reset	Reset the sprit level
Format	Slot1, Slot2	Format SD cards

My Menu

Item	Range	Description
	Add, Sorting, Delete, Display from My Menu	Roll your own up to23 items

Playback Menu

Item	Range	Description
Slide Show	Up, Down, Menu/Set	Select files to show
Playback Mode	Effect, Duration, Repeat, Sound	Controls for slide show
Protect		Select file(s) to protect
Rating	1 ~ 5	Select file and rating, Menu/Set to set
Title Edit	test	Select file and enter/edit title
Face Rec Edit	Replace, Delete	Menu/Set to confirm
RAW Processing	White Balance, Brightness Correction, Photo Style, i.Dynamic, Contrast, Highlight, Shadow, Saturation/Color Tone, Hue/Filter Effect, Noise Reduction, i.Resolution, Sharpness, More Settings	Post-processing. Select and image file then … and Menu/Set to confirm
4K Photo Bulk Saving		Burst-mode stills – up to 5 seconds
4K Photo Noise Reduction	Auto, Off	Burst mode
Light Composition		Burst mode, see the manual, p 274
Clear Retouch		Wipe stuff off a still, see the manual p.275

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Test Stamp	Shooting Date, Name, Location, Travel Date, Title	Add stuff to stills
Copy	1 to 2, 2 to 1	Copy between cards
Resize		Resize stills
Cropping		Crop stills
Rotate		Rotate stills 90 degrees
Video Divide		Select a file, L/R to set point, Up to divide
Time Lapse Video		Make Time Lapse from recorded pictures
Rotate Disp		For stills
Anamorphic Squeeze Display	On, Off	Use with anamorphic 2:1 lens
HLG View Assist	Mode 2, Mode1, Off	HLG LUT
LUT Monitor Display		Use appropriate LUT
Picture Sort	File Name, Date/Time	
Delete Conformation	Yes, No	

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3. Measurements

All measurements were made on frames captured in the camera onto SDHC card using 10-bit 4:2:2. Live viewing was done on a 50" HD/UHD LCD television display (Panasonic 50DX750). 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 unnecessary scaling.

The camera serial number was WH8AB005834. The lens was a Lumix 12~35mm (F/2.8) zoom rather than the SLR Magic fixed focal length 25mm F/0.95 supplied with the camera.

3.1. Colour performance

A standard Colorchecker chart was exposed, using tungsten illumination. The camera has many 'modes' which affect colour rendition, some of these were tested. It would seem to be wrong to compare these without including the post-processing and display system for which each may be intended, but there is no reason to expect the resulting colour performance to be affected by these settings, provided the correct post-production operations are done on them.

Fig. 1 shows the results for seven modes. Like709 is the most accurate reproduction (Knee was turned off for this test), but the orange patches are a little on the blue side. There is little or no difference when switching between ISO400 and ISO2500. Also, there is little to choose between Like709, Natural and Standard, and the two Cine modes both show significant desaturation as expected. HLG looks right when viewed on a display with HLG decoding, and V-LogL looked right but dim using standard display gamma.

There was no evidence of any Infra Red response; there must be an IR filter.

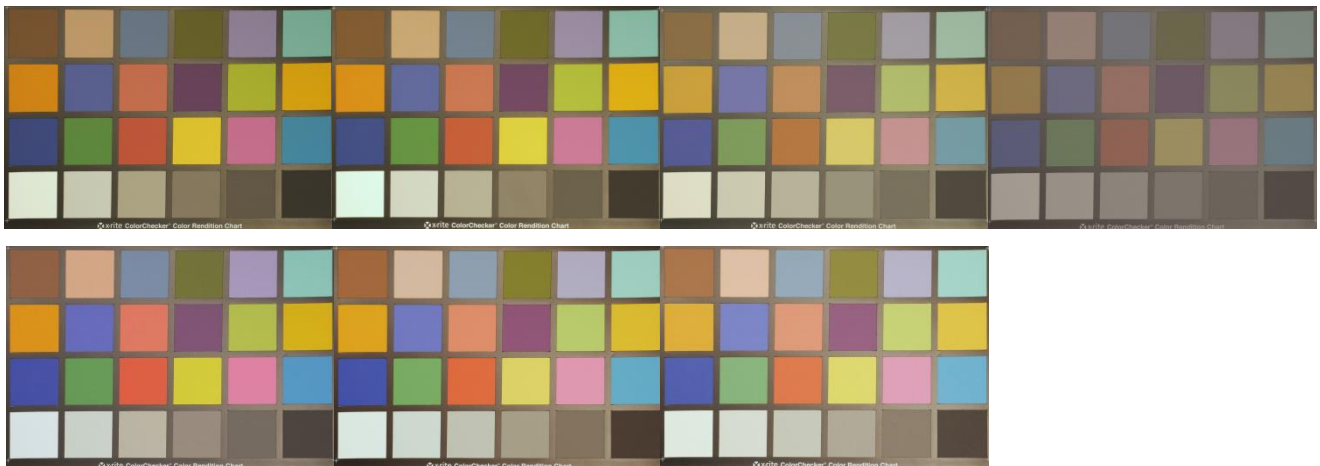All of the modes are acceptable – there are no surprises here.

Figure 1 Colour performance, Colorchecker

a) Like709 ISO400	b) Like709 ISO2500	c) HLG	d) V-LogL
e) CineLike-D	f) CineLike-V	g) Natural	

3.2. Gamma curves (opto-electronic transfer characteristic) and Dynamic Range

The Colorchecker chart was exposed with tungsten illumination, using the Like709, HLG, V-LogL and and CineLike-D modes. Multiple exposures, using shutter and aperture, provided many exposure levels from which it is possible to extract the curves from the grey scale patches.

