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USER REQUIREMENTS FOR VIDEO MONITORS IN TELEVISION PRODUCTION

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Conformance Notation

This document contains both normative text and informative text.

All text is normative except for that in the Introduction, any section explicitly labeled as 'Informative' or individual paragraphs which start with 'Note:'.

Normative text describes indispensable or mandatory elements. It contains the conformance keywords 'shall', 'should' or 'may', defined as follows:

'Shall' and 'shall not':	Indicate requirements to be followed strictly and from which no deviation is permitted in order to conform to the document.
'Should' and 'should not':	Indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others. OR indicate that a certain course of action is preferred but not necessarily required. OR indicate that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.
'May' and 'need not':	Indicate a course of action permissible within the limits of the document.

Informative text is potentially helpful to the user, but it is not indispensable and it does not affect the normative text. Informative text does not contain any conformance keywords.

Unless otherwise stated, a conformant implementation is one which includes all mandatory provisions ('shall') and, if implemented, all recommended provisions ('should') as described. A conformant implementation need not implement optional provisions ('may') and need not implement them as described. Where a monitor can only reproduce one of the HDR options in ITU-R BT.2100 (HLG OR PQ) then that monitor shall be considered conformant if it satisfies all the conditions for that option (HLG OR PQ) for the targeted Grade (Grade 1A or Grade 1B or Grade 2).

Contents

User Requirements for Video Monitors in Television Production

EBU Committee	First Issued	Revised	Re-issued
(PMC) ECV, BHD, VS	2007*	2008, 2010, 2014, 2017	

Keywords: User Requirements, Professional Video Monitors, Television Production

Scope

This document defines classes of broadcast video monitors, and their application areas in television production. It also defines the technical characteristics required for these monitors. EBU Tech 3325 specifies the measurement methodologies for each of the parameters described here.

Broadcast monitors are used in a professional TV production environment for evaluation and control of the images being produced, and as such shall provide reliable and repeatable results.

The purpose of a monitor is to display the signal as it is, and it shall not attempt to 'enhance' or otherwise alter the image. It is therefore unlikely that consumer devices will be able to meet these requirements for use in a television production environment. Home television receiver requirements and monitor requirements for computer and data processing techniques are not within the scope of this document.

It should be noted that the HDR Standards referred to in Part 2, are still relatively immature and it is expected that updates and revisions to these Standards documents will occur. This document represents the requirements of EBU members. It will be revised as and when needed to reflect the published versions of the HDR Standards documents and internationally agreed best industry practice.

Structure

Part 1 Describes the HDTV monitor with Standard Dynamic Range capabilities (e.g. Grade 1 SDR).

Part 2 Describes the HDTV and UHDTV monitor with High Dynamic Range and Wide Colour Gamut capabilities (e.g. Grade 1 HDR).

Annex A Describes the Gamma (EOTF) considerations that apply within this document.

Annex B Contains explanations on the tolerance space L*u*v*.

Annex C Contains a checklist that can be used when assessing a monitor's performance.

Annex D Discusses concerns and possible solutions regarding discrepancies observed between colour measurements of and visual perception on different types of display technology.

* First issued in May 2007. Re-issued as version 1.0a with corrected chapter numbering in June 2007.

1. High Definition, Standard Dynamic Range

1.1 Definition of a Grade 1 monitor

Grade 1 monitors are devices for high-Grade technical quality evaluation of images at key points in a production or broadcast workflow. They are used for critical evaluation during image capture, post-production, transmission and storage. As a minimum requirement, these monitors shall have the quality properties of the image system they are used to evaluate. It is expected that all applied technologies are state-of-the-art at this level. This means that artefacts should not be unduly masked nor should additional artefacts be introduced.

As a reference device, the settings of this type of monitor should be adjustable as well as lockable (mechanically or electrically), so that only authorized access is possible.

The Grade 1 monitor is a ‘measuring instrument’ for visual evaluation of image quality. Therefore, it would be highly desirable for the monitor to be able to reproduce the native scanning mode of the presented signal (i.e. progressive or interlaced) or as it is intended to be viewed (e.g. 50 Hz presentation of 25p material).

Typical applications for Grade 1 monitors are for example camera control, colour grading and quality control, and possibly lighting control positions. These are areas where video technical quality parameters are evaluated, controlled, and corrected as needed.

1.2 Definition of a Grade 2 monitor

A Grade 2 monitor may have wider specification tolerances than a Grade 1 monitor, and as such, can be priced significantly lower, or be smaller in size or weight than a Grade 1 monitor. Grade 2 monitors are used in applications where the tighter tolerances of a Grade 1 monitor (for example on accuracy of colour reproduction and stability) or the additional features of a Grade 1 monitor, are not necessary.

Grade 2 monitors are usually used for image preview, control walls, edit suites, and control rooms where no picture quality manipulation is carried out.

It should be possible for Grade 2 and Grade 1 monitors to be used together, for example in television production control walls.

1.3 Definition of a Grade 3 monitor

Grade 3 (observation or presence) monitors are devices equivalent in many respects to high end domestic or consumer displays. The important considerations for use in television production applications include the availability of professional interfaces, mechanical robustness (including the ability to mount in racks or stacks), transportability, electromagnetic compatibility and acoustic noise level.

Grade 3 monitors are typically used in audio production and dialogue dubbing areas, signal presence monitoring, commentator positions and displays for the audiences in television studios.

1.4 Special application of displays

1.4.1 Viewfinder monitors

Monitors used as viewfinders for television cameras are in many respects similar to Grade 2 monitors. Picture quality requirements such as geometry and stability are important. A higher maximum brightness will be required, to allow for very different ambient lighting conditions and as a viewfinder, then monitor shall provide facilities to assist in focus adjustment.

1.4.2 Displays used in vision[1]

Television productions often use modern flat panel displays “in vision”, for example to produce large in-shot images as part of the set design. The unique factors for such monitors include the ability to match studio lighting (i.e. tungsten light, white balanced to 3200 K). They should also have a particularly wide viewing angle and low delay.

1.4.3 Displays used in location shooting, or on set/studio floor

These monitors are used by the director, director of photography, or lighting cameraman, on set, both indoors and outdoors, for viewing material directly from the camera. There is a potential requirement for such monitors to include the ability to simulate grading or other post-production processes. The video data from the camera may for example be raw, logarithmic data, rather than matrixed and gamma-corrected data, and the director may therefore wish to preview a simulation of the intended output appearance that will be achieved at a later stage in the production workflow.

1.5 Requirements

Note: The specifications in this section are to be measured in accordance with EBU Tech 3325 [8]. All specifications shall be capable of being met simultaneously.

1.5.1 Luminance ranges

The monitor should provide an adjustable pre-set level and include the ability to produce a reference luminance level. This should be capable of adjustment so that the 100% luminance (see Notes 1, 2 &3) on the screen can be set to provide luminance levels within the ranges:

Grade 1 Monitor:	70 to at least 100 cd/m^2 (Note 4).
Grade 2 Monitor:	70 to at least 200 cd/m^2.
Grade 3 Monitor:	70 to 250 cd/m^2 or to 400 cd/m^2 in adverse conditions.

Note 1: 100% luminance on the screen corresponds to a 10-bit luma signal of digital level 940, and the black level corresponds to a 10-bit luma signal of digital level 64. The highest value of 10-bit luma signal is digital level 1019. The luma level 1019 is called ‘Super-white’ or ‘109% white’, by the formula (1019 - 64)/(940 - 64) = 1.09.

Note 2: 100% luminance on the screen is defined as the luminance of a luma signal of digital level 940, but levels 941 through 1019 should also be correctly displayed and should track any adjustment made to the 100% luminance level.

Note 3: The 100% luminance is measured on a white patch occupying the central 13.13% horizontally and vertically (as described in EBU Tech 3273, § 3.5), perpendicular to the centre of the screen.

Note 4: ITU-R BT.500-11 requires monitor brightness up to 200 cd/m^2 for tests simulating domestic viewing conditions.

Note 5: Automatic brightness limiters shall not be used for Grade 1 or Grade 2 Monitors.

[1] These are commonly referred to as “Practical Displays”.

1.5.2 Black level

The luminance level measured from a full screen 10-bit luma signal at digital level 64 should be adjustable to be:

Grade 1 Monitor:	below 0.05 cd/m^2.
Grade 2 Monitor:	below 0.4 cd/m^2.
Grade 3 Monitor:	below 0.7 cd/m^2.

It shall be possible to adjust black level with a PLUGE test signal (which includes sub-black portions) according to the procedure outlined in ITU-R Rec. BT.814. It is expected that Grade 1 and 2 monitors will be used in control rooms with subdued lighting, for example ISO 12608 *'Cinematography - Room and conditions for evaluating television from telecine reproduction'*.

The black level shall also be adjustable between the minimum achievable and 1 cd/m^2. Levels below black (i.e. levels between 4 and 64 in 10-bit systems) shall not be clipped and shall therefore become visible, subject to appropriate ambient lighting levels.

Care shall be taken to avoid veiling glare in the measurement instrument, by the use of a mask or a frustum, as described in EBU Tech 3325 [8].

Note: If the viewing conditions are standard dim surround (15% as in ITU-R Rec. BT.500-11) then the remission factor of the display shall also be considered:

- *The remission factor is the sum of absorption and reflection of a surface.*
  - *The remission value (also called remission factor) is the ratio between reflected light from the surface of the monitor (display off) and the reflected light from a reference white surface under the same condition, whereby a diffuse light source is used.*
  - *The reflection is measured with angle of -45° perpendicular to the screen with a light source at an angle of +45°. Remission is measured perpendicular to the screen with a light source at an angle of +45°.*

In the case of a CRT, it appears that the black level measured with the screen switched off, in a typical production environment, is between 0.05 and 0.1 cd/m^2, and about 0.01 cd/m^2 higher with the screen switched on.

For a typical LCD the remission factor is significantly lower and so a higher light output at black can be tolerated. It is the sum of the reflected light and of the transmitted light which is the important factor in a typical (dim surroundings) production environment.

Modulation of the back light of a transmissive display (global or local dimming) to improve the black-level performance shall neither cause visible artefacts (even if the monitor is viewed from very close viewing distances) nor hide artefacts present in the signal being monitored. If such a feature is present on the monitor it shall be possible to disable the function. It may in the future be necessary to define additional requirements and test conditions to characterise any monitors using these techniques.

1.5.3 Contrast ratio

Depending on the luminance level set for 100% white, the following full screen contrast ratio may be achieved in relation to the appropriate minimum black level.

Full screen (1% patch) contrast ratio shall be:

Grade 1 Monitor:	above 2000 to 1 (1400 to 1 with 100% white at 70 cd/m^2)
Grade 2 Monitor:	above 500 to 1
Grade 3 Monitor:	above 300 to 1 (142 to 1 with 100% white at 100 cd/m^2, since black may be 0.7 cd/m^2)

Simultaneous contrast ratio (with EBU box pattern) should be:

Grade 1 Monitor:	above 200 to 1
Grade 2 Monitor:	above 100 to 1
Grade 3 Monitor:	above 100 to 1

Note: 'Full screen (1% patch) contrast' is defined in EBU Tech 3325 [8].

1.5.4 Gamma characteristics

1) The luminance gamma characteristic (electro-optical transfer function) of the screen should be equivalent to that of a reference CRT with the rendering intent (dim-surround) expected of a TV system. It is recommended that a nominal value of 2.4 be used.

See **Annex A** and the Important Note below.

2) The transfer functions of the green, red and blue components of the monitor shall be sufficiently similar as to meet the requirements of § 5.5 below.

