Colorimetric and Resolution requirements of cameras

Alan Roberts

ADDENDUM 20 : Sony HVR-Z1E and FX1E

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

Data for this addendum is taken from a short examination of one production model of the Sony Z1E HDV camcorder and from the manual for the similar and cheaper FX1E. This is a HDTV camcorder, physically very similar to the standard-definition PD150/170, with 3 ⅓" ccds, the manual gives no direct clues to the sensor resolutions. It records HDTV using the HDV algorithm onto standard DV tapes (1080i and 1080psf), and SDTV using DVCAM (miniDV on the FX1) format.

The camera is relatively light (about 2.5kg) and has an integral lens and viewfinder, with side lcd panel, and seems aimed at the high-end consumer/professional market rather than full broadcast, which would normally demand interchangeable lenses.

It has internal menus for setting the performance, not as complex as in a full broadcast camera, but enough to control some of the important features, albeit only in "on/off" states. It is not suited to multi-camera operation. It has analogue-only video outputs (components and SD-composite via a multi-pin connector and S-video SD) and digits via IEEE1394 Firewire. This alone puts the camera in the consumer/semi-pro market, rather than broadcast, which would normally expect either HDSDI or BNC connectors for analogue.

The same assessment procedure was used as for other HD cameras, partly attempting to get a good "film-look", and the settings reflect that. However, because of the lack of internal test signals, it was necessary to make more complex measurements than normal, through the lens. Since many camera parameters are undefined in the specifications, more measurements than usual were necessary. In the search for a "film-look" setting it is normal to think of the camera to be mimicking a film camera and telecine, with "best light" transfer to tape, with about 10 stops of tonal range. Assuming that a grading operation will be used in post-production, the settings attempt to give the colourist the same range of options as with film, but without achieving the full 10-stop dynamic range. The recommended settings allow about 1.3 stops of over-exposure and one of under-exposure relative to normal operation. This is not as good as can be achieved in 2"/3 cameras, and arises from the difference in pixel size (the pixels here are much smaller, so sensitivity is maintained at the expense of highlight handling and video noise).

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Addendum 20: Sony-HVR Z1E/FX1E

Data for this is taken from a long examination of a production model of the Sony HDV camcorder, HVR-Z1E, and comparison with a HVR-FX1E. This is a HDTV camcorder, physically very similar to the standard-definition PDX10, with three 1"/3 ccd sensors (5.9mm diagonal, each approximately 990x1080 with precise half-pixel offset of green from red and blue). It records in HDV (1080i/25, 50Hz interlaced) format onto miniDV tapes, and standard definition (576i/25) as either miniDV or DVCAM.

The camera is essentially a pro-sumer model; the Z1 has some professional features such as having XLR connectors at mic or line level, and slightly different features from its companion, the FX1. Both have an integral lens (Zeiss Sonnar, 4.5~54mm, F/1.6 maximum aperture ramping to F/2.8) and viewfinder, with side top lcd panel, and seem aimed at the pro-sumer and low-end professional market rather than broadcast, which would normally demand interchangeable lenses and higher resolution sensors, together with greater control through the menus. Minimum exposure is claimed to be 3 lux.

The cameras have many internal menus for setting the performance and a reasonable selection of external controls. There are analogue-only video outputs (components and composite plus S-video at SD, all via multi-pin connectors) and digits via IEEE1394 Firewire (known as "i.Link" by Sony).

Measurements were made only on a Z1. The normal assessment procedure for cameras could not be used, largely because the Z1 does not have a selectable test signal. Therefore, testing had to be done the hard way, via the lens. Recommended settings allowing for a "video-look" and a "film-look" have been derived, although there are some significant compromises that have to be taken into account.

It is useful to think of the camera, when used with "film-look", to be mimicking a film camera and telecine, with "best light" transfer to tape. Measurement results are given after the settings tables, in order to explain the decisions. At best, the camera can deliver about 10 stops of exposure range, similar to other HD cameras, but it is easy to set the camera such that exposure range drops to 7 stops or less. In the target market for this camera, a grading operation may well not be used in post-production, so the settings should be used with care.

While HDV performance is just about acceptable, there are significant problems with its performance as an SD camera for professional or broadcast purposes. Performance with the recommended settings is probably adequate for consumer use, but better performance can be expected with a professional hardware down-converter. The reasons for this statement are given in the measurements section (2.2.4 and 2.2.5) of this document.

The controls for these cameras are not as flexible as for full "broadcast" cameras, so more effort was expended in measuring performance than in trying to derive a specific "look" for it. Very small lens apertures (less than F/4) soften the picture and produce visible colour-fringing due to diffraction effects in the iris, the included neutral density filters are the better alternative to small apertures when shooting in very bright light.

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, the values indicate the range, and no scales are given. The numbers represent the count of bars in the thermometer presentation from the left, usually 1 to 16 with 8 being the central (default) value. Default settings are underlined. My recommendations are in the last column, labelled "use", where appropriate. Settings are given for:

v Television production
f Film-look television

In the tables, items that have an important effect on picture appearance are highlighted with grey background. Items are marked F or Z in the **cam** column to show which camera they exist in (FX1/Z1).

Rather than just making assertions about performance, I have included measurement results that illustrate the reasons for recommending settings. Virtually all picture control is in the **Profile** menus.

Note that, in each power-switch mode, the menus can be separately customised, adding or removing any menu item from the entire set of menus.

