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

Alan Roberts, November 2012

SUPPLEMENT 004 : Assessment of a RED Epic 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.

Data for this addendum is taken from a short examination of a RED Epic camera, (software build 1.6.20, July 7, 2011) and on a production model (software build 3.3.14, November 2012).

The camera is of highly unusual form, breaking most of the "rules" for video or film cameras. It has a single large CMOS sensor (Mysterium-X, super 35mm film, 27.7mm x14.6mm, with photo-sites at 5.41 micron spacing), 5120x2700 with Bayer pattern photo-sites. The normal lens mount is PL, taking 35mm movie-style lenses, and other mounts are available to permit the use of other large-format camera lenses. The camera system is clearly intended primarily for high-end cinema production rather than television, although it is possible to produce television output from it. According to the specification, at 5k resolution it will make pictures at up to 120fps, while at 2k it will go up to 300fps.

The camera is supplied bare, with no accessories. There is only one significant control on the camera itself, a large red button which functions both as a power switch and as record/stop control, all other controls are via accessories. A touch-sensitive LCD screen (800x480), and monocular viewfinder are both available as options. The camera can be controlled from the LCD screen, or via an external remote controller, or the optional side handle.

There is a live HDSDI output (1920x1080, 1280x720) irrespective of the camera mode. The camera's main output is on solid-state cards (proprietary SSD, only one slot in the camera), with considerable picture processing done in custom software (e.g. RED's free REDCine-X, Davinci, or any of many other software packages).

Since the camera records in a proprietary compressed (wavelet-based) RAW format, there are very few controls in the camera that affect the image. Most of the image control is done in post-production. Therefore, there was no attempt made to establish good settings for it, only to establish what it can do.

The camera can be set to record in 'HDRx™' mode, in which two recordings are made simultaneously, but with different nominal exposures. This can be used in RedCine to effectively increase the dynamic range of the camera (claimed to be from 13.5 stops normal to 18 stops maximum), or to affect motion portrayal. This feature was not tested.

Four channels of sound can be recorded, 24bit/48kHz, either at mic or line level.

Power consumption is approximately 12 Amps from a nominal 12 Volt supply (11.5~17V DC). Power comes from either proprietary RED batteries or via a standard 4-pin XLR socket. The bare camera is 98(w)x147(h)x115.8(d)mm and weighs 5lbs (about 2.3kg). The PL lens mount projects a further 32mm.

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Information for this section comes directly from the camera manual; few of the items were explored for the tests which follow.

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. Default settings, where known, are underlined. Nested menu items are inset below the items (in bold font) which call them.

Measurement results are given in section 2, after the menus.

1 Menus and settings

MAIN MENU

select on LCD touch-screen

Item	*Range*	*description*	*Pref*
FPS	1~24~300, Manual		
Manual	1~300		
ISO (sensitivity)	250, 320, 400, 500, 640, 800, 1000, 1280, 2500, 4000, 5000, 6400, 12800		
/F (F-stop)		Relevant only with Canon EF lenses	
1/sec	1/24~1/48~1/8000, Manual	Also direct entry as 1/sec, msec, or degrees	
Speed	1/24~1/75301sec	These interact with each other and the frame rate	
Time	0.1~20.833~41.708msec		
Angle	1.0~360.0deg		
White balance	1700~5600~10000K, Manual		
Preset	Shade, Cloudy, Daylight, Flash, Fluorescent, Tungsten, Incandescent		
Color temp	1700~5600~100000K		
Tint	-100~0~+100		
Calc WB	****	calculates current white balance CCT	
Apply		Execute what's entered	
Resolution	5k, 5k2:1, 5kWS, 5kANA. 4k, 4kHD, 3k, 2k, 2kWS, 1k		
Redcode quality	3:1~8:1~18:1	Video compression	

