EBU – TECH 3325

Methods for the Measurement of the performance of Studio Monitors

Source: P/Display

Status: Final Report

Geneva
September 2008

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Contents

Methods for the Measurement of the performance of Studio Monitors

EBU Committee	First Issued	Revised	Re-issued
PMC	2008		

Keywords: Professional Video Monitor, Performance Measurement

Introduction

This document describes the measurement methods and procedures for video monitors used in broadcast environment. The measurement methods and procedures are independent of the classification of video monitors, and their application areas in television production.

For the purposes of specifying and assessing the performance of a television picture monitor, it is necessary to measure or characterise the following parameters:

- Acoustic noise
- Achievable contrast
- Black level
- Chromaticity of the primary red (R), green (G), and blue (B) light emissions
- Colour gamut
- Colour temperature
- Contrast ratio
- Delay time
- Gamma characteristics
- Grey scale reproduction
- Image scaling, de-interlacing and overscan
- Image sticking (long-term afterimage)
- Luminance ranges
- Motion artefacts
- Mura (imperfections in LCD panels)
- Pixel defects
- Ringing and handling of under- and over-shoots
- Screen resolution
- Screen size
- Signal interfaces
- Stability
- Streaking (also known as overspill or shadowing)
- Transfer characteristics (gamma)
- Treatment of illegal signals
- Uniformity
- Viewing-angle dependency
- White uniformity over the picture area

The specification and tolerances for the EBU standard definition primaries have been defined in EBU document Tech 3213 [1]. ITU-R BT.709 [2] specifies primaries for a single worldwide HDTV system, but no tolerances. The EBU may specify tolerances for Rec.709 primaries, possibly based on the work of BBC R&D (Roberts, BBC RD 1995/10 [3]. SMPTE standard definition primaries and tolerances are defined in SMPTE RP145-2004 [4].

The techniques described in this document can be applied equally to conventional television displays with either 4:3 or 16:9 aspect ratio, and to HDTV displays, both CRT and matrix. Requirements specific to CRT displays are noted where necessary.

***Warning**: Some of these tests carry with them the possibility of damage to the equipment* *being tested. Users should seek confirmation from manufacturers that they are happy for these tests to be applied to their products.*

Signal level definitions:

“Peak White” for a 10-bit digital video signal is 940 for the digital luma level and 512 for the digital chroma level (i.e. R=G=B=940).

“Super White” (109% white), a 10-bit digital video signal, is 1019 for the digital luma level and 512 for the digital chroma level (i.e. R=G=B=1019).

Black level is a 10-bit digital signal level of 64 for the luma and of 512 for the chroma (i.e. R=G=B=64).

50% signal level is defined in 10-bit digital representation as luma 502, chroma 512 (or R=G=B=502). In 8-bit digital representation, 50% signal level has 126 for the luma level, as specified in ITU-R BT.815 [5].

1. Procedures

1.1 Measurement conditions and precautions

A number of methods have been developed for the measurement of a light source. It is sufficient to select suitable methods that can be applied to the particular characteristics of a picture monitor that has a discontinuous light output by reason of the scanning process and the nature of the spectral and temporal characteristics of the phosphor or other light source.

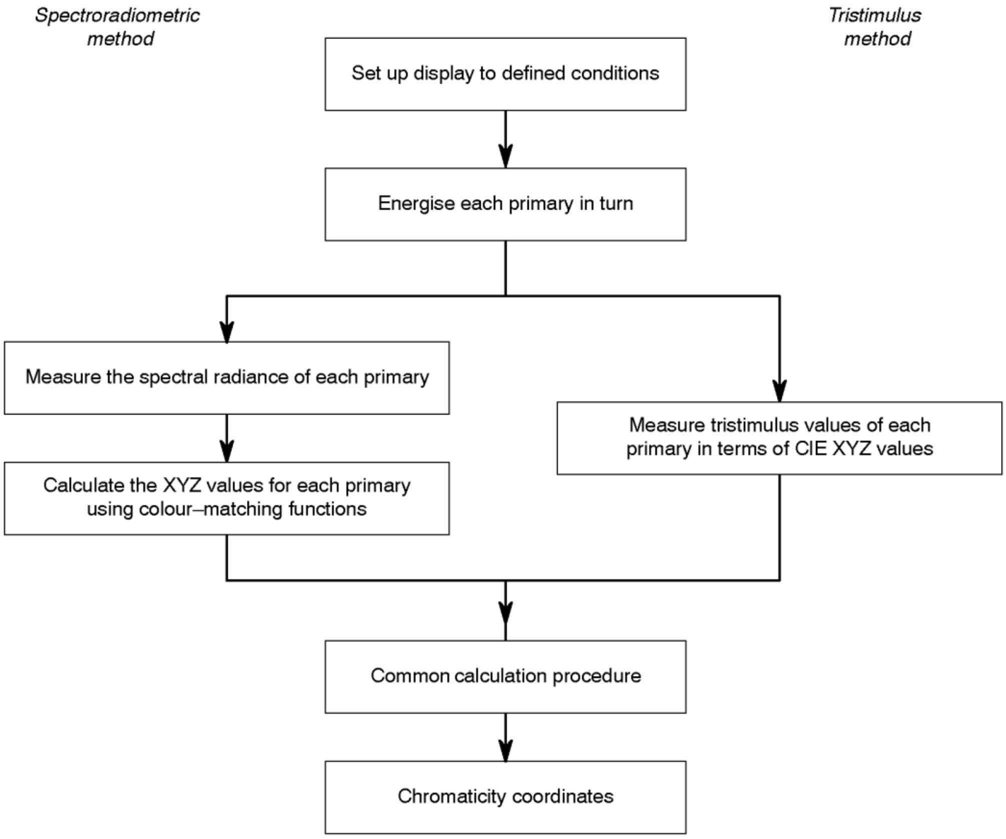


Figure 1: The two measurement methods with common calculation procedure.

Two methods have been established which give similar results; the spectroradiometric method, and the tristimulus method. Figure 1 indicates the process of measurement and computation for both these methods. Detailed procedures for measurement, computation and presentation are given below.

1.1.1 Suitable measuring techniques

All techniques involve measuring, wavelength-by-wavelength (λ), the light energy coming from the monitor. The spectral power distribution thus obtained (Pi), may be converted to tristimulus values by multiplying it by each of the colour matching functions ($\bar{x}$, $\bar{y}$, $\bar{z}$) in turn and integrating the resultant curves. Chromaticity coordinates may then be obtained by normalisation.

The colour matching functions, representing the amount of each CIE XYZ primary required to match the individual wavelengths in the colour under test are shown in Figure 2. They are the results of measurement of the colour vision of a number of observers by Wright and others before 1931 and were accepted by the CIE as the definition of the CIE 2° Standard Observer; they are thus uniquely defined and provide the only basis for an objective measurement system.

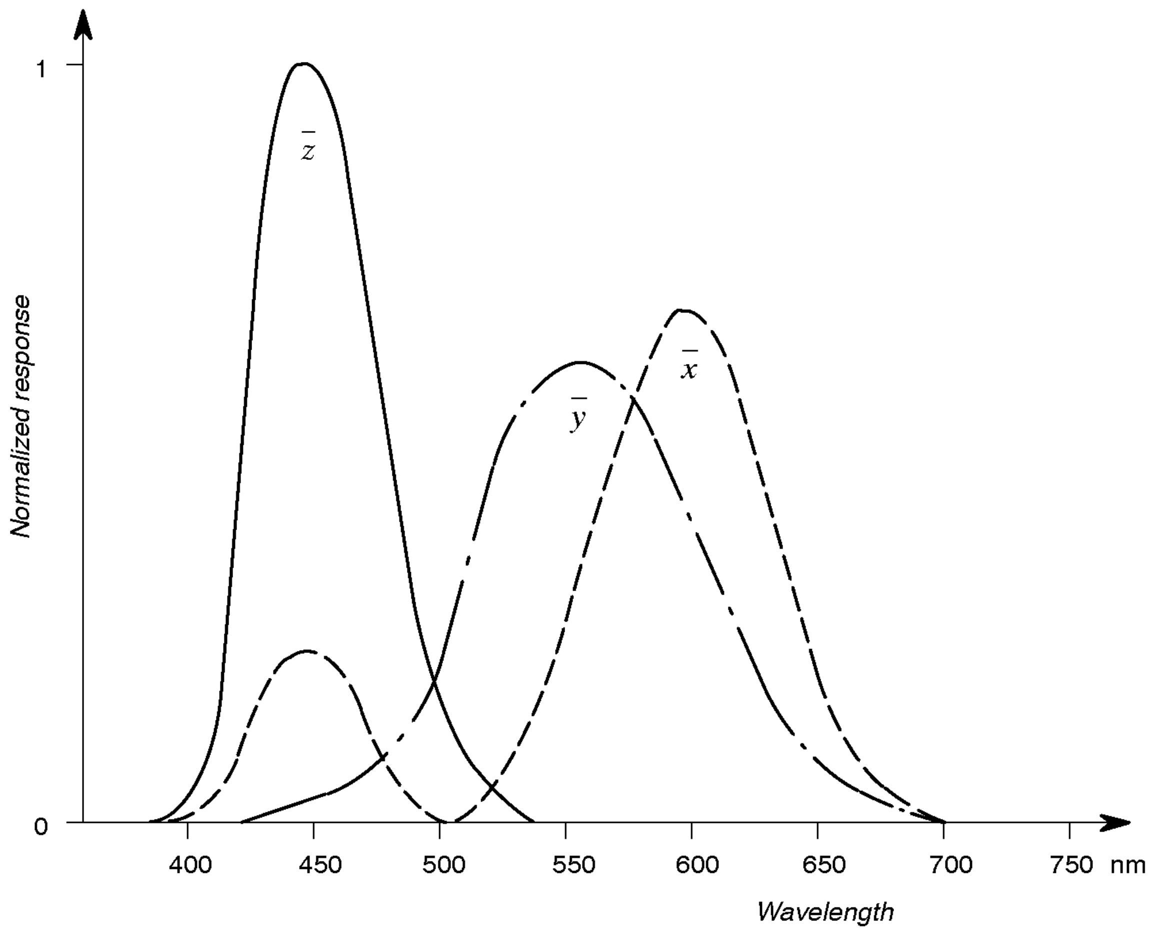


Figure 2: The colour matching functions (1931 2° Standard Observer).

Two methods of measurement are described; a spectroradiometric method by which the spectrum is measured wavelength by wavelength, and a tristimulus method that directly yields the tristimulus values and chromaticity coordinates. This latter method uses a tristimulus meter in which the total light energy from the monitor is modified using filters designed to replicate each of the colour matching functions to give the tristimulus values directly.

1.1.2 Spectroradiometry

Spectroradiometric equipment comprises a means of measuring the light energy, wavelength by wavelength, across the whole spectral range and a data processor which calculates the tristimulus values by multiplication of this spectrum with the colour matching functions and then integration. Thus, provided that the bandwidth of the wavelength-scanning device is accurately controlled and its gain characteristic is known, accurate results are obtained.

Two variations of the spectroradiometric method are now available. Simultaneous measurement uses a spectrum splitter and an assigned sensing cell for each wavelength. The wavelength scanning method uses one sensing cell at the output of a scanning spectrum splitter (monochromator).

Either method will produce the spectral radiance, Pi, of the colour. This should be measured over the visual part of the spectrum; 380 to 760 nm is a typical range. The instrument's calibration must be traceable to a standards bureau. Tristimulus values are then derived by multiplication and integration as described above, using data values of the appropriate colour matching functions tabulated by the CIE:

$$X = \int_{380}^{760} P_\lambda . \bar{x}_\lambda . d\lambda \qquad Y = \int_{380}^{760} P_\lambda . \bar{y}_\lambda . d\lambda \qquad Z = \int_{380}^{760} P_\lambda . \bar{z}_\lambda . d\lambda$$

Equation 1: Tristimulus equations.

1.1.3 Tristimulus meter

This equipment usually comprises three light sensitive cells, with spectral sensitivities modified by filters to mimic the colour matching functions ($\bar{x}$, $\bar{y}$, $\bar{z}$). Thus the electrical outputs of the cells give a direct reading of the tristimulus values (X, Y, Z) of the test colour, from which the chromaticity coordinates can be calculated. Clearly, it is essential that the cell responsivities precisely match the colour matching functions, and that the instrument should be calibrated by measurement of a standard white source and some typical colour primaries. This calibration should be traceable to a standards bureau.

The merit of the tristimulus meter is that it can be a small, hand–held device that produces instant readings. Its disadvantage is that its accuracy depends, to some extent, on the smoothness of the spectrum it is measuring. With a smooth spectrum, small errors in the cell responsivities are of little significance, but with light sources whose spectra do not vary smoothly, such as rare-earth phosphors and discharge lamps, the light energy may be in the form of a small number of narrow–band peaks occurring at wavelengths where even small filter errors can produce inaccurate tristimulus values.

1.1.4 Measurement points

Measurements are made at standardised positions within the screen area defined in terms of screen height and width; these are indicated in Figure 3.

Depending on the measurement, a subset of these measurement points can be defined.