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

1 Switches and Menu settings

SWITCHES and BUTTONS				
name	**place**	**cam**	**feature**	**comment**
Zebra/Peaking	Back	F/Z	Zebra/Off/Peaking	Affects viewfinder/lcd only
Audio Select Ch1	Back	Z	Manual/Auto	Gain control
Gain Ch1	Back	Z	Thumb wheel	
Audio Select Ch2	Back	Z	Manual/Auto	Gain control
Gain Ch2	Back	Z	Thumb wheel	
Audio Gain	Back	F	Auto/Man	
Audio Gain	Back	F	Thumbwheel	
Status Check	Back	F/Z	Push	Reports lots of things
Picture Profile	Back	F/Z	Push	Into Profiles menu
Menu	Back	F/Z	Push	Into other menus
P-menu	Back	F/Z	Push	Into Personal menu
Sel/Push/Exec	Back	F/Z	Up/Down/Push	Menu navigation
Auto Lock	Left	F/Z	Auto Lock/Off/Hold	Exposure control
White Balance	Left	F/Z	Push	Manual control/indicator
Shutter Speed	Left	F/Z	Push	Manual control/indicator
Gain	Left	F/Z	Push	Manual control/indicator
Iris	Left	F/Z	Push	Manual control/indicator
1 to 6	Left	Z	Push	User buttons
1 to 3	Left	F	Push	User buttons
Rec review	Left	F	Push	View latest shot
Back light	Left	F	Push	Exposure up
Spot light	Left	F	Push	Exposure down
Focus	Left	F/Z	Auto/Manual/Push Infinity	
Auto	Left	F/Z	Push	One shot auto focus when in manual focus
White Balance	Left	F/Z	Push	Perform white balance when not in Preset
White Balance	Left	F/Z	A/B/Preset	
Gain	Left	F/Z	H/M/L	
Iris	Left	F/Z	Knob	
ND filter	Left	F/Z		
Zoom	Left	F/Z	Ring/Lever remote	Disconnects zoom ring for servo operation
Power	Right	F/Z	Camera/Off/VCR	
Input 1 Phantom	Front	Z	On/Off	XLR mic power
Input 2 Phantom	Front	Z	On/Off	
Zoom	Top	F/Z	Rocker	
Expanded focus	Top	F/Z	Push/Push	2:1 enlarge in viewfinder/lcd
Transition controls	Top	F/Z	Store/Check/Exec and A, B	
VTR controls	Handle	F/Z		
Volume	Handle	F/Z	+/-	
LCD brightness	Handle	F/Z	+/-	
LCD backlight	Handle	F/Z	Off/On	
Display/Batt info	Handle	F/Z	Push	Toggles display data
Data Code	Handle	F/Z	Push	Toggles replay display of camera data
End Search (VCR)	Handle	F/Z	Push	
Bars	Handle	F/Z	Push	Toggles colour bars
TC/U-bit	Handle	Z	Push	Toggles timecode/user bits display
Zero set memory	Handle	F	Push	Mark place on tape for finding later
Zoom	Handle	F/Z	Rocker	
Zoom	Handle	F/Z	H/L/Off	Zoom speed or disable handle zoom
Rec start/stop	Handle	F/Z	Push	Also has lock to prevent accidents

CAMERA SET menu				Basic camera settings	
item	**cam**	**mode**	**range**	**comments**	**BBC**
WB preset	F/Z	C	A, B	Select A/B preset then push to balance	
WB outdoor lvl	Z	C	-7~+7	Colour offset for preset white (blue-red)	
AE response	F	C	Fast, Middle, Slow	Speed of auto response	
Gain setup	F/Z	C	0,3,6,9,12,15,18dB	Set gain for each position of the gain switch	
Shot trans	F/Z	C	A, B	Refer to manual	
Time	F	C	2~15, 4	Transition time, seconds	
Curve	F	C	Linear, Soft stop, Soft trans	Type of transition	
Color corrct	Z	C		See manual, colour correction system	
Steadyshot	F/Z	C	On, Off		
Steadyshot type	F/Z	C	Hard, Standard, Soft, Wide conv.	Use Wide Conv with wide angle adaptors	
Peaking	Z	C		Focus aid, highlights sharp edges	
Color	Z	C	White, Red, Yellow	Colour of sharpest edges	
Level	Z	C	High, Middle, Low	Level control	
AF assist	Z	C	Off, On	Use focus ring for fine focus adjust in auto	
AE response	Z	C	Fast, Middle, Slow	Speed of auto response	
Marker	Z	C	Off, On	V/f markers	
Marker sel	Z	C	Center, 4:3, Safety zone		
Flikr reduce	F/Z	C	On, Off	Supposed to reduce lighting flicker	
Handle zoom	F/Z	C	H, L (1~8)	Select H or L, then select action speed for the handle zoom switch	
Zebra level	F/Z	C	70%~100%, 100+%	Set level ±5%, 100+ shows anything over 100%	
Bars type	Z	C	Type1, Type2	Type1=SMPTE	Type1
Setup	Z	C	0%, 7.5%	Black level, 7.5% only for NTSC (US style)	0%
Centre marker	F	C	Off, On	Viewfinder marker	
Frame rec	F/Z	C	Off, On	Off= normal, On=animation (waits for Rec Start/Stop, records 0.1 second each press)	
DV wide rec	F	C	Off, On	16:9 or 4:3 DV recording	

AUDIO SET menu

item	cam	mode	range	comments	BBC
Audio moni	Z	C/V	CH1CH2, CH1, CH2, CH1+CH2	Sound source to phones and speaker	
Multi-sound	F	C/V	Stereo, 1, 2	Select playback channels	
Audio mix DV	Z	C/V	CH1CH2, MIX, CH3CH4	Select playback channels	
Audio mix DV	F	C/V		Balance between stereo1 and stereo 2	
Audio output	Z	C/V	1Vrms, 2Vrms	Audio output level	
Audio mode DV	F/Z	C/V	32k 12bit, 48k 16bit	Records 12bit 32kHz or 16bit 48kHz	
Audio loock DV	Z	C/V	Unlock, Lock	DVCAM is automatically locked	
Audio limit	Z	C/V	Off, On	Only when in Manual audio level	
Mic NR	Z	C/V	On, Off	Mic noise reduction	
Mic select	Z	C/V	Internal, XLR	Mic source	
Int mic set	Z	C/V		Settings for internal mic	
Sens	Z	C/V	Normal, High	Sensitivity, coarse	
Wind	Z	C/V	Off, Auto	Some wind noise reduction	
Wind	F	C/V	On, Off	Some wind noise reduction	
XLR set	Z	C/V		Settings for external sources	
CH sel	Z	C/V	CH1, CH1CH2	CH1=stereo input, CH1CH2=input 1 to both	
XLR AGC link	Z	C/V	Separate, Linked	Link for stereo (valid for Auto level only)	
Input1 level	Z	C/V	Mic, Line		
Input1 trim	Z	C/V	-18, -12, -6, 0dB, +6, +12dB	Mic level	
Input1 wind	Z	C/V	Off, On	Wind noise reduction	
Input2 level	Z	C/V	Mic, Line		
Input2 trim	Z	C/V	-18, -12, -6, 0dB, +6, +12dB	Mic level	
Input2 wind	Z	C/V	Off, On	Wind noise reduction	
Mic/line in	F	C/V	Ext mic, Line	XLR input type	

LCD/VF SET. menu

Viewfinder

item	cam	mode	range	comments	BBC
LCD color	F/Z	C/V	1~16, 8	Side lcd saturation	
LCD BL level	F/Z	C/V	Normal, bright	Brightness, always Bright on external power	
VF b.light	F/Z	C/V	Normal, bright	Brightness, always Bright on external power	
VF color	Z	C/V	On, Off	Set v/f to monochrome	
VF power	Z	C/V	Auto, On	Auto switches vf off when lcd is open	