SECONDARY MENUS

select on menu icon or menu button

Item	*Range*	*description*	*Pref*
HDR	Off, On	Dual recording mode	
Stops	1, 2, 3, 4, 5, 6		
Focus			
Mode	Manual, Confirm, Single, Continuous, Touch track, Rack		
Manual	Manual, Confirm		
Zone	Center, Spot		
Exposure		Not implemented in this camera	
Presets			

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User defined	unspecified		
Apply		Applies the selected preset	
Create	****	Input a name, and select settings	
Import/Export			
Camera presets		Select on-camera preset, save externally	
Disk presets		Import from external to camera	
RMD preset			
Delete		Delete preset from camera	
Media, Select Media		Select media location	
Format		Set current media properties	
Eject		Wipe, and set reel no., ID etc	
Utilities		Do it safely	
Settings			
Display			
Tools			
Off		Switch tools on/off	
Magnify		Toggle focus magnify on/off	
Exposure			
Focus			
Video			
Edge			
RAW			
Zebra			
Zebra 1	Off, On		
High IRE	93~108~109	Nice to see the range specified, not just the level	
Low IRE	75~99~107		
Zebra 2	Off, On		
High IRE	1~99		
Low IRE	0~48~84		
Overlay		Tick boxes for LCD display items	
Modes			
Exposure	Time, Angle		
Shutter mode	Absolute, relative		
Aperture	1/3F#, 1/4F#	Size of increment shown	
Focus distance	Metric, Imperial		
Frame Guide			
Size	Off, Full, 4:3, 16:9, 1.85:1, 1.9:1, 2.4:1, User		
User			
Aspect	** : **	Select precise ratio	
Scale	** **	Set X and Y , each 0~100%	
Color	White, Gray, Teal, Purple, Yellow, Green, Blue, Red, Black		
Transparency	0, 25, 50, 75, 100%		
Area Guides			
Title Guide			
Aspect	Off, 16:9, 14:9, 4:3, 2.4:1, 1.85:1, User	Select precise ratio	
Scale	** : **	Select precise ratio	
Color	White, Gray, Teal, Purple, Yellow, Green, Blue, Red, Black	Select precise ratio	
Line style	Solid, Dashed, Bracket		
Transparency	0, 25, 50, 75, 100%		
Action Guide			
Aspect ratio	Off, 16:9, 14:9, 4:3, 2.4:1, 1.85:1, User	Select precise ratio	
Scale	** : **	Select precise ratio	
Color	White, Gray, Teal, Purple, Yellow, Green, Blue, Red, Black	Select precise ratio	

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Transparency	0, 25, 50, 75, 100%		
Line style	Solid, Dashed, Bracket		
Monitor		Touch control gestures	
Look			
Color			
Saturation	0.0~1~4.0		
Contrast	-1.0~0~+1.0		
Brightness	-10.0~0~+10.0		
Gain			
Red	0.0~1.0~10.0		
Green	0.0~1.0~10.0		
Blue	0.0~1.0~10.0		
FLUT			
FLUT	-8.0~0.0~+8.0		
Exposure	-7.0~0.0~+7.0		
Shadow	-2.0~0.0~+2.0		
Color/Gamma			
Space/Gamma	RedGamma2, RedGamma3, RedLogFilm, User		
User details	****	Control user curve at black, toe, centre, knee, white	
Project			
Timebase FPS	23.98, 24.00, 25.00, 29.97, 47.96, 48.00, 50.00, 59.94		
Timecode	External Analog ,Int User provided		
Sensor			
Time code disp	TOD, Edge		
Time code src	External, User-provided		
User RTC time			
Set manually			
Hours			
Minutes			
Seconds			
Audio/Video			
Audio In analogue	Enable, 0~10~83dB		
Audio Out	Vol, Mute	includes volume	
Audio Chan			
Input ch 1/2	Link On, Off, Limiter On, Off		
Source	Cam ana, Pro I/O AES A, Pro I/O AES B, Pro I/O and		
Mode	Unbalanced, Balanced		
Input ch 3/4	Link On, Off, Limiter On, Off		
Source	Cam ana, Pro I/O AES A, Pro I/O AES B, Pro I/O and		
Mode	Unbalanced, Balanced		
Output			
Cam	Link On, Off		
Pro I/O	Link On, Off		
Monitor Cntl			
LCD/EVF mode	Menus, Clean, 3D left, Preview, Overlay, 3D right		
HDMI			
Mode	Off, Preview, Overlay, 3D right, Menus, Clean, 3D left		
Resolution	Auto, 720p, 1080p		
HDSDI			
Mode	Off, Preview, Overlay, 3D right, Menus, Clean, 3D left		
Resolution	Auto, 720p, 1080p		