	Coordinates (rel. to screen centre)	
Measuring Point	**w**	**h**
1 (screen centre)	0	0
2 and 5	0	±0.4 H
9 and 12	±0.4 W	0
3, 4, 6 and 7	±0.35 H	±0.2 H
8, 10, 11 and 13	±0.4 W	±0.4 H
Area of measurement should not be greater than a circle of diameter 0.1 H		

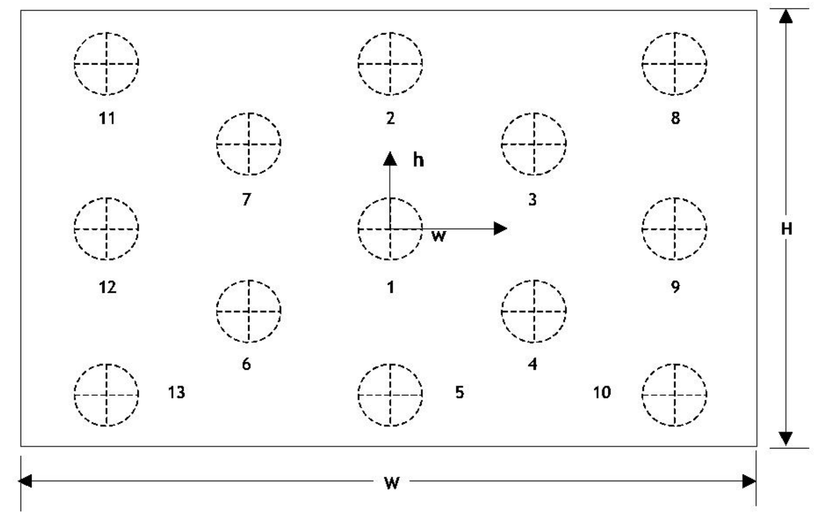


Figure 3: Measurement points within the screen.

1.1.5 Measurement conditions

To ensure absolute and repeatable measurements, the following conditions should be observed:

- Measurements should be made in a darkened room (VESA FPDM2 [6] specify this as less than 1 Lux room brightness)
- Measurement distance is recommended to be 3 to 4 times picture height. It must be arranged such that the measurement window of the measuring device is entirely within the measurement patch on the display.
- Except in the case of viewing angle, the measurements should be made perpendicular to the surface of the display.
- The display should be placed away from surfaces that might reflect light into the measuring equipment.
- Equipment indicator lamps etc. should be shielded from the measuring equipment.
- The monitor must be allowed to warm up for 30 minutes while displaying a grey signal that gives a luminance of 15cd/m^2.
- The monitor should be set for a peak white of 80 cd/m^2 and adjusted to the manufactures procedures for the white colour temperature for D65. The full image area should be visible (i.e. no overscan).
- The black level should be set on the monitor using a PLUGE test signal such as that specified in ITU-R BT.814-2 [7].
- *Cathode-ray tube displays are affected by magnetic fields and so should be placed such that the effects of any magnetic field is minimised.*
- *The cathode-ray tube display ideally should be degaussed with an external coil. If this is not possible, the internal degaussing coil must be used.*
- *CRT-Displays should be checked for adjustment of purity, scan size and linearity, convergence, focus, grey-scale tracking, and achieved white colour temperature for D65 following the procedures specified in EBU R23 [8]. If the adjustment is in error, corrections must be made where possible, according to the manufacturer's procedures.*
- *During measurements, cathode-ray tube displays must not be subjected to long-term high-level full-field signals which might cause mask heating and consequent distortion.*

1.1.6 Measurement precautions

There are several precautions that should be considered. These relate mainly to the characteristics of the measuring equipment used.

- The instrument optical axis should be normal to the surface of the display. Small deviations are probably not significant since most detectors use integrating apertures or diffusers.
- The instrument entrance aperture should be fully illuminated to prevent uneven illumination of the sensor(s).
- For flat panel displays, with potentially large variations in light output with viewing angle, only equipment using relay optics can be used, rather than meters which sit on the surface of the screen.
- The detector temporal performance must be linear. Due to the different ways in which different display technologies create luminance levels in time and the limited area of measurement, the detector may not be continuously illuminated by a constant light level. The temporal performance and integration characteristics must be linear and peak excitation must not cause overloading.
- Precautions must be taken to avoid the effects of veiling glare. VESA FPDM2 A101 [6] describes this in detail, and Kelly[1] gives much of the background. The simplest method is to mask the area surrounding the measurement point with a flat, velvet-covered card. If this might affect the temperature of the screen surface by preventing natural cooling, then a gloss-black frustum (cone) of 45° should be used.

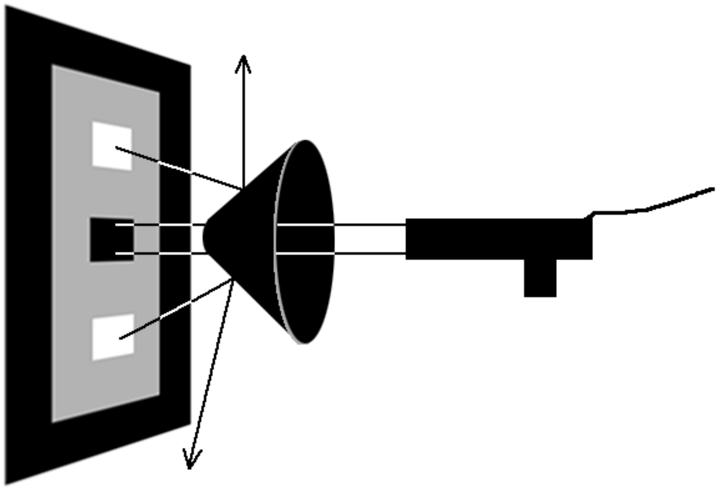


Figure 4: Arrangement of the measuring instrument and frustum to avoid veiling glare.

- Spectroradiometer slit and incremental wavelength must match each other. The slit widths define the effective "bandwidth" and aperture shape of the radiometer; these must match the incremental wavelength in order to resolve spectral emissions optimally. A pre-run should be performed to determine peak response and to ensure that overloading does not occur.
- Noise and zero levels should be checked. Detector sensitivity should be such that noise levels are not significant. Extraneous light can contribute to noise in the detected signal. Zero levels can be affected by electrical offsets and detector dark-current; these should be allowed for.
- Repeatability of measurements should be checked, and measures such as averaging several readings used if found not to be repeatable enough for the required accuracy of the measurement.

[1] ftp://ftp.fpdl.nist.gov/pub/overview/NIST-Centennial.pdf

1.2 Test patterns

	Coordinates (rel. to screen centre)	
Measuring Point	**w**	**h**
1 (screen centre)	0	0
2 and 5	0	±0.4 H
9 and 12	±0.4 W	0
Each patch is a square of dimension H/7.5 (13.35% H)		

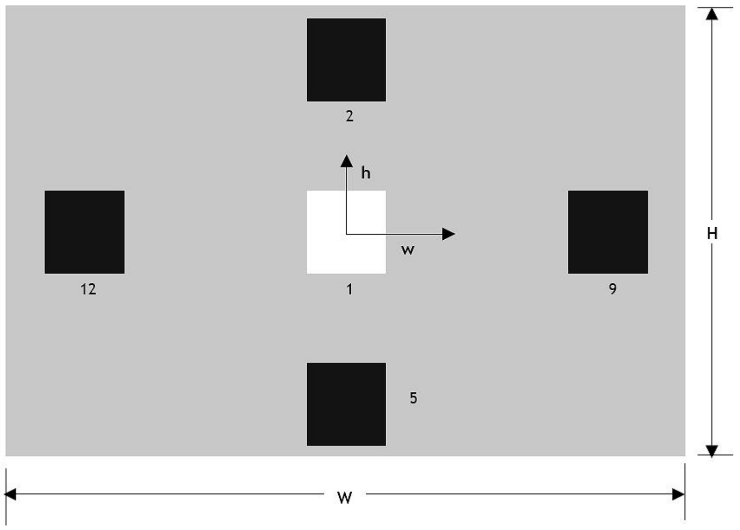


Table 1:Test pattern 1, Black, white and simultaneous contrast.

Test pattern 1 (see Figure 5) consists of a peak white level patch surrounded by four black level patches, all set against a background of 50% grey signal. The digital references to these levels are defined in the preamble.

Test pattern 2 is the same as pattern 1, except that the white patch is now 109% “Super white”. The pattern should include text to indicate this.

Test pattern 3 provides white patches at all 13 test points defined in Figure 3, on a black field. A set of 13 patterns (pattern 3-1 to 3-13) illuminates each individual patch in turn. Pattern 3-black is a completely black image. Pattern 3-white is a completely (100%) white field.

	Coordinates (rel. to screen centre)	
Measuring Point	**w**	**h**
1 (screen centre)	0	0
2 and 5	0	±0.4 H
9 and 12	±0.4 W	0
3, 4, 6 and 7	±0.35 H	±0.2 H
8, 10, 11 and 13	±0.4 W	±0.4 H
Each patch is a square of dimension H/7.5 (13.35% H)		

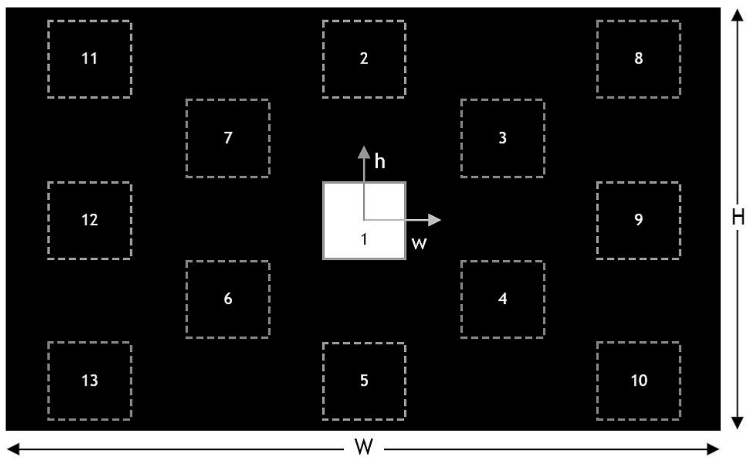


Table 2: Test pattern 3 and 3-1.

Test patterns 3-1-4, 3-1-25 and 3-1-81 are versions of 3-1 but with the white patch occupying respectively 4%, 25% and 81% of the screen area.

Test patterns 4-2 to 4-18 are similar to 3-1 but with the patches having the grey-scale values as set out in the table in section 2.3.1. Pattern 4-1 is the same as 3-black. Pattern 4-19 is the same as 3-1. Pattern 4-20 has the patch at 109% white.

Test pattern 5 is a series of patterns based on pattern 3-1 but with red, green, blue and the 15 EBU test colours. These are patterns 5-red, 5-green, 5-blue, and 5-1 to 5-15. The definitions of the colours are listed in section 2.5.1

Test sequence 6 is scrolling text, both horizontally (6-h) and vertically (6-v), with font Arial bold at sizes 8,12,16 and 20 pixels height, moving at speeds (for 1920x1080) of 200, 400, 600, 800, 1000 and 1200 pixels/sec. The 720p and 576i sequences should have the same font sizes but the scrolling speed adjusted to give the same rate of motion across the screen. The text used should be a random selection of characters for each size and speed.

Test pattern 7 is designed to enable a visual evaluation of various elements of monitor performance including fine gradations of colour, overscan, and filtering/scaling performance.

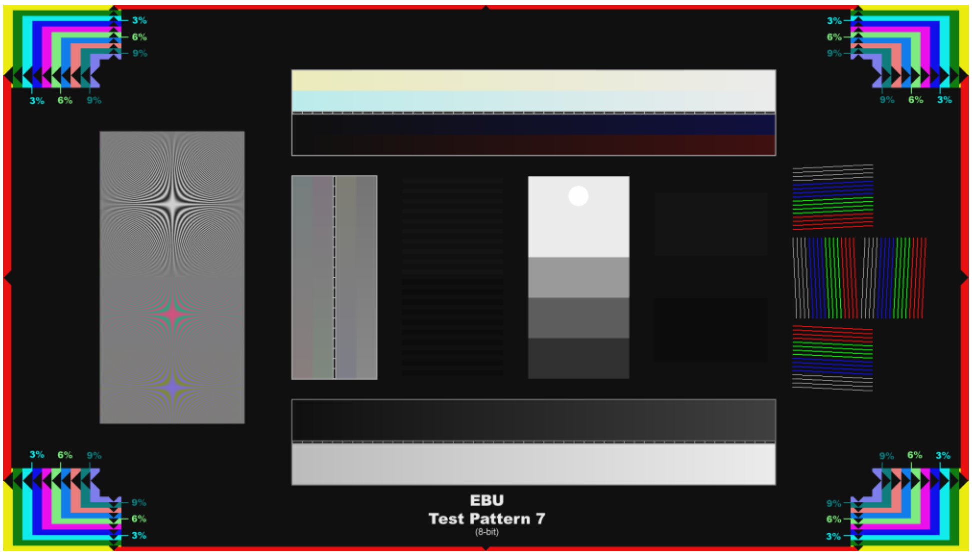


Figure 5: Test pattern 7.

Test sequence 8 (interlace formats only) includes moving zone plates designed to indicate whether a display can indicate incorrect field order.

Test sequences 9-top and 9-centre provide a 5-line flash in a single field for determining delay.

Test pattern 10 has a light grey square of size 1/7.5 H at position 1, video level 213(8 bit) respectively 852 (10 bit) on a dark grey background of video level 38 (8 bit) respectively 152 (10 bit), conditioned by the appropriate channel filter. Pattern 10-r is the inverse of this.

Test pattern 11 includes a ramp of luma from sub-black to super-white, with similar ramps for each chroma signal superimposed on it.