IN/OUT REC menu

VTR matters

item	cam	mode	range	comments	BBC
VCR HDV/DV	F/Z	C/V	Auto, HDV, DV	iLink/firewire connection format, disconnect to force system to set itself correctly	
Rec format	F/Z	C	HDV1080i, DV	Recoding format	
Rec mode DV	Z	C/V	DVCAM, DV SP	Obvious stuff	
Rec mode DV	F	C	SP, LP	Obvious stuff	
DV wide rec	Z	C	On, Off	16:9/4:3 recording (DV only)	
Ext rec ctrl	Z	C		See manual for details	
Component	Z	C/V	SDi, SDp/SDi, 1080i/SDi	Select type of display for viewing components, SD is 576 or 480 according to model/setting	
Component	F	C/V	SDi, 1080i/SDi	Select type of display for viewing components	
i.Link conv	F/Z	C/V	Off, On (HDV to DV)	Off is normal, On always outputs DV	
Audio lock	Z	C/V	Lock, Unlock	Selected locked audio (DVCAM)	
Down convert	Z	C/V	Squeeze, Letter box, Edge crop	SD output format	
TV type	F	C/V	16:9, 4:3	Output display type	
A/V to DV out	F/Z	V	Off, On	On allows the camcorder to work as an adc	

TC/UB SET menu

Timecode etc

item	cam	mode	range	comments	BBC
TC preset	Z	C/V		Set TC, see manual	
UB preset	Z	C/V		Set User Bits, see manual	
TC format 60i	Z	C/V	Auto, DF, NDF	Auto reads the tape and sets the same format, NDF not available in 50i	
TC run	Z	C/V	Rec run, Free run	Free run is real time	
TC make	Z	C/V	Regnerate, Preset	Regen sets Rec Run	
UB time rec	Z	C/V	Off, On	On sets real time in User Bits	

OTHERS menu

item	cam	mode	range	comments	BBC
Assign buttons	Z	C/V	Fader, Backlight, Spotlight, AE override, WB outdoor+, WB outdoor-, Hypergain, Marker, Allscan mode, Steadyshot, Index mark, Audio dub, Rec review, Display, Bars	Assign any to buttons 1~3 for FX1, 1~6 for Z1	
	F	C/V	Fader, Steadyshot, Index save, Audio dub, Display, Bars		
Clock set	F/Z	C/V		This comes up every time the camera powers up until you set the time/date	
World time	F/Z	C/V		Select local time relative to GMT	
Language	Z	C/V	German, Greek, English, Simplified English, Spanish, French, Italian, Dutch, Portuguese, Russian, Arabic Persian	Slightly different lists for the P models, these are for the E models. How do you get back if you select a language you can't read? ☺	

Language	F	C/V	English, Simplified English, Canadian-French, Latin American Spanish, Brazilian-Portuguese, Traditional-Chinese, Korean		
Quick rec HDV	Z	C	Off, On	On is quicker, but breaks the MPEG GoP structure, may not work with some NLEs	
Beep	F/Z	C/V	Melody, Normal, Off	Warning sounds	
Rec lamp	F/Z	C	On, Off	Front and rear	
Format lamp	F/Z	C/V	On, Off	Rec Format indicator lamp	
Iris dial	F/Z	C	Normal, Opposite	Reverses the iris ring	
Data code	F/Z	C/V	Date/Cam, Date	What you see when you press DATA CODE	
Letter size	F/Z	C/V	Normal, 2x	Changes menu text size	
Remaining	F/Z	C/V	Auto, On	Auto shows remaining tape for a few seconds	
Disp output	F/Z	C/V	Lcd Panel, V-out/Panel	Puts v/f data on output	
Zoom display	Z	C	Bar, Number	Show 0~99 zoom setting	
Exp.focus	Z	C	Auto off, Manual off	Auto/manual switch off for focus expander	
Hours meter	Z	C/V		VTR hours meters display	
Date rec	Z	C	Off, On	Burns time/date onto recording	
Remote4 ctrl	F/Z	C/V	On, Off	Disables remote control	
50i/60i sel	Z	C/V	60i, 50i	System speed, needs reboot to enforce	

PICTURE PROFILES menus, default settings

Camera control

item	cam	mode	range	comments	BBC
PP1	F/Z	C		"Normal HDV"	
PP2	F/Z	C		"Normal DV"	
PP3	F/Z	C		"For recoding people"	
PP4	F/Z	C		"Film-like"	
PP5	F/Z	C		"Sunsets"	
PP6	F/Z	C		"Monochrome"	

PICTURE PROFILES menus, manual settings

Camera control

item	cam	mode	range	comments	BBC
Color level	F/Z	C	-7~+7, -8	Saturation, -8=monochrome	0
Color phase	F/Z	C	-7~+7	Greenish to reddish	0
Sharpness	F/Z	C	0~15	Detail enhancement	0
Skintone dtl	F/Z	C	Off, Type1, Type2, Type3	Anti-wrinkle cream: 1=narrow, 2=wider, 3-very wide	Off
Skintone lvl	Z	C	High, Low	Boost/restrain skintone detail	
AE shift	F/Z	C	-7~+7	- is darker, + lighter	0
AGC limit	F/Z	C	Off, 12dB, 6dB, 0dB	Video upper gain limit, Off=+18dB	12[1]
AT iris lmt	F/Z	C	F/11, F/6.8, F/4	Set smallest aperture	6.8[2]
WB shift	F/Z	C	-7~+7	Shift aim point, - for blue, + for red	0
ATW sense	F/Z	C	High, Low,	High reduces offsets, Low increases offsets	
Black stretch	Z	C	On, Off	Gain near black	On (v), Off (f)[3]
Cinematone γ	Z	C	Off, Type1, Type2	Film-type gamma curves	Off (v), Type1 (f)[4]
Cinematone γ	F	C	On, Off	Film-type gamma curve	Off (v), On (f)
Cineframe	F/Z	C	30, 25, 24, Off	Progressive recording, 24/30 at 60i, 25 at 50i	Off[5]
Copy	F/Z	C		Copy these settings to another profile	
Reset	F/Z	C		Resets profile to default settings	

[1] Setting *AGC limit* to 12dB avoids excessive noise.
[2] Lens diffraction effects start to become visible at around F/5.6, looking like chromatic aberration. Avoid small apertures for best performance. Use the neutral density filters for exposure control.
[3] *Black Stretch* may be useful in film-look shooting, but will add some noise near black, up to 3dB.
[4] Avoid over-exposure in *Cinetone* gamma; there is no head-room, highlights will clip hard. In *Normal* gamma, there is about 125% head-room available for highlights.
[5] Do not use *Cineframe* mode if you can avoid it, there is no gain in vertical resolution (frames are made from single 540-line fields). For a decent film-look it is probably better to shoot interlaced and use a proper hard-ware converter (e.g S&W ARC) to get the progressive look.