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Frequency	Auto, 23.976/24, 25, 29.976, 47.952/48, 50, 59.94		
Test Signals	Chip Chart, SMPTE HD		
Setup			
Keys		Look all this up in the manual	
Key source			
User key			
Key Action			
Date/Time	MM/DD/YY HH/MM/SS		
Comm		Enter IP address/HDCP control	
Serial Protocol	None, Element Technicia, 3Ality SPC 7100, 3Ality SPC7000		
Redmote		Tick boxes for IDs and wireless channel	
GPIO/Sync			
Camera Input	Sync In, General Purpose In		
Camera Output	Sync Out, General Purpose Out		
Sync mode	Off, Genlock, Shutter, Internal, Proxy, Slave		
System			
Fan Control			
Fan Control	Manual, Auto		
Rec Speed	25~50~100%		
Stby Speed	25~75~100%		
Indicators			
Beep Speaker	Off, Record/Stop		
EVF Tally Light		Tick box	
Maintenance			
Sys Status		Shows system configuration	
Sys Info		Shows camera PIN and software ver	
Save Log		Saves log file to external media	
SW Update		Checks external media for new software	
Calibration			
Ur. Cal map	Factory, User HS		
Black Shading		Prompts to do black shading (24fps)	
Black Shading		Prompts to do black shading (at current fps/shutter setting)	
Self Test			
Sensor test pattern	Enable, Disable		
Touch-screen		Calibrates the touch screen	
Restore Sys		Factory reset	
Rediscover		Looks for attached hardware, needs reboot	
Playback		Playback clips in the camera	
Power			
Shutdown		Safely switch off	

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Local monitoring of the camera proved to be potentially difficult. The usual 32" Sony CRT monitor would not display pictures from the HDSDI feed because they were purely progressive at 1920x1080 rather than psf, and 1280x720 would not have been adequate. Therefore, a Dolby reference display was used, together with a digital waveform monitor. The monitoring was used only for lining up the test cards and lighting.

All recordings were made using RedCode with 8:1 compression.

1. Colour rendering

A conventional Colorchecker ('Macbeth') chart was used, illuminated at P3200, and the camera set to P3200 white balance. **RedGamma2** was used as the transfer characteristic.

Figure 1 Colorchecker

On the display, all the colour patches were judged to be desaturated, but there were no serious shifts in hue. The camera is unlikely to be used to generate live television for recording via HDSDI, but should video recordings be made this way RedGamma3 will preserve contrast well for use in post-prodcution.

For this test, a recording was made, and processed in RedCine to output a still frame.

The result is slightly 'warm', and so I have applied some simple colour correction (only white balancing) in video editing software (Edius 6.03), which not only corrected the balance, but slightly raises the saturations towards an acceptable level. The resulting reproduction shows that colour performance is acceptable and easily treatable.

The camera does not produce any response to infra-red, IR.

2. Resolution and Aliasing

The camera delivers images at several resolutions. Measurements were made using a circular zone-plate test chart, designed for 1920x1080 television. Since BBC use of the camera is expected to be restricted to output at HDTV (1920x1080) or in 4k mode, the ways of achieving that performance were tested on this occasion. No differences were found between the prototype and the production model.