Test pattern 12-grey is a flat 50% grey field. Test pattern 12-burn has 90% grey on the left hand side of the screen and 10% grey on the right with a gentle transition at the join)

These test patterns are available as a zip file on the EBU web site in uyvy 10-bit and .v210 format.

2. Measurements

2.1 Luminance range

2.1.1 White level

The monitor is set to display Test pattern 1 (Figure 5).

Measurement points: 1 in Figure 3

Measurement equipment: Luminance meter

Note: other measurement methods are possible, for example using a tristimulus meter or spectroradiometer equipment.

Measurements are made to establish that the monitor is able to meet the specifications set out in EBU Tech 3320, and these results are reported in the table below.

2.1.2 Super white level

This is measured using test pattern 2, ensuring that super white can be correctly displayed over the range of settings described above to produce the required range of "peak white" levels.

Results:

Grade / Luminance settings	Grade 1			
	70 cd/m^2		100 cd/m^2	
Grade / Luminance settings	Grade 2			
	70 cd/m^2		200 cd/m^2	
Grade / Luminance settings	Grade 3			
	70 cd/m^2		250 or 400 cd/m^2	
Measuring	White	109%	White	109%
-number / -point	1	2	3	4
1				
Average				

Table 3: Super White measurement result representation.

2.1.3 Black level

Use Test pattern 1 (Figure 5).

White level is set to 80 cd/m^2 (except Grade 3, which should be set to 250 cd/m^2). Black level set using Pluge test signal. During the adjustment, it should be checked whether the sub-black of the Pluge test signal is observable. (Note: it is not considered acceptable for a monitor acting as a measurement tool to electronically clip the sub-black signal).

Measurement points: 2, 5, 9 and 12 in Figure 3

Measurement equipment: Luminance meter

Note: other measurement methods are possible, for example using a tristimulus meter or spectroradiometer equipment

Measurement result:

Measuring	Black	
-number / -point	1	
2	0.3333	cd/m^2
5	0.2222	cd/m^2
9	0.4444	cd/m^2
12	0.6666	cd/m^2
Average	0.417	cd/m^2
Measurement tool:	e.g. tristimulus meter, average of 5 readings	
Sub-black can be made visible:	yes	

Table 4: Black Level measurement result representation.

2.2 Contrast ratio

The contrast of a display can be defined as follows:

$$C = \frac{L_{\max}}{L_{\min}}$$

Equation 2: Contrast ratio equation.

Where L_{max} is the luminance reproduced with peak white and L_{min} that reproduced with black. Assuming that black level has been set correctly, then in a darkened room L_{min} may be zero with no signal and hence contrast could theoretically be infinite. However, in the presence of ambient lighting, inaccurately set black level, or due to limitations of the display technology, L_{min} will be non-zero thus giving rise to a wide range of values for contrast.

Clearly, the use of separate white and black signals for the measurement of L_{max} and L_{min} can result in many different values for contrast, and therefore contrast must be calculated using measurements of white and black from within only one test. The simultaneous contrast thus derived may contain an element of flare due to the presence of peak white and, again, the result will depend on the nature of the test signal and the manner in which the display was set up. It is however considered a realistic measure of contrast under real viewing conditions for real picture content.

For measurement conditions see 1.1

2.2.1 Simultaneous contrast

A suitable test signal for contrast measurement is Test pattern 1. Therefore the measurements made in section 2.3 above may be used.

2.2.2 Full screen contrast

Suitable test signals for full screen contrast measurement are:

- Test pattern 3-1 i.e. a peak (100%) white patch occupying 1% of the screen area in the centre of a black screen.
- A completely black screen, test pattern 3-black, (with the set switched on and set up as for the other measurements) in a dark room.

Further test patterns (patterns 3-1-4, 3-1-25 and 3-1-81), with the white patch occupying a larger percentage of the screen area. IEC 60107-1:1997 7.1.4 [9] describes a peak luminance measurement (and hence contrast) using input signals displaying different window sizes (1%, 4%, 25%, 81%) of white area.

The black level L_{min} should be the mean of measurements made of the four positions (2, 9, 5, 12), the white level L_{max} should be measured in the central position (1).

"Full screen (1% patch) contrast" is defined as the ratio between the luminance of the screen when displaying peak white on 1% of the screen area, and the luminance measured when displaying full screen black.

If a display is found to exhibit a fall-off in peak brightness with the size of the white patch, then 4%, 25% and 81% contrast measurements should also be made. “Full screen (x% patch) contrast” is defined as the ratio between the luminance of the screen when displaying x% area patch of white and when displaying full screen black level measured in a completely dark room.

Note: The measurement must be performed in a completely dark room. Before making these measurements, white is set at 80cd/m^2 (250cd/m^2 for Grade 3 monitors) *using Test pattern 1, and black level set using PLUGE.*

Measurement equipment: Luminance meter

Note: *other measurement methods are possible, for example using a tristimulus meter or spectroradiometer equipment*

Measurement result:

	Simultaneous Contrast			Full Screen Contrast		
Measuring	White	Black	Contrast	White	Black	Contrast
-number / -point	1	2	C_s	3	4	C_f
1	80.11			83.3300		
2		0.3333			0.4000	
5		0.2222	192.283		0.3000	238.086
9		0.4444			0.3000	
12		0.6666			0.4000	
Average:	80.110	0.417		83.330	0.350	
Measuring tool:	e.g. xyz tristimulus, average of 5 readings					

Table 5: Full Screen contrast measurement result representation.

2.3 Electro-Optical Transfer Function (Gamma)[1]

2.3.1 Measurement procedure

For this measurement it is essential that the measurement conditions described in 1.1 are correctly set.

When measuring transfer function it is required to measure the light output level over the complete nominal range between black (digital luma signal level of 64 in 10-bit digital representation and 512 for chroma), and peak white (digital luma signal level of 940 in 10-representation and 512 for chroma).

The test inputs (patterns 4-1 to 4-19) are a series of test patches in measurement position 1 (Figure 3) in the centre of an otherwise black field. The patch is a square of dimension H/7.5 (13.35 % of picture height, H) having levels disposed between digital luma levels 64 and 940, such that there is an equal interval between each, except near black and white, according to the table below:

Grey-scale Measurement Number	Luma level in 8-bit	Luma level in 10-bit
1	16	64
2	22	86
3	35	138
4	48	190
5	61	242
6	74	294
7	87	346

[1] Electro-Optical Transfer Function (EOTF) is often in the television world known as display gamma, or display transfer characteristic. These are different terms for the same thing, although “gamma” tends to imply a single numerical value which is a considerable simplification of the function.

Grey-scale Measurement Number	Luma level in 8-bit	Luma level in 10-bit
8	100	398
9	113	450
10	126	502
11	139	554
12	152	606
13	165	658
14	178	710
15	191	762
16	204	814
17	217	866
18	230	918
19	235	940

Table 6: Grey-scale levels values for 8bit and 10bit.

The brightness and contrast settings of the monitor must not be altered during the course of measurement.

Measurement equipment: Luminance meter

Note: other measurement methods are possible, for example using a tristimulus meter or spectroradiometer equipment

2.3.2 Presentation of the Measurement results

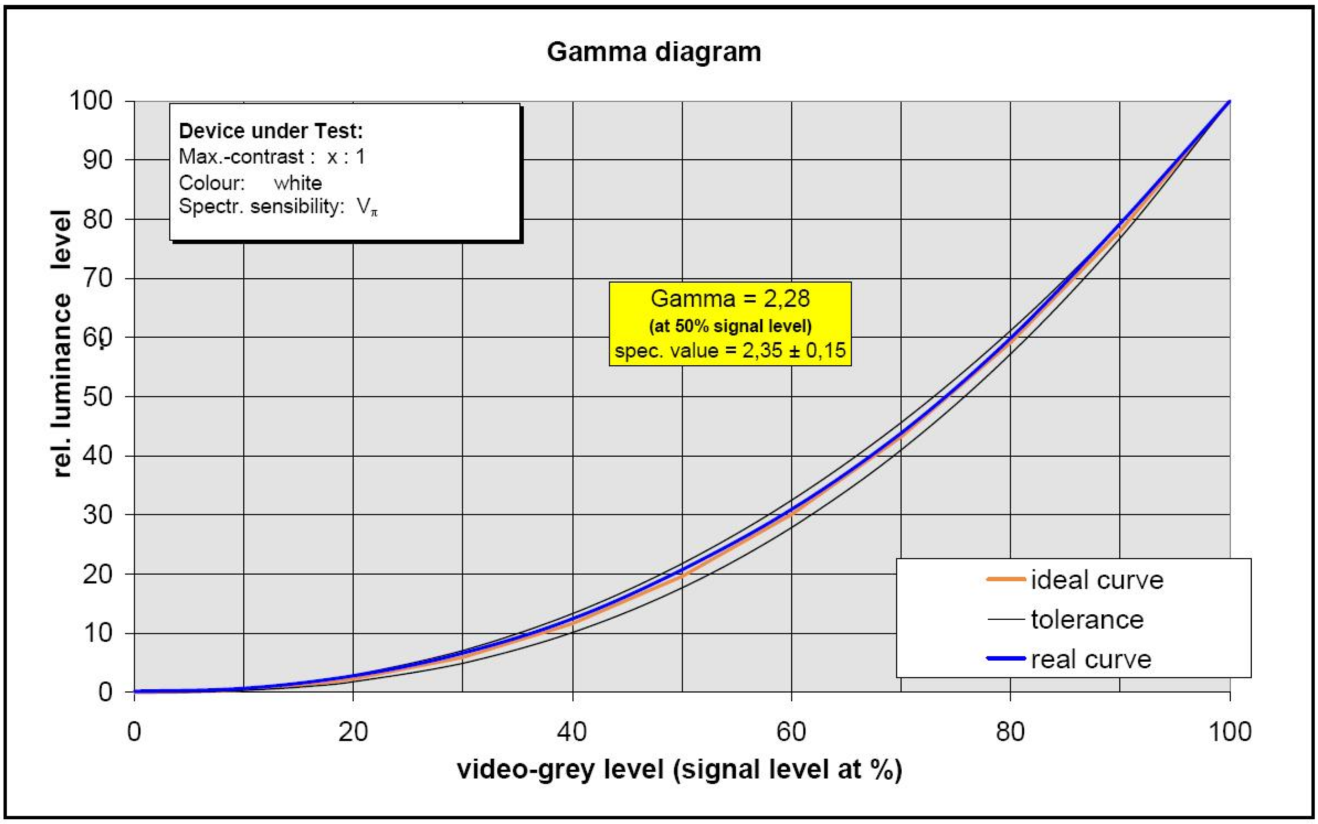


Figure 6: Presentation of Gamma - rel. Luminance level vs gray level (%).

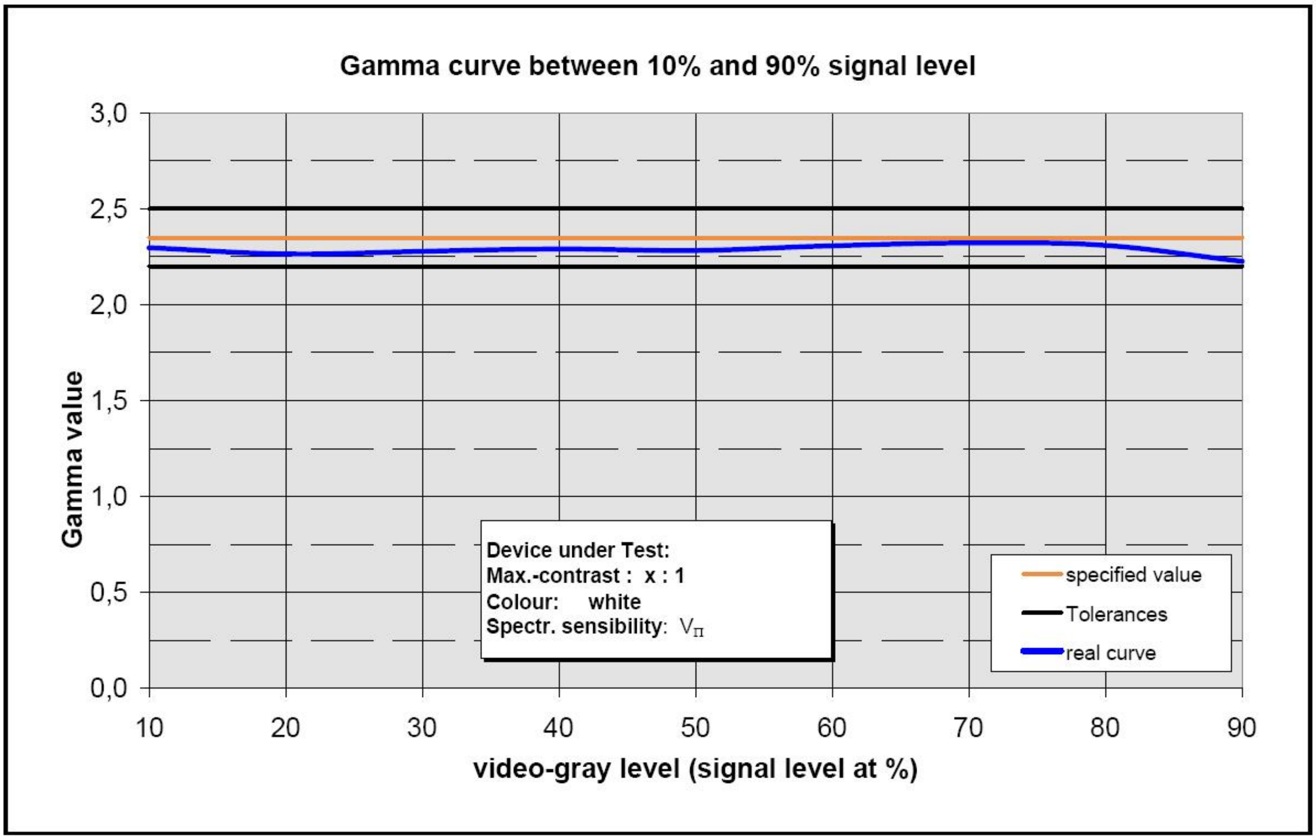


Figure 7: Presentation of Gamma – Gamma value vs. grey level (%).