3) The ideal electro-optical transfer function shall be followed (for Grade 1 and Grade 2 Monitors) such that it remains within a tolerance of ±0.10 of the ideal gamma value from 10% to 90% of input signal level, using the analysis technique described in EBU Tech 3325 [8]. The transfer function shall remain monotonic throughout the full signal range. For Grade 1 and Grade 2 Monitors, a 10-bit input signal shall result in a 10-bit presentation on the screen (always allowing that only 877 video levels are specified between black and 100% white).

Note: The electro-optical transfer function of a monitor is based on the following requirements:

Whilst the camera may have a nominal opto-electrical transfer function according to ITU-R Rec. BT.709, this is in practice modified by the intention of the director in camera control or in grading.

The television system has been deliberately designed with an end-to-end system gamma of about 1.2, to provide compensation for the 'dim surround' effect [6]. Therefore, the monitor gamma is not, and never has been, the inverse of the camera gamma.

The reference for archived and, until recently, for current programmes has been a Grade 1 CRT monitor.

The measurement is made in a completely darkened room, and the display shall be correctly set up using the PLUGE signal under those conditions. The measurement conditions are thus different from normal operational conditions.

Any new monitor technology should retain the same electro-optical transfer function that has historically been used.

BBC R&D Report RD 1991/6, ‘Methods of measuring and calculating display transfer characteristics (gamma)’ by Alan Roberts [4], indicates a method of performing such measurements, and has yielded results which indicate that the gamma of a Grade 1 CRT monitor is typically in the region of 2.3 to 2.4. See also [5].

The overall electro-optical transfer characteristic will therefore consist of this gamma curve, sitting on top of an adjustable offset of the light-output at ‘black’ as set using a PLUGE test signal to meet the requirements of the viewing environment. Annex A gives further information.

Note: ***IMPORTANT****: This section has been revised to be consistent with ITU-R Rec. BT.1886.*

1.5.5 Grey scale reproduction

1) Grey scale tracking between colour channels shall be within the circles defined:

Grade 1 Monitor:	0.5 Δu*v* relative to the measured white point of the monitor (CIE 1976 L*u*v* Colour Space differences [see Annex B]) for luminance from 1 cd/m^2 to 100 cd/m^2 and deviation from grey should not be visible for luminances below 1 cd/m^2
Grade 2 Monitor:	1 Δu*v* for luminances from 1 cd/m^2 to 200 cd/m^2 and deviation from grey should not be visible for luminances below 1 cd/m^2
Grade 3 Monitor:	1.5 Δu*v* for luminances from 1 cd/m^2 to 250 cd/m^2 and deviation from grey should not be visible for luminances below 1 cd/m^2

2) When a luma signal of black level (digital level 64 in 10-bit systems) through 109% white (1019) is input, grey scale tracking should be maintained.

*Note: The tolerance for Grade 1 is based on a difference of 1 Δu*v* being visible, thus a tolerance range of 0.5 Δu*v* will ensure invisibility.*

1.5.6 Colour gamut and colour reproduction

1) The intention is that colours within the relevant system gamut should be reproduced such that the human eye perceives them to be identical to the presentation on an ideal CRT monitor, that is, a metameric match should be achieved. Reproduction of the EBU test colours (EBU Tech 3237 and its supplement) should be to a tolerance of 4 Δu*v*, except in the case of the two skin tone test colours, where the tolerance should be 2.6 Δu*v* (which corresponds to the tolerance on the skin tone of ±0.003 Δu’, Δv’ defined in EBU Tech 3273 [1]). In addition, if there is a variation in the reproduced brightness of test colours, ΔE* should lie within the above tolerances. These tolerances are all relaxed to 7 ΔE* for Grade 2 and Grade 3 monitors.

2) The monitor should present pictures with the colour primaries and reference white specified in the relevant video standard (ITU-R BT.1360, ITU-R BT.601, ITU-R BT.709, ITU-R BT.1700 or SMPTE ST 274:2008, SMPTE ST 170:2004 and SMPTE ST 296:2012). The displayed primaries for standard definition signals should fall within the tolerance boxes for EBU primaries (EBU Tech 3213). For high definition signals, the reproduction of the ITU-R Rec. BT.709 primaries should be within 4 Δu*v* of the target primaries for Grade 1 monitors and 7 Δu*v* for Grade 2 and Grade 3 monitors. In addition, if there is a variation in the reproduced brightness of the primaries, ΔE* should lie within the above tolerances.

Note: For monitors intended for use as props in studio sets, some pre-distortion of their *colour rendition may be desirable to achieve the required look on camera.*

1.5.7 Colour temperature

1) The monitor should present pictures with a reference white colour D_{65} (see Annex B) when feeding the monitor with primary signals of equal amplitude.

2) Practical monitors to be used in vision as part of a studio set design shall be able to be adjusted to approximately 3200 K.

Grade 1 Monitor:	Default D_{65}
Grade 2 Monitor:	Default D_{65} and optionally switchable to 3200 K for use in set design
Grade 3 Monitor:	Default D_{65} and optionally switchable to 3200 K for use in set design

3) Tolerances to be applied to the white point, D_{65}, should be 1.3 Δu*v* (which corresponds to a tolerance based on a circle or radius 0.0010 in Δu', Δv', which is the historical tolerance used within the EBU [1] and which corresponds to a just noticeable difference between adjacent monitors). The tolerance allowable for Grade 2 and Grade 3 monitors should be 4 Δu*v* (which corresponds approximately to the tolerance of ±0.003 Δu', Δv').

Whilst the CIE 1931 measurement system has been satisfactory in the measurement of CRT displays, there is some evidence that it may not be sufficiently accurate to characterise and obtain metameric matching with some of the more recent display devices [7]. Current practical workarounds to this problem include a calculated offset applied to CIE 1931 xy values. More details are included in **Annex D**.

*Note: A difference greater than 1 Δu*v* might be visible between two colour patches on the same screen, implying a tolerance of ±0.5 Δu*v*. However, we are here considering the visibility of colour differences between adjacent screens, hence the greater permissible tolerance.*

1.5.8 Viewing-angle dependency

In many applications, where the monitor is being viewed by more than one person or where several monitors are being viewed together, accurate picture reproduction over a range of viewing angles is of vital importance. Even where a single monitor is being viewed by just one person, it is important that the image reproduction is consistent over a more limited, but still significant, range of viewing angles.

1) For Grade 1 and Grade 2 Monitors, deviations in reproduced colour on the screen should not be visible to a human observer when viewing the screen from an angle of up to ±45° horizontally or ±20° vertically in any direction from the perpendicular axis to the centre of the screen.

2) As a guide to an acceptable numerical value for Grade 1 and Grade 2 Monitors, Δu*v* (calculated as changes from the measurements made normal to the screen) should be less than 6.8 for 20% grey-scale and 6.0 at 50% grey-scale, white, and with any of the EBU test colours when measured from viewing angles in the range described above. These tolerances can be relaxed to 9 Δu*v* for Grade 3 Monitors.

3) Having set the black level to the limit specified in section 5.2, the contrast ratio on the screen for Grade 1 and Grade 2 Monitors, when measured from viewing angles in a rectangle of ±30° horizontally and ±15° vertically should drop by no more than 20% of the contrast measured along an axis perpendicular to the centre of the screen. When measured from viewing angles in a rectangle of ±45° horizontally and ±20° vertically, the contrast ratio should drop by no more than 50%. These tolerances can be relaxed to 35% (±30° horizontally and ±15° vertically) and 50% (±45° horizontally and ±20° vertically) for Grade 3 Monitors.

Note: Ideally a technology where viewing angle is not an issue should be used. The above tolerances, whilst not ideal, are those which can probably tolerable.

In certain conditions, the viewing angle requirement for some monitors, such as those used in a wall of monitors in a production gallery, may actually be more critical than the Grade 1 monitor placed in the centre of such a wall of displays. However, clearly the viewing angle performance of a monitor used in an environment such as audio editing is less important.

1.5.9 Motion artefacts

Motion artefacts that are introduced by specific display technologies (such as blur and other effects on moving images) are an area of great concern. It is undesirable for a monitor to introduce motion artefacts of its own.

However, motion effects which are included in the input signal by, for example, a failure to anti-alias filter moving graphics, or blurring of the image caused by camera integration over the shutter opening, should be represented on the display.

Note 1: Reference document about Moving Picture Response Time (MPRT) measurements is available (under development by ICDM as the Display Measurement Standard).

Note 2: Motion blur (in moving edges and texture) in LCDs is caused by a combination of:

- 'Sample and hold' type presentation;
- Intrinsic response time of the panel;
- Signal processing such as de-interlacing.

Note 3: Other technologies introduce other motion effects, such as colour fringing on moving edges and false contour generation.

1.5.10 Screen resolution

The resolution required of a monitor will vary depending on screen size and application.

Grade 1 Monitor:	At least as many pixels as the signal format to be displayed, with the ability to display a pixel-mapped image.
Grade 2 Monitor:	At least as many pixels as signal format to be displayed.

Note 1: Large screens intended for multi-viewers may require substantially higher resolution.

Note 2: There are some advantages in having super-sampled displays, such that the pixel structure and shape no longer affect the visible image. For example, a 1920 x 1080 image might be displayed on a 4k (horizontal pixel) screen.

1.5.11 Image scaling, de-interlacing and overscan

1) Image scaling should be done in such a way as to avoid the introduction of artefacts, such as excessive ringing, aliases or banding, etc.

2) Monitors should offer a choice of de-interlacing modes (see section below on delay). Progressive (segmented field or film-mode) material should be detected and not passed through a de-interlacer.

3) Monitors shall be able to expose 'field dominance' errors which occur when the fields of an

interlaced signal are presented in the wrong order.

4) In the default more, the monitor should display without overscan, that is, showing the full active image area right to its edges. This should be the optimal mode for scaling quality and one-to-one pixel mapping is preferred.

5) The edges of the picture shall not be obscured by a bezel.

6) All monitors should be adjustable to allow an overscan of 3.5%, corresponding to viewing of the Action Safe Area according to ITU-R BT1848 "*Safe areas of wide screen 16:9 aspect ratio digital productions*" and EBU R 095 – *"Safe areas for 16:9 television production"*.

Note: The requirement for a monitor to detect and not de-interlace film-mode material is incompatible with the traditional requirement that a monitor should indicate that vertical (interlace) twitter is present. This is an issue which broadcasters shall be aware of during the transition in the domestic environment from CRTs to flat panels.

1.5.12 Delay time

The delay time in each display mode shall be explicitly specified, and optionally indicated on the screen. The delay reported should be the delay between arrival of the serial electrical signal at the monitor input and the 50% point in the rise of the light output from the screen.

In the case of Grade 2 and Grade 3 monitors, it is essential that models should be available that include a 'short delay display mode'. A short delay display mode is useful when strict timing accuracy is required for example in video switching or editing, or when used to cue musical performers. This mode may have lower picture quality (due to simpler de-interlacing etc.) than the normal display mode. For this reason, the availability of such a mode is not expected in Grade 1 monitors.

In a short delay display mode, pictures should preferably be displayed with a latency of no more than 10ms between the input signal and the 50% point in the rise of the light output from the screen. The intent is to minimise the lip-synchronization errors that occur, causing annoyance both to viewers and production staff.

1.5.13 Screen size

The screen size of the monitor is at the discretion of users, but may need to be larger than usual to achieve the target viewing distance of three times picture height required for adequate monitoring of HD. Production areas have limited space and this may have an impact on maximum size of the monitor being used to assess HD image quality. Multi-view (tiled) large screen monitors are increasingly used as source monitoring, which are usually included in the Grade 3 monitor category, but might also be classified as Grade 2 monitors under certain circumstances.