Figure 2 Resolution, 5K, luminance

2.1 Resolution at 5k HD (4800x2700)

This is the native photo-site count of the sensor, and so the test chart should be expected to show some luminance and coloured spatial aliasing, due to the use of a single, Bayer-patterned, sensor. The test chart was

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framed to fit 40% of the width and height of the 16:9 image, thus the chart explored the full resolution of the camera and the resolution limits of the chart can be interpreted as 4800x2700. In a Bayer-patterned single-sensor camera, the maximum resolution that can be expected to be delivered is about 70% of the photo-site count, both horizontally and vertically, since the coloured pattern of pixels has to be decoded in order to generate the R, G and B signals.

This (Figure 2) small part of the chart is one quadrant (upper right) of a luminance pattern, reaching nominally 1920 horizontally and 1080 vertically (actually 4800x2700 since the chart was framed 40%), low frequency being at the large central spot, and frequencies increasing linearly from it.

Resolution is clean up to about 67% of the format's nominal limits of 4800x2700. Some low-level coloured aliasing is visible above these frequencies along the horizontal and vertical axes, where the decoding is confused by the high spatial frequencies and produces low-frequency colours as well as high-frequency grey-scale. The presence of these aliases indicate that the camera's optical bi-refringent filtering is aimed at suppressing frequencies near to and above the 5k format limit, and not intended to eliminate frequencies above 2/3 of that count, which would be needed to fully suppress aliasing.

This is perfectly normal for any of the Bayer-patterned high-performance cameras.

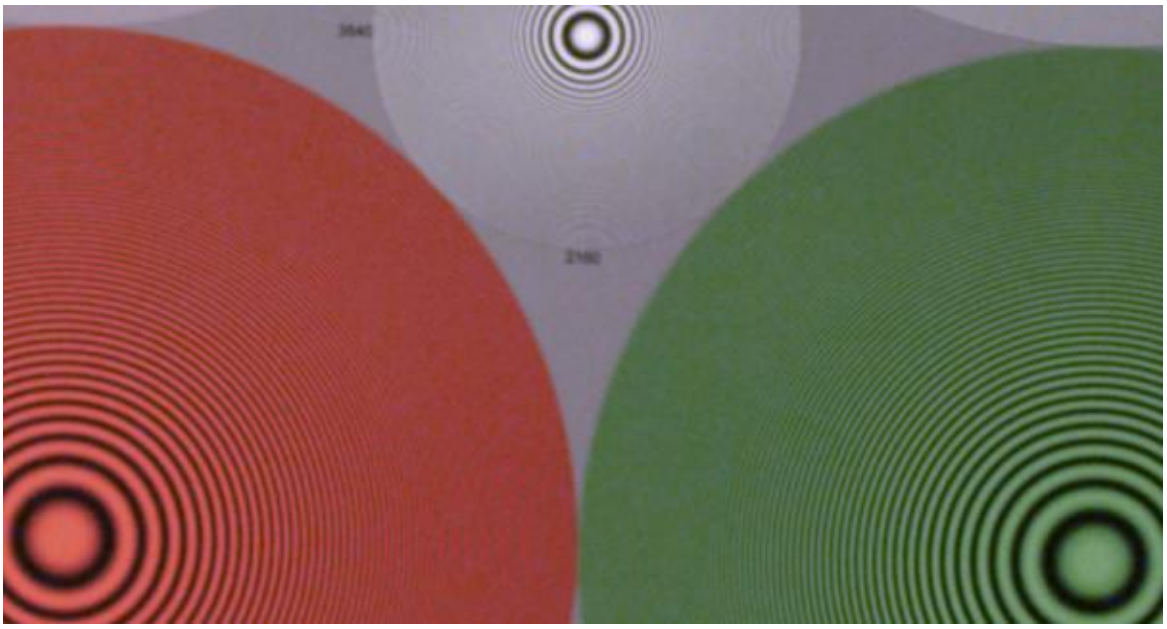

Figure 3 Resolution, 5k HD, red and green

Figure 3 shows that the resolution in red (and therefore blue as well) is rectangular, limiting at 2400x1350 (half the sensor pixel count), and that the resolution in green is diamond shaped, reaching both 4800 and 2700 but not simultaneously, there is a diagonal extinction band joining the horizontal and vertical limits, beyond which spatial aliasing is visible. This is perfectly normal, and it is difficult to see how this performance can be improved except by using far more complex decoding, probably with an element of adaptive filtering.