2 Measurements

Measurements were made only on a Z1, the FX1 is expected to have the same performance where relevant (i.e. where the same settings are available). In order to explore the gamma-correction curves (and thus to establish the exposure range over which the camera works) tests had to be done via the lens, since there is no internal test signal. All measurements were made on frames extracted from recordings, either HDV or DV as appropriate, thus they deal with pictures as they are available to the normal user, and not to a user who takes the camera output to some other recording format.

2.1 Gamma correction and exposure range

A calibrated Macbeth chart (Fig.1) was used, exposed at one-stop intervals, extending the exposure range with the neutral density filter; the grey scale on the chart thus presented a large number of data points on the curve throughout the contrast range. ***Black Stretch*** was found to operate on all the gamma-correction curves.

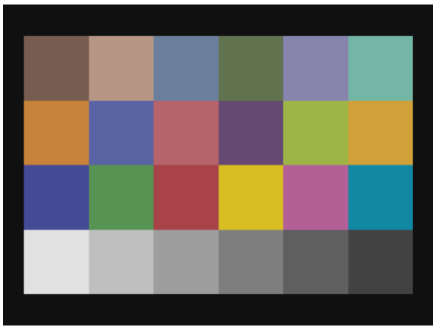

Figure 1, Macbeth chart

***Normal gamma-correction*:**

$V = 4L$ for L<0.018, else $V = (1 + 0.099)L^{0.465} - 0.099$

Fig.2 shows the raw data and the estimated curve up to the knee point. There is a knee at about 85%, compressing highlight by 4.2:1 up to about 225% exposure, about 1.3 stops above normal peak white exposure. The data deviates from a smooth curve because the lens aperture markings may not relate precisely to transmittance, but the deviations are small enough to be ignored for this purpose. The found equation is reasonably close to that of ITU.709, specified for HDTV cameras:

$$V = 4.5L \text{ for } L<0.018, \text{ else } V = (1 + 0.099)L^{0.45} - 0.099$$

The exposure level which produces a video signal of 2% is approximately 0.5%, thus the exposure range is approximately 225/0.5=450:1, about 8.8 stops. The choice of 2% as the smallest output signal matches the monitor line-up precision achievable using a PLUGE signal, or SMPTE colour bars. Noise level appears to be low enough for this level to be relevant.

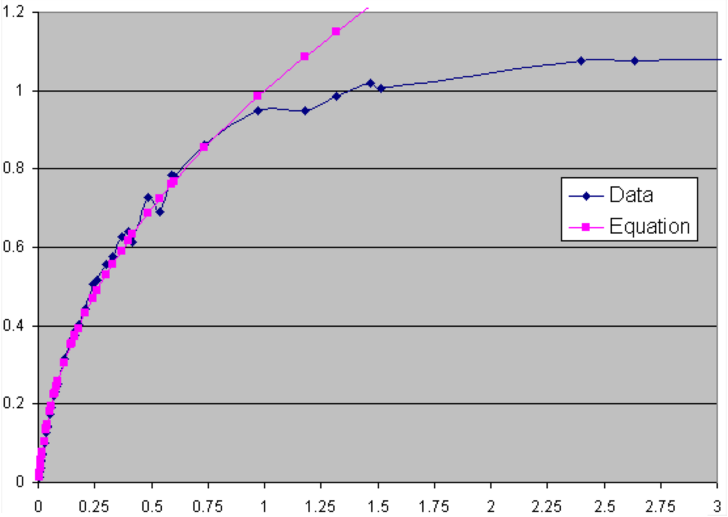

Figure 2, Normal gamma-correction

With ***Black Stretch*** switched on, the slope near black is raised to about 6.2, a surprisingly high value for such a camera. Then, the exposure level to produce a 2% output is 0.3%, implying an exposure range of 225/0.3=750:1, about 9.6 stops.

***Cinetone1*:**

$V = 2.4L$ for L<0.02, else

$V = (1 + 0.06)L^{0.6} - 0.06$

Exposure range is 225/0.7=320:1, about 8.25 stops. ***Black Stretch*** raises the gain near black to about 4.2, and the exposure range is then 225/0.5=450:1, about 8.9 stops. The curve is more gentle than the ***Normal*** curve and may well offer a film-like performance at the expense of contrast range.

***Cinetone2*:**

$$V = 1.5L \text{ for L<0.02, else } V = (1 + 0.005)L^{0.884} - 0.005$$

Exposure range is 225/1.3=175:1, about 7.5 stops. ***Black Stretch*** raises the gain near black to about 2.25, and the exposure range is then 225/0.85=265:1, about 8 stops. The curve is much more gentle than the ***Normal*** curve.

Black Stretch raises the gain near black by about 50% in each case, and extends the exposure range by between 0.5 and 0.8 stops. For each curve, maximum exposure is about 225% of that which would cause peak white were it not for the in-built knee compression.

The curves are plotted together in Fig.3. These need to be interpreted in light of the way in which they will be used:-

Normal curve will deliver good colour rendering using only about 45% of the sensors' exposure range (the normal television mode), reserving the remainder of the range for highlights, significantly compressed.

Cinetone curves reasonably mimic the performance of film, where the whole dynamic range is used. Thus, the slope near black should be numerically multiplied by 2.25 to make fair comparisons, so ***Cinetone 1*** has a black slope of 2.4*2.25=5.4 (6.3 with ***Black Stretch***) while ***Cinetone 2*** achieves 1.5*2.25=3.375 (5 with ***Black Stretch***). In film terms, ***Cinetone 1*** performs rather like a reversal stock while ***Cinetone 2*** is rather like a flat negative stock. Neither ***Cinetone*** curve captures a high exposure range (negative stocks often capture 15 stops or more), the ***Normal*** curve is better for that, particularly with ***Black Stretch***.