The method of calculating the values of gamma with signal level is given in Annex 1.

2.4 Grey scale reproduction

2.4.1 Measurement conditions

The test input is test patterns 4-2 to 4-20.

For this measurement it is essential that the measurement conditions described in 1.1 are correctly set.

Measurement points: 1

Measurement equipment: Tristimulus meter or spectroradiometer equipment

2.4.2 Presentation of the Measurement results

Measurement result:

"EBU-Grade 1"	within the red ellipse
"EBU-Grade 2"	within the violet ellipse
"EBU-Grade 3"	within the blue ellipse

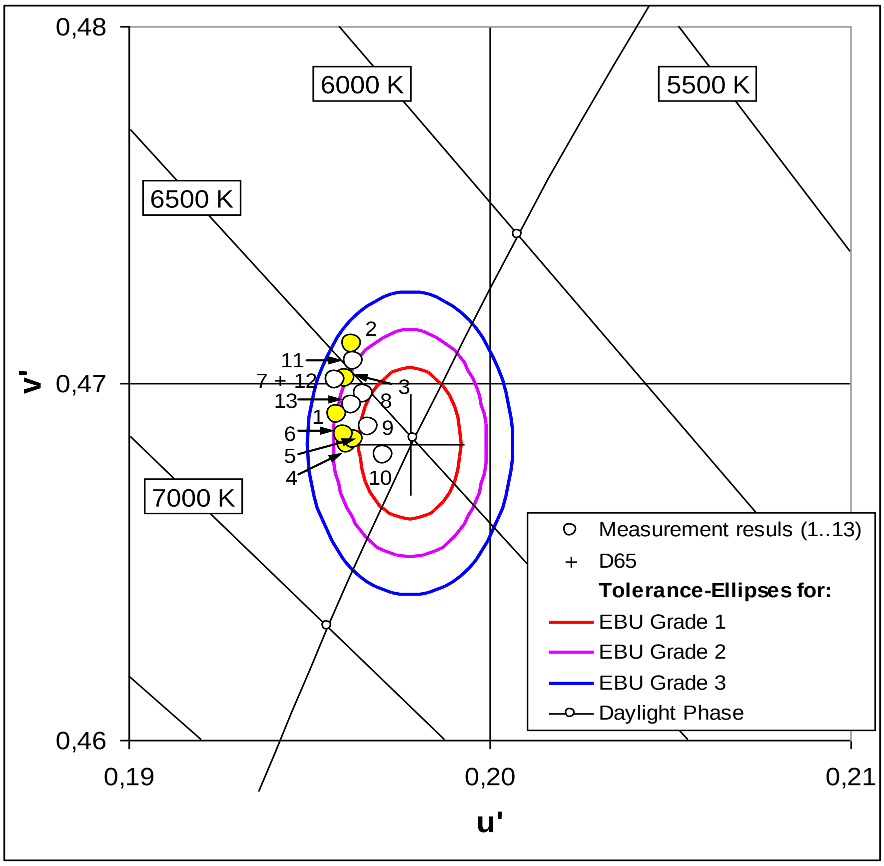


Figure 8: Gray-scale reproduction measurements results on tolerance ellipses.

The following diagram may be used where the points fall outside those above.

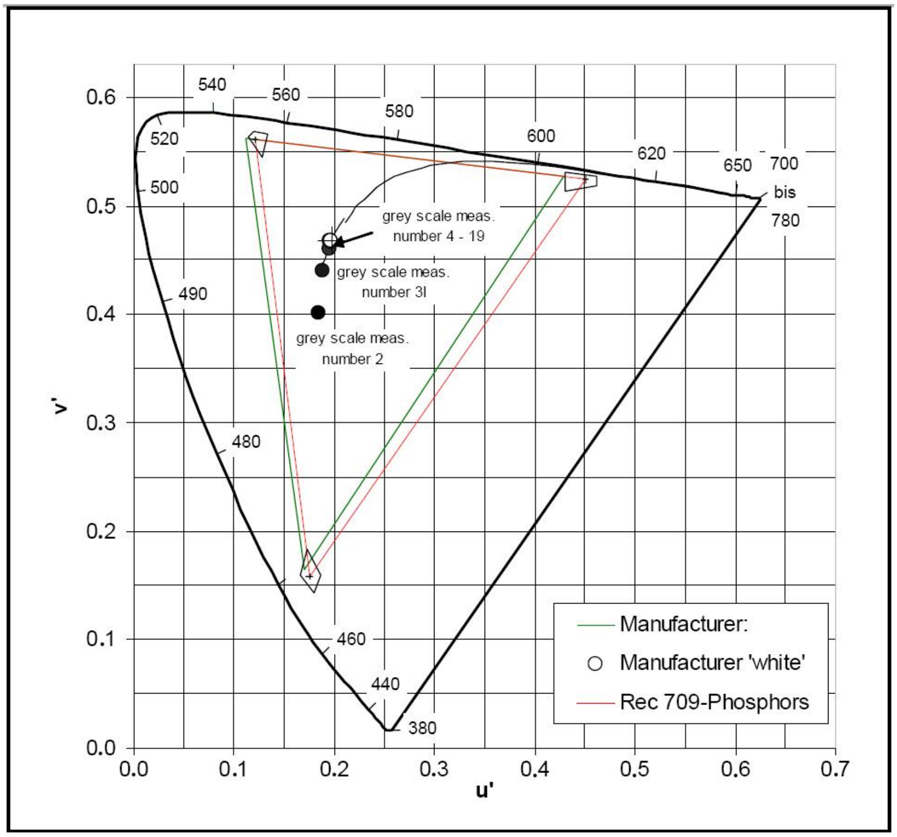


Figure 9: Gray-scale measurements.

2.5 Colour gamut and colour reproduction

2.5.1 Measurement conditions

The test inputs for colour gamut are test patterns 5-red, 5-green and 5-blue.

For this measurement it is essential that the measurement conditions described in 1.1 are correctly set.

The primary colour patches should be set to following digital (10-bit) values (HDSDI – Rec.709-5 part 2 [10]) calculated according to the procedure set out in ITU-R BT.1120 [11].

Note: *ITU-R BT.1361 [12] provides a procedure for this 8-bit to 10-bit calculation, but rounds down, whereas BT.1120 rounds to closest integer, which is to be preferred.*

Primary	D'_Y	D'_{CB}	D'_{CR}
Red	250	409	960
Green	691	167	105
Blue	127	960	471

Table 7: Primaries values for colour gamut and colour reproduction measurement.

A set of 15 EBU test colours was defined in EBU Tech 3237 and its supplement [13], based on certain Munsell chips, and these are also a useful set of test colours for characterising a display. Whilst these test colours were originally intended as camera input test colours, here we use these colours referred to the output of the display.

For the measurement of the EBU test colours (based on sample data given in EBU Tech 3237 and its supplement [13], and assuming a display gamma of 2.35) the field patches should be set to the digital 10-bit values given in the table below.

		10-bit code values at monitor input			Expected monitor output		
Sample	Description	D'_Y	D'_{CB}	D'_{CR}	Y (%)	u'	v'
EBU 1	Dark Skin	381	470	578	9.6	0.2530	0.5015
EBU 2	Light Skin	636	457	599	37.7	0.2366	0.4931
EBU 3	Light Greyish Red	582	478	592	29.8	0.2364	0.4848
EBU 4	Light Yellow Green	577	340	480	29.9	0.1807	0.5452
EBU 5	Light Bluish Green	579	544	411	29.8	0.1629	0.4552
EBU 6	Light Violet	586	597	543	30.1	0.2087	0.4157
EBU 7	Foliage	433	443	487	13.4	0.1813	0.5207
EBU 8	Medium Red	460	465	703	19.4	0.3248	0.4974
EBU 9	Medium Green	658	380	370	43.6	0.1505	0.5329
EBU 10	Medium Blue	470	639	468	17.2	0.1791	0.3706
EBU 11	Dark Red	319	490	616	6.5	0.3046	0.4895
EBU 12	Dark Green	487	422	396	19.9	0.1462	0.5321
EBU 13	Dark Blue	321	617	491	6.0	0.1825	0.3422
EBU 14	Medium Yellow Red	655	349	673	43.5	0.2726	0.5273
EBU 15	Medium Purple	494	601	593	20.0	0.2349	0.4034

Table 8: EBU test colour values.

These are provided as test patterns 5-1 to 5-15.

Measurement points: 1

Measurement equipment: Tristimulus meter or spectroradiometer equipment

2.5.2 Presentation of the Measurement results

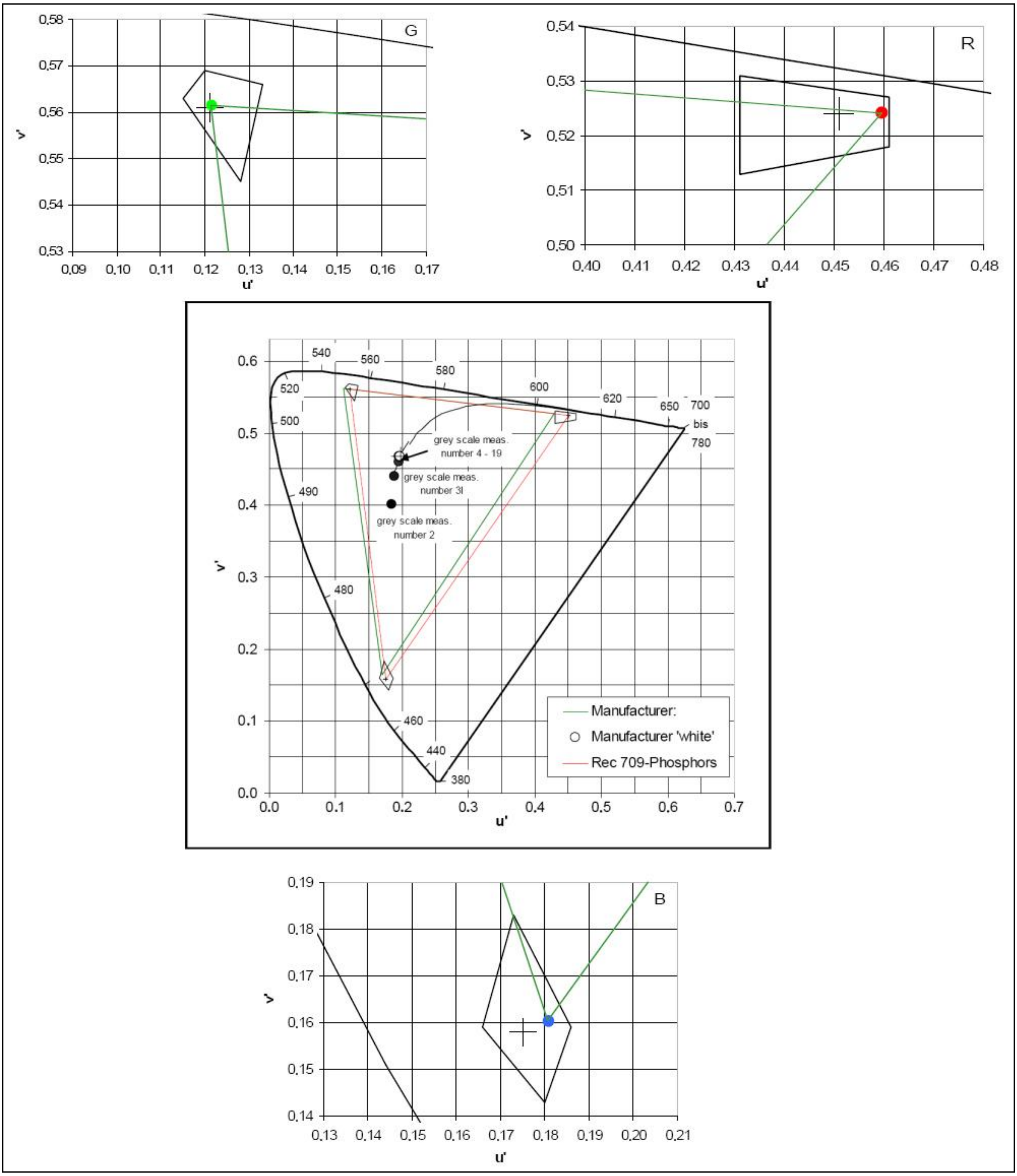


Figure 10: color gamut and color reproduction measurement results representation.