2.2 Resolution at 2k

For this test, the chart was made to fill the horizontal limits of the 2k image. In changing the camera settings from 5k HD to 2k, the image automatically zoomed in to this setting, indicating that the lower resolution settings are cropped from the sensor, rather than using the full sensor. Thus, in 2k mode, the camera is no

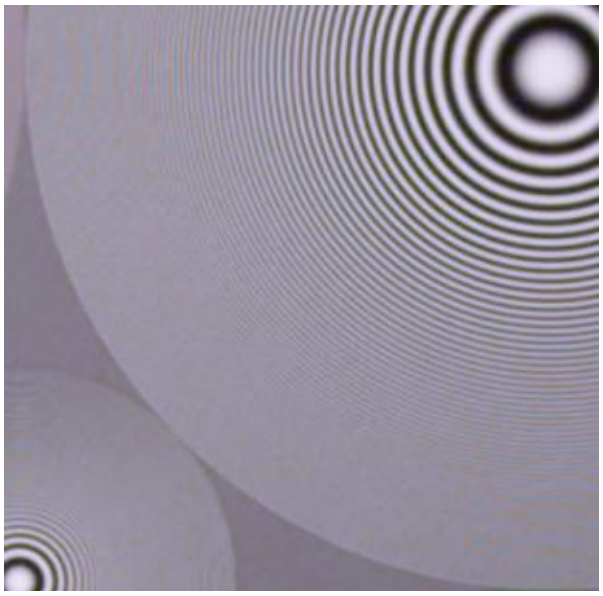

Figure 4 Resolution, 2k (1920x1080), luminance

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longer super35mm format, but is 16mm format.

Figure 4 shows a quadrant (lower left, since the upper part is cropped in the image) from the luminance pattern, which reveals that the resolution is identical to that at 5k HD.

This makes practical sense since there is then no need to develop complex down-converters for use in the camera. It also means that it does not matter what the shooting format is, the delivered resolution is always the same in terms of cycles per mm on the sensor. And it means that, when shooting for 1920x1080 TV output, the aliasing can be reduced dramatically by using slightly softer lenses and setting the camera to 5k or 4k mode, since the down-conversion in RedCine uses the Lanczos algorithm, which appears to be the best option available at present.

2.3 Comments on resolution

In a single-sensor camera with Bayer-pattern colour filters, both red- and blue-sensitive photo-sites interleave with green, such that the red and blue resolution limits are each only half that of the sensor. Therefore, the clean resolution limit of this camera is, theoretically, 2560x1300. In practice, it is possible to do a little better than this by using intelligent decoding algorithms and this camera shows just such performance. However, since the Bayer-pattern decoding is the same for all its resolution settings (there is no down-conversion or scaling in the camera, apart from the live HDSDI output), the same low-level of luminance and coloured aliasing is visible at all resolutions.

It is also worth noting that, since the lower-resolution settings do not use all of the sensor area, the image format (and, therefore, the actual view angle of the lens) effectively changes as well. Even the 5k mode does not use all the sensor in 16:9 mode, here are the image format sizes, and the approximate image sizes:

	Photosites		Physical size	
	W	H	W mm	H mm
Native	5120	2700	27.7	14.6
5k HD	4800	2700	25.97	14.6
4k	3840	2160	20.78	11.68
3k	2880	1620	15.58	8.76
2k	1920	1080	10.39	5.84
1k	1280	720	6.93	3.89

The 1k mode is nearly equivalent to super8mm film (6.35mm wide), 2k mode is similar to television ⅔" (9.6mm wide), 3k is similar to television 30mm or 1¼" (15mm wide) and so on. It is only in 4k and 5k HD modes that the sensor is truly near to film super 35mm size.