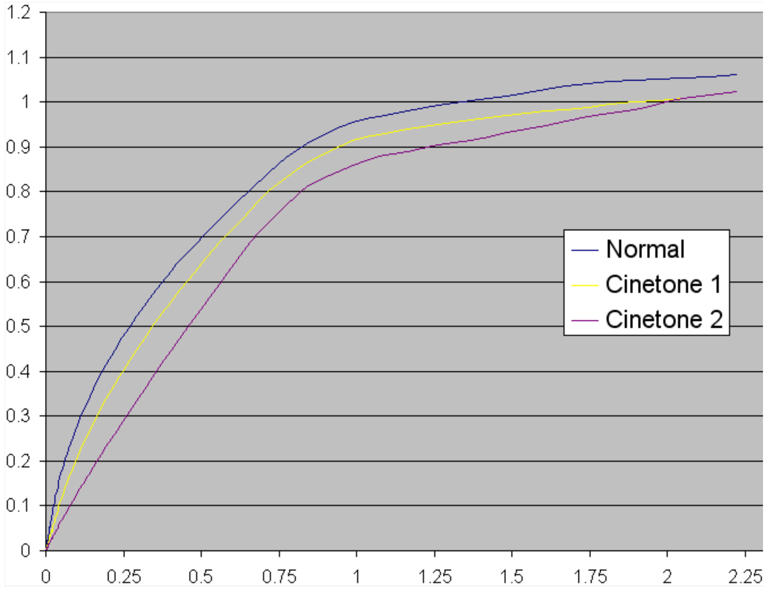

Figure 3, Gamma-correction curves

Normal should be used, with ***Black Stretch***, if the intention is to capture a large dynamic range and use post-processing to achieve a film look, while ***Cinetone*** should be used if the intention is to produce a film look without further processing.

Fig.4 shows a chromaticity diagram of the Macbeth chart colours, each colour is shown as a coloured blob where it should be, and a cross shows where the camera reproduces it. In reds and blues, saturation is increased, while magentas are hue shifted towards red. Flesh tones are fairly accurate. Overall, performance is adequate for this class of camera.

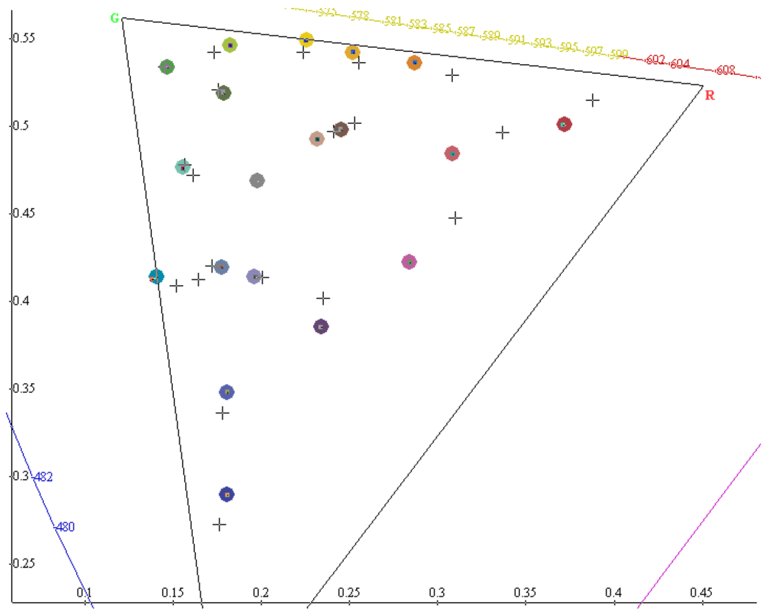

Figure 4, Chromaticity at F/8

2.2 Sharpness and resolution

The camera has sensors of about 990 by 1080 pixels, with green offset from red and blue to enhance horizontal resolution beyond the limit of the sensors, this is normal practice in 3-sensor cameras. However, the horizontal count in this camera is rather low, so it should struggle for resolution, and some spatial aliasing is to be expected within the video bandwidth. It also works in three modes (HD video, HD Cineframe, SD video), the requirements for each being quite different.

The test card was a BBC Zone Plate, designed for 1080-line television. This reproduction of it (Fig.5) shows the layout, but also shows considerable aliasing caused by the scaled reproduction here. The label was there to hold identify camera settings. Each circular zone is a phase-space of spatial frequencies, with zero (dc) in the middle, extending to 1080 lines/picture height (l/ph) vertically, and 1920 lines/picture width (l/pw) horizontally. The scales are linear, so it is relatively easy to make measurements. In the camera, the image is recorded as 1440 pixels by 1080 lines, i.e. a pixel-based aspect ratio of 4:3, but this illustration is shown with the correct aspect ratio.

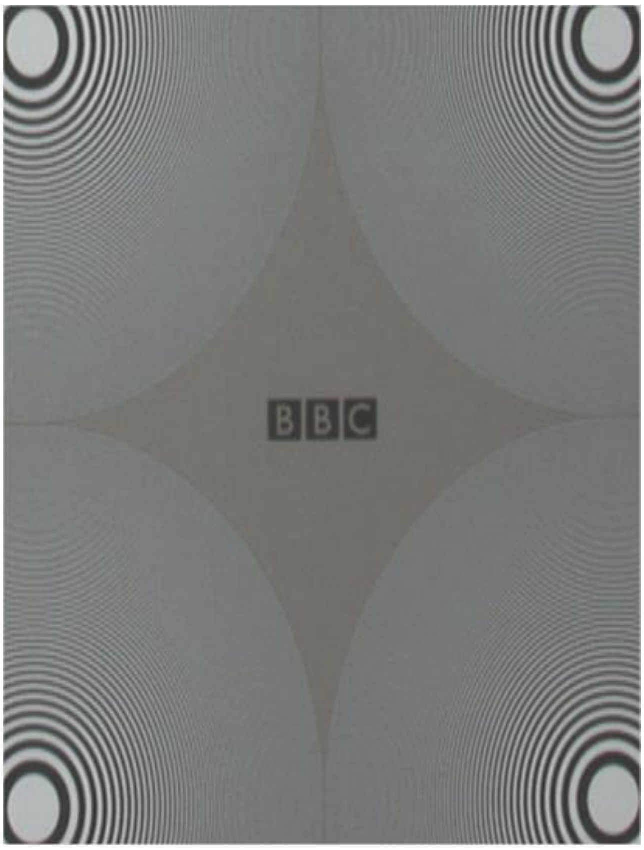

Figure 6, part of zone platetest chart

Recordings were made in each camera mode, at F/4, with *Sharpness* settings from minimum to maximum sharpness. Software then extracted frequency responses from captured still frames such as this, a cropping of one circular zone, shown here (Fig.6) as parts of four elliptical zones because of the HDV non-square pixel sampling. Alias patterns are clearly visible as circular patterns not centred on dc, the centres of these are fairly easy to locate. The direct measurement of these frames is highly confusing, some skill is needed to interpret them, so I have drawn the extracted responses as graphs.

Data-extraction is non-trivial; specialised software was used to establish the frequency response, plus a considerable degree of interpretation was needed to make sense of the results, which must not be taken as 100% reliable, they are intended only to illustrate what is going on, and not as a set of exact measurements. Nevertheless, sufficient data could be extracted to produce a reliable analysis of the camera's performance.