1.5.14 Uniformity

Large area uniformity

The minimum uniformity of large area white level raster (that is, a smooth drop-off in luminance towards the edges of the screen) that is acceptable is 80% for a CRT, but for flat panel monitors, the luminance should be uniform across the screen with a tolerance of ±5% of the mean luminance.

The uniformity of chromaticity should be within 2.6 Δu*v* of the measured white at the centre of the screen, for Grade 1 monitors (which corresponds to the tolerance of ±0.002 Δu', Δv'), and 4 Δu*v* for Grade 2 and Grade 3 monitors.

Small area uniformity

The use of a few fixed measurement positions could potentially result in missing a periodic uniformity error or some other pattern. To avoid this, a measurement technique taking into account the whole screen is desirable, and should be used in place of the large area measurement if it is feasible for the organisation making the assessment. A standard deviation (divided by the average level) of 5% in luminance is thought to be realistic for a Grade 1 monitor.

In the extreme, fixed pattern noise is a type of non-uniformity, and if necessary should be counteracted by pre-correction in the monitor.

1.5.15 Mura (imperfections in LCD panels)

Mura shall not be visually detected on the screen regardless of reproduced luminance levels or colour saturation.

Whilst Mura is not expected to be a problem in practice, for completeness it is included here.

Note: 'Mura' is a defect that looks like a small-scale crack with very small changes in luminance or colour. 'Mura' is likely to be noticeable in the flat portions of images even if the size of the Mura is very small. Mura will be revealed in a small area uniformity test.

1.5.16 Streaking (also known as crosstalk, overspill or shadowing)

The effect, shown in Figure 1, is the result of horizontal or vertical crosstalk between the signal in different parts of the line or column in the monitor.

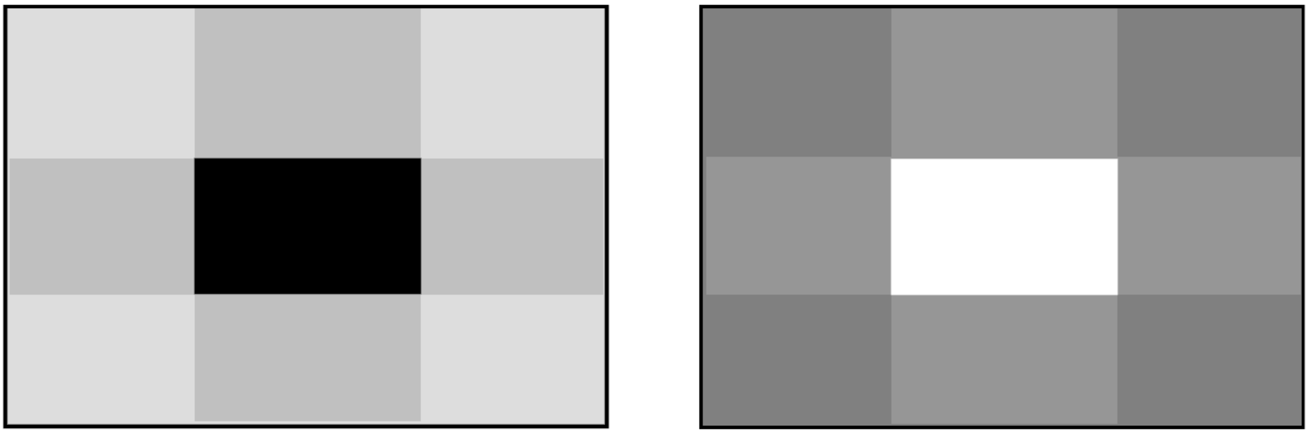

Figure 1: Examples of shadowing (in this case both horizontal and vertical)

When the input signal is a rectangle of 100% white near the centre, surrounded by a grey area, the difference in luminance between the horizontal and vertical belt-like portions and the other grey portions shown in Figure 1 should not be greater than 0.5% for Grade 1 monitors, 1% for Grade 2 monitors, and 2% for Grade 3 monitors. The same should apply to a black rectangle on a grey surround.

1.5.17 Stability and environmental conditions

The monitor, if correctly aligned in an environment with an ambient temperature of between 15° and 25°C (calibration range), shall continue to perform in accordance with this specification across an operational range where the ambient[2] temperature is between 10° and 40°C.

Given an ambient temperature within the operational range specified above, a period of twenty minutes shall be allowed after the monitor is powered before it is expected to perform in accordance with the specification. The monitor shall then maintain this performance for a period of at least twenty-four hours.

One minute after it has been powered, the monitor should produce subjectively acceptable pictures. For guidance, it is anticipated that the monitor will perform with tolerances no worse than twice those indicated in this specification during the first twenty minutes of operation.

The monitor, when operated at an ambient temperature between 0° and +45°C, shall continue to function without failure.

The monitor shall continue to function in accordance with this specification in a humidity range of 10% to 75% (non-condensing).

The monitor shall function in accordance with this specification at an altitude of up to 3000 m.

Within a temperature range of -35° to +70°C, it should be possible to store the monitor without damage.

1.5.18 Pixel defects

Defects are classified according to the severity of their visual impact. ISO 13406-2 provides more information and a classification of different types of pixel defects.

1) Grade 1 and Grade 2 monitors shall have no visible pixel defects (defined as pixel defect category I in ISO 13406-2).

2) Grade 3 monitors shall have no visible pixel defects in the central area covering 50% of the display area, and fulfil pixel defect category II outside this area.

3) There should never be coupled pixel defects (defined as pixel cluster defect category I in ISO 13406-2).

Note: *A useful explanation is given at:* http://www.maxdata.com/repository_com/downloads/Pixel_monitors.pdf

1.5.19 Ringing and handling of under- and over-shoots

Ringing or overshoots should not be introduced by any processing in the monitor if the input signal is suitably conditioned (i.e. is within Nyquist limits). See also below.

Grade 1 and Grade 2 monitors should not have a ‘sharpness’ control and should not introduce any other image ‘enhancements’.

Monitors should not cut off under- or over-shoots, or sub-black and super-white levels.

1.5.20 Treatment of illegal signals

Signals which contain significant frequency components outside the Nyquist limit (i.e. have not been anti-alias filtered) should be displayed in such a way that any ringing or aliasing inherent in such signals DOES become visible.

[2] Ambient temperature here specifies the air temperature in the vicinity of the display.

Professional interfaces and standards for the carriage and gamut mapping on a display of wide-colour gamut signals in the broadcast environment have not yet become established. It is also unclear exactly how a monitor should handle out-of-gamut signals, but Grade 1 and Grade 2 monitors are expected to have a mode (or modes) which will indicate out of gamut colours, and not attempt to correct such colours.

1.5.21 Image sticking (long-term after-image)

The characteristics for image sticking (long-term afterimage) on the screen should be comparable to or better than that of the CRT monitor.

Broadcasters should bear in mind that fixed service idents on multi-viewer screens may cause problems on some monitors. In general, the guidelines [9] for avoiding image sticking should be adhered to.

1.5.22 Supported Standards, and signal interfaces

The monitors should handle the signal formats listed below. It is not necessary for a monitor to support all formats (but see EBU D 97-2005). The manufacturer shall state which of the formats are supported by each available interface.

Format	Relevant standard
480i/30 (29.97)	ITU-R Rec. BT.601-7
576i/25	ITU-R Rec. BT.601-7
720p/50	SMPTE ST 296:2012
720p/60 (59.94)	SMPTE ST 296:2012 ITU-R Rec. BT.1543
1080i/25	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080i/30 (29.97)	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5

Format	Relevant standard
1080p/24 (23.98)	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080psf/24 (23.98)	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080p/25	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080psf/25	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080p/30 (29.97)	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080psf/30 (29.97)	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080p/50	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5
1080p/60 (59.94)	SMPTE ST 274:2008 ITU-R Rec. BT. 709-5

Some signal formats are available in 4:4:4 in addition to 4:2:2, and these formats shall also be supported where applicable.

All inputs should provide an indication of the signal standard detected. The monitors should have the following interfaces:

	Grade 1	Grade 2	Grade 3	Set design	Relevant standard
SDI *	A, at least 2	A, at least 2	A	A	SMPTE ST 259:2008, ITU-R Rec. BT.656-5
HD-SDI *	A, at least 2	A, at least 2	A	A	SMPTE ST 292-1:2011
3G-SDI	B	B	B		SMPTE ST 424:2012 SMPTE ST 425-1:2008
HDMI **	B	B	B	B	High-Definition Multimedia Interface (www.hdmi.org)
DVI 1.0 **	B	B	B	B	www.ddwg.org
Component RGB, Y C_rC_b	B	B	B	B	
CVBS (PAL, SECAM & NTSC)	B	B	B	B	ITU-R BT.470-7
RF (Analogue)			C	C	
RF (DTT)			C		DVB-T

A = mandatory, B = available as an option, C = should be available at least as an external module

* Should be auto-sensing SDI/HD-SDI.

** HDCP shall be available on the input, so that the picture is always shown.

Note: At present there are a number of additional candidate interface technologies to carry the highest data rate signals, in compressed and uncompressed forms. The adoption of these interfaces in the professional broadcasting environment is still open. Examples include 10 Gbit Ethernet and forms of intermediate (quasi-lossless) compression.

1.5.23 Other facilities

The following switchable features are also necessary:

Features	Grade 1	Grade 2	Grade 3	Set design
4:3 and 16:9 aspect ratio mode	M	M	M	M
safe title and aspect ratio markers	M	M		
tally lamp (red, green, yellow)	M	M	*	
RS 232 and/or GPI remote control	M	M		
over scan / full screen / 1 to 1 pixel-map modes	M	M		
H/V delay	M	M		
blue only mode	M	M		
mono mode	M	M		
ext. sync in	M	M		
Stereo loudspeaker			**	

M = Mandatory

* required in some applications

** required in some applications, and may include an indication of the audio standard

1.5.24 Acoustic Noise

Acoustic noise standards used are the Noise Rating (NR) curves defined by Kosten and van Os [10] and standardised in now-withdrawn versions of ISO 1996. The relevant curves are reproduced in Figure 2.