3. Contrast range

Contrast range was not measured directly, but it can be inferred from the noise measurements.

4. Noise

Frames were captured at 2k resolution, 1920x1080. Four frames were captured with the camera 'speed' set to 800 ISO (which can be regarded as 0dB gain), to explore the relationship between noise level and video signal level. Captured frames were high-pass filtered with a further 6dB gain which helps in the calculations, the effect of this processing gain is eliminated in the results table. Software noise analysis was used.

Figure 5 shows the results. The relationship between signal level and noise level should follow the slope of the camera non-linearity, which would, in a normal television camera, be the ITU.709 gamma curve. In this case, however, a quasi-logarithmic curve is used, so it is less obvious what this relationship should be. Nevertheless, the rise in noise levels as the video level falls is reassuring, and the limiting of the noise level near black is due to clipping, where noise excursions fall below black and are clipped off.

Normally, the noise level at about 50% video-level represents the noise with gamma switched off (since at this level the slope of the ITU.709 gamma curve is unity), but it is unclear where this assessment should be made in this camera. The camera specification claims the noise level to be -66dB, but does not say at what ISO (gain) setting, or whether any form of weighting is used in the measurement. Adding a visual weighting to the measurements usually drops the value by about 6dB from the unweighted measurements I make, but even so, the -66dB value cannot be confirmed.

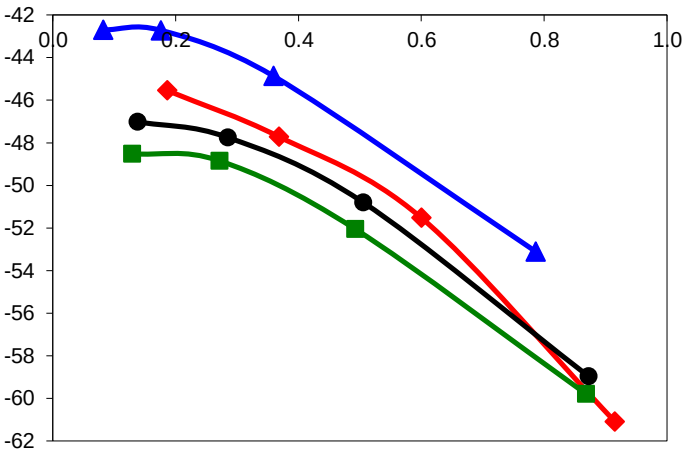

Figure 5 Noise distribution, ISO800

Noise performance at 800 ISO is typical for high-end HDTV cameras of ⅔" format. This is hardly surprising, since the pixel pitch in this camera is 27.7/5120=5.41µm, while a ⅔" camera's pixels for 1920x1080 are spaced at 5µm, thus the sensitivity and noise figures ought to match, which they do.

Another set of frames was captured by setting the camera to several of its 'speed' settings, and then adjusting exposure to achieve 50% video signal level as judged on a digital waveform monitor.

Figure 6 shows how the noise levels change with camera 'speed' settings. Since the noise is almost exclusively derived from the sensor itself, there should be a 2:1 relationship between camera gain and noise level (i.e. for every change in gain of 6dB there should be a change in noise level of 3dB, since the video signal is correlated while the noise is not).