2.2.1 1080 horizontal

The camera's horizontal response (Fig.7) has a deep dip at 1440 l/pw, caused by the HDV sampling. The frequency responses (see Figs.13,14 for images) (red curve, *Sharpness*=0, green is *Sharpness*=7, blue is maximum=15) clearly show some aliasing between about 1000 and 1920, this occurs because the Zeiss lens is a little too sharp for the camera (and there is no optical spatial filtering) and recording system. The sensors have only about 1000 pixels horizontally; the green is half-pixel offset from red and blue, this produces more horizontal resolution but also results in some visible aliasing. The frequency range from 960 to 1440 is confusing, since it contains both baseband (wanted) and aliased (unwanted) components. All the frequency response graphs are shaded to show the region of this content confusion. The level of

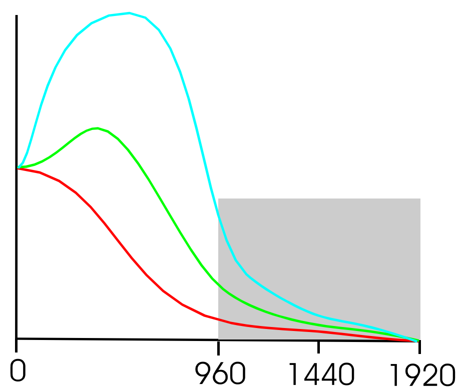

Figure 7, HD horizontal response

aliasing is not necessarily a problem (it is actually quite low), but the effect on a real picture will be to produce some artificial "busy-ness" on high detail such as cloth patterns, roofing tiles etc., and this may cause problems in keying and matteing operations.

The effect of the *Sharpness* control is to boost content centred on about 600 l/pw (green curve is mid setting, blue maximum). However, the control is rather vicious, setting about mid causes clearly visible ringing on edges. The performance of the Sharpness control is typical of a three-tap filter with coefficients of -¼, ½, -¼, the simplest possible filter used for such purposes.

2.2.2 1080i vertical

Vertical response is far more interesting, because the camera needs to make two phase-interleaved 540-line fields, so it ought to be easy given access to the full 1080-line data from the sensors, but it rarely is (Fig.8). At 540 l/ph there is a dip in the response, but not exactly a null; this is partly caused by the simple interpolation used to derive the fields from the progressive sensors, so frequencies near and above 540 are a mixture of base-band (wanted) and aliased (unwanted) frequency content (the shaded zone).

The *Sharpness* control appears to produce a boost centred on about 270 l/ph (1080/4) or perhaps 288 (576/2). The shape of the boosting appears to match a filter with coefficients of -¼, 0, ½, 0, -¼, i.e. the same filter as is used horizontally, but used in the lines of the field rather than the frame, as would be expected in an interlaced camera.

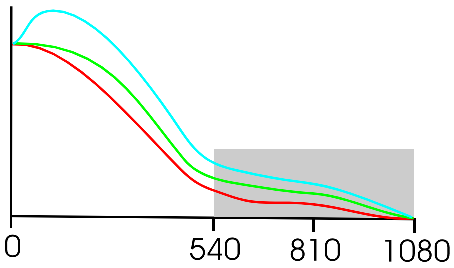

Figure 8, HD interlaced vertical response

Again, a *Sharpness* setting of 7 produces acceptable pictures, higher settings show significant ringing on edges and produce disturbing inter-line twitter on interlaced displays.

2.2.3 1080 cineframe vertical

The *Cineframe* settings are supposed to produce a "film-look", presenting complete frames rather than interlaced fields. Delivery of such signals is known as Progressive with Segmented Frames (psf) and is the conventional way that film is scanned for television. In conventional film scanning, each field is derived directly from the film frame, but many electronic cameras and image processing systems use the interlaced signal to derive the film-like frame. When done well (e.g. in a Snell & Wilcox hardware Arc) this is very successful because it uses more than one input frame for analysis and may be adaptive as well. The cheapest way to do this is to duplicate alternate fields, throwing away the others, which can look very nasty indeed.

When done properly in the camera, the sensor could be progressively scanned, so the interlace artefacts should go away, and *Sharpness* could work at higher vertical frequencies as well. But the same basic shape is clearly present (Fig.9); and there is the same confusion of base-band frequencies and aliases above 540. This confirms that the *Cineframe* mode does not derive the entire frame directly from the sensor, but interpolates it from one of the interlaced fields (i.e. field-doubling). This comes both as a surprise and a disappointment.

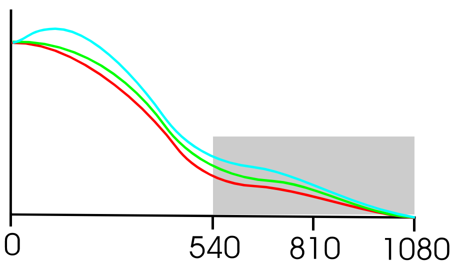

Figure 9, HD Cineframe vertical response

The *Sharpness* control is still centred on about 270 or 288 l/ph indicating that the same filter has been used, and acts upon alternate lines of the frame, with coefficients -¼, 0, ½, 0, -¼. However, there is a difference, the responses above 540 l/ph are all a little lower in amplitude than in the interlaced case, confirming production of the frame from a single interlaced field rather than the simplistic field duplication.

It is probably best to ignore the *Cineframe* camera mode and always shoot interlaced, using a software de-interlacer to mimic film motion. Combined with use of the *Cinetone1* gamma curve, this should result in a reasonable film-look. The simplistic processing used in the camera does not perform too well. However, if a slight lens diffuser is used, the alias content may well be low enough to avoid problems from the aliases (by eliminating the higher frequencies that cause aliases) and this mode may be useful. For example, a wide-angle lens adaptor may well be exactly the right solution for shooting film-style since they generally do not transmit the full spatial frequency range with full amplitude, acting as a softening filter or diffuser.

Again, a *Sharpness* setting of 7 seems suitable, if *Cineframe* is to be used at all.

Enlarged images (Figs 13,14), showing the aliasing, are given at the end of this document.

2.2.4 576i horizontal

The camera can be used to record standard definition (SD) pictures conventional DVCAM format. For this, it must perform a down-conversion.