The camera does not appear to offer any control over the gamma curve, other than the 'mode' selection, apart from the Knee function in Like709. Knee was switched off for this test, since the other curves ought to handle highlights better anyway.

Fig. 2 shows the curves for four of the modes. I have drawn the standard ITU.709 curve in grey for reference. In each case, the curve has been scaled horizontally such that the curve matches the real 709 curve below about 40%. Steps and irregularities are down to small difference between measurements at nominally

the same input level. I have deliberately left these anomalies in to show that the measurements are real, no fakery here.

Like709 appears to have a residual knee at about 90% such that peak white (vertical = 1) is reached at about 1.3 times nominal 100% exposure (horizontal=1). CineLike-D clips at about 430% exposure, HLG doesn't clip until exposure reaches at least 700%, and V-LogL never goes above 80% which it reaches at about 650% exposure.
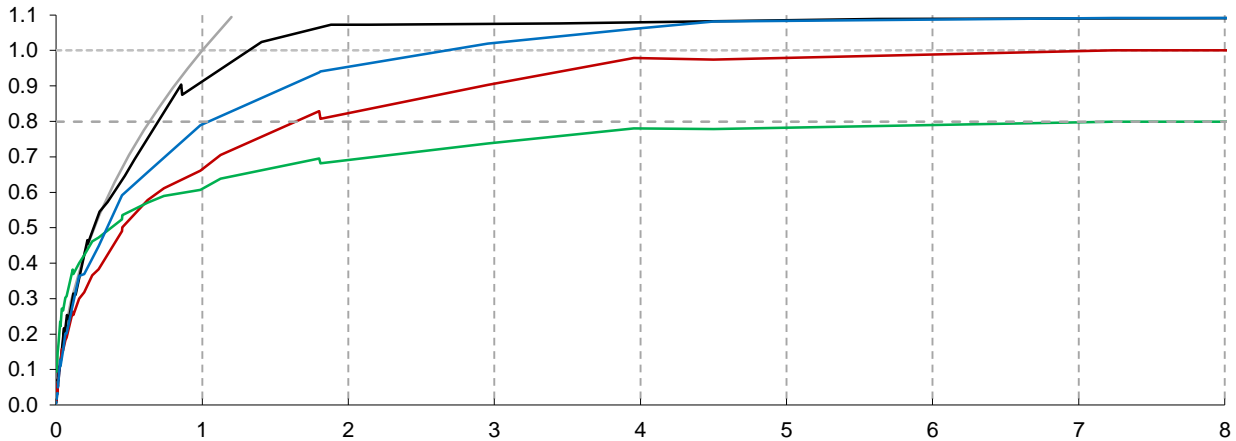

Figure 2 Gamma curves, linear axes: Like709, HLG, V-LogL, CineLike-D, ITU.709

So, Like709 copes with 25% headroom natively, HLG copes with at least 620%, V-LogL with about 600%, CineLike-D with 340%. I did not test Like709 with the Knee on because CineLike-D does a better job anyway.

Fig. 3 shows the same data plotted with logarithmic axes. It appears that all the curves are very similar except V-LogL, which is surprising. In most cases, the dynamic range appears to be about 10,000:1, or about 13 stops. However, the lines are still curving gently at the lower end, so the dynamic range may actually be greater (or less), subject to noise levels.
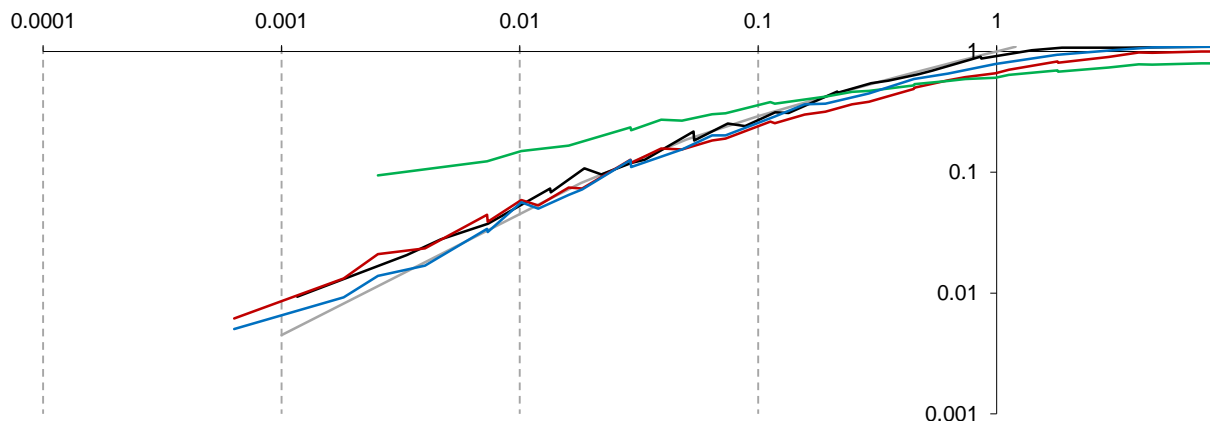

Figure 3 Gamma curves, log axes: Like709, HLG, V-LogL, CineLike-D, ITU.709

3.3. Resolution and aliasing

The camera has HD (1920x1080), UHD (3840x2160) and 4K (4096x2160) modes. 4K is normally known as DCI, Digital Cinema Image format. Only HD and UHD were recorded (although I checked that the 4K performance was consistent with that for UHD, by inspection on the UHD display).

