Colorimetric and Resolution requirements of cameras

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ADDENDUM 9 : Tests on

Sony DVW 790WSP, Digibeta camcorder

1 Introduction

The menus are listed in numerical order. For these tests, the "Service" level was used, having set both the "Engineer" and "Cameraman" levels to factory norms. This approach is not normally available to the casual user, hardware switches have to be set within the camera; the reader of this addendum is not expected to know how to do this.

Since this document is not intended to be an aid in setting the camera, no details will be offered on how to access either the Service or Engineer menus. Each menu maintains its reference number at each level; at the lower levels, menus can be promoted to the higher levels. Thus the menus available at the Cameraman level usually leave the cameraman only with the controls that he might reasonably need, preventing inadvertent mis-adjustment of the camera. It is not possible to conduct these measurements using only those menus. Little detail or explanation of the menus is given here, except in those items that were explored for the tests. Test results and calculations are given after the listing. For each test, menu settings are given in square brackets thus, [Master:+99], where they differ from zero settings.

The settings used for the calculations should not be taken as preferred BBC settings for this camcorder.

2 Menus found

	Title	Comment
01	Markers 1 of 3	
02	Markers 2 of 3	
03	Markers 3 of 3	
04	VF Disp 1 of 2	
05	VF Disp 2 of 2	
06	Master Gain	
07	Shot ID	
08	Shot Disp	
09	Shutter ON/OFF	
10	! LED	
11	Setup card	
12	Function 1 of 2	Main switches, e.g. gamma, detail, knee, test sawtooth
13	Function 2 of 2	Main switches, e.g field/frame
14	Widescreen	
15	VF settings	Zebra controls
16	Level 1	Detail enhancement, 16:9 settings
17	Level 2	Knee detail, 16:9 settings
18	Level 1#4:3	Detail enhancement, 4:3 settings
19	Level 2#4:3	Knee detail, 4:3 settings
20	Level 3	
21	Level 4	Video clip and knee settings
22	Level 5	

23	Level 6	
24	Level 7	
25	Level 8	Video gamma and black gamma settings
26	Level 9	Matrix
27	Level 10	Matrix
28	Level 11	
29	Level 12	
30	W-Shading G	
30-2	W-Shad G	
31	W-Shading R	
31-2	W-Shad R	
32	W-Shading B	
32-2	W-Shad B	
33	DDC Adj	Auto knee
34	Offset Wht	
35	Preset Wht	
36	Operation 1	Switches
37	Operation 2	
38		There is no menu #38
39	SG Adj	
40	Enc Adj	
41	Data Reset	Recall factory settings, all levels
42	Menu Sel 1	Assign menus to Cameraman level
43	Menu Sel 2	
44	Menu Sel 3	
45	Menu Sel 4	
46	Menu Sel 5	
47	Measurement	
48	B-Shading G	
49	B-Shading R	
50	B-Shading B	
51	TG Adj	
52	VA Adj 1 of 2	
53	VA Adj 2 of 2	
54	AD Adj	
55	ND Comp	
56	VTR Adj	
57	Device Sts	
58	Camera Diag	

3 Exposure range measurements (Contrast)

There is a commonly held belief that television cameras have a contrast range of about 30:1 (5 stops of exposure). That may have been true in the days of tube cameras with valve or transistor electronics and diode-approximations for gamma-correction, but it seems highly unlikely with modern cameras, particularly since HDTV camcorders are now known to record at least 10 stops, 11 with care. Film negative copes with 11 stops, and some HDTV cameras can match that, but how far short do SDTV cameras fall of that target? The following measurements were set up to examine that question.

Tests signals and pictures were recorded onto Digibeta tape, dubbed to miniDV tape via a Miranda DV Bridge (thus making a fully digital copy), captured into a DV NLE and frames exported as BMP graphics images. They were converted to RAW graphics images in Paint Shop Pro, and a

BBC BASIC programme produced sets of numerical data by averaging some or all lines in the image. These results were imported into Excel and plotted.