EBU Colour	Y (%)	u'	v'	Δu'	Δv'	ΔY(%)
1	9,6	0,2530	0,5015	0,00185	-0,00206	-0,202
2	37,7	0,2366	0,4931	0,00044	-0,00264	0,176
3	29,8	0,2364	0,4848	0,00043	-0,00265	0,159
4	29,9	0,1807	0,5452	-0,00188	-0,00164	0,112
5	29,8	0,1629	0,4552	-0,00181	-0,00254	-0,011
6	30,1	0,2087	0,4157	0,00030	-0,00174	0,004
7	13,4	0,1813	0,5207	-0,00152	-0,00169	-0,092
8	19,4	0,3248	0,4974	0,00366	-0,00257	0,031
9	43,6	0,1505	0,5329	-0,00270	-0,00301	0,257
10	17,2	0,1791	0,3706	-0,00103	-0,00311	-0,168
11	6,5	0,3046	0,4895	0,00874	-0,00227	-0,338
12	19,9	0,1462	0,5321	-0,00321	-0,00203	0,108
13	6	0,1825	0,3422	-0,00093	-0,01192	-0,324
14	43,5	0,2726	0,5273	0,00163	-0,00199	0,515
15	20	0,2349	0,4034	0,00118	-0,00292	-0,058

Table 9: Measurement results for EBU-test colours

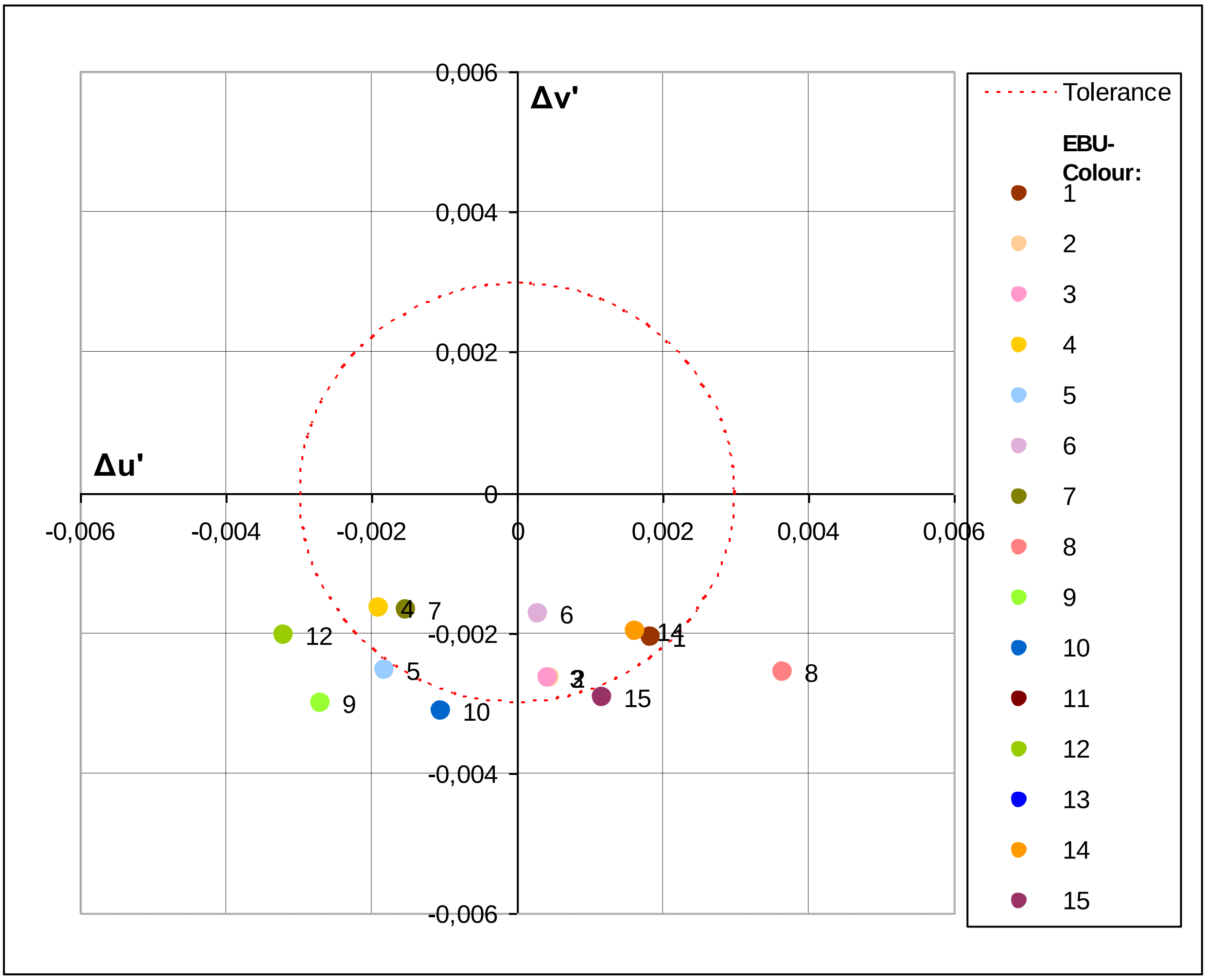


Figure 11: Measurement result representation in .

The following diagram may be used where the points fall outside those above.

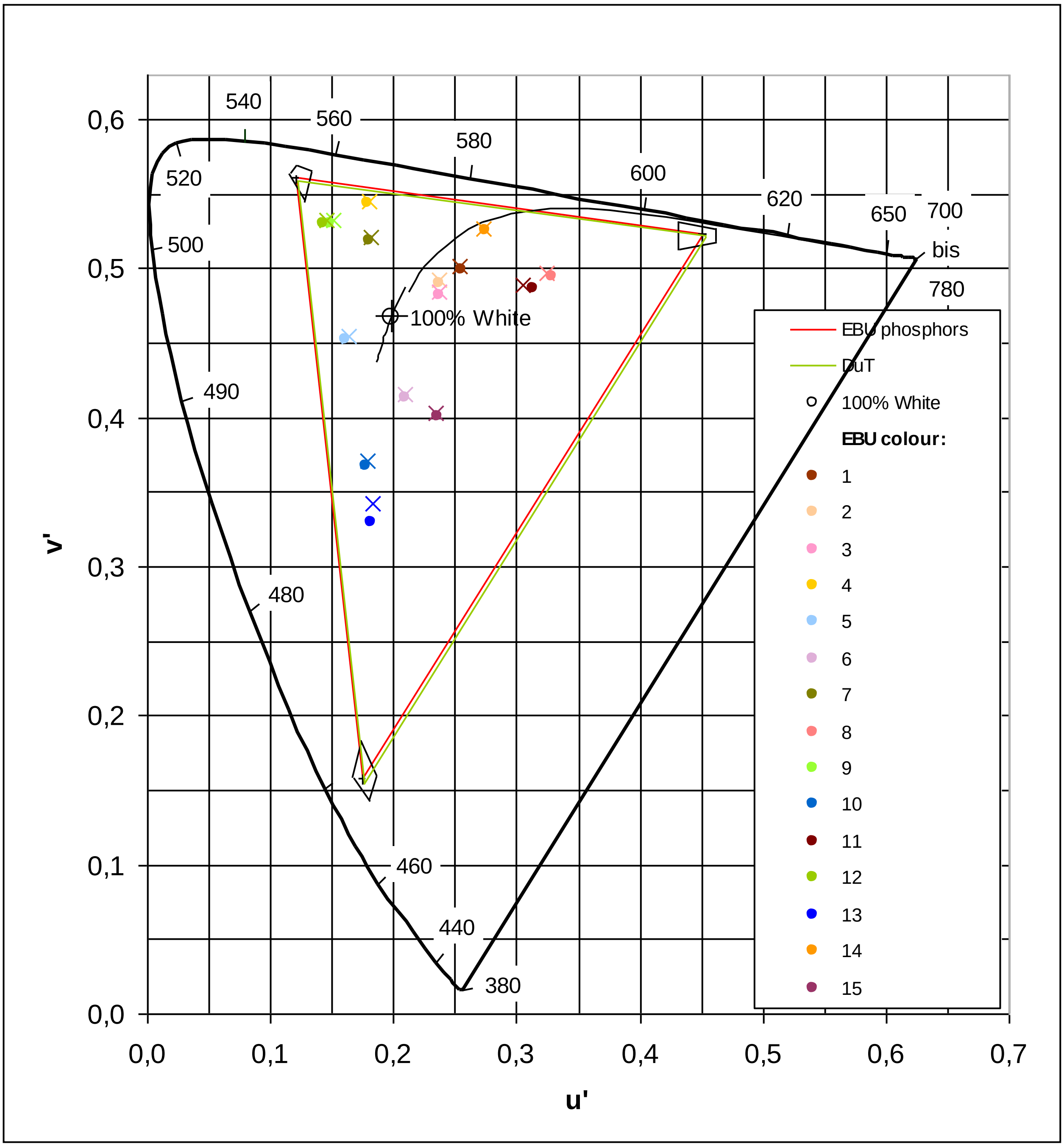


Figure 12: Measurement results representation 2 .

2.6 Colour temperature and uniformity

2.6.1 Definition of uniformity

Uniformity is defined as the evenness of light output and chromaticity over the picture area.

2.6.2 Measurement conditions – colour temperature

The input test signal is a test pattern having a 100% white field, such as test pattern 3-white. If the display is not able to maintain adequate output level with this pattern, test pattern 3, or test patterns 3-1 to 3-13, where only one patch at a time is illuminated, may be used. All measurements are made parallel to a line perpendicular to the centre of the display.

Measurement points: 1 to 13

Measurement equipment: Tristimulus meter or spectroradiometer equipment

2.6.3 Presentation of the Measurement results for colour temperature

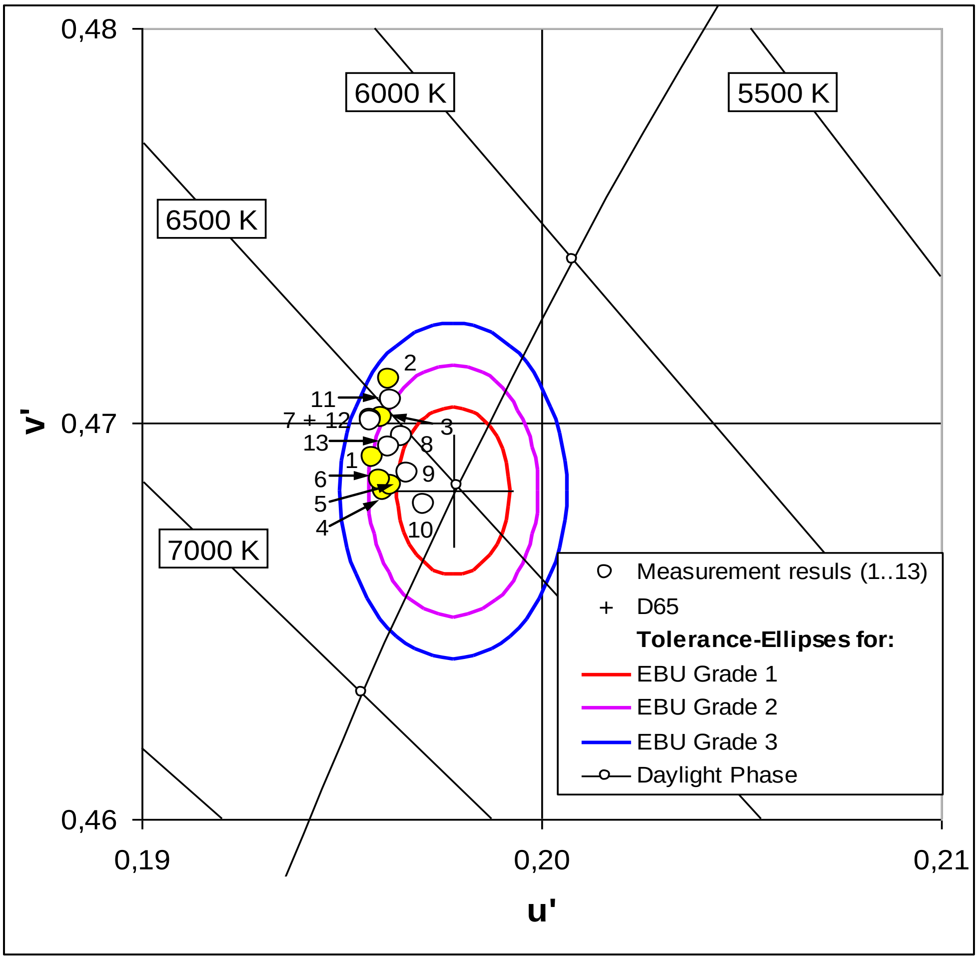


Figure 13: Color temperature measurements results representation on Tolerances ellipses.

2.6.4 Measurement procedure: Luminance large area uniformity

Measurements are to be carried out at all thirteen standardised positions within the screen area, and may be made at the same time as the chrominance measurements. The display should be driven with a peak white video signal across the whole field. A suitable signal is test pattern 3-white.

Measurement points: 1 to 13

Measurement equipment: Tristimulus meter or spectroradiometer equipment.

Presentation of results:

Luminance (Y)

Test point	cd/m2	% of pt 1
1	80.32	100%
2	80.32	100%
3	80.32	100%
4	80.32	100%
5	80.32	100%
6	80.32	100%
7	80.32	100%
8	80.32	100%
9	80.32	100%
10	80.32	100%
11	80.32	100%
12	80.32	100%
13	80.32	100%

Table 10: result representation for color temperature measurements.

2.7 Viewing-angle dependency

2.7.1 Measurement conditions

The test input is series of test patches in measurement position 1 (Figure 3) in the centre of an otherwise black field. The patch is a square of dimension H/7.5 (13.35 % of picture height, H), and level as per the table below. Test patterns 4-1, 4-2, 4-10 and 4-19 may be used.