The usual zone-plate test chart was used, fully framed for HD, framed to fill exactly half the image height for UHD.

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3.3.1 .Resolution and aliasing for HD 1920x1080

Fig. 4 shows the resolution for HD for the Lumix lens using the Like709 gamma mode.

The image is quite clean, with very little aliasing and resolution well-handled up to near the limits for HD. There is very little evidence of aliasing beyond the limits (in the smaller quadrant which explores the limits of UHD) – this shows that the down-scaling to HD is done very well.

The sharpness control has a nicely limited range. Presumably, the minimum setting (-5) implies no enhancement, so Fig.4a shows the native performance of the camera. Even with the maximum setting (Fig.4c, +5) performance is not bad, and the default value is a very good compromise. It is rare to see down-scaling done so well in a camera.
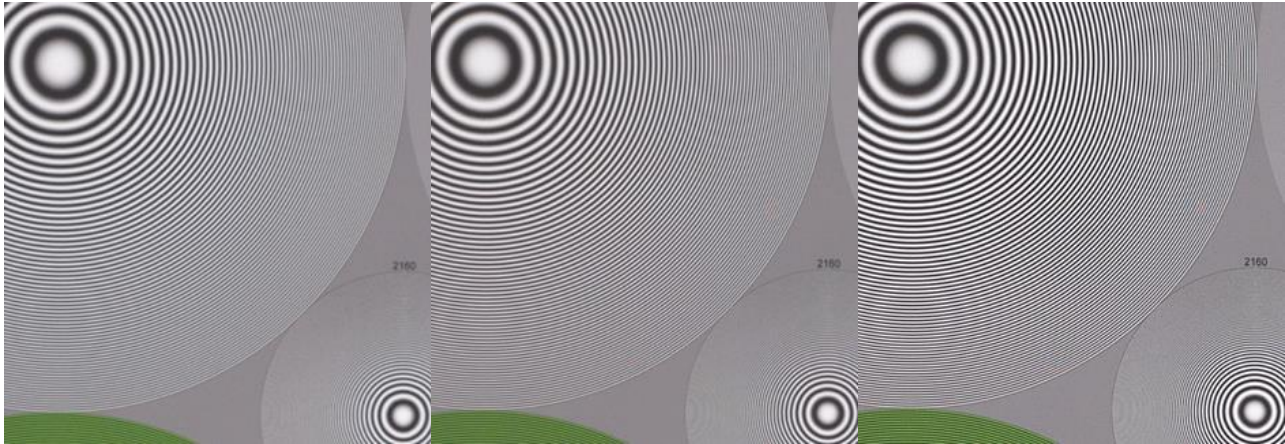

Figure 4 Resolution: HD, Lumix lens F/5.6
    a)   Sharpness = -5   b)   Sharpness = 0   c)   Sharpness = +5

Fig.5 shows the results for the SLR Magic lens. It appears to be a little sharper at this aperture, but gets soft very quickly as the iris is opened. Nevertheless, performance is still good with little evidence of aliasing.
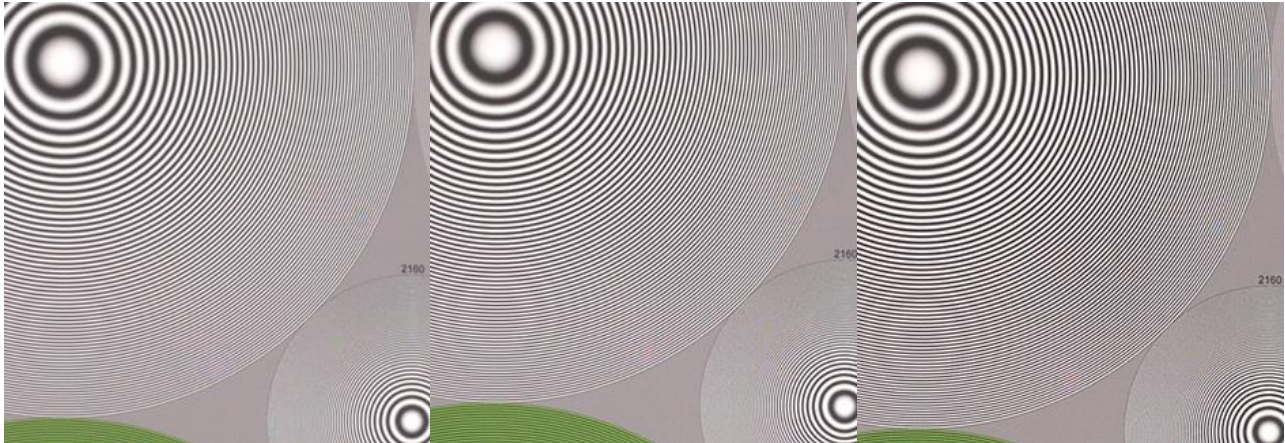

Figure 5 Resolution: HD, SLR Magic lens F/4
    a)   Sharpness = -5   b)   Sharpness = 0   c)   Sharpness = +5

3.3.2. Resolution for UHD 3840x2160

The HD zone plate chart was reframed so that it filled exactly half the frame height.

Fig. 6 shows one luma quadrant for the Lumix lens.

As expected, there is significant aliasing both horizontally and vertically, because the image appears to be taken from an area of the sensor which matches the UHD resolution. Thus the red and blue channel resolutions are only HD (1920x1080), whilst the green channel resolution is confused by the camera's improved manner of decoding luma information from a larger-than-normal number of neighbouring photo-sites. There appears to be an optical low-pass filter, preventing resolution beyond the limits of UHD from

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Figure 6 Resolution: UHD, Lumix lens F/5.6

    a)   Sharpness = -5   b)   Sharpness = 0   c)   Sharpness = +5

reaching the sensor – the evidence is in the smaller quadrant which now reaches the limits of UHD2 (7860x4320) where there is very little content outside UHD (3840x2160).