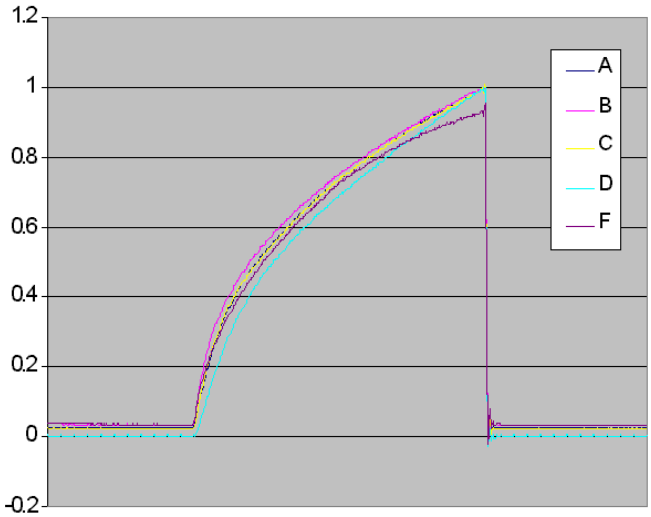
3.1 Sawtooth test signal

3.1.1 Basic gamma settings

There are five basic gamma curves. Curve B has maximum slope near black, and is probably intended to be a "BBC" curve, which should have a maximum slope near black of 5. Curve D has lowest slope near black. It is evident from the slight disparity in black levels, that the camera's black level was set a little high. This was not adjusted throughout the measurements.

Curve F is presumably for "film-look". It does not reach 100% output for 100% input; this indicates a premature knee compressor.

Further tests have concentrated on Curve B to establish the maximum achievable exposure contrast, and Curve F for highlight handling.



[Gamma Table:A,B,C,D,F]

Curve	Slope
A	4
B	5
C	4.3
D	3
F	4

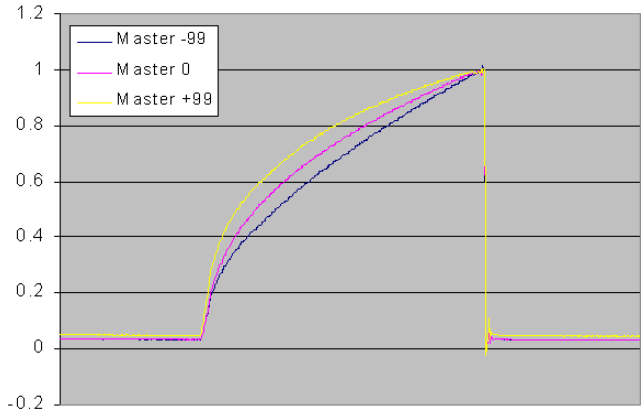
From the measured data, it was easy to calculate the maximum slopes near black, and this exercise also established the exact positions of "zero exposure" and "peak exposure" on the horizontal axis, at samples 176 and 528.

3.2 Master gamma range

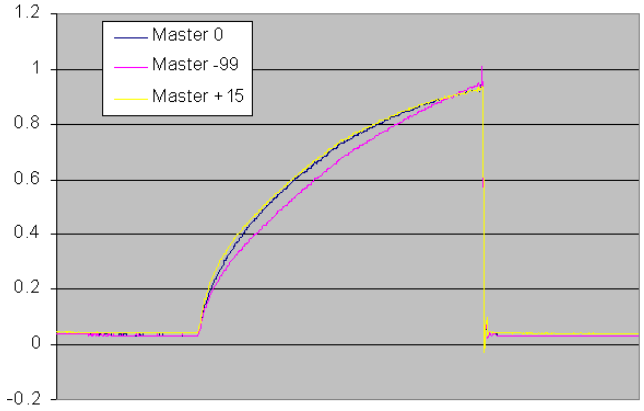
Curve B reaches 100%, and the Master control has considerable effect on the curve above about 10%. The usual guide for this is to check the output level for 20% input level; in the "BBC 0.4" curve, this value is very near 50%. The range measured here is from 44% to 59%, the value at Master=0 is almost exactly 50%, and so this value is used for later tests. Slope near black varies from 4.5 to 6.8. Since the value of slope at Master=0 is 5, the value required by the BBC laws, Master Gamma was set to zero for all later tests.

The effect of the Master control on Curve F is much less pronounced and will have much more subtle effects on the image. Note that Curve F does not allow positive values of Master Gamma greater than +15. The slope near black is much lower than for Curve B, varying from 4 to 5.5.