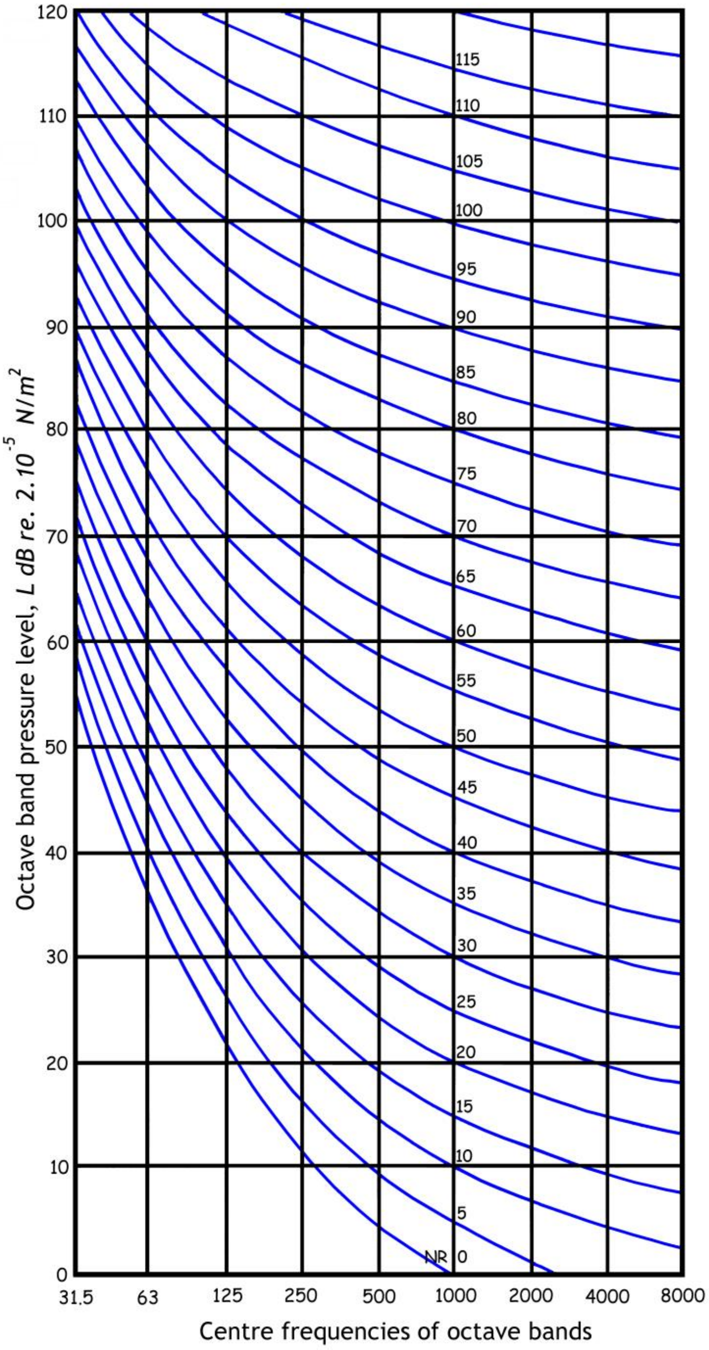

Figure 2: Noise Rating (NR) Curves

1) Monitors intended for use in audio-edit areas, in set design or as camera viewfinders shall not produce acoustic noise in excess of NR5.

2) Monitors that may be used on the studio floor or in edit areas shall not produce acoustic noise in excess of NR10.

3) Monitors used in technical areas shall not produce acoustic noise in excess of NR20.

1.5.25 Surface reflectivity (glare)

Surface reflectivity is likely to be a greater issue in monitors used in less-controlled viewing environments (i.e. with high ambient light levels), so is likely to be more important for a Grade 3 monitor than Grade 1 or 2. Because every such viewing condition is different, it is not possible to specify a required limit on reflectivity, but it is an issue of which users may need to be aware.

2. Ultra-High Definition (UHD) and High Definition (HD) High Dynamic Range

2.1 Definition of a Grade 1 HDR Monitor

Grade 1 HDR monitors are devices for high-Grade technical quality evaluation of images at key points in a production or broadcast workflow. They are used for critical evaluation during image capture, post-production, transmission and storage.

At present, it is not possible for Grade 1 HDR monitors to display the full quality properties of the ITU-R BT.2100 [11] signals e.g. few, if any, monitors can yet display the full colour gamut or display images up to the 10000 cd/m^2 specified in ITU-R BT.2100 PQ[3]. Thus, two Grade 1 monitors are standardised within this document Grade 1A HDR – the preferred specification - and Grade 1B HDR – a reduced Gamut and/or limited brightness specification. Grade 1B HDR may be withdrawn at a future date.

Where a Grade 1B monitor is unable to correctly display an input signal, e.g. it cannot physically display colours conveyed in an ITU-R BT.2100 signal, it shall by default apply a hard clip of the linear display signals to the available colour volume whilst maintaining the ITU-R BT.2100 white point, rather than applying a soft clip. This limitation shall be shown in the monitor specification[4] and the presence of a hard clip shall be able to be displayed to the viewer e.g. via an illuminated LED and user switchable on-screen display of the pixels with signal levels beyond the capability of the display (e.g. false colours for both luminance and chrominance).

It is expected that all applied technologies are state-of-the-art at this level. Artefacts should not be unduly masked nor should additional artefacts be introduced. As a reference device the settings of this type of monitor should be adjustable as well as lockable (mechanically or electrically), so that only authorized access is possible.

It is recommended that all Grade 1A and Grade 1B HDR monitors should be capable of displaying both ITU-R BT.2100 HLG and ITU-R BT.2100 PQ signals.

The Grade 1 HDR monitor is a ‘measuring instrument’ for visual evaluation of image quality. Whilst all HDR signals are progressive, it is expected that any such monitors will also be designed to allow Grade 1 viewing of conventional video signals, therefore it is highly desirable to have the ability to reproduce the native scanning mode of the signal (i.e. progressive or interlaced) or as it is intended to be viewed (e.g. 50 Hz presentation of 25p material shall be by frame-repetition). Grade 1 HDR monitors shall not use motion interpolation.

Typical locations for Grade 1 HDR monitors are: camera control, colour grading and quality control, and lighting control positions. These are areas where video technical quality parameters are evaluated, controlled, and corrected as needed.

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[3] Report ITU-R BT.2390 suggests 10000 cd/m^2 is a potential for the HDR systems defined in ITU-R BT.2100

[4] The displayable colour volume of the display should be expressed in the accompanying literature as human readable values in line with terminology in ST 2086:2014 “Mastering Display Color Volume Metadata Supporting High Luminance and Wide Color Gamut Images”.

2.2 Definition of a Grade 2 HDR Monitor

A Grade 2 HDR monitor may have wider tolerances on its specification than a Grade 1 HDR monitor and, as such, can be significantly lower priced, be smaller in size or weigh less than a Grade 1 HDR monitor.

Grade 2 HDR monitors are used in applications where tighter tolerances or the ability to display the entire luminance range, are not necessary.

Grade 2 HDR monitors are usually used for preview, control walls, edit suites, and control rooms where accurate measurement and display of the entire signal is not required.

It should be possible for Grade 2 HDR and Grade 1 HDR monitors to be used together, for example in television production control walls.

2.3 Requirements

Note: The specifications in this section are to be measured in accordance with EBU Tech 3325 [8]. All specifications shall be capable of being met simultaneously.

2.3.1 Luminance Ranges

2.3.1.1 HDR HLG Monitors

When a luma signal of 100% white (digital level is 940 in 10-bit narrow range systems, see Note 1, and 1023 in 10-bit full range systems, see Note 2) is presented, the display should be capable of producing an adjustable reference peak luminance level for 1% of the screen area measured in accordance with EBU Tech 3325 with the following minimum values:

Grade 1A HDR HLG Monitor:	≥1000 cd/m^2
Grade 1B HDR HLG Monitor:	≥1000 cd/m^2
Grade 2 HDR HLG Monitor:	≥600 cd/m^2

Note 1: In narrow range, 100% luminance on the screen corresponds to a luma signal of digital level 940 (in 10-bit), and the black level corresponds to a luma signal of digital level 64 (in 10-bit). The highest value of luma signal is digital level 1023 (in 10-bit). The luma level 1023 is called '109% white', luma levels above 940 are called 'Super-whites'.

Manufacturers shall include a presentation mode which displays these discrete levels by reducing the contrast of the image. The manufacturer should ensure that display gamma is set according to the equation given in ITU-R BT.2100 Table 5 (Hybrid Log Gamma System reference transfer functions) to reflect the nominal peak brightness of the display at 100% luminance level rather than 109% luminance level.

Note 2: In full range, 100% luminance on the screen corresponds to a luma signal of digital level 1023 (in 10-bit), and the black level corresponds to a luma signal of digital level 0 (in 10-bit). Not all of these signal levels can be transferred via Serial Digital Interface.

Note 3: Screen settings which are dependent on screen brightness, for example display gamma, should either track screen adjustment or should be user adjustable.

Grade 1B HDR HLG monitors may have a limited chrominance range compared to a Grade 1A HDR HLG monitor. When presented with a signal outside of the chrominance range that the Grade 1B HDR HLG monitor is able to display, the monitor shall not manipulate the signal (i.e. a hard clip shall be applied to the linear RGB channels) and shall show an on screen indication of pixels with signal levels beyond the capability of the screen (e.g. false colours). This on-screen indication shall be user-switchable on and off. When presented with a signal within the chrominance range that the Grade 1B HDR HLG monitor can display, the monitor should look essentially similar to a Grade 1A HDR HLG monitor presented with the same signal.

For Grade 1 HDR HLG monitors, a 75% (code value 721, 10-bit narrow range) full screen, uniform field input signal shall be displayed without power limiting. (Output level 203 cd/m^2 when digital level 940 is set to 1000 cd/m^2)

The manufacturer should include two pre-sets within the display for monitoring backwards compatibility. The first should show the ITU-R BT.2100 HLG signal combined with an ITU-R BT.1886 electro-optical transfer function. The second should display the ITU-R BT.2100 HLG signal combined with a typical broadcast quality down conversion to an ITU-R BT.1886 electro-optical transfer function. Both of these pre-sets should be able to be displayed with varying ITU-R BT.1886 peak brightness, for example the relevant brightness given in section 1.5.1 to replicate an SDR monitor or with a peak brightness which allows consistent shadow and mid-tone brightness when switching between HDR and backwards compatible modes.

2.3.1.2 HDR PQ Monitors

ITU-R BT.2390 states "*the PQ HDR system generates content that is optimum for viewing on a reference monitor in a reference viewing environment. The reference monitor would ideally be capable of accurately rendering black levels down to or below 0.005 cd/m^2, and highlights up to 10000 cd/m^2*"

When a luma signal, consisting of the brightest PQ code value the monitor is capable of displaying is presented, the display should be capable of producing a fixed reference peak luminance level for 1% of the screen area measured in accordance with EBU Tech 3325 within the following ranges. The monitor does not have to be able to produce the entire range of peak luminance levels listed:

Grade 1A HDR PQ Monitor:	10000 cd/m^2
Grade 1B HDR PQ Monitor:	≥1000 cd/m^2 (See Note 3)
Grade 2 HDR PQ Monitor:	≥600 cd/m^2

Note 1: In narrow range, 100% luminance on the screen corresponds to a luma signal of digital level 940 (in 10-bit), and the black level corresponds to a luma signal of digital level 64 (in 10-bit).

Note 2: In full range, 100% luminance on the screen corresponds to a luma signal of digital level 1023 (in 10-bit), and the black level corresponds to a luma signal of digital level 0 (in 10-bit). Not all of these signal levels can be transferred via Serial Digital Interface.

Note 3: Grade 1B HDR PQ monitors are permitted to have a smaller luminance and chrominance range than those of a Grade 1A HDR PQ monitor. The requirements of a Grade 1B HDR PQ monitor are given in the following paragraphs.

Grade 1B HDR PQ monitors may have a limited luminance and chrominance range compared to a Grade 1A HDR PQ monitor but the peak luminance must be ≥1000 cd/m^2. When presented with a signal outside of the luminance and/or chrominance range that the Grade 1B HDR PQ monitor is able to display, the monitor shall not manipulate the signal (i.e. a hard clip shall be applied to the linear RGB channels) and shall show an on screen indication of pixels with signal levels beyond the capability of the screen (e.g. false colours). This on-screen indication shall be user-switchable on and off. When presented with a signal within the luminance and chrominance range that the Grade 1B HDR PQ monitor can display, the monitor should look identical to a Grade 1A HDR PQ monitor presented with the same signal.

For Grade 1A HDR PQ or the Grade 1B HDR PQ monitors, a 199.2 cd/m^2 (code value 592, 10-bit full range) full screen, uniform field input signal shall be displayed without power limiting.