This is highly encouraging, and although the Sharpness control appears to be working a little too hard (the default value produces excessive aliasing without improving the resolution), the images look surprisingly clean for a camera using a Bayer patterned sensor with the same photo-site count as the image format.

Fig.7 shows the results for the SLR Magic lens. The aliasing level is much higher although there is little content above the UHD limits. This confirms that there is a proper optical low-pass filter, and that, for UHD, the Sharpness control should be set at not more than about -3 or -2 for acceptable results.
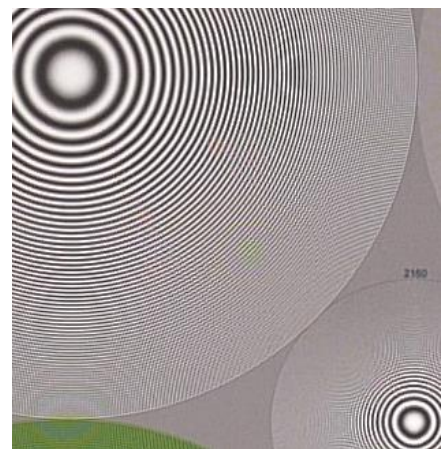
Overall, UHD performance is reasonable for a Bayer-patterned sensor, but not really good enough for high-end television production.

Figure 7 Resolution: UHD, SLR Magic lens F/4, Sharpness = 0

Resolution normally changes with camera gain. Figs. 8 and 9 show this, using the Lumix lens.

Figure 8 Resolution: HD, Lumix lens F/5.6

    a)   ISO 160   b)   ISO 640   c)   ISO 2,500

Up to ISO 2,500, nothing changes, but by ISO 10,000 some loss is visible, along with a small increase in noise levels. At ISO 40,000 and above, the resolution clearly drops and noise is becoming a problem.
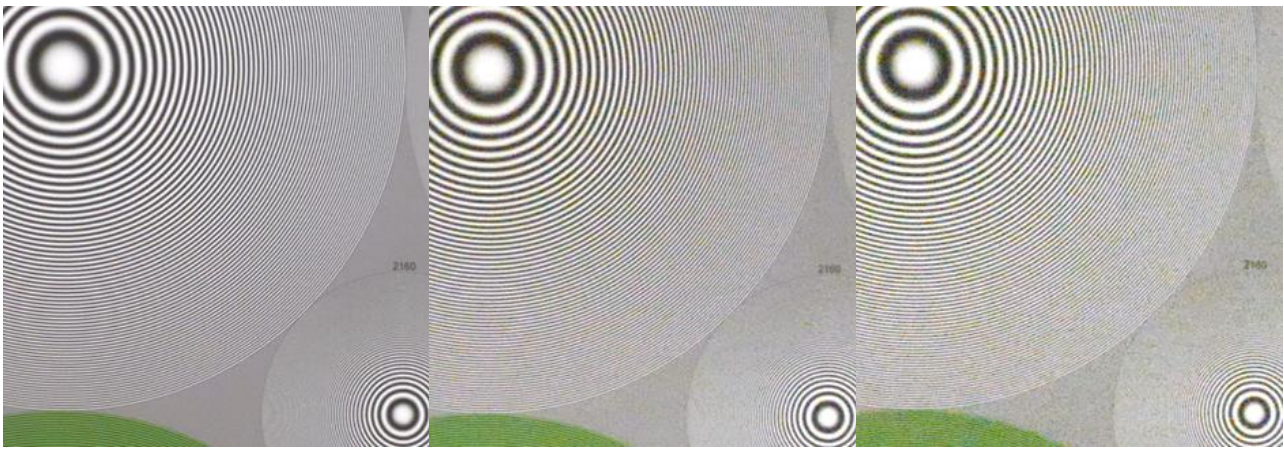
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Figure 9 Resolution: HD, Lumix lens F/5.6

   a)   ISO 10,000   b)   ISO 40,000   c)   ISO 80,000

3.4. Noise

3.4.1. Noise levels

The exposures of the Colorchecker used in section 3.2 were used to measure noise levels in the grey scale. All measurements were made in HD mode (1920x1080). Noise levels in UHD and 4K modes ought to be similar.

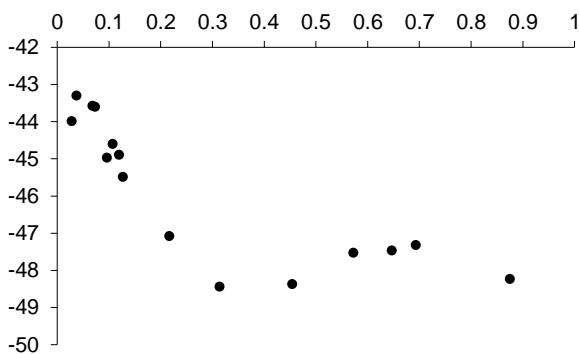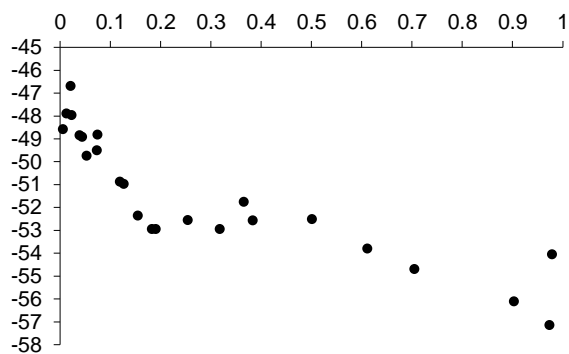Figs. 9 and 10 show the noise profiles at ISO400 for four modes.