Grey-scale Measurement Number	Luma level in 8-bit	Luma level in 10-bit
1	16	64
2	22	86
10	126	502
19	235	940

Table 11: Grey scale levels for viewing angle dependency measurement.

The measurements must take place in a darkened room, avoiding any extraneous light falling on the sensor.

Luminance is measured for grey-scale measurement numbers 1 and 19. Chrominance (in CIE 1976 u'v') is measured for grey-scale measurement numbers 2, 10 and 19.

A series of luminance measurements is taken over the horizontal range of viewing angles from -30° to +30° with the white patch (pattern 4-19), with vertical inclinations of 15 degrees below horizontal (-15°), horizontal (0°) and at 15 degrees above horizontal (+15°).

A series of luminance measurements is taken over the horizontal range of viewing angles from -45° to +45° with the black patch (pattern 4-1), with vertical inclinations of 20°, 0° and +20°.

A series of luminance and chrominance measurements is taken over the horizontal range of viewing angles from -45° to +45° with the white patch (pattern 4-19), with vertical inclinations of 20°, 0° and +20°.

A series of chrominance measurements is taken over the horizontal range of viewing angles from -45° to +45° with the grey patches (patterns 4-2 and 4-10) with vertical inclinations of 20°, 0° and +20°.

Measurement points: 1

Measurement equipment: Tristimulus meter or spectroradiometer equipment.

2.7.2 Presentation of the Measurement results

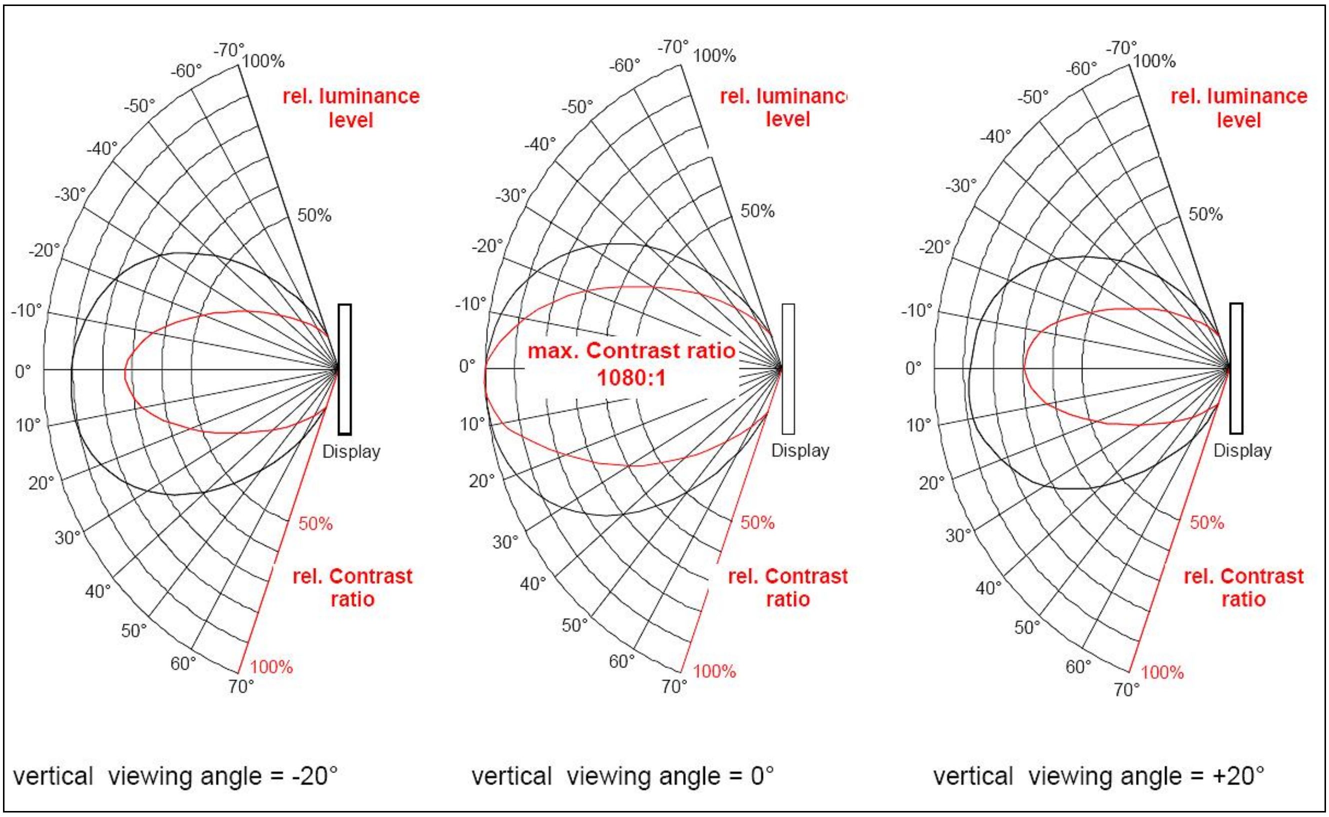


Figure 14: Viewing Angle Dependency.

The example above is for 20°, and the same diagrams are used for 15°.

For the chrominance measurements the results should be tabulated, and presented on diagrams as below.

		vertical									
		-20°		-15°		0°		+15°		+20°	
horizontal in °	Lum. in %	u'	v'	u'	v'	u'	v'	u'	v'	u'	v'
-50	3	0,1949	0,3935	0,1957	0,3959	0,1960	0,3972	0,1953	0,3954	0,1954	0,3973
	50	0,1970	0,4656	0,1971	0,4660	0,1976	0,4664	0,1979	0,4671	0,1976	0,4669
	100	0,1982	0,4701	0,1972	0,4698	0,1979	0,4696	0,1987	0,4699	0,1987	0,4698
-40	3	0,1949	0,3932	0,1936	0,3980	0,1961	0,3958	0,1961	0,3974	0,1964	0,3991
	50	0,1967	0,4656	0,1970	0,4665	0,1976	0,4675	0,1978	0,4684	0,1975	0,4671
	100	0,1994	0,4699	0,1976	0,4707	0,1989	0,4698	0,1974	0,4709	0,1989	0,4704
-30	3	0,1949	0,3935	0,1957	0,3959	0,1960	0,3972	0,1953	0,3954	0,1954	0,3973
	50	0,1970	0,4656	0,1971	0,4660	0,1976	0,4664	0,1979	0,4671	0,1976	0,4669
	100	0,1982	0,4701	0,1972	0,4698	0,1979	0,4696	0,1987	0,4699	0,1987	0,4698
-20	3	0,1941	0,3955	0,1945	0,3940	0,1957	0,3966	0,1947	0,3945	0,1968	0,3944
	50	0,1970	0,4654	0,1972	0,4654	0,1973	0,4660	0,1974	0,4662	0,1973	0,4661
	100	0,1981	0,4686	0,1980	0,4688	0,1978	0,4691	0,1988	0,4687	0,1975	0,4684
-10	3	0,1960	0,3916	0,1969	0,3942	0,1949	0,3925	0,1929	0,3889	0,1942	0,3921
	50	0,1969	0,4650	0,1969	0,4653	0,1972	0,4655	0,1974	0,4656	0,1971	0,4654
	100	0,1981	0,4676	0,1970	0,4684	0,1977	0,4686	0,1981	0,4691	0,1975	0,4686
0	3	0,1952	0,3918	0,1954	0,3904	0,1937	0,3963	0,1939	0,3961	0,1926	0,3891
	50	0,1972	0,4649	0,1970	0,4652	0,1970	0,4652	0,1972	0,4655	0,1969	0,4652
	100	0,1970	0,4685	0,1971	0,4694	0,1978	0,4683	0,1977	0,4681	0,1977	0,4684
10	3	0,1950	0,3862	0,1897	0,3606	0,1947	0,3926	0,1954	0,3942	0,1889	0,3723
	50	0,1971	0,4649	0,1971	0,4654	0,1968	0,4651	0,1970	0,4654	0,1967	0,4646
	100	0,1980	0,4687	0,1978	0,4678	0,1979	0,4683	0,1977	0,4687	0,1984	0,4673
20	3	0,1946	0,3943	0,1941	0,3831	0,1942	0,3931	0,1948	0,3939	0,1940	0,3928
	50	0,1970	0,4656	0,1970	0,4656	0,1970	0,4655	0,1972	0,4657	0,1966	0,4651
	100	0,1971	0,4687	0,1982	0,4691	0,1978	0,4678	0,1978	0,4689	0,1976	0,4685
30	3	0,1941	0,3937	0,1951	0,3951	0,1932	0,3948	0,1942	0,3950	0,1948	0,3951
	50	0,1970	0,4657	0,1972	0,4662	0,1972	0,4659	0,1971	0,4661	0,1967	0,4658
	100	0,1970	0,4694	0,1987	0,4686	0,1971	0,4701	0,1971	0,4700	0,1981	0,4693
40	3	0,1947	0,3946	0,1943	0,3931	0,1949	0,3980	0,1946	0,3950	0,1927	0,3873
	50	0,1969	0,4664	0,1971	0,4668	0,1970	0,4669	0,1972	0,4670	0,1967	0,4666
	100	0,1979	0,4694	0,1984	0,4698	0,1977	0,4695	0,1975	0,4704	0,1973	0,4694
50	3	0,1971	0,3984	0,1967	0,3997	0,1965	0,3965	0,1943	0,3962	0,1947	0,3922
	50	0,1970	0,4672	0,1970	0,4674	0,1970	0,4678	0,1973	0,4678	0,1969	0,4675
	100	0,1982	0,4699	0,1979	0,4709	0,1971	0,4708	0,1973	0,4716	0,1982	0,4699

Table 12:Chrominance Measurement result tabulated representation.

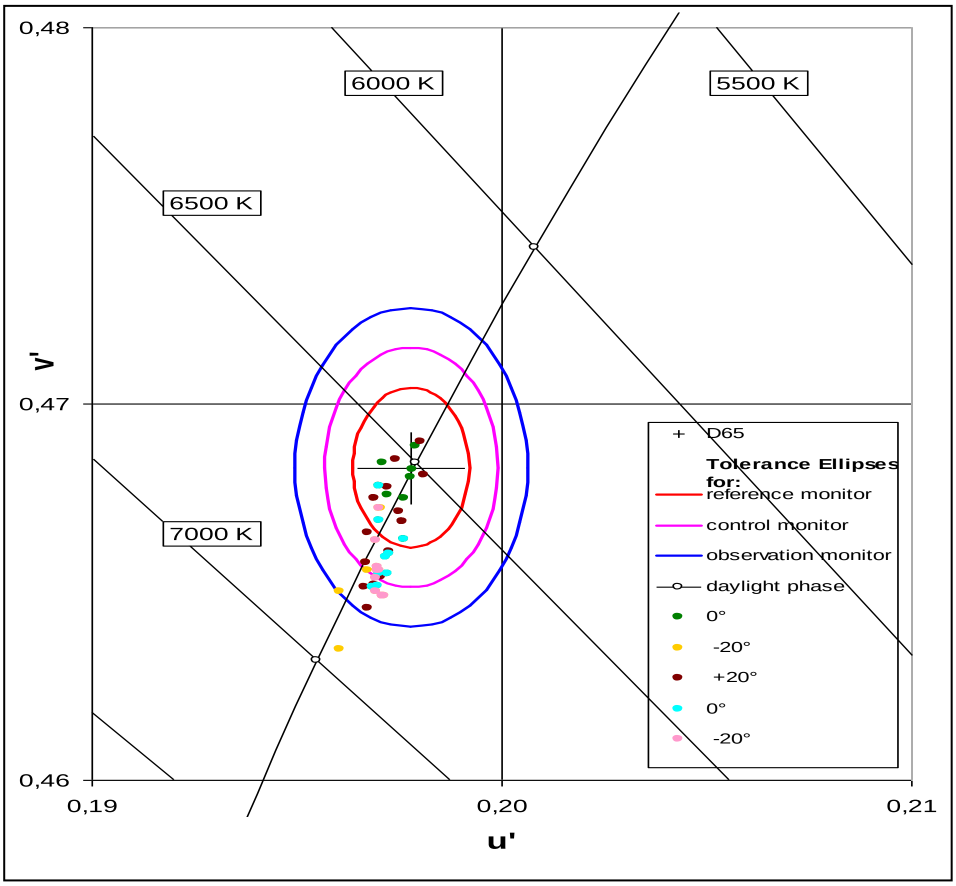


Figure 15: Gray level 50%

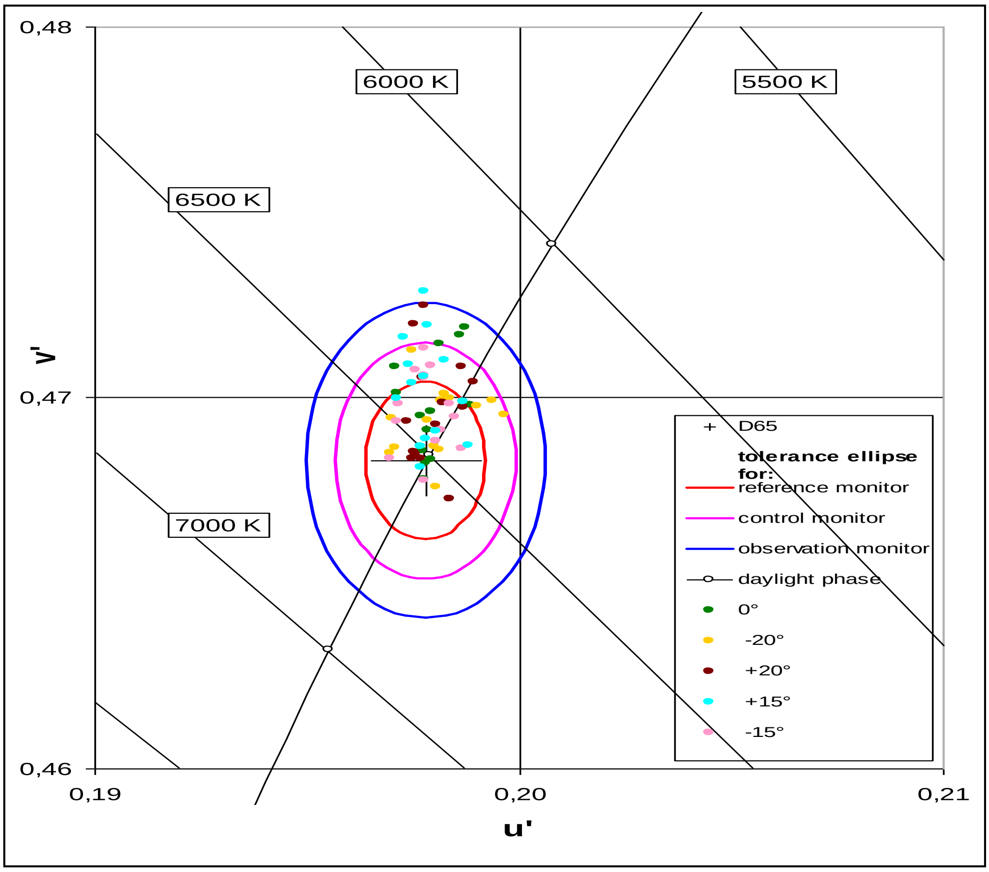


Figure 16: Grey Level 100%.