The horizontal response (Fig.10) shows a deep slope towards 720 l/pw as expected. Aliases are present from the higher frequencies, which have not been fully suppressed in the down-conversion, this is a very disappointing and confirms that the down-conversion is simplistic and not up to broadcast standards. There is also non-removable boost at around 360 l/pw, this again indicates a simple down-conversion filter, perhaps with only 3 taps rather than the more usual 11 or so in a good converter. Thus, the camera's *Sharpness* control effect has been significantly enhanced by the down-conversion process. It is also obvious that the *Sharpness* filter has the same form as for vertical HD, i.e. -¼, 0, ½, 0, -¼.

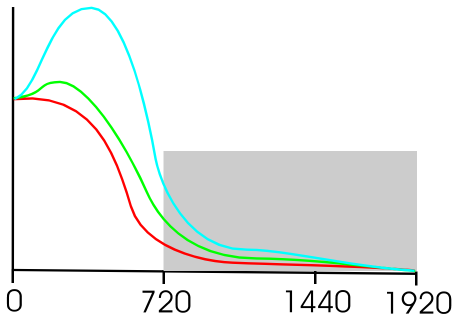

Figure 10, 576i horizontal response

As a result, very little extra *Sharpness* is needed, perhaps none at all. There is no setting of *Sharpness* that does not produce overshoots on edges, setting Sharpness is a compromise between attaining adequate frequency response, and avoiding edge ringing and aliases. The default setting of 7 produces significant overshoots, which may be acceptable for consumer production.

2.2.5 576i vertical

The vertical response does not change when *Cineframe* mode is used. Fig.11 shows that the down-conversion is done on the interlaced HD signal and not on the sensor output, again using a less-than ideal interpolator. The basic responses have deep dips at 576 l/ph as expected, and shows some visible aliasing above 576. Since the 576i system is not normally expected to carry content above about 70% of 576 l/ph (about 400 l/ph), this is a little worrying as it causes significant interlace twitter, and is quite visible as a general "busy-ness" in real pictures.

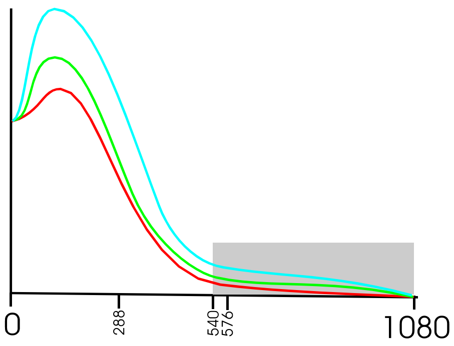

Figure 11, 576i vertical response

The *Sharpness* control has its peak below 288 l/ph, maybe 144 l/ph. A filter that has such a response has coefficients -⅛, -⅛, 0, 0, ½, 0, 0, -⅛,-⅛ which uses inputs from the lines of the original HDTV signal, but omitting alternate pairs of lines. It boosts frequencies between 490 and 980 as well as those below 490, greatly adding to the alias content of the picture There is no *Sharpness* setting that delivers vertical resolution that does not have clearly visible aliasing. This is a disappointment, leading to a conclusion that this camera is not well suited to shooting SD, better to shoot HDV and perform the down-conversion in software or hardware after recording.

2.3 Video noise

The camera manual gives no specification for video noise level, but video noise plays a crucial part in pros-production operations such as matteing, keying and colour manipulation.

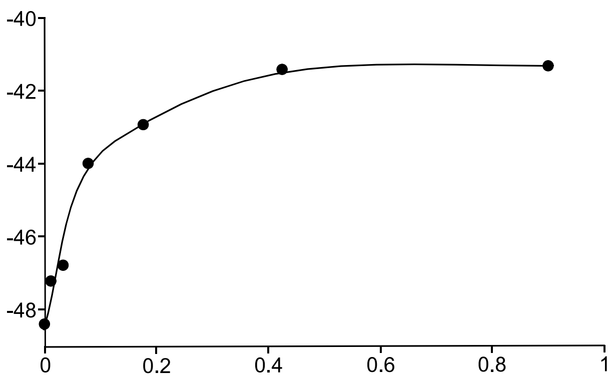

Figure 12, luma noise, dB

For noise level measurements, a plain white card was evenly illuminated, and recorded at HDV resolution with various exposures. A high-pass spatial filter was used to reject low frequencies. Fig.12 shows the results, plotted in signal-to-noise ratio (dB vertically against luma amplitude (percentage) horizontally. Values were obtained mathematically and are unweighted.

The curve exhibits a very odd effect; the noise level actually drops as exposure is reduced. Normally, noise levels would be expected to increase as video level drops, because the gamma-correction curve applies more gain at low levels than at high levels. Nevertheless, this camera does exhibit the inverse performance. One possible explanation for this could be the use of analogue head amplifiers with limited gain-bandwidth product (i.e. cheaper). Thus, as the gain increases, the bandwidth reduces and output noise level goes down. Measurement of captured resolution is too difficult to do at low video levels (because of noise), so this explanation remains unconfirmed. However, the net result is that the noise performance appears to be better than it is, a desirable thing for such a camera. Perhaps this was a design decision, if so, it has worked.

Even so, noise performance is not up to the standards of “proper” HDTV cameras (where 54dB is expected), but the performance is not particularly bad. Such noise levels are not generally a problem for programme production, but would be regarded as poor if the production involved any significant amount of colour-keying or matteing, for whatever reason. This noise level, combined with the relatively low chroma resolution (in the MPEG2 4:2:0 configuration) leads to overall poor keying performance.

After down-conversion to SD, the noise at 50% luma level was 42.1dB, 0.8dB worse than at HD. This shows that the frequency distribution of the noise is fairly even, not especially high- or low-frequency.