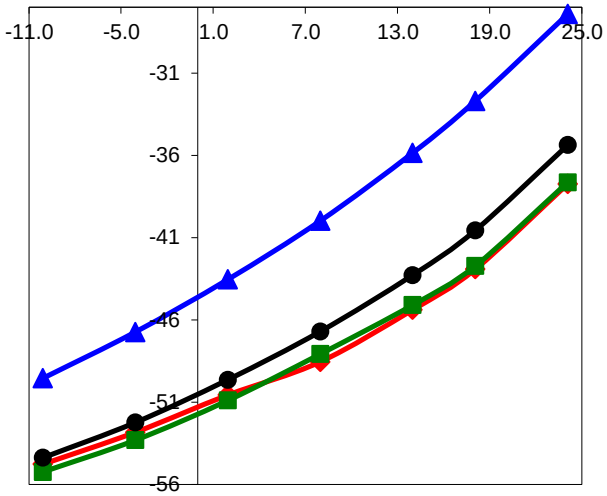

Figure 6 Noise versus speed

For this figure, the camera speeds have be expressed as gain in dB. The vertical axis is presented at the 0dB gain point, equivalent to 800 ISO, and so 250ISO is -10dB, 12800 ISO is +24dB. Blue channel noise is consistently about 8dB worse than that of red or green, and explains why the luma channel noise is about 1.5dB worse than that of red or green. This is normal, since the camera is designed to be naturally balanced to daylight rather than tungsten illumination, and this requires more analogue gain in the blue channel, which produces more noise. Also, silicon, the light-sensitive material of the sensor, is far more sensitive to red than blue, so more gain is needed in blue, which creates more noise.

At gain settings higher than about +16dB (about 5000 ISO) the noise level is quite visible, and could be disturbing, being typical of small, consumer HD camcorders with ⅓" sensors. At -10dB (250 ISO) the noise level is impressively low.

Based on these figures, the dynamic range ought to be greater than 11 stops, and probably significantly better since in this test overexposure was not tested directly. The camera's specification claims a signal to noise ratio of 66dB and 13.5 stops, but these noise measurements do not confirm that, 12 stops ought to be possible. If the HDRx mode (dual channel recording) is used, the dynamic range ought to increase, but this was not tested.

5. Fixed pattern noise

No fixed pattern noise was visible at any speed setting.

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6. Rolling shutter

In a conventional CMOS-sensor camera, the sensor is not read out as a still frame, it is continuously scanned in a process known as "rolling shutter". Although the RED Epic has a rolling shutter, the images do not suffer particularly from it.

Figure 7 shows stills from a captured sequence of a small rotating fan, at 300fps. In the left-hand frame, the blades are identical, but in the right-hand frame, the right-hand blade is about 32% wider, caused by the lengthening effect of the rolling shutter when motion is in the same direction as the shutter. Therefore, the left-hand blade is being narrowed 16% while the right-hand blade is widened by 16%.

Figure 7 Rolling shutter effect

This result is far better than is normal for a rolling-shutter sensor, and reveals that considerable efforts have been taken to improve the process of reading the sensor. The most likely reason for this is that the sensor reading process takes significantly less time than the frame interval. Since the camera can record at 120fps even in 5k mode, it is likely that the reading process takes a maximum of 1/120 second (8.3msec), which would reduce this distortion even at low frame rates.

7. Conclusion

The RED Epic is different from other cameras. It deals with images differently, and has to be treated differently to get the best from it. When set to 5k HD or 4k mode, it makes very nice pictures with content up to about 3.7k, but when making 2k pictures directly it is a little disappointing except that the frame rate can be raised dramatically.

The noise and contrast range are, effectively, the same as the best of the current HDTV cameras, but contrast can be handled rather differently (HDRx mode), requiring considerable post-production effort but achieving a higher contrast range (not tested). Nevertheless, the performance is as expected, given that all HD cameras use the same materials (silicon) in the sensors, and that it is the photo-chemistry of silicon that defines the limitations.

Although not assessed here in any detail, the HDSDI feed appears to be fit for live recording for programme use at 1920x1080.

It is difficult to place this camera within the tiering structure of EBU R.118. If it is used in 5k mode, it qualifies easily for the LS category since the noise level is acceptable at ISO 800 and the sensor size is a little larger than 1". Arguably, the 4k mode could also qualify for LS.

However, in the lower-resolution modes, the image format size reduces proportionally, thus in 2k mode, the image format is only 10.39x5.84mm, only slightly larger than the conventional ⅔" format of 9.6x5.4mm, and the resolution is little better than 1360x810. Therefore, it properly qualifies for the SP tier, Special Purposes, where reduced resolution and noise are traded for high-speed shooting.