Figure 9 Noise levels versus video signal levels

   a)   Like709   b)   HLG

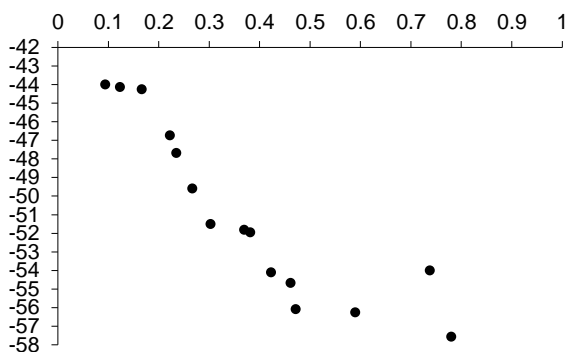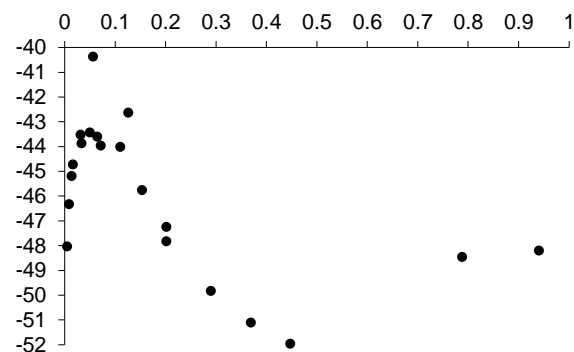**Figure 10 Noise levels versus video signal levels**

   a)   V-LogL   b)   CineLike-D

Photon noise (properly known as Shot Noise) must increase with signal level, but this can be countered by analogue gamma correction in which noise levels rise towards black. All except CineLike-D appear to have noise levels rising near black, which seems to imply that the gamma-correction is being done in analogue before the colour matrix. Whilst unconventional, this can result in pictures which look less noisy than they

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actually are because noise levels near mid-grey can be lower. The down-side of such processing is that colour performance may not be constant with changes of signal level.

The result for V-LogL shows a much more pronounced rise towards black. At about 50% signal level, the noise level is about -48dB for Like709 mode and -52dB for HLG and CineD modes.

Inspection of the measurement data, searching for the lowest exposure level which produces a change of 2 quantum levels in the recorded 10-bit signal, reveals the dynamic range, since:

$$Dynamic\ Range = \frac{Max\ exposure}{Min\ exposure}$$

Mode	Min exposure	Max exposure	Ratio	Stops
Like709	0.001	1.25	1,250:1	10.3
HLG	0.0003	7.2	24,000:1	14.6
V-LogL	0.0006	7	11,700:1	13.5
CineLike-D	0.0003	4.5	15,000:1	13.9

Note that these figures are a little speculative and subjective: it is up to the user to decide whether the performance at the extreme ends of the dynamic range are acceptable, thus there is an uncertainty of about 1 stops in all these results.

If the camera is used in 8-bit recording, the dynamic ranges will all be lower because the quantum changes are bigger, so at least one stop will be lost in the blacks.

3.4.2. Noise change with ISO setting

Further exposures to the Colorchecker chart were made over a range of ISO settings, and measurements made to establish the noise level at exactly 50% video signal level each time. Monitoring was not sufficiently precise to be able to set the exposure correctly, so interpolation was used between the two patches at which the signal level was just above and just below 50% signal level.
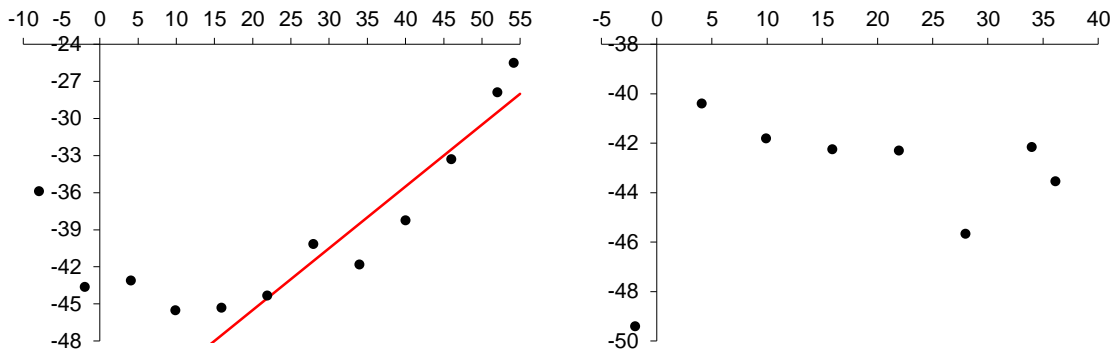

Figure 11 Noise at mid-grey versus ISO setting
    a)   Like709

Fig. 11 shows the results for Like709 and V-LogL. The results are for Like709 and V-LogL modes because they represent the two extremes of the modes. The horizontal axis is marked in dB of gain, with zero corresponding to the reference 'speed' setting of ISO400; thus ISO160 is -8dB, and ISO2,500 is +15.9dB.