In Reference viewing environments according to ITU-R BT 2100, it is expected that the relationship between code values and displayed luminance (and chromaticity) should not be considerably altered, i.e. HDR PQ monitors shall be equipped with brightness adjustment to set viewable black level (i.e. E` = 0.0) using an HDR PLUGE signal in accordance with the ITU-R Operational Practice guidelines (to be published), but shall not be equipped with contrast adjustment (except for authorized maintenance).

For Grade 1A HDR PQ or the Grade 1B HDR PQ monitors, 12-bit input signals shall be displayed and processed at 12-bits. Manufacturers shall include a 10-bit viewing mode for 12-bit signals using truncation.

The manufacturer should include two pre-sets within the display for monitoring backwards compatibility. The first mode should display the ITU-R BT.2100 PQ signal clipped to the limits of an ITU-R BT.709 signal combined with an ITU-R BT.1886 electro-optical transfer function. The second mode should display the ITU-R BT.2100 PQ signal combined with a typical production quality down conversion to an ITU-R BT.1886 electro-optical transfer function. Both of these pre-sets should be able to be displayed with varying ITU-R BT.1886 peak brightnesses, for example the relevant brightness given in section 1.5.1 to replicate an SDR monitor or with a peak brightness which allows consistent shadow and mid-tone brightness when switching between HDR and backwards compatible modes.

2.3.2 Black Level

With a luma signal at black level (digital level 64 in 10-bit narrow-range. In ITU-R BT.2100 black level for 10-bit full-range is defined as digital level 0, however in SDI-based systems digital levels 0-3 are used for timing references and not allowed for active video), with a full-screen black test signal, the luminance level measured from the screen in accordance with EBU Tech.3325 should be capable of adjustment down to:

Grade 1A, 1B HDR Monitor:	0.005 cd/m^2.
Grade 2 HDR Monitor:	0.01 cd/m^2.

It shall be possible to adjust black level with an HDR PLUGE test signal (which includes sub-black portions – test signal yet to be defined). It is expected that Grade 1 HDR and Grade 2 HDR monitors will be used in a range of viewing environments including subdued lighting, for example ISO 12608 ‘Cinematography - Room and conditions for evaluating television from telecine reproduction’.

The black level shall also be adjustable between the minimum achievable and 1 cd/m^2. Levels below black (i.e. levels between 4 and 63 in 10-bit narrow range) shall not be clipped and shall therefore become visible, subject to appropriate ambient lighting levels.

Care shall be taken to avoid veiling glare in the measurement instrument, by the use of a mask or a frustum, as described in EBU Tech 3325 [8].

Note: If the viewing conditions are standard dim surround (5 cd/m^2 as in ITU-R Rec. BT.2100) then the remission factor of the display shall also be considered:

- *The remission factor is the sum of absorption and reflection of a surface.*
    - *The remission value (also called remission factor) is the ratio between reflected light from the surface of the display (display off) and the reflected light from a reference white surface under the same condition, whereby a diffuse light source is used.*
    - *The reflection is measured with angle of -45° perpendicular to the screen with a light source at an angle of +45°. Remission is measured perpendicular to the screen with a light source at an angle of +45°.*

Modulation of the back light of a transmissive display (global or local dimming) to improve the black-level performance shall neither cause visible artefacts (even if the monitor is viewed from very close viewing distances) nor hide artefacts present in the signal being monitored. It may in the future be necessary to define additional requirements and test conditions to characterise any displays using these techniques.

2.3.3 Minimum Colour Gamut

Two subclasses of Grade 1 HDR monitor are classified, 1A and 1B. Currently, Grade 1A monitors are difficult to manufacture, so an interim Grade 1B sub-classification is used. This may be withdrawn at a future date. The minimum colour gamut of the monitors shall be bounded by:

Red Primaries

Table 1: Red primary tolerances

Red	Grade 1A				Grade 1B and Grade 2			
	x	*y*	*u′*	*v′*	*x*	*y*	*u′*	*v′*
R0	**BT.2020**				**BT.2020**			
	0.7080	0.2920	0.5566	0.5165	0.7080	0.2920	0.5566	0.5165
R1	624.9 nm				613.2 nm			
	0.7005	0.2994	0.5397	0.5190	0.6754	0.3244	0.4875	0.5268
R2					700 nm			
	0.7347	0.2653	0.6234	0.5065	0.7347	0.2653	0.6234	0.5065
R3	0.7263	0.2614	0.6202	0.5022	0.7263	0.2614	0.6202	0.5022
R4	0.6877	0.2939	0.5340	0.5135	0.6569	0.3166	0.4790	0.5195

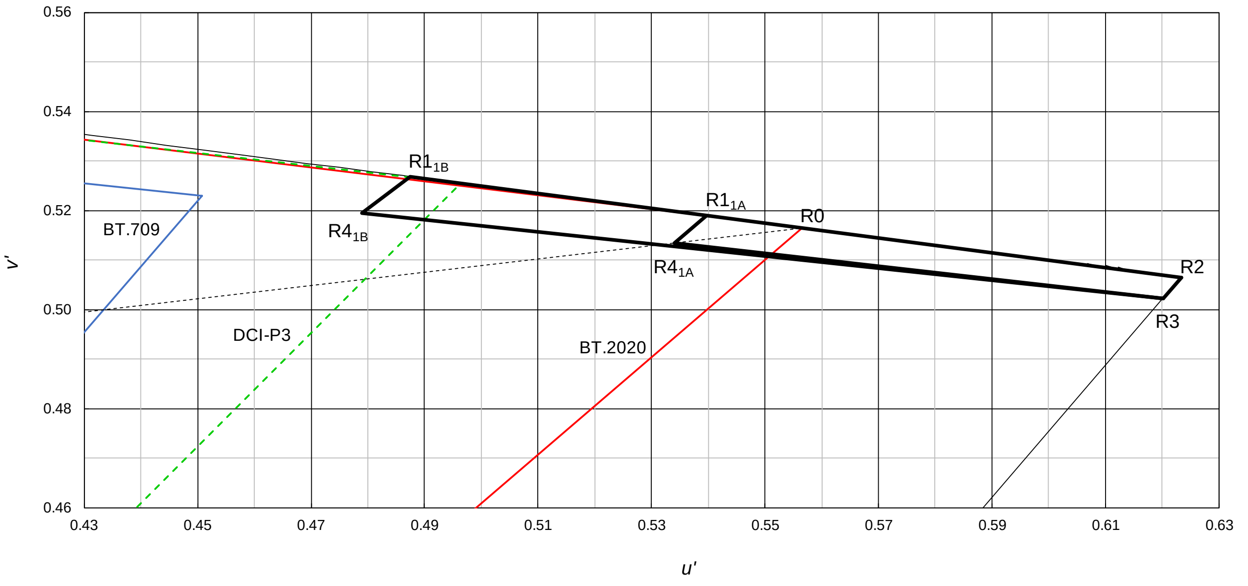

Figure 3: CIE u'v' diagram of red primary tolerances

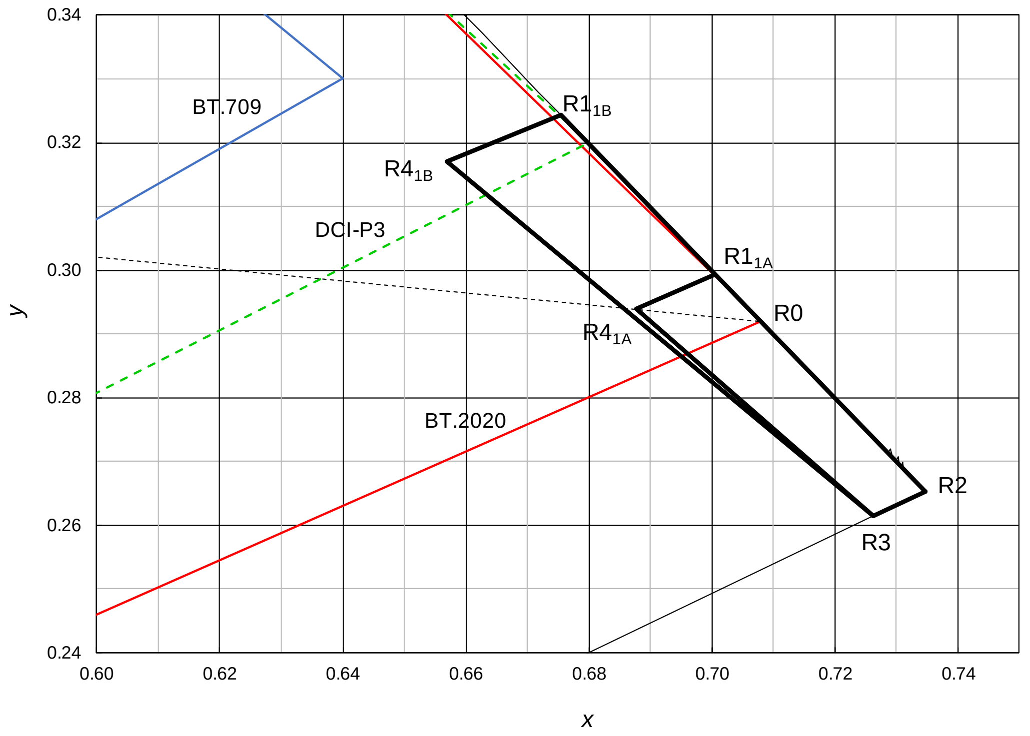

Figure 4: CIE xy diagram of red primary tolerances

Green Primaries

Table 2: Green primary tolerances

Green	Grade 1A				Grade 1B and Grade 2			
	x	*y*	*u′*	*v′*	*x*	*y*	*u′*	*v′*
G0	BT.2020				BT.2020			
	0.1700	0.7970	0.0556	0.5868	0.1700	0.7970	0.0556	0.5868
G1	526.5 nm				517.6 nm			
	0.1262	0.8210	0.0401	0.5864	0.0568	0.8279	0.0177	0.5812
G2	533.0 nm				536.8 nm			
	0.1783	0.7914	0.0587	0.5867	0.2063	0.7720	0.0696	0.5863
G3	0.1773	0.7730	0.0595	0.5836	0.2022	0.6915	0.0742	0.5713