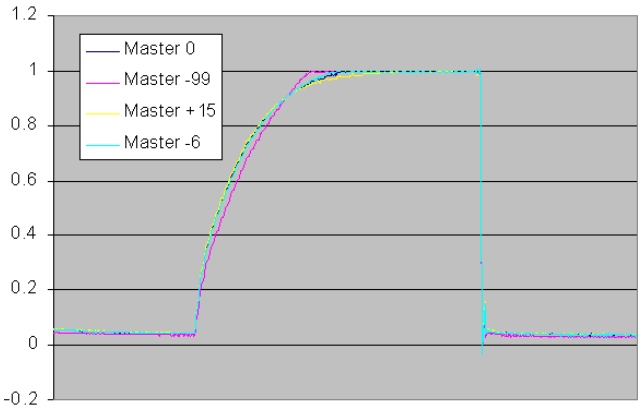
The Master Gamma value of –6 is significant in that it avoids a problem with the Knee



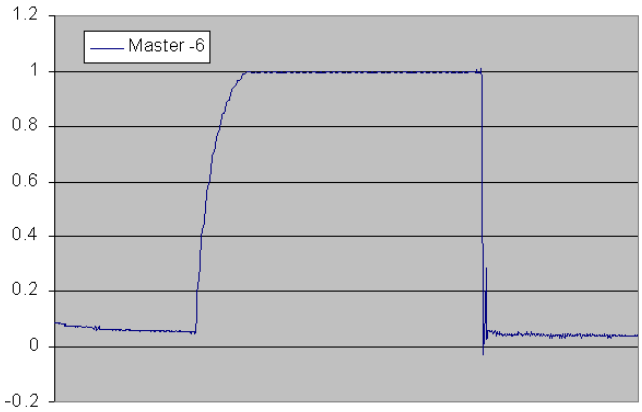
[Gamma:Table:B, Master Gamma:–99/0/+99]



[Gamma Table:F, Master Gamma: –99/0/+15]



[Gamma Table:F, Master Gamma:-99/-6/0/+15, Gain:+9dB]



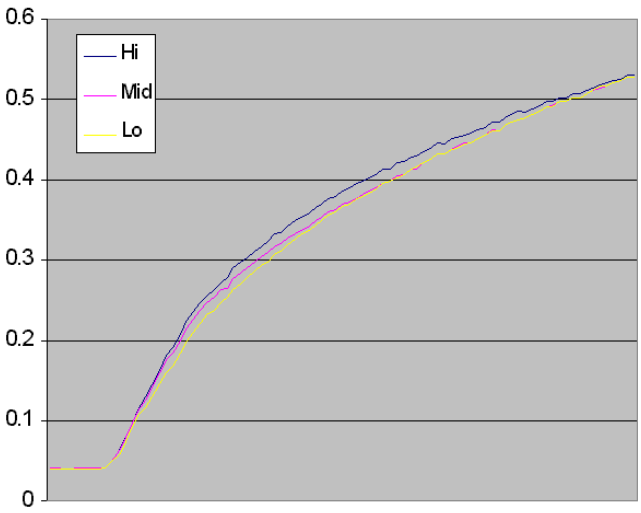
[Gamma Table:F, Master Gamma:-6, Gain:+18dB]

setting. It seems that the knee circuit may not cover the full exposure range, the sawtooth curve was seen to suddenly change slope at about +15dB exposure, as though the line of the non-knee-compressed were continuing beyond the effect of the knee. Setting Master Gamma to –6 seemed to avoid this becoming a problem.

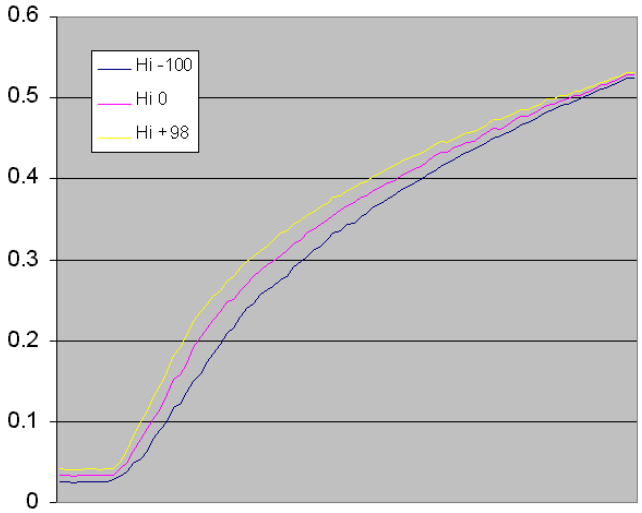
3.2.1 Black Stretch

Black Stretch is rarely used in normal television shooting, because it introduces camera head noise near black. However, it improves the accuracy of colour rendering of saturated colours (by desaturating and shifting them away from primary and secondary colours), at the expense of some "zing" in the pictures. For News and Light Entertainment, this is probably a bad thing, but for Drama it is crucial in that it maintains subtlety that is otherwise lost.

In Drama, and other genres that benefit from being shot on film or from appearing so to do, use of Black Stretch extends the exposure contrast range of the camera to mimic that of film. In Post-Processing, pictures may be subsequently black crushed to reduce the noise and increase saturation, but that is a decision that is best taken in grading rather than during shooting.