The following diagram may be used where the points fall outside those above.

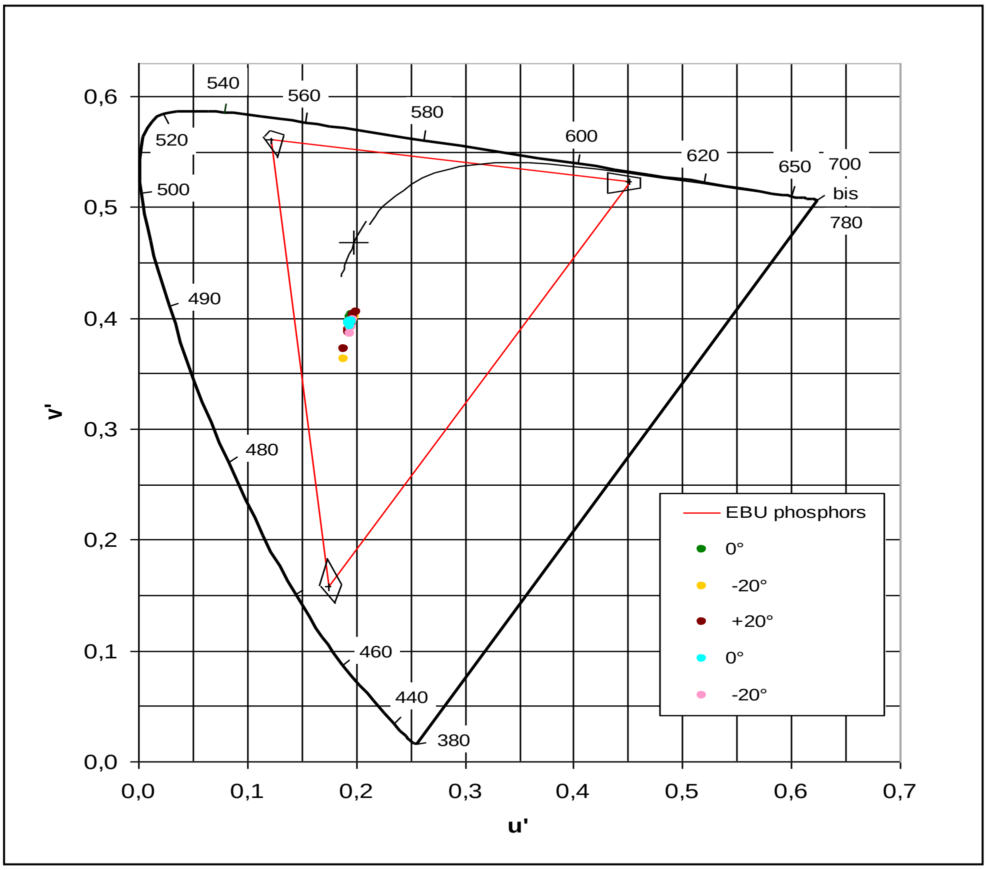


Figure 17: Gray Level 3%

2.8 Motion artefacts

At the present time (June 2008) a method for the quantitative measurement of motion artefacts cannot be recommended. Moving Picture Response Time (MPRT) measurement is a strong candidate, and is under development by VESA for FPDM2 [6]. The Institut fuer Rundfunktechnik is also working on measurement techniques.

To provide a visual check on motion rendition a test sequence with scrolling text is provided as test sequence 6.

2.9 Screen resolution

Whilst the manufacturers' data should indicate conformance with the requirement, a visual check of conformance can be performed by conducting a set of tests using (e.g.) test pattern 7,in 720x576, 1280x720 and 1920x1080 versions.

Presentation of results:

Resolution:	Manufacturers Data:	'x'	Confirmed: Yes ▫ , No ▫

2.10 Image scaling, de-interlacing and overscan

Test pattern 7 will also enable the visual confirmation of the scaling quality, overscan and, for HD progressive inputs, that the image is not inappropriately de-interlaced.

A valid conclusion of this test might be that the monitor is not suitable for monitoring signals that have a pixel structure that does not scale well to the native resolution of the display.

Test sequence 6, with scrolling text, is available as an aid to assessment of de-interlacing quality. PSF (progressive segmented frame) versions are provided for assessment of the display's ability to correctly display such material.

To test for the presence of a field dominance problem, test sequence 8, which includes a portion with field lines out of order, may be used.

Presentation of results (example):

Test signal:	1920x1080i	1280x720p	720x576i
Scaling quality (Overscan off):	Appears to be unscaled - good	Some slight ringing on horizontal edges	Poor, with multiple aliases
Interlace material displayed native?	Yes ▫ , No ▫	N/A	Yes ▫ , No ▫
De-interlacing modes: Short delay display mode: normal display mode:	 Some compromises evident Good	 N/A 	 Poor – very blurred Good
Film mode/ psf detection: Short delay display mode: normal display mode:	 Yes ▫ , No ▫ Yes ▫ , No ▫	 N/A N/A	 Yes ▫ , No ▫ Yes ▫ , No ▫
Field dominance problem exhibited?	Yes ▫ , No ▫	N/A	Yes ▫ , No ▫
Entire picture seen with overscan off?	Yes ▫ , No ▫	Yes ▫ , No ▫	Yes ▫ , No ▫
Overscan mode available?	Yes ▫ , No ▫	Yes ▫ , No ▫	Yes ▫ , No ▫

Table 13: Image scaling, de-interlacing and overscan measurement result representation.

2.11 Delay time

A variety of methods can be used to measure the delay between the arrival of the electrical signal and its appearance on the screen. A scanning display will have a different characteristic from a display that reads a whole frame before displaying it.

For the following measurements, test signals 9-top and 9-centre are used. These contain five lines of peak white in a single field (i.e. a white flash in an otherwise black signal). The transition between black and white is at the top of the screen (9-top) for the first measurement and at the middle of the centre line (9-centre) for the second measurement.

Manufacturers are requested to explicitly state the delay time relating to the top line of the screen, and so the delay at this point on the screen should be measured:

Note: The delay reported should be the time between the arrival of the timing transition in the serial electrical signal at the monitor input and the moment at which the light output from the screen has risen to 50% of its final value.

The most important issue is that of lip-sync and to assess this, a second test position at the centre (both vertically and horizontally), of the screen is used.

Note: The delay reported should be the time between the arrival of the timing transition in the serial electrical signal representing the middle line of the image at the monitor input and the moment at which the light output from the screen has risen to 50% of its final value.

Any variation between these two measurements is interesting as part of the understanding of the delay characteristic of the screen.

The usual test method to detect the light output from the screen will involve the use of a photo-diode that only covers a few display lines. The time delay between the electrical and optical signals is determined on an oscilloscope. Since the delays concerned are of the order of ms, the ramp-up of the photo diode detector (of the order of 100s of µs) as the 5 lines are illuminated in sequence is not significant. Any A-to-D or D-to-A converters that are included in the test arrangement should be tested to confirm that they have negligible delay, or that their delay is accounted for.

A block diagram showing the possible arrangement of the equipment is shown below.

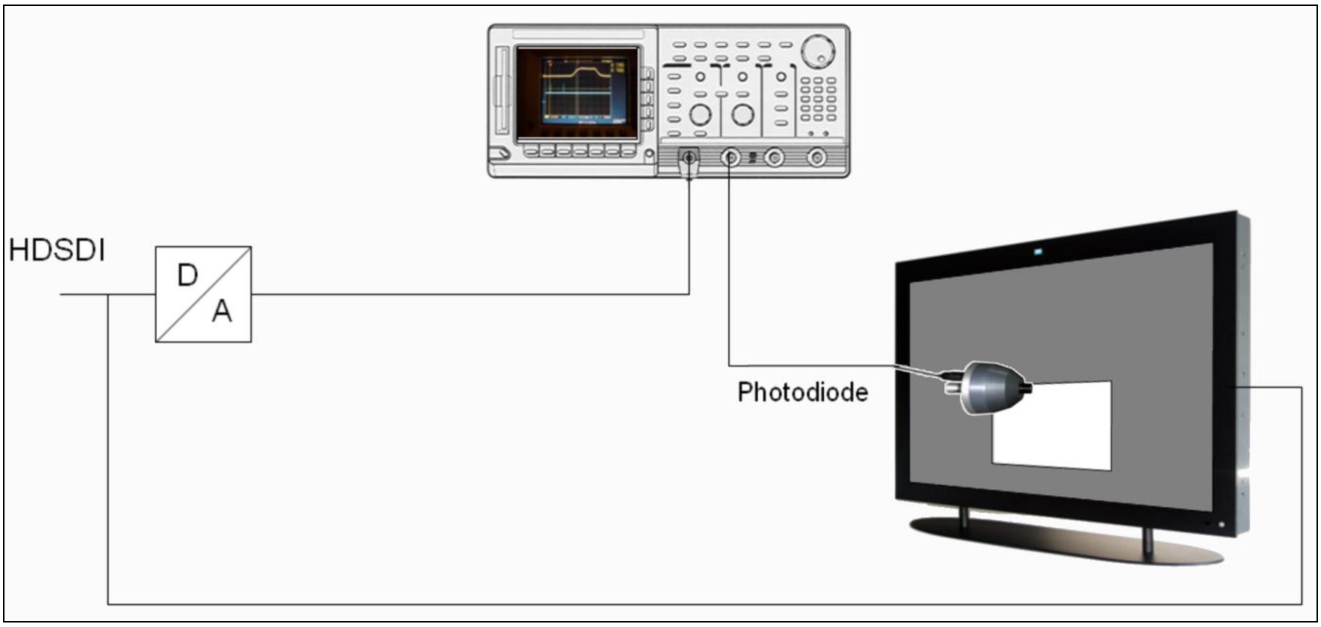


Figure 18: Arrangement of equipment for measurement of A/V delay.

Presentation of results:

Test signal:	1920x1080i/25	1280x720p/50	720x576i/25
Short delay display mode:	Top: delay: . . . . ms Centre: delay: . . . . ms	Top: delay: . . . . ms Centre: delay: . . . . ms	Top: delay: . . . . ms Centre: delay: . . . . ms
Normal display mode:	Top: delay: . . . . ms Centre: delay: . . . . ms	Top: delay: . . . . ms Centre: delay: . . . . ms	Top: delay: . . . . ms Centre: delay: . . . . ms

Table 14: Delay Measurement results representation.

2.12 Mura (imperfections in LCD panels)

VESA FPDM2 [6] section 301-3D defines a suitable test procedure.

2.13 Streaking (also known as overspill or shadowing)

The method and reporting format specified in VESA FPDM2 section 303-4 should be used.

2.14 Stability

Stability of black level, white level and colour temperature should be measured regularly over the first 30 minutes, and then at intervals over a period of 24 hours. Results for black and white levels should be normalised to 100% and plotted against time. Colour temperature variations with time should be plotted on a diagram shown in section 2.6 above. Any variation in black level visible using PLUGE should be reported.

2.15 Pixel defects

Pixel defects, classified according to ISO 13406-2 [14], should be reported.

2.16 Ringing and handling of under- and over-shoots

A visual check at a viewing distance of 1H is made using test pattern 10. The inverse of this video pattern (pattern 10-r) may additionally be used. Any visible ringing or overshoots generated by the display should be reported.

If sub-black and super-white patches of a test signal (for example, test pattern 7) are not reproduced, this should be reported, since it indicates that overshoots present in the signal may be disguised.

2.17 Treatment of illegal signals

Hyperbolic zone plates such as those in test pattern 7 provide a useful indication of the behaviour of a display in handling frequency components beyond the theoretical channel limit.

A test pattern (e.g. test pattern 11) that includes illegal colours should be used to check how the display handles such colours.