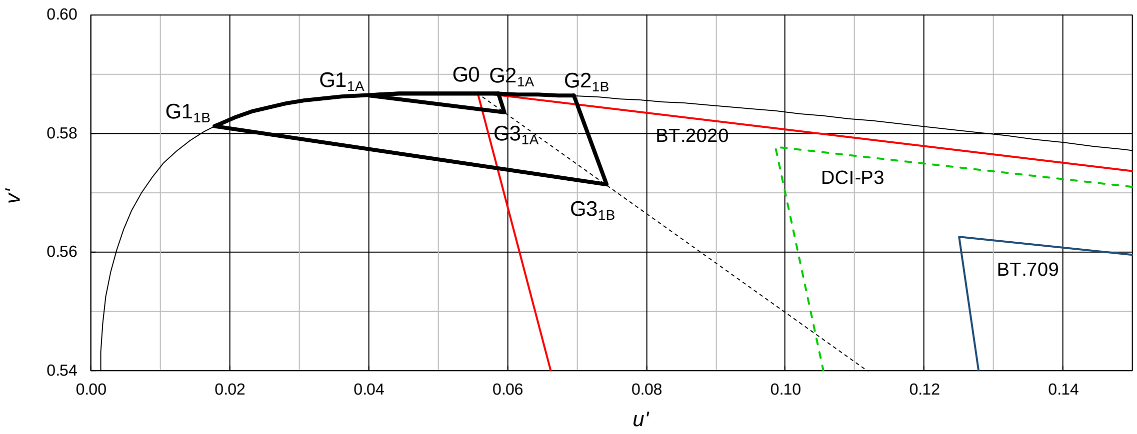

Figure 5: CIE u'v' diagram of green primary tolerances

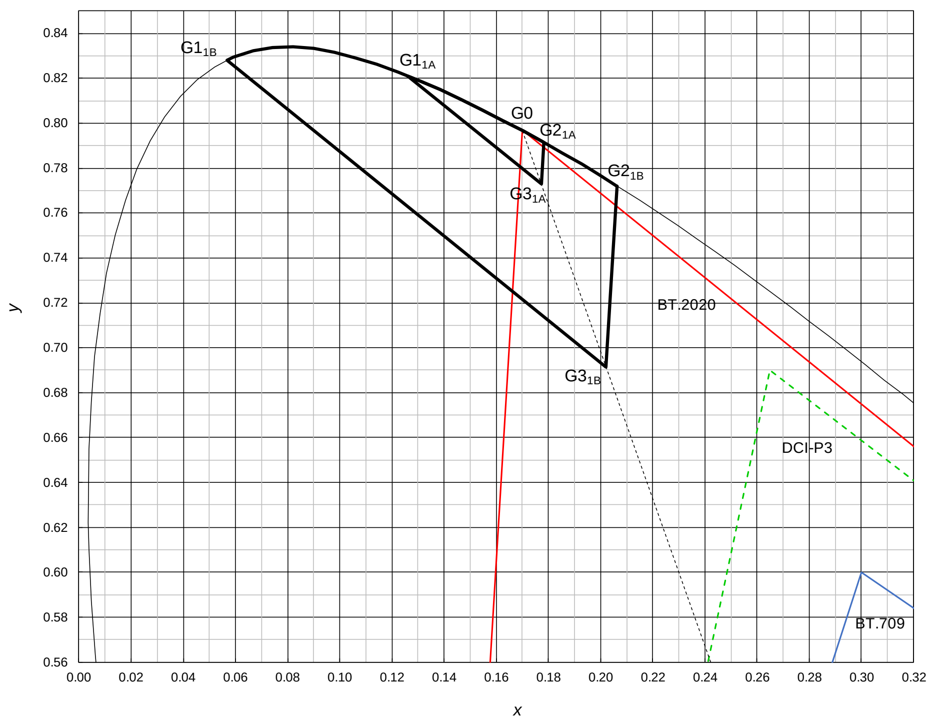

Figure 6: CIE xy diagram of green primary tolerances

Blue Primaries

Table 3: Blue primary tolerances

Blue	Grade 1A				Grade 1B and Grade 2			
	x	*y*	*u′*	*v′*	*x*	*y*	*u′*	*v′*
B0	**BT.2020**				**BT.2020**			
	0.1310	0.0460	0.1593	0.1258	0.1310	0.0460	0.1593	0.1258
B1	463.1 nm				461.2 nm			
	0.1390	0.0353	0.1768	0.1010	0.1421	0.0317	0.1836	0.0921
B2	467.8 nm				467.8 nm			
	0.1295	0.0487	0.1558	0.1318	0.1295	0.0487	0.1558	0.1318
B3					**BT.709**			
	0.1400	0.0545	0.1660	0.1454	0.1500	0.0600	0.1754	0.1579

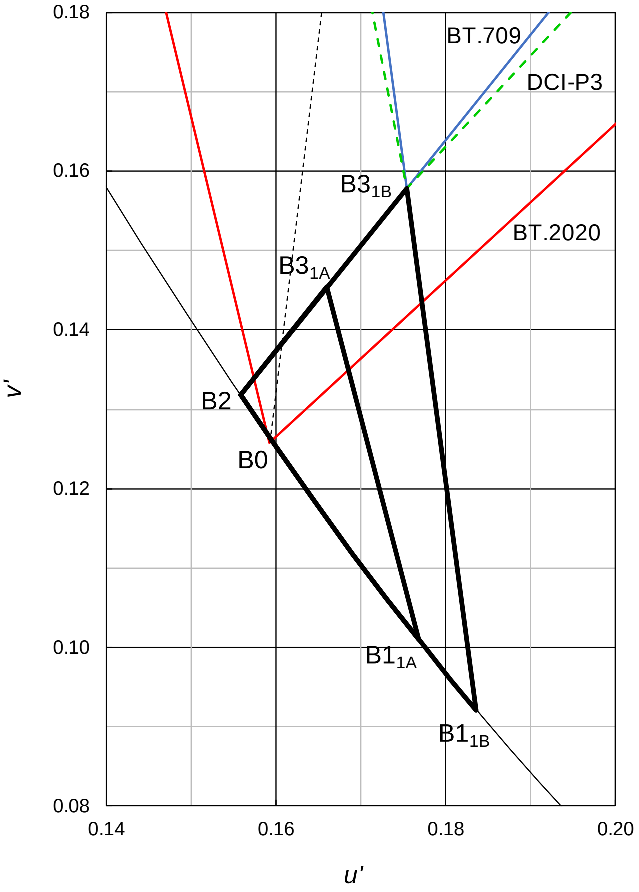

Figure 7: CIE u’v’ diagram of blue primary tolerances

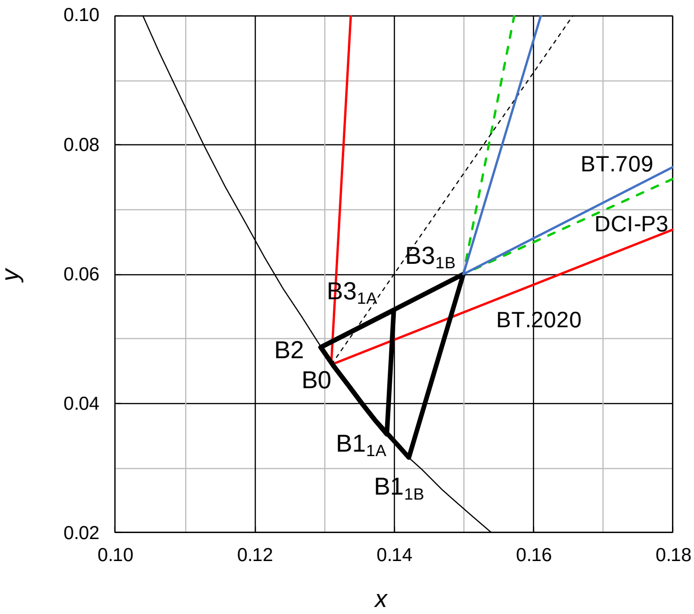

Figure 8: CIE xy diagram of blue primary tolerances

Note 1: Tolerances of display primaries of Grade 1 HDR monitors are determined so that the following two conditions are satisfied:

1) *Area coverage of the BT.2020 gamut (to be calculated in the xy coordinate) shall be ≥90% for Grade 1A HDR and ≥60% for Grade 1B HDR and Grade 2 HDR. This can be achieved when the distance between the actual primary and D65 white point is equal to the distance between the BT.2020 primary and D65 multiplied by $0.9^{1/2}$ and $0.6^{1/2}$, respectively.*
2) *Area coverage of the BT.709 gamut shall be 100%.*

2.3.4 Contrast Ratio

Simultaneous contrast ratio (with EBU box pattern) should be:

Grade 1A and 1B HDR Monitor:	above 10,000 to 1
Grade 2 HDR Monitor:	above 10,000 to 1

2.3.5 Transfer Function Characteristics

The luminance transfer function of the screen should be equivalent to those listed in ITU-R BT.2100 with the rendering intent (dim-surround) expected of an HDR TV system.

The ideal opto-optical transfer function shall be followed such that it is monotonic and, for ITU-R BT.2100 HLG, remains within a tolerance of ±0.025 of the ideal value from 5% to 80% of input signal level using the analysis technique described in EBU Tech 3325 [8]. Tolerance values for ITU-R BT.2100 PQ are currently under investigation. A 10-bit input signal shall result in a 10-bit presentation on the screen.

The overall transfer characteristic will therefore consist of this transfer curve, sitting on top of an adjustable offset of the light-output at ‘black’ as set using a PLUGE test signal to meet the requirements of the viewing environment.

2.3.6 Grey Scale Reproduction

Grey scale tracking between colour channels shall be within the circles defined:

Grade 1 HDR Monitor:	0.5 Δu*v* relative to the measured white point of the monitor above 1 cd/m^2, and deviation from grey should not be visible for luminances below 1 cd/m^2

When a luma signal of black level (digital level 64 in 10-bit systems) through 100% white (940) is presented, grey scale tracking should be maintained.

*Note: The tolerance for Grade 1 is based on a difference of 1 Δu*v* being visible, thus a tolerance range of 0.5 Δu*v* will ensure invisibility.*

2.3.7 Colour Gamut and Colour Reproduction

Reproduction of the EBU test colours (EBU Tech 3237 and its supplement) should be to a tolerance of 4 Δu*v*, except in the case of the two skin tone test colours, where the tolerance should be 2.6 Δu*v* (which corresponds to the tolerance on the skin tone of ±0.003 Δu’, Δv’ defined in EBU Tech 3273 [1]). In addition, if there is a variation in the reproduced brightness of test colours, ΔE* should lie within the above tolerances.

The display should present pictures with the reference white specified in the relevant video standard (ITU-R BT.2100).

2.3.8 Colour Temperature

See section 1.5.7, Grade 1 Monitor.

2.3.9 Viewing Angle Dependency

See section 1.5.8, Grade 1 Monitor.

2.3.10 Motion Artefacts

See section 1.5.9, Grade 1 Monitor

2.3.11 Screen Resolution

The resolution of an HDR monitor shall be:

Grade 1A & 1B HDR Monitor:	At least as many pixels as the signal format to be displayed, with the ability to display a pixel-mapped image.
Grade 2 HDR Monitor:	At least as many pixels as the signal format to be displayed when using a monochrome test signal (i.e. WRGB panels permitted), with the ability to display a pixel-mapped image.

Note 1: For a display, a 'pixel' is a collection of individual display elements which when taken together are able to reproduce the full colour range of which the display is capable. For example a pixel might be formed of RGB sub-pixels or WRGB sub-pixels.

Note 2: Large screens intended for multi-viewers may require substantially higher resolution.

Note 3: There are some advantages in having super-sampled displays, such that the pixel structure and shape no longer affect the visible image. For example, a 1920 x 1080 *image might be displayed on a UHD1 screen.*

2.3.12 Image Scaling, De-interlacing and Overscan

1 Image scaling should be done in such a way as to avoid the introduction of artefacts, such as excessive ringing, aliases or banding, etc.

2 HDR material is progressively scanned and such material shall not be passed through a de-interlacer.

3 The image shall be displayed without overscan, that is showing the full active image area right to its edges.

4 The edges of the picture shall not be obscured by a bezel.

2.3.13 Delay Time

See section 1.5.12.

2.3.14 Screen Size

The screen size of the display is at the discretion of users, but may need to be larger for adequate monitoring of 2160p (due to the target viewing distance of 1.5 times picture height) and 1080p (due to the target viewing distance of three times picture height). Focus and resolution should only be judged on a screen that is sufficiently large to allow viewing at 1.5 times picture height.

2.3.15 Uniformity

2.3.15.1 Large Area Uniformity

See section 1.5.14.1. Large area white level is defined for HLG as code value 721 (10-bit narrow range) and for PQ as code value 592 (10-bit full range).

2.3.15.2 Small Area Uniformity

See section 1.5.14.2.

2.3.16 Mura (Imperfections in LCD Panels)

See section 1.5.15.

2.3.17 Streaking (Also Known as Crosstalk, Overspill or Shadowing)

See section 1.5.16.

2.3.18 Stability and Environmental Conditions

See section 1.5.17.