[Gamma Table:B, Master Black Gamma:+98, Black Gamma Range:High/Mid/Low]



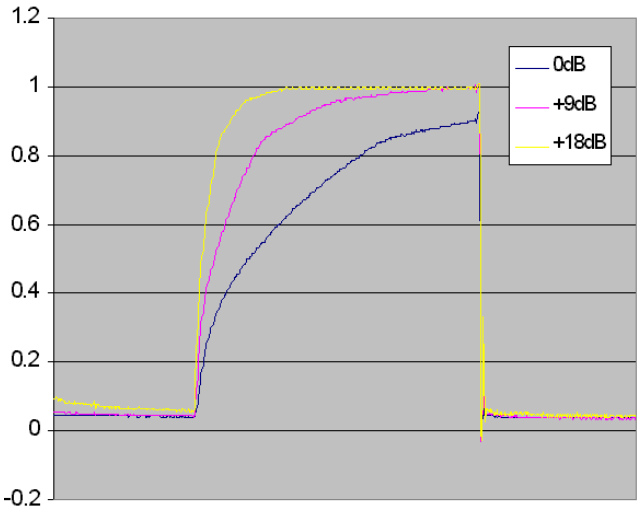
[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:-100/0/+98]

These measurements are magnifications of Curve B. Clearly, the Range control "High" setting extends to about 60%, "Mid" to about 40%, "Low" to about 20%, but the curves remain curved (maximum slopes are 5.6, 5.5, 5.2, indicating that it is genuinely extent and not slope that is being modified). The "High" setting was therefore examined further since it effectively increases the exposure contrast range. The Master control has most effect at about 20% (output, 1.5% input)

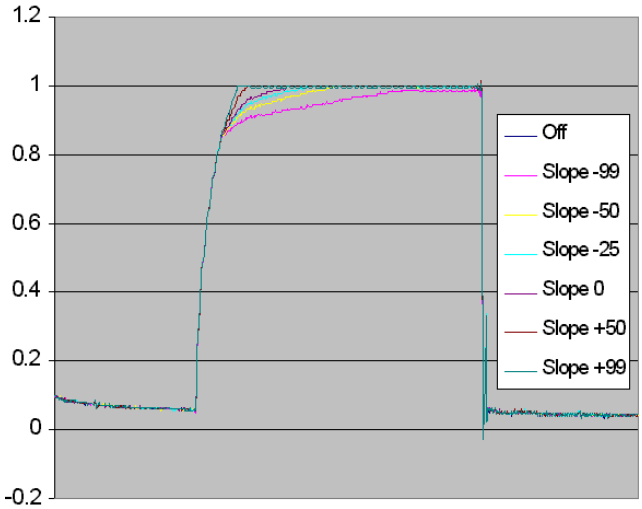
where levels change between about 16% and 24%. Slope near black is 4.3, 5, 5.6 for the three settings tested. Setting Master to +98 and High range represents about one extra stop of exposure range.

3.2.2 Knee

Camera ccd output is usually amplified before digitising and gamma-correction. It is rare for the entire dynamic range of the ccds to be exploited. Thus the normal exposure contrast range of 100% does not fully use the capabilities of the ccds themselves. The normal way to exploit the extra dynamic range is to differentially compress the signals, at high output levels. The gamma curve has a knee in it, above which contrast is compressed. The knee point and the curve slope above that point are both controllable. To capture the maximum exposure contrast range, a combination of point and slope must be chosen such that the signal coding range reaches maximum just as the ccds reach saturation.



[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:0, Gain:0/+9dB/+18dB]

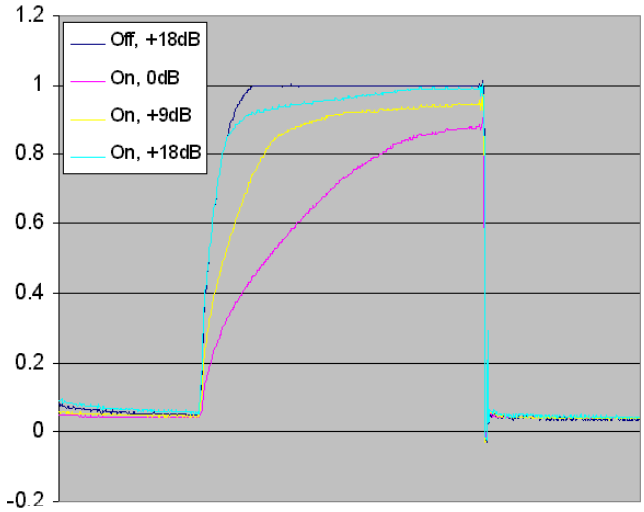


[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:-99/-50/-25/0/+50/+99, Gain:+18dB]

Clearly, the Knee Point calibration is correct, the curves all break at 85%. Using Curve B, and with Knee Slope set at 0, exposure contrast is increased by about 1.3 stops. With Knee Slope set to –99, the extra contrast is about 2.5 stops but that may not look particularly good on real pictures since detail becomes highly compressed.