Neither set of measurements shows this slope of 0.5 (the red line in the Like709 plot, but noise levels at lower ISO settings rise substantially from a minimum at around ISO2,000. The V-LogL plot shows no particular trend, except for the sudden drop at -1.9dB or ISO320.
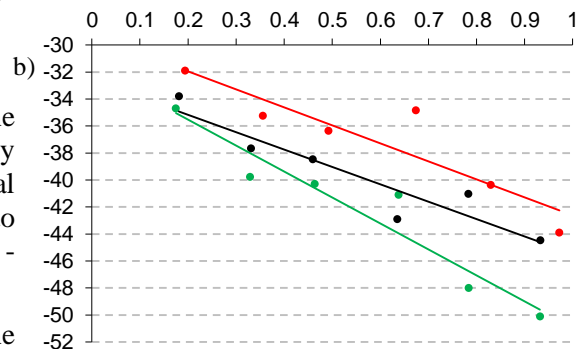

Figure 12 Noise reduction, -5   0   +5

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3.4.3. Noise reduction

Further exposures to the Colorchecker chart were made at ISO20,000 to check the effectiveness of noise reduction (all the previous measurements were made in the default mode with Noise Reduction set to zero. 20,000 was chosen because the pictures a fairly noisy.

Fig.12 shows the distribution of noise versus signal level for three settings of noise reduction. Clearly, there is about a 3dB improvement with the default (zero) setting, but increasing it beyond zero has little effect in areas of high noise (nearer to black). So the camera is actually about 3dB noisier than it appears to be from these tests.

Fig.13 shows how the resolution changes with noise reduction. Somewhat surprisingly, far from reducing the effective resolution, noise reduction appears to improve it. So there appears to be little reason to avoid it, and the higher settings may well be acceptable. If so, then a further 2dB improvement in noise (but only when the noise levels are already high) might be achieved. This is encouraging, if rather surprising.
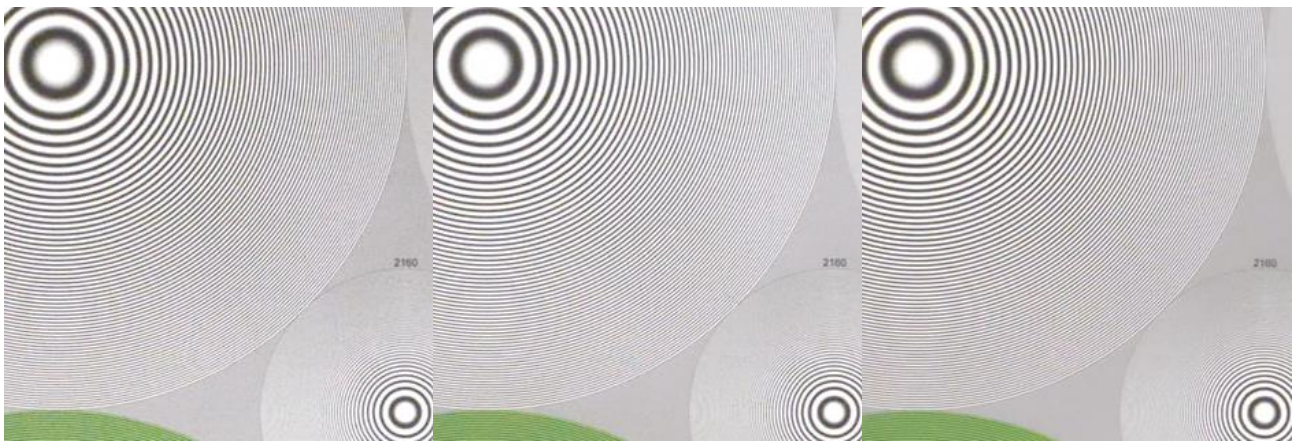

Figure 13 Resolution, the effect of noise reduction
    a)   NR = -5   b)   NR = 0   c)   NR = +5

3.5. Noise reduction

In a television camera, sensitivity is normally defined as the lens aperture required to produce 100% peak white from a white card with a reflectance of 90%, lit by 2000 lux. This usually assumes a standard setup condition of either no gamma-correction or a curve which follows the normal equation, i.e. without a knee, and with interlaced scanning using 1/50 exposure interval.

However, the camera specification does not use this system, only quoting ISO ratings. Therefore, I exposed a Kodak Gray card to 2000lux illumination (using two cards to show 90% and 18% together) and set the camera to Like709 with the Knee Off and Shutter at 1/50, then adjusted the aperture (using the Lumix lens) to get the 18% grey to be exactly 50% mid-grey. At this setting, the 90% white also made 100% video level, an encouraging result.

At ISO 400 setting, the value was F/8.0, while at ISO 2,500 setting it was F/16. Both values appear to be relevant and usable.

3.6. Motion portrayal

The sensor is CMOS, which can, in theory, be read either by scanning or by instantaneous transfer into a readout store. Scanning produces the so-called 'rolling shutter' effect. The simple test for this is to use a small desk fan, and to adjust the clockwise rotation speed such that strobing holds the blades almost stationary. Then, if the sensor is being scanned, the down-ward moving blade will be widened and the upward-moving blade narrowed. The effect is made much more visible by using a short shutter.

Figure 14 Motion, 1/1000 shutter

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Fig. 14 shows a still frame, in HD with the shutter set to 1/1000. The fan blades filled about 75% of the image height when they were above and below the spindle, a fairly critical condition. Although the right-hand (falling) blade is widened and the left-hand (rising) blade is narrowed, the effect is not serious. Evidently, the sensor is not read out at video speed but much faster. The result is acceptable for this class of camera.