2.3.19 Pixel Defects

See section 1.5.18.

2.3.20 Ringing and Handling of Under- and Over-shoots

See section 1.5.19. Adjustments to the 100% brightness level (contrast control) should force other system parameters to track, e.g. system gamma.

2.3.21 Treatment of Illegal Signals

See section 1.5.20.

2.3.22 Image Sticking (Long-term After-image)

See section 1.5.21.

2.3.23 Supported Standards, and Signal Interfaces

The manufacturer shall state which of the formats are supported by each available interface.

Raster	Frame rate	Grade 1A HDR	Grade 1B HDR	Grade 2 HDR UHD	Grade 2 HDR HD
2160p	120 and 120000/1001	M	O	O	N/A
2160p	100	M	O	O	N/A
2160p	60 and 60000/1001	M	M	M	N/A
2160p	50	M	M	M	N/A
2160p	30 and 30000/1001	M	M	M	N/A
2160p	25	M	M	M	N/A
2160p	24 and 24000/1001	M	M	M	N/A
1080p	120 and 120000/1001	M	M	M	M
1080p	100	M	M	M	M
1080p	60 and 60000/1001	M	M	M	M
1080p	50	M	M	M	M
1080p	30 and 30000/1001	M	M	M	M
1080p	25	M	M	M	M
1080p	24 and 24000/1001	M	M	M	M

M = mandatory, O = optional, N/A = not applicable.

It is expected that monitors will also be capable of the appropriate Grade of viewing of ITU-R BT.709 HD video signals, i.e. 1080p, 1080i and 720p at appropriate frame rates.

Some signal formats are available in 4:4:4 in addition to 4:2:2, and these formats shall also be supported where applicable.

All inputs should provide an indication of the signal standard detected. When using SDI-based interfaces, the monitor should utilise the payload identifier within the SDI-signal (e.g. colour space, EOTF). There should be a user override for this function.

The monitors should have the following interfaces:

	Grade 1 and 2 HDR	Relevant standard
Quad 3G-SDI	O	SMPTE ST 425-5
Dual 3G-SDI	O	SMPTE ST 425-3
12G-SDI*	M	SMPTE ST 2082-10
6G-SDI*	M	SMPTE ST 2081-10
3G-SDI*	M	SMPTE ST 425-1
HD-SDI*	M	
IP	O	SMPTE ST 2110
USB-C	O	
HDMI**	O	

M = mandatory, at least one A classified input shall be available, O = available as an option

* Should be auto-sensing 12G/6G/3G/HD-SDI.

** Shall support relevant HDMI specifications for required video standards. HDCP shall be supported on the input, so that the picture is always shown.

2.3.24 Other Facilities

The following switchable features are also necessary:

Features	Grade 1
safe title and aspect ratio markers	M
tally lamp (red, green, yellow)	O
RS 232 and/or GPI remote control	M
H/V delay	O
blue only mode	M
monochromatic mode	O
ext. sync in	M
Overscan/full screen/1:1 pixel map modes	M
Video waveform overlay	O
Audio output	O
Stereo loudspeaker	O

M = Mandatory, O = Optional

2.3.25 Acoustic Noise

See section 1.5.24.

2.3.26 Surface Reflectivity (Glare)

See section 1.5.25.

3. References

[1] EBU Tech 3273: Methods of Measurement of the Colorimetric Performance of Studio Monitors

[2] ITU-R Rec.BT.709: Basic Parameter Values for the HDTV Standard for the Studio and for International Programme Exchange (1990)

[3] CIE (Commission Internationale de l'Eclairage) Standard S 014-2/E (2006): Colorimetry - Part 2: CIE Standard Illuminants

[4] Roberts, A.: Methods of measuring and calculating display transfer characteristics (Gamma) BBC Research Department Report RD 1991/6.

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[6] Hunt, R.W.G: 'Corresponding colour reproduction' in *The reproduction of colour*, ed. 6, pp. 173, Wiley & Son, 2004.

[7] Csuti, P, and Schanda, J.: Colour Matching Based on Fundamental Spectral Sensitivity Functions, ISCC/CIE Expert Symposium 2006, Ottawa, Ontario, Canada.

[8] EBU Tech 3325: Methods of Measuring the Performance of Studio Monitors

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[10] Kosten and van Os, 'Community reaction criteria for external noises,' National Physical Laboratory Symposium, No. 12, 1962, p. 377, London H.M.S.O.

[11] ITU-R Rec.BT.2100: Image parameter values for high dynamic range television for use in production and international programme exchange (2016)

[12] SMPTE ST 431-1: D-Cinema Quality – Screen Luminance Level, Chromaticity and Uniformity (2006)

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- Video Electronics Standards Association (VESA) Flat Panel Display Measurements Task Group - FLAT PANEL DISPLAY MEASUREMENTS STANDARD Version 2.0 (FPDM2)
- Tolerances on 'Illegal' colours in television, EBU R 103-2000 (https://tech.ebu.ch/publications/r103)
- Measuring Colour (Third Edition, Fountain Press, 1998) R.W.G. Hunt
- Circles of Confusion (EBU, 2009) A. Roberts
- Colour Reproduction in Electronic Imaging Systems (Wiley, 2016) M.S. Tooms

Annex A: Gamma considerations

Television has evolved to give pleasing results in a viewing environment described by colour scientists as 'dim surround' [6].

This outcome includes three invariant components:

- the requirement to match luminance level coding (whether analogue or digital) to the approximately logarithmic characteristic of the human vision system by means of an appropriate nonlinear coding or 'perceptual' coding of level. Such a characteristic has the effect of equalizing the visibility over the tone scale of quantizing in a digital signal, or noise in an analogue one. A linear or other non-perceptual based characteristic would require greater dynamic range (bandwidth or bit rate) for the same perceptual quality, with adverse economic consequences;
- the immovable legacy effect of the CRT gamma characteristic on which the entire television system was empirically founded. This legacy consists of both archived content and world-wide consumer display populations;
- gamma is also the characteristic which coding schemes such as MPEG-2 and MPEG-4 AVC are designed to match, and any other characteristic will be less than ideal in terms of artefact and noise visibility, to the extent that much of the impairment seen these days on transmitted television material, when viewed on flat screen displays, is caused by the failure of the display to adhere closely to a gamma characteristic, particularly near black.

It has been found [6] that the end-to-end or 'system' gamma for images captured in nominal daylight conditions, adapted for the dim-surround consumer-viewing environment is approximately 1.2, i.e. it is definitely not linear.

The system gamma can be expressed as:

System gamma = camera encoding gamma (OETF) x display gamma (EOTF**)*

It has been found from measurement techniques, progressively refined over several decades, that a correctly designed CRT display has an EOTF gamma of approximately 2.35 [5]. This is part of the 'immovable legacy effect' of the CRT.

Therefore our system gamma equation is rewritten as

System gamma = 1.2 = OETF gamma x 2.35

Therefore OETF (camera) gamma = 0.51.

Since a pure gamma curve would require infinite gain to be applied to camera signals near black, resulting in unacceptable noise; in practice this curve is modified to consist of a small linear region near black in combination with a reduced gamma curve of 0.45 [2]. Note however, that a 'best fit' single power law curve for this characteristic comes out as 0.51, the same as the calculation above.

From the above, since the consumer viewing environment does not change, and the OETF gamma cannot change (for compatibility reasons and for the continuation of an optimal perceptual coding characteristic), the EOTF gamma shall also remain at 2.35, regardless of which new physical display

* OETF: Opto-electrical transfer function

** EOTF: Electro-optical transfer function device is used to implement it.

In January 2014 a study was made at the IRT in Munich, comparing a variety of video material, and film material graded for video, on three monitors set for gamma values of 2.2, 2.35 and 2.4. An analysis of the comments and views of the vision engineers and colourists who took part in the study concluded that monitors set to 2.35 and 2.4 were so similar that no substantial difference would have occurred had the material been graded at one or other setting.

The EBU has therefore taken the decision to drop its preference for a gamma of 2.35 to bring this document into line with other international standards bodies (who in general took the view that the value need only be specified to one decimal place), and the EBU are thus accepting a gamma value of 2.4, because:

a) having two marginally different standards for no good reason could be harmful and confusing to the television industry;

b) in practice we have observed production areas using some monitors set to 2.35 and others to 2,4, and the users have been unaware of any difference;

c) the change is sufficiently small that we do not believe it would cause any director or colourist to make a substantial or material change to any earlier colour grading decisions, were they to revisit their output;

d) the change will have no effect on the archive held by broadcasters, which is still broadcast to an extensive legacy base of existing receivers.

Annex B: CIE 1976 – the L*u*v* uniform colour space

The comparison of colour differences on chromaticity diagrams such as CIE 1976 Yu'v' is only applicable at one given luminance level, because the perception of colour differences is dependent on the luminance level. The CIE L*u*v* (or CIELUV) space is therefore used to provide tolerances of approximately equal visibility. It is used here as a compromise between a standardised and easily calculated measure of colour differences, and more sophisticated and complex models of colour vision. L* is termed 'Lightness'.

General formula:

$L_{a/n}^* = 116(Y_a/Y_n)^{1/3} - 16$ for $Y_a/Y_n > 0.008856$

$L_{a/n}^* = 903.3\ (Y_a/Y_n)$ for $Y_a/Y_n \le 0.008856$

$u_a^* = 13\ L_{a/n}^*\ (u'_a - u'_n)$

$v_a^* = 13\ L_{a/n}^*\ (v'_a - v'_n)$

Y_n, u'_n and v'_n are the chromacities of the reference white. The *a* index is for the desired calculation point (can be substituted by *m*, *w*, *D65* or *ref* in function of which L*,u* or v* is desired)

$\Delta u_m^* = u_m^* - u_{ref}^*$

$\Delta u_m^* = u_m^* - u_{ref}^*$

$\Delta u_m^* = 13\ L_{m/n}^*\ (u'_m - u'_n) - 13\ L_{ref/n}^*\ (u'_{ref} - u'_n)$

Δv_m^* is calculated in the same way

where *m* is for the measured chromaticity, and *ref* is the reference from which Δu_m^* is calculated.

For tolerances to be applied to the white point:

- ref is D65 with chromaticity coordinates $u'_{D65} = 0.1978$ and $v'_{D65} = 0.4683$ [6].
- m becomes w for measured white
- n is D65
- For Grade 1 monitors Y_n is taken as 100 cd/m^2, for Grade 2, 200 cd/m^2, and for Grade 3 as 250 cd/m^2
- The generalized formula can be simplified as:
  $\Delta u_w^* = 13\ L_{w/n}^*\ (u'_w - u'_{D65})$

  $\Delta v_w^* = 13\ L_{w/n}^*\ (v'_w - v'_{D65})$

For grey-scale tracking calculations:

- ref is the measured white point and becomes w
- m becomes g for grey-scale
- n is the measured white point, w
- The generalized can be simplified as:
  $\Delta u_g^* = 13\ L_{g/w}^*\ (u'_g - u'_w)$

  $\Delta v_g^* = 13\ L_{g/w}^*\ (v'_g - v'_w)$

For test colour and primary reproduction calculations:

- ref is the expected test colour and becomes ex

- m becomes c for colour
- n is the measured white point, w
- The generalized formula can be simplified as:
  $\Delta u_c^* = 13\ L_{c/w}^*\ (u'_c - u'_w) - 13\ L_{ex/w}^*\ (u'_{ex} - u'_w)$

  but $L_{ex/w}^*$ is replaced by $L_{c/w}^*$ to remove the effect of EOTF error of the display

  $\Delta u_c^* = 13\ L_{c/w}^*\ (u'_c - u'_{ex})$

  $\Delta v_c^* = 13\ L_{c/w}^*\ (v_c' - v_{ex}')$

Deltas:

$\Delta u^*v^* = \sqrt{(\Delta u^{*2} + \Delta v^{*2})}$

$\Delta E^*_{uv} = \sqrt{(\Delta L^{*2} + \Delta u^{*2} + \Delta v^{*2})}$ (simplified in this document as ΔE^*)

For further information, please refer to §§ 3.8 to 3.10 of 'Measuring Colour' (see bibliography).