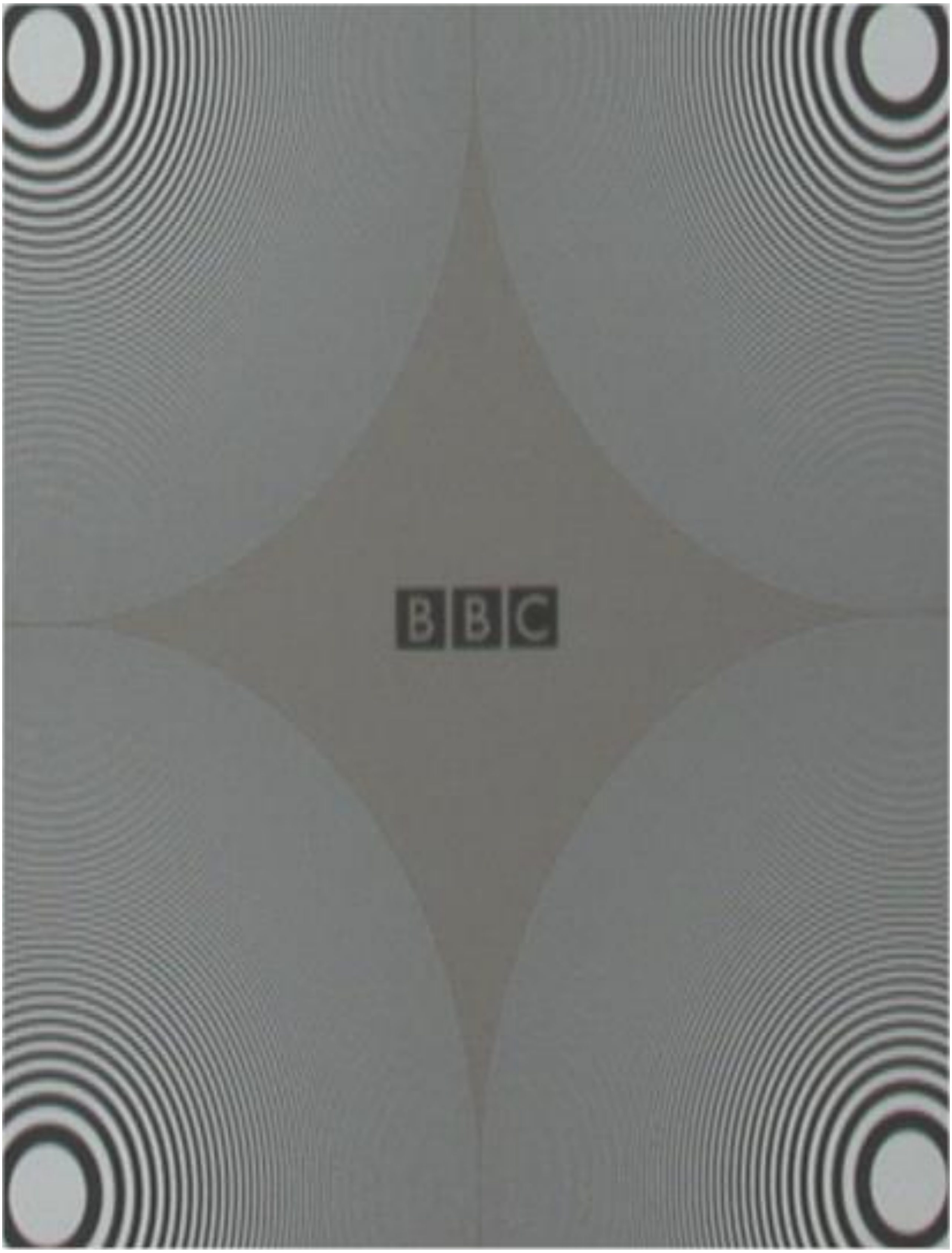

Figure 13, single zone, *Interlaced* mode, *Sharpness*=7

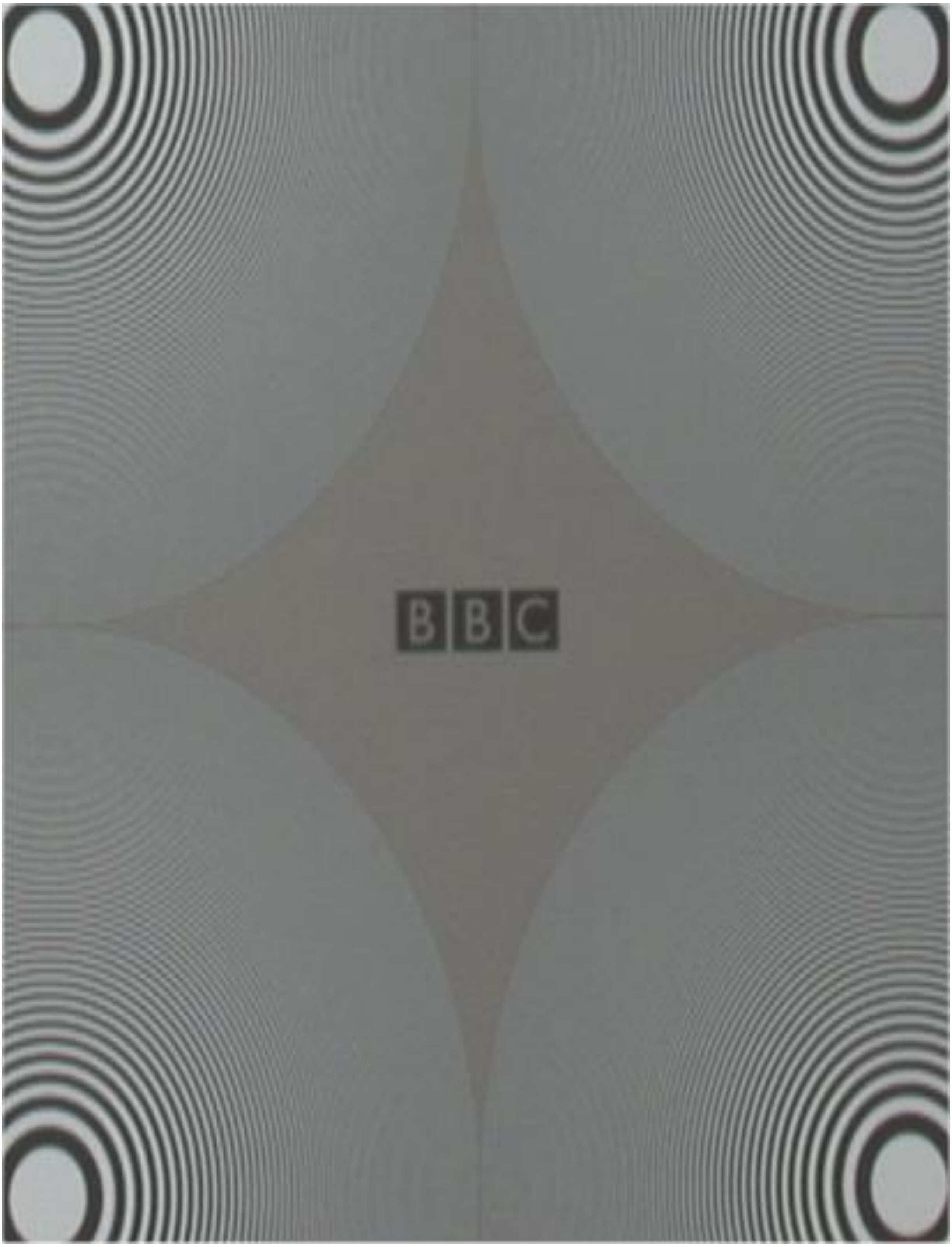

Figure 14, single zone, *Cineframe* mode, *Sharpness*=7