Curve F shows similar effects, but the change of direction at the knee is more gentle, because the gamma curve itself is less steep at 85%. Also, the in-built knee in the gamma curve itself tends to blend with the applied knee.

Taken together the Exposure contrast is similarly extended by 1.3 stops when Knee Slope is 0, 2.5 stops when set to –99.



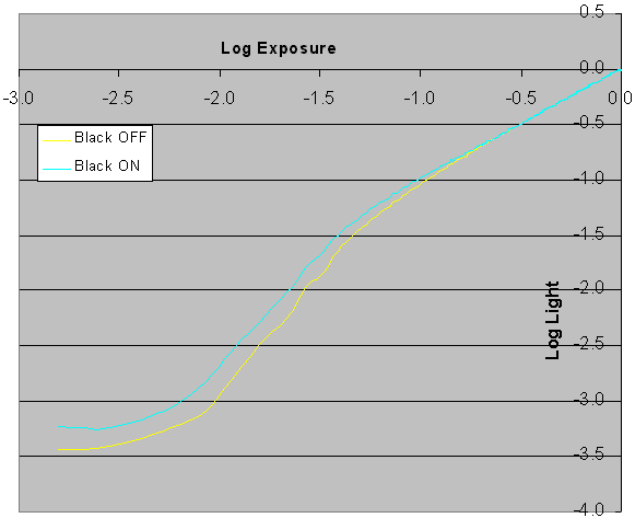
[Gamma Table:F, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:0, Gain:0/+9dB/+18dB]

3.3 Overall transfer characteristics

So far, all the results have been presented as waveform diagrams of the camera transfer characteristics, as could be seen on an oscilloscope or waveform monitor. However, it is far more revealing to plot the overall performance of the camera and a reference display, and to plot it in a visually linear way rather than the electrically linear presentation of the waveform diagrams. The reference display has a gamma value of 2.35, which is the measured value for a range of typical crt displays, both at standard and high definition. Display measurements for this were done using procedures defined by the EBU[1].

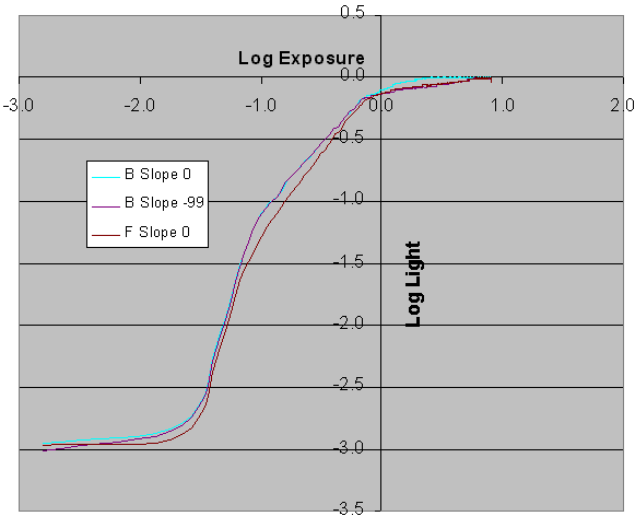
Logarithmic scales are used since the human eye responds logarithmically to light intensity. The resulting graphs resemble the familiar "D/LogE" curves of film, where the density of the negative (itself a logarithmic measure) is plotted against the logarithm of exposure.

The exact lower limits of these curves depends crucially on estimation of black level, i.e. where the sawtooth test signal actually starts to rise. Since the data values are sampled by the pixel structure of the video recording, this only required a decision as to which point to assume to be "zero". For this measurement, "zero exposure" was taken as the last sample before significant change in signal level at +18dB. The effects of the non-zero black level have been ignored, i.e. they are still present in these signals.