Annex C: Checklist of parameters and values

Parameters	Sub-parameters	Values per Display Grade								Comments
		Grade 1		Grade 2		Grade 3		Set Design		
Luminance adjustment range	100%	70 to ≥100 cd/m²		70 to ≥200 cd/m²		70 to ≥250 cd/m²				
	Coverage up to 109%	Continuous		Continuous		Continuous				
Black Level	Full screen black	< 0.05 cd/m²		< 0.4 cd/m²		< 0.7 cd/m²				
	No clipping by the monitor, of sub-blacks.	Mandatory		Mandatory		Mandatory				
Contrast ratio	Full Screen (1% patch)	1400:1 to ≥ 2000:1		> 175:1		> 100:1				
	Simultaneous	> 200:1		> 100:1		> 100:1				
Gamma Characteristics*	Luminance gamma characteristic: 2.4	Mandatory		Mandatory		Mandatory				
	R, G, B transfer functions: as grey scale reproduction	Mandatory		Mandatory		Mandatory				
	Transfer function within ±0.10% of ideal gamma value (10-90%)	Mandatory		Mandatory		Optional				
	10-bit input shall result in a 10-bit representation	Mandatory		Mandatory		Optional				
Grey Scale Reproduction	For luminance from 1 – 100 cd/m² (tolerance from white point)	0.5 Δu*v*		1 Δu*v*		1.5 Δu*v*				
	For Luminance <1 cd/m², deviation from grey	Not visible		Not visible		Not visible				
Colour Gamut and test colour reproduction	EBU test colours	4 Δu*v*		7 Δu*v*		7 Δu*v*				
	Skin Tone Colours	2.6 Δu*v*		7 Δu*v*		7 Δu*v*				
	SD (compliant with EBU Tech 3213)	EBU Boxes		EBU Boxes		EBU Boxes				
	HD primaries	4 Δu*v*		7 Δu*v*		7 Δu*v*				
Colour Temperature	Default	D65		D65		D65				
	Switchable to 3200K	N/A		Optional		Optional				
Viewing-angle dependency	Visibility in colour deviation for: ±45° (Hor) and ±20° (Vert)	Not visible		Not visible		Not visible				
	Tolerance for 20% grey scale	<6.8 Δu*v*		<6.8Δu*v*		<9 Δu*v*				
	Tolerance for 50% grey scale	<6 Δu*v*		<6 Δu*v*		<9 Δu*v*				
	Contrast ratio drop for ±30°H and ±15°V	drop ≤20%		drop ≤20%		drop ≤35%				
	Contrast ratio drop for ±45°H and ±20°V	drop ≤50%		drop ≤50%		drop ≤50%				
Motion artefacts	Input artefacts should be represented faithfully	Mandatory		Mandatory		Optional				
	Display should not introduce artefacts	Mandatory		Mandatory		Optional				
Screen resolution	At least as many pixels as the input signal	Mandatory		Mandatory		Optional				

Parameters	Sub-parameters	Values per Display Grade								Comments
		Grade 1		Grade 2		Grade 3		Set Design		
	Ability to display a pixel-mapped image	Mandatory		Optional		Optional				
Image scaling, de-interlacing and overscan	Image scaling: minimize artefacts (state of the art)	Mandatory		Mandatory		Mandatory				
	Choice of deinterlacing modes (bypass for progressive input)	Mandatory		Mandatory		Optional				
	Exposition of 'field dominance' problems (wrong order of interlaced fields)	Mandatory		Mandatory		Mandatory				
	Default mode: no overscan (maybe one-to-one pixel mapping)	Mandatory		Mandatory		Mandatory				
	Edges of the picture should not be obscured by a bezel	Mandatory		Mandatory		Mandatory				
	Adjustable to have an overscan of 2%	Mandatory		Mandatory		Mandatory				
Delay time	Short delay display mode (lower picture quality):	Optional		preferably ≤10ms		preferably ≤10ms				
Screen size	Target viewing distance for HDTV	3x Picture height		3x Picture height		3x Picture height				
Uniformity	Large area – Luminance tolerance	+/-5% of mean		+/-5% of mean		+/-5% of mean				
	Large area – Chrominance tolerance	<2.6 Δu*v*		<4 Δu*v*		<4 Δu*v*				
	Small area – Luminance tolerance	std dev. 5%		std dev. 20%		std dev.<35%				
Mura (imperfections in LCD panels)	Not visually detectable	Mandatory		Mandatory		Mandatory				
Streaking (crosstalk, overspill or shadowing)	Tolerance	<0.5%		<1%		<2%				
Stability and environmental conditions	Sustain same performance within temperature range of 0°C to 40°C	Mandatory		Mandatory		Mandatory				
	1 min max warm up time for acceptable pictures display	Optional		Mandatory		Mandatory				
	Maximum stabilisation duration: 20 min	Mandatory		Mandatory		Mandatory				
	Sustained Humidity: 10% to 75%	Mandatory		Mandatory		Mandatory				
	Sustained altitude : Up to 3000m height	Mandatory		Mandatory		Mandatory				
	Sustained storage: -35°C to +70°C	Mandatory		Mandatory		Mandatory				
Pixel defects	Central 50% area of the screen:	no visible defects		no visible defects		no visible defects				
	Outside 50% area:	no visible defects		no visible defects		defect cat. II				
Ringing and handling of under- and over-shoots	Sharpness control	No		No		Optional				
	Image enhancements	No		No		Optional				
Treatment of	Aliasing shall be visible	Mandatory		Mandatory		Mandatory				

Parameters	Sub-parameters	Values per Display Grade								Comments
		Grade 1		Grade 2		Grade 3		Set Design		
illegal signals	Mode to indicate out of gamut colours	Mandatory		Mandatory		Optional				
Image sticking (long-term after-image)	Comparable to or better than that of the CRT monitor	Mandatory		Mandatory		Mandatory				
Supported standards	480i/30 (29.97)	Mandatory		Mandatory		Mandatory				
	576i/25	Mandatory		Mandatory		Mandatory				
	720p/50	Mandatory		Mandatory		Mandatory				
	720p/60 (59.94)	Mandatory		Mandatory		Mandatory				
	1080i/25	Mandatory		Mandatory		Mandatory				
	1080i/30 (29.97)	Mandatory		Mandatory		Mandatory				
	1080p/24 (23.98)	Optional		Optional		Optional				
	1080psf/24 (23.98)	Optional		Optional		Optional				
	1080p/25	Optional		Optional		Optional				
	1080psf/25	Mandatory		Mandatory		Mandatory				
	1080p/30 (29.97)	Optional		Optional		Optional				
	1080psf/30 (29.97)	Optional		Optional		Optional				
	1080p/50	Optional		Optional		Optional				
	1080p/60 (59.94)	Optional		Optional		Optional				
Supported signal interfaces	SDI	Mandatory (≥2)		Mandatory (≥2)		Mandatory		Mandatory		
	HD-SDI	Mandatory (≥2)		Mandatory (≥2)		Mandatory		Mandatory		
	Dual HD-SDI or 3Gbit/s (*mandatory if 1080p/50-60 supported)	Av. As an option*		Av. As an option*		Av. As an option*		Av. As an option*		
	HDMI	Av. As an option		Av. As an option		Av. As an option		Av. As an option		
	DVI 1.0	Av. As an option		Av. As an option		Av. As an option		Av. As an option		
	Components RGB, YcrCb	Av. As an option		Av. As an option		Av. As an option		Av. As an option		
	CVBS (PAL, SECAM, NTSC)	Av. As an option		Av. As an option		Av. As an option		Av. As an option		
	RF (analogue)	N/A		N/A		Opt. As external		Opt. As external		
	RF (DTT)	N/A		N/A		Opt. As external				
Other facilities	4:3 and 16:9 aspect ratio mode	Mandatory		Mandatory		Mandatory		Mandatory		
	safe title and aspect ratio markers	Mandatory		Mandatory		Optional				

Parameters	Sub-parameters	Values per Display Grade								Comments
		Grade 1		Grade 2		Grade 3		Set Design		
	tally lamp (red, green, yellow)	Mandatory		Mandatory		* Only for certain applications				
	RS 232 and/or GPI remote control	Mandatory		Mandatory		Optional				
	overscan / full screen / 1 to 1 pixel-map modes	Mandatory		Mandatory		Optional				
	H/V delay	Mandatory		Mandatory		Optional				
	blue only mode	Mandatory		Mandatory		Optional				
	mono mode	Mandatory		Mandatory		Optional				
	ext. Sync in	Mandatory		Mandatory		Optional				
	stereo loudspeaker	optional		optional		* Only for certain applications				
Acoustic Noise	For display used for audio edit, set design, view finders: < NR5									
	For displays in studio floor, edit areas: < NR10									
	For displays in technical areas: < NR20									
Surface reflectivity (glare)	Reflectance should be below 10%. Relevance depends on the control on light in the viewing environment.	Mandatory		Mandatory		Mandatory				

Annex D: Colour Matching Functions and metamerism.

The CIE 1931 colour matching functions (CMFs) are the basis of all colorimetric measurement systems in practical use worldwide. In 1951 Judd[1] provided a modified set of modified colour matching functions, which were improved by Vos[2] in 1978. These were intended to correct historical imperfections in the original data used as the basis of the CIE 1931 CMFs, but like the CIE 1964 Supplementary Standard Observer, have never found widespread favour, because they result in different numbers across the whole colour-space. Dr Abhijit Sarkhar attempted to define a more accurate CMF. His work[3] resulted in a set of CMFs which solve the metamerism issue for discrete populations of individuals but this would probably not be practical in an operational environment.

These inaccuracies were not a problem when all display devices were CRTs with colour reproduction based on very similar phosphors. With the introduction of LCD displays with LED backlights, and now OLED displays, it has become apparent that these errors result in displays where the white points match when measured may look different, and when matched visually may measure differently.

Different approaches exist. For example an offset can be applied to the CIE 1931 measurements. This approach (colorimetric offsets derived from Judd/Vos modified CMFs)[4], or others achieving an equivalent practical outcome, may be a practical compromise such that the display may meet both the requirements of written standards, and enable the visual match that is so important in the television production environment.

[1] CIE, Compte Rendu, 12th Session, Stockholm, Vol.1, Committee No.7, Colorimetry, pp. 11-52 (1951)

[2] Vos, J. J., Colorimetric and photometric properties of a 2° fundamental observer, Color Res. & Appl. 3 p.125 (1978)

[3] “Identification and Assignment of Colorimetric Observer Categories and Their Applications in Color and Vision Sciences", A. Sarkar, Université de Nantes, 2011. http://www.abhijitsarkar.com/documents/PhDThesis/PhDThesis_Sarkar_2011.pdf

[4] An approach adopted by Sony, described in their White Paper “Colour Matching Between OLED and CRT” published in February 2013 is to apply an offset to the CIE 1931 measurements, calculated using the Judd/Vos method, such that specifications and measurements continue to be referenced to the 1931 standard.
http://www.keycodemedia.com/images/stories/products/Sony/WhitePaper_ColorMatching_2013_02_15.pdf