3.7. Conclusion

The sensor has about 11 megapixels according to the specification, and is a Micro Four Thirds format (sensor size 17.3x13mm which means 4:3 aspect ratio). The specification says that only "10.28 Megapixels are active", making the resolution about 3704x2778 if it's 4:3. So the individual photo-sites must be about 4.7µm square, about the same as a conventional 3-sensor HDTV camera. Neither of these sets of dimensions is enough for 4096x2160 recording unless my assumptions are over-simplifications − which seems likely from the measurements above.

For acceptance in the EBU Tiering system, the camera should be used with the optional sound module to allow for XLR audio connections. Monitoring connections are only just adequate, only HDMI is provided, but this connection can carry all the resolutions so this ought not to be a problem.

Colour performance is good and there was no evidence of any Infra-Red response.

The sensor is evidently scanned, the so-called 'rolling shutter' effect. Rotating motion is not ideal but is quite acceptable.

Resolution at HD is very good, with very little spatial aliasing. At UHD (and therefore at 4K as well) resolution is good but not as good as at HD, and there is inevitable coloured aliasing horizontally and vertically, and diagonal luminance aliasing, but neither is at a high level. This confirms that there is a good optical low-pass filter in the camera, and that the down-scaling to 1920x1080 HD is done with a good algorithm.

The dynamic range is about 14.6 stops in HLG, a creditable performance. CineLike-D is about 13.9 stops and Like709 about 10.3 stops with the Knee switched off. However, all of this is using the 4:2:2 10-bit recording modes. Using any of the 8-bit recording modes will automatically reduce the dynamic range by at least a stop. However, the dynamic range of Like709 can be extended by using the Knee function. Previous tests, not published, showed that the knee can capture about 2.5 times normal exposure (+1.3 stops), so the dynamic range for Like709 can be extended to about 11.6 stops − even with 8-bit recording.

Noise levels are acceptable. The EBU R.118 noise-level target at mid-grey for HD Tier 2 is -44dB, which the camera meets comfortably in all modes. The target for Tier 1 HD is -48dB which is also met using all modes. Best performance appears to be at ISO 2,500, with noise deteriorating at both higher and lower speeds. For UHD, the noise target of -50dB can be met at some ISO settings.

The camera achieves HD Tier 1 because the sensor size, while smaller than the preferred 1" size, is greater than the minimum-acceptable ⅔" size. The wording of R.118 is not completely consistent on this because testing is required whatever the sensor size, but the camera passes the tests anyway.

The camera cannot achieve Tier 1 or 2 for UHD broadcast or cinema because the sensor resolution is inadequate. However, the performance at UHD is probably adequate for use in productions provided it is not the prime camera.

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Measurement files – not for inclusion in the final report.

1 Colour performance, tungsten auto WB CC with all presets

BMP extract, <u>crop</u>

      <u>1   CC HD50p ISO400 Like709KneeOff</u>
      <u>2   CC HD50p ISO2500 Like709KneeOff</u>
      <u>3   CC HD50p ISO400 HLG (looks muddy on TV HLG)</u>
      <u>4   CC HD50p ISO400 Vlog-L (looks right on TV trad)</u>
      <u>5   CC HD50p ISO400 CineLike-D</u>
      <u>6   CC HD50p ISO400 CineLike-V</u>
      <u>7   CC HD50p ISO400 Natural</u>
      No hint of IR response

2 Gamma curves and dynamic range

BMP extract, <u>crop</u>, <mark><u>hpfx2</u></mark>

      <mark>*<u>8   CC HD50p ISO400 Like709KneeOff Sh50 F/4</u>*</mark>
      <mark>*<u>9   CC HD50p ISO400 Like709KneeOff Sh50 F/8</u>*</mark>
      <mark>*<u>10   CC HD50p ISO400 Like709KneeOff Sh50 F/16</u>*</mark>
      <mark>*<u>11   CC HD50p ISO400 Like709KneeOff Sh200 F/16</u>*</mark>
      <mark>*<u>12   CC HD50p ISO400 Like709KneeOff Sh800 F/16</u>*</mark>

      <mark>*<u>13   CC HD50p ISO400 HLG Sh25 F/2.8 (top 3 clip of TV HLG)</u>*</mark>
      <mark>*<u>14   CC HD50p ISO400 HLG Sh100 F/2.8 (top clip on TV HLG)</u>*</mark>
      <mark>*<u>15   CC HD50p ISO400 HLG Sh100 F/5.6</u>*</mark>
      <mark>*<u>16   CC HD50p ISO400 HLG Sh100 F/11</u>*</mark>
      <mark>*<u>17   CC HD50p ISO400 HLG Sh100 F/22</u>*</mark>
      <mark>*<u>18   CC HD50p ISO400 HLG Sh400 F/22</u>*</mark>

      <mark>*<u>19   CC HD50p ISO400 Vlog-L Sh25 F/2.8</u>*</mark>
      <mark>*<u>20   CC HD50p ISO400 Vlog-L Sh100 F/2.8</u>*</mark>
      <mark>*<u>21   CC HD50p ISO400 Vlog-L Sh100 F/5.6</u>*</mark>
      <mark>*<u>22   CC HD50p ISO400 Vlog-L Sh100 F/11</u>*</mark>
      <mark>*<u>23   CC HD50p ISO400 Vlog-L Sh100 F/22</u>*</mark>

      <mark>*<u>24   CC HD50p ISO400 CineLike-D Sh50 F/2.8</u>*</mark>
      <mark>*<u>25   CC HD50p ISO400 CineLike-D Sh50 F/5.6</u>*</mark>
      <mark>*<u>26   CC HD50p ISO400 CineLike-D Sh50 F/22</u>*</mark>
      <mark>*<u>27   CC HD50p ISO400 CineLike-D Sh200 F/22</u>*</mark>
      <mark>*<u>28   CC HD50p ISO400 CineLike-D Sh800 F/22</u>*</mark>