[Gamma Table B: Black Gamma Range:High, Master Black Gamma:+98]

Noise is the limiting factor in contrast capture; the three lowermost points on the curve for Curve B are near the noise limit for the camera. Camera black level is 3.5% of signal range, the third point is at 4.1%, corresponding to –2.25 on the Log Exposure scale. Thus the camera is capturing 2.25 decades of exposure contrast (177:1, 7.47 stops) even without Knee and Black Stretch. Using the same criterion, Black Stretch extends that range to 2.5 decades (316:1, 8.3 stops). Therefore Black Stretch adds about 0.8 stops to the exposure capture range.



[Gamma Table:B/F, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:-99/0, Gain:+18dB]

Comparison between the Knee effect on Curves B and F were done with gain at +18dB. Again, noise is the limiting factor, and it is reasonable to take the same lower limit, at one step above black level. Thus –2.5 decades is the noise floor. Curve B reaches maximum at +0.4 decades, so contrast is 2.9 decades (790:1, 9.6 stops), even with Knee Slope set to the default value 0. Lowering the Knee Slope to –99 (minimum value) extends the higher limit to about +0.7 decades, making overall contrast of 3.2 decades (1584:1, 10.6 stops). The reduced slope of Curve F near white resembles a knee; setting Knee Slope to 0 produces the same contrast extension above normal as is achieved with the lowest Knee Slope for Curve B. Nevertheless, the sharp bend in the curve where the knee occurs in Curve F is likely to cause colour rendering problems, and is probably best avoided.

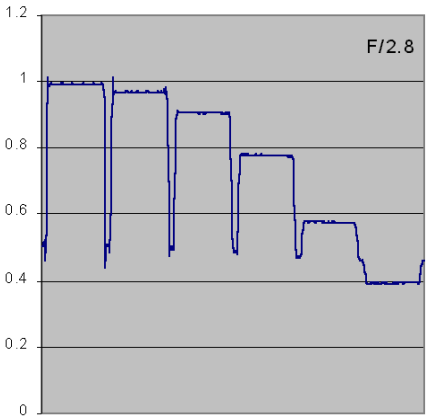
3.4 Macbeth/Collmorgen colour patches test chart

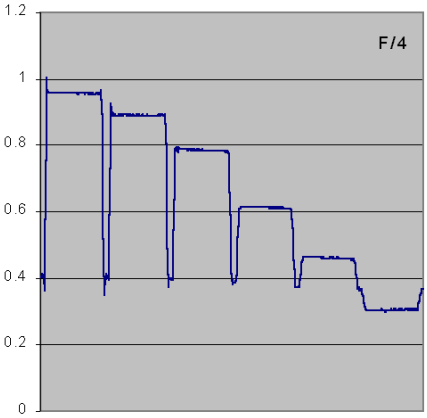
So far, all measurements have been of test signals. To be convincing, some real pictures must be used. A Macbeth chart had previously been calibrated, and was known to have a 30:1 contrast range (i.e. about 5 stops in linear light) between the white and black patches of the grey scale. It was viewed in an office, using office lighting, a mixture of fluorescents and natural daylight. This is a fairly unfriendly but not untypical situation for the camera, and so provided a significant test.

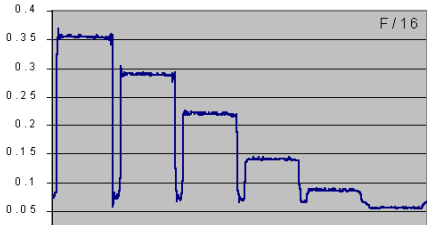
The lens was a reference zoom, used in the testing of HDTV camcorders for several years. It had also been used for some experimental programme making. Its performance is well understood, and placed no constraint on these tests.

F/4 is probably not optimum exposure at standard gain, since the knee is already compressing the brightest patches somewhat. At F/2.8, the brightest patches are being significantly compressed, but are still easily discriminable. At F/16, the "black" patch is being compressed a little because the slope at black is not infinite, as is required for perfect colour analysis.

Thus exposure latitude for this set of patches at standard gain is from F/2.8 to F/16, a range of 5 stops. Since the test chart has a reflectance range of 5 stops as well (30:1), the captured exposure range must





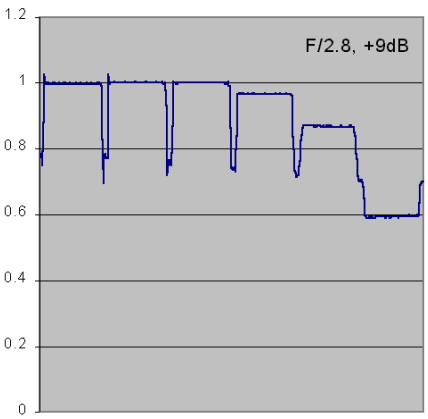


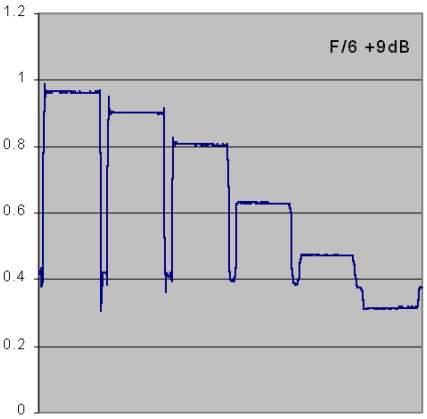
[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:0, F:2.8/4/16]