2.18 Image sticking (long-term after-image)

The luminance levels are measured on a 50% grey field (test pattern 12-grey) at measurement locations 9 and 12. A test pattern having 90% grey on the left hand side of the screen and 10% grey on the right (and with a gentle transition at the join – test pattern 12-burn) is displayed for 1 hour. Then the 50% grey field is displayed for 1 hour. At the end of that time the measurements are repeated, and the results tabulated.

If image sticking or burn-in appears to be an issue, the user might, in consultation with the manufacturer, consider conducting a test such as that specified in VESA FPDM2 [6] section 305-2.

2.19 Signal interfaces

Measurements of conformance to interface standards may be undertaken as specified in the relevant interface standards documents. For SDI interfaces, EBU R57-1998 [15] is relevant. Testing for conformity with ITU-R Recs BT.601 and BT.656.

2.20 *Acoustic Noise*

Acoustic noise standards used are the Noise Rating (NR) curves defined by Kosten and van Os [13] and standardised in now withdrawn versions of ISO 1996. An example of the presentation of results is shown below.

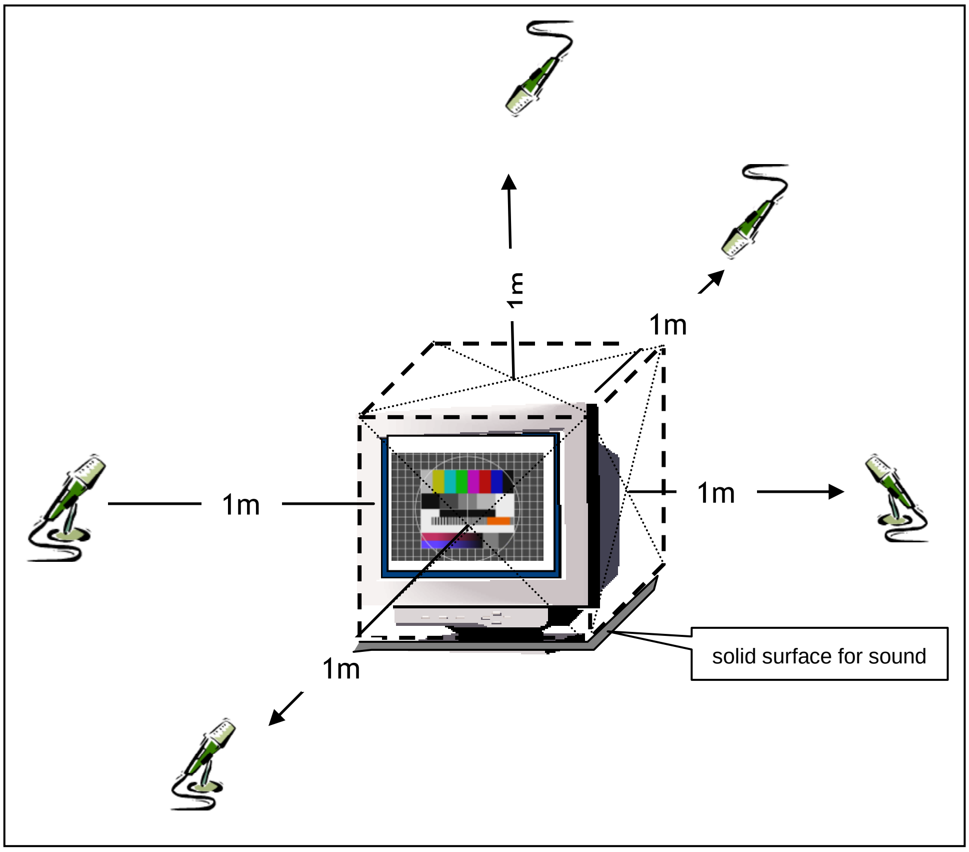


Figure 19:Measurement positions for Acoustic noise.

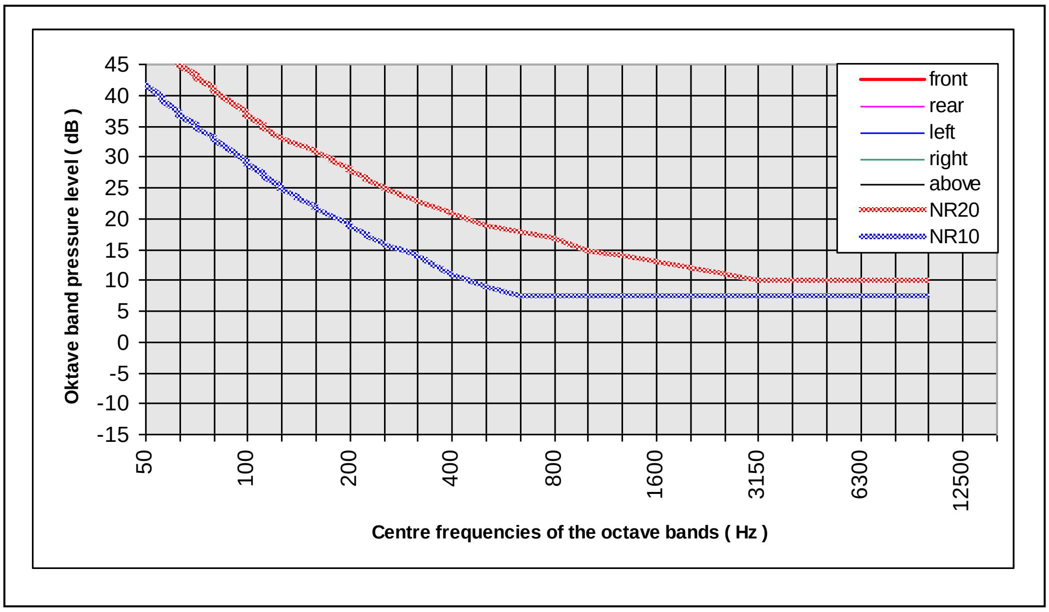


Figure 10:Noise Rating (NR) Curves

References

[1]	EBU Tech 3213	"EBU Standard for Chromaticity Tolerances for Studio Monitors"
[2]	ITU-R BT.709	"Parameter values for the HDTV standards for production and international programme exchange"
[3]	BBC RD 1995/10	"A method for the calculation of tolerances for display primary chromaticity coordinates" – Roberts.
[4]	SMPTE RP 145-2004	"Color Monitor Colorimetry"
[5]	ITU-R BT.815	"Specification of a Signal for Measurement of the Contrast Ratio of Displays"
[6]	VESA FPDM2	"Video Electronics Standards Association (VESA): Display Metrology Committee (DMC) I"Flat Panel Display Measurements Standard"
[7]	ITU-R BT.814-2	"Specifications and Alignment Procedures for Setting of Brightness and Contrast of Displays"
[8]	EBU R23	"Procedure for the operational alignment of Grade-1 colour picture monitors"
[9]	IEC 60107-1:1997	"Methods of measurement on receivers for television broadcast transmission. General considerations. Measurements on displays at radio and video frequencies"
[10]	ITU-R BT.709-5-	"Parameter Values for the HDTV Standards for Production and International Programme Exchange"
[11]	ITU-R BT.1120	"Digital interfaces for HDTV studio signals-(Question ITU-R 42/6)"
[12]	ITU-R BT.1361	"Worldwide Unified Colorimetery and Related Characteristics of Future Television and Imaging Systems"
[13]	EBU Tech 3237	"Methods of measurement of the colorimetric fidelity of television cameras"
[14]	ISO 13406-2	"Ergonomic requirements for work with visual displays based on flat panels -- Part 2: Ergonomic requirements for flat panel displays"
[15]	EBU R57-1998	"Testing for conformity with ITU-R Recs BT.601 and BT.656"
[16]	Kosten and van Os	"Community reaction criteria for external noises," National Physical Laboratory Symposium, No. 12, 1962, p. 377, London H.M.S.O.

Annex 1: Calculation procedures for Gamma

For luminance Y-or R,G,B –gamma (γ):

For 8 Bit Systems

$$\gamma_N = \frac{\log\left[\frac{(L_N - L_{MIN})}{L_{MAX}}\right]}{\log\left[\frac{(Y_{IN} - 16)}{(235-16)}\right]}$$

Equation 3: gamma equation for 8bit systems.

For 10 Bit Systems :

$$\gamma_N = \frac{\log\left[\frac{(L_N - L_{MIN})}{L_{MAX}}\right]}{\log\left[\frac{(Y_{IN} - 64)}{(940-64)}\right]}$$

Equation 4: Gamma calculation for 10bit systems.

Y_{IN} = Input signal level for 8-bit (from 16 to 235) or 10-bit (from 64 to 940) systems.

L_N = luminance or R,G,B measurement samples (in cd/m^2) for N ={10%,20%, …,90%} grey level.

L_{Max} = measured luminance or R,G,B with an input signal $Y_{235/940}$ in cd/m^2

Annex 2: Calculation procedures for Chromaticities

Chromaticity coordinates in the CEI 1931 colour space can be obtained for each primary from the tristimulus values:

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

Equation 5: Equations of tristimulus values.

The third coordinate, z, is not required since x + y + z = 1. For television purposes, it is more customary to use coordinates in the CIE 1976 colour space, derived either by transformation from x and y or, more-directly, from the tristimulus values:

$$u' = \frac{4x}{-2x+12y+3} = \frac{4X}{X+15Y+3Z} \qquad v' = \frac{9y}{-2x+12y+3} = \frac{9Y}{X+15Y+3Z}$$

Equation 6: CIE 1976 colour space coordinates derivation equations base don tristimulus values.

The u’v’ coordinates can be plotted directly on a chromaticity diagram as shown in Figure 7, and the results presented as shown in Chapter 3.

The three quadrilaterals shown in the CIE 1976 u’v’ (Figure 7), define the tolerances allowed for each of the three primaries. The exact coordinates of each corner of the tolerance quadrilaterals are listed in the table at the bottom of Figure 7.

For the calculation of colour reproduction errors and the presentation of white-uniformity results, these coordinates should also be transformed into CIELuv units. This system is preferred because it more-closely relates objective measurements to subjective experience. The units are:

$$L* = 116(Y \mid Y_0)^{1/3} - 16$$

$$u* = 13L*(u' - u'_0) \qquad v* = 13L*(v' - v'_0)$$

Equation 7: CIE Luv units equations.

where:

Y_0 = 1,
u'_0 = 0.1978,
v'_0 = 0.4683

these being the values for the television system white point, D_{65}.

A further value C* can be derived, this being the correlate of subjective chroma; it is similar to television saturation:

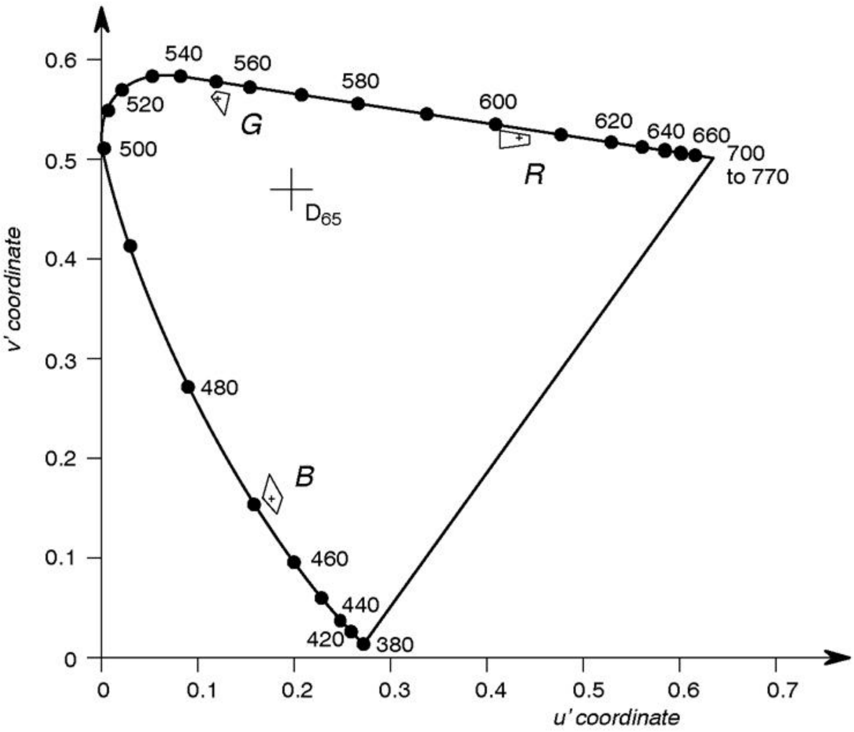
$$C* = u^{*2} + v^{*2\ldots1/2}$$

Equation 8: Chroma correlate equation.

The results should be given in difference units, for example:

$$\Delta L* = L*_d - L*_s$$

Equation 9: Units difference.



Primary	Coordinates	
	u’	v’
Red	0.451	0.524
Green	0.121	0.561
Blue	0.175	0.158
D_{65}	0.1978	0.4683

Primary	Coordinates of corners of tolerance quadrilaterals							
	u'_1	v'_1	u'_2	v'_2	u'_3	v'_3	u'_4	v'_4
Red	0.461	0.527	0.461	0.518	0.431	0.513	0.431	0.531
Green	0.113	0.566	0.128	0.545	0.115	0.563	0.120	0.569
Blue	0.186	0.159	0.180	0.143	0.166	0.159	0.173	0.183

Figure 20: Intrinsic chromaticity tolerances for the standardised primaries.