3 Resolution
      ZP 709, sharpness, lens

BMP extract, <u>crop</u>

      <u>57   ZP HD50p Like709 ISO400 F/5.6 Lumix 12~35mm zoom</u>
      <u>58   ZP HD50p Like709 ISO400 F/4 SLR Magic 25mm</u>
      <u>60   ZP UHD25p Like709 ISO400 F/4 SLR Magic 25mm</u>
      <u>61   ZP UHD25p Like709 ISO400 F/5.6 Lumix 12~35 zoom</u>
      <u>62   ZP UHD25p Like709 ISO400 F/5.6 Lumix Sharp-5</u>
      <u>63   ZP UHD25p Like709 ISO400 F/5.6 Lumix Sharp+0</u>
      <u>64   ZP UHD25p Like709 ISO400 F/5.6 Lumix Sharp+5</u>
      <u>65   ZP HD50p Like709 ISO400 F/5.6 Lumix Sharp-5</u>
      <u>66   ZP HD50p Like709 ISO400 F/5.6 Lumix Sharp+0</u>
      <u>67   ZP HD50p Like709 ISO400 F.5,6 Lumix Sharp+5</u>
      <u>68   ZP HD50p Like709 ISO400 F/5.6 SLR Magic Sharp+5</u>
      <u>69   ZP HD50p Like709 ISO400 F/5.6 SLR Magic Sharp+0</u>
      <u>70   ZP HD50p Like709 ISO400 F.5.6 SLR Magic Sharp-5</u>

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ZP with gain
71   ZP HD50p Like709 ISO160 F/56 Lumix Sharp+0
72   ZP HD50p Like709 ISO640
73   ZP HD50p Like709 ISO2,500
74   ZP HD50p Like709 ISO10,000
75   ZP HD50p Like709 ISO40,000
76   ZP HD50p Like709 ISO80,000

4 Noise

CC Profile noise vs level

uses gamma files from section 2

BMP extract, crop, hpfx2

8   CC HD50 ISO400 Like709KneeOff Sh50 F/4
9   CC HD50 ISO400 Like709KneeOff Sh50 F/8
10   CC HD50 ISO400 Like709KneeOff Sh50 F/16
11   CC HD50 ISO400 Like709KneeOff Sh200 F/16
12   CC HD50 ISO400 Like709KneeOff Sh800 F/16

13   CC HD50p ISO400 HLG Sh25 F/2.8 (top 3 clip of TV HLG)
14   CC HD50p ISO400 HLG Sh100 F/2.8 (top clip on TV HLG)
15   CC HD50p ISO400 HLG Sh100 F/5.6
16   CC HD50p ISO400 HLG Sh100 F/11
17   CC HD50p ISO400 HLG Sh100 F/22
18   CC HD50p ISO400 HLG Sh400 F/22

19   CC HD50p ISO400 Vlog-L Sh25 F/2.8
20   CC HD50p ISO400 Vlog-L Sh100 F/2.8
21   CC HD50p ISO400 Vlog-L Sh100 F/5.6
22   CC HD50p ISO400 Vlog-L Sh100 F/11
23   CC HD50p ISO400 Vlog-L Sh100 F/22

24   CC HD50p ISO400 CineLike-D Sh50 F/2.8
25   CC HD50p ISO400 CineLike-D Sh50 F/5.6
26   CC HD50p ISO400 CineLike-D Sh50 F/22
27   CC HD50p ISO400 CineLike-D Sh200 F/22
28   CC HD50p ISO400 CineLike-D Sh800 F/22

CC Profile noise vs gain

BMP extract, crop, hpfx2

29   CC HD50p Like709 ISO160
30   CC HD50p Like709 ISO320
31   CC HD50p Like709 ISO640
32   CC HD50p Like709 ISO1,250
33   CC HD50p Like709 ISO2,500
34   CC HD50p Like709 ISO5,000
35   CC HD50p Like709 ISO10,000
36   CC HD50p Like709 ISO20,000
37   CC HD50p Like709 ISO40,000
38   CC HD50p Like709 ISO80,000
39   CC HD50p Like709 ISO160,000
40   CC HD50p Like709 ISO2,048,000

41   CC HD50p Vlog-L ISO320
42   CC HD50p Vlog-L ISO640
43   CC HD50p Vlog-L ISO1,250

17

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.

44   CC HD50p Vlog-L ISO2,500
45   CC HD50p Vlog-L ISO5,000
46   CC HD50p Vlog-L ISO10,000
47   CC HD50p Vlog-L ISO20,000
48   CC HD50p Vlog-L ISO256,000
CC Noise reduction at ISO20,000
49   CC HD50p Like709 ISO20,000 NR-5
50   CC HD50p Like709 ISO20,000 NR+0
51   CC HD50p Like709 ISO20,000 NR+5
52   scrap
ZP Losses with Noise reduction at ISO20,000
53   ZP HD50p Like709 ISO20,000 NR-5
54   ZP HD50p Like709 ISO20,000 NR+0
55   ZP HD50p Like709 ISO20,000 NR+5

5 Sensitivity

Kodak 90% white or 18& grey, at 2000 lux

HD50p Like709 ISO400 18% gray=50% white=100% F/8.0
HD50p Like709 ISO2500 18=% gray=50% white=100% F/16

6 Motion

Fan

BMP extract,crop

77   Fan HD50p Sh1,000 Like709

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