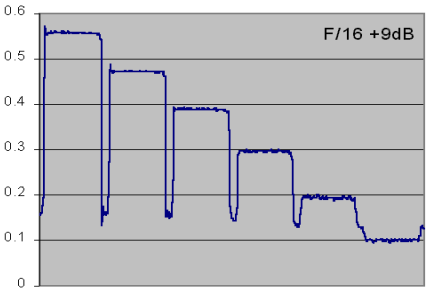
be 10 stops. This coincides nicely with the calculated 9.6 stops range from Section 3.2 for this setting. The patches are not uniformly spread over the contrast range, thus grading would be essential to make these pictures credible. Nevertheless, the camera has captured 10 stops of exposure.

Testing again at +9dB gain, the nominal exposure was set to F/6. Clearly, at F/2.8 patches are clipped, while at F/16 the black patch is not at black level. This provides confirmation of the 10-stop range.

4 Exposure duration (Field/Frame mode and Shutter)



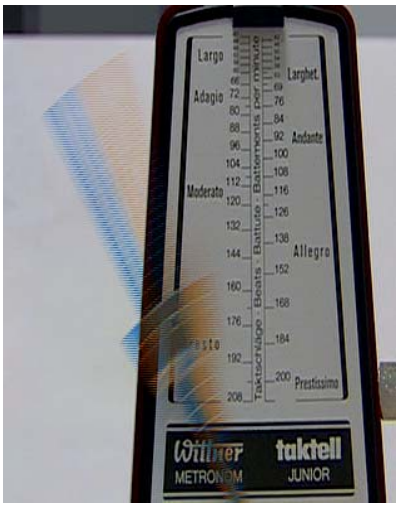




[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:0, Gain:+9dB, F:2.8/6/16]

The camera has Field and Frame modes, and the usual range of shutter settings.

A musical metronome was used as a source of repeatable and controllable motion, to investigate the effects of various options. The results are not clear. The illustrations are of two successive frames, superimposed. One frame has been tinted orange, the other cyan, to show the two integrations of the position of the swinging pendulum.



[Field Mode]

[Frame Mode]

In Field mode, clearly each frame is self-contained, there is no overlap. It is difficult to be precise about exposure duration because the frame comprises interlaced fields recorded at successive instants.

However, in Frame mode there seems to be some overlap in the frames. This implies that the temporal integration for each field spans more than the field interval. Moving images will be less sharply defined. It is unclear what this option is for.

5 Resolution

A circular zone plate was used as a test chart. This reveals camera resolution and the effects of detail enhancement. The whole chart comprises concentric sets of circles; each set is the phase space of spatial frequencies for the camera, low frequency in the middle. Only half of one set is shown here.

The chart was not aligned as accurately as is needed for precise measurement, only relative measurements are important here. Also, since the chart has a 4:3 aspect ratio, and the camera was in 16:9 mode, horizontal frequencies are squeezed by ¾.


[Detail:OFF]

Even at the low setting levels offered by the factory settings, detail is enhanced considerably, the effect is of lightening those areas that are affected. Horizontal detail appears to be more affected than vertical.

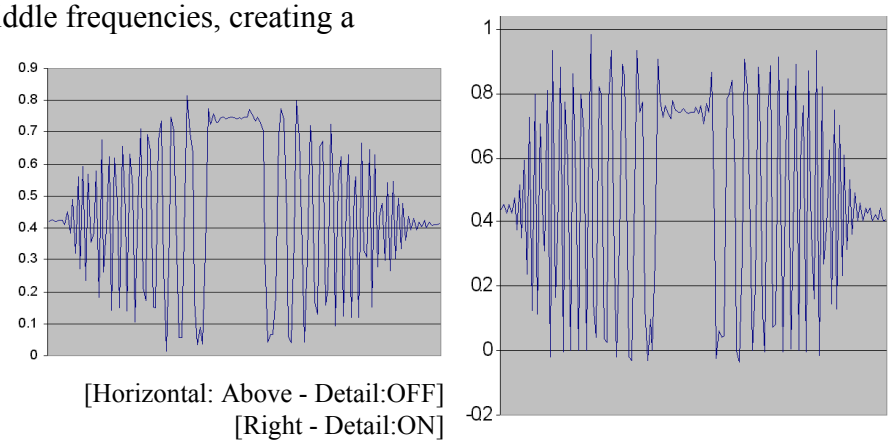
One fact about the circular zone plate allows a more analytical approach; any section through the chart explores a linear frequency sweep, even if that sweep does not pass through the centre. Thus it is possible to measure frequency response in any direction. The BBC Basic programme was run on these images, taking a horizontal slice through the centre to show horizontal frequency response. The results are not ideal, partly because of noise, and partly because the zone plate patterns are square waves. It is extremely difficult to print a sinusoidal pattern in either transmissive or reflective test charts, only BBC Test Card 60 approaches acceptable performance as a transparency. The particular chart used for this set of tests was a reflective sample kept from the development period of the test chart.


[Detail:ON (factory settings)]

The horizontal responses show that the inherent camera response falls smoothly from dc. The results of factory default detail settings raises the response significantly, even at low frequencies. The increase is about 5dB at middle frequencies, creating a "hump".

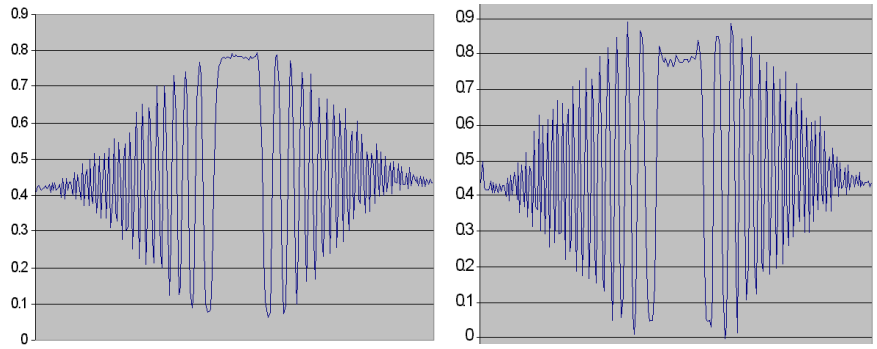
This will cause visible ringing, a characteristic of conventionally set cameras. Ringing is best avoided if the camera is intended to be used in a "film-look" shoot.

Taking a vertical slice through the chart gives the vertical frequency response.



[Horizontal: Above - Detail:OFF]
[Right - Detail:ON]

As expected, the response has been made to roll off earlier than has horizontal, to avoid interline twitter due to interlacing. Also, the amount of enhancement in the factory settings is quite low, but will still be enough to cause twitter.



[Vertical: Left – Detail:OFF]
[Right – Detail:ON]

6 Conclusions

The camera can capture about 7.5 stops of exposure contrast, just by using the BBC gamma curve (Gamma Table:A) without recourse to anything else. If Black Gamma and Knee are applied, this range can be raised to about 10 stops, 2 extra in highlight, 0.5 in low light. This compares with about 11 stops for recent HDTV cameras and for conventional negative film. Although the transfer characteristic does not have the "lazy S" curve of film, it can capture contrast well enough to allow a Colourist to manipulate the images to achieve most effects. There is no evidence for the conventional belief that video cameras have a contrast range as low as 30:1 (5 stops).

Detail enhancement is likely not to be wanted at all if the camera is used in any attempt to mimic film. Factory settings are a little excessive for film-look shooting, but probably acceptable for normal television use. This conclusion, alone, is enough to mark "film-look" shooting apart from "video-look".

7 References

1 "Methods of measurement of the colorimetric performance of studio monitors", EBU Tech.3273-E, October 1993

APPENDIX: Oscilloscope photographs

[Gamma Table:B]

[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98]

[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:0, Gain:+9dB]

[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:+99, Gain:+9dB]

[Gamma Table:B, Knee Point:85%, Knee Slope:0, Gain:+18dB]

[Gamma Table:B, Black Gamma Range:High, Master Black Gamma:+98, Knee Point:85%, Knee Slope:-99, Gain:+18dB]

[Gamma Table:F, Gain:+9dB]

Note sudden rise where knee "runs out".

[Gamma Table:F, Gain:+18dB]

Note sudden rise where knee "runs out".

[Gamma Table:F, Knee Slope:0, Master Gamma:-6, Clip:ON, Gain:+18dB]

Master Gamma set to cure rise after knee "runs out".