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User requirements for a Flat Panel Display (FPD) as a Master monitor in an HDTV programme production environment

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REPORT ITU-R BT.2129*

User requirements for a Flat Panel Display (FPD) as a Master** monitor in an HDTV programme production environment

(2008)

Introduction

Flat panel displays will replace CRT based master monitors in TV programme production, and monitoring, it is therefore urgent that a set of user requirements be addressed. Flat panel displays have recently shown display performance closely emulating that of the CRT, as with most technologies the performance characteristics improves over time. It is the aim of this Report to be technology agnostic, although it should be remembered that certain technologies have characteristics that can not be ignored.

As of this writing, technologies such as Plasma, LCD, and FED may all be contenders for consideration as Master monitors. In all cases, commercial products may well vary in their performance, generally based on price.

In developing this Report the following assumptions are being made:

1 A master monitor is a measuring instrument of image quality in TV programme production. The purpose of a monitor is to faithfully and reliably display the signal as it is, and it must not attempt to "enhance" or otherwise alter the image. To do this, the input signal should be subjected to as little signal processing as possible.

2 A FPD will be used in the same way as a CRT master monitor in daily operation of TV programme production.

3 The focus of this Report is the display of HDTV images.

4 Recommendation ITU-R BT.709 was developed based on the assumed characteristics of CRT monitors (ex. colour gamut, gamma characteristics). Master monitors play a critical role of being utilized as a measuring instrument which displays the image in accordance with the specification of Recommendation ITU-R BT.709. FPD when used as a master monitor should have the same or similar characteristics as those of the CRT.

5 The input signals should have 10 bit pixel depth.

* Radiocommunication Study Group 6 made editorial amendments to this Report in 2009 in accordance with Resolution ITU-R 1.

** The term Master monitor is also called Reference monitor, or Grade 1 monitor in different regions.

CONTENTS

1 User requirements – Image quality

In reviewing the user requirements, the reader should be cautioned that the parameter values noted are a moving target and the performance will no doubt be improved over time.

1.1 Peak luminance/all-white luminance

When a luma signal of level 940 (100% white) is input, the display should be adjusted so that the peak luminance on the screen can be set at any luminance level within the range of 100 to 250 cd/m^2.

When a luma signal of level 64 (black) through 1 019 (109% white) is input, grey scale tracking should be performed on each level between level 64 and 1 019.

The above conditions must be met for a colour temperature of 6 500 K (*D*65) (in some regions the above conditions must be met for a colour temperature of 9 300 K (*D*93)).

ABL (Automatic Brightness Limiter) function if provided should be disabled.

1.2 Black

When a luma signal of level 64 (black) is input, the luminance level on the screen should be less than 0.01 cd/m^2.

Measurement for this item must be conducted after adjustment of the display using the PLUGE test signal specified in Recommendation ITU-R BT.814, in case of LCD monitors, neither automatic nor manual control of backlight intensity should be active during the measurement of black level. This measurement may prove to be difficult under some conditions.

1.3 Contrast ratio

Contrast ratio should be more than 350:1.

The FPD is adjusted using the PLUGE test signal as specified in Recommendation ITU-R BT.814 so that the luminance setting of the 100% white part on the screen becomes 100 cd/m^2. Then, contrast ratio is measured as the ratio between the luminance of the part displaying 100% white (luma signal of value 940) on the screen, and that corresponding to displaying only the black level (luma signal of value 64) in a completely dark room when the signal specified in Recommendation ITU-R BT.815 for measurement of contrast ratio is input. Neither automatic control nor manual control of backlight intensity should be active during the measurement of contrast ratio.

1.4 Gamma characteristics

The gamma characteristics (electro-optical transfer characteristic) of the display should be equivalent to those of a reference CRT. The value for Gamma is still under discussion, the intent is that the final value should emulate the CRT or at minimum produce image characteristic that closely match the CRT.

Appendixes A and B – These appendixes reflect the finding of two industry bodies that have been investigating this issue. This information should be considered informative. It is expected that further information will be available in 2008/2009.

1.5 Tone reproduction (Grey scale)

Grey scale tracking in *R*, *G* and *B* components should be performed with no less than 10-bit precision. Grey scale tracking between colour channels shall be within ellipses defined:

> ±0.0010 $\Delta u'$, ±0.0015 $\Delta v'$ (CIE 1976 chromaticity differences) for luminances 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.

The suggested tolerances may need further definition in the range above reference white up to the limit of 109% white (1019).

1.6 Colour gamut

The FPD should display images with the colour gamut specified in Recommendation ITU-R BT.709.

1.7 Colour temperature (White)

The FPD should display pictures with a reference white colour temperature of 6 500 K(*D*65)

> ±0.0010 Δ*u*′, ±0.0015 Δ*v*′ (CIE 1976 chromaticity differences) or (in some regions of the world 9 300 K (*D*93) is used)[1].

1.8 Viewing-angle dependency

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 and vertically in any direction from the perpendicular axis to the centre of the screen (see Appendix C).

As a guide to an acceptable numerical value, Δ*u*′, Δ*v*′ (CIE 1976 chromaticity differences) should be less than 0.01 for any of the colours within the Recommendation ITU-R BT.709 gamut.

As a guide to an acceptable numerical value, the luminance value should drop less than 10% for viewing angles within ±30° horizontally, vertically, and diagonally, and less than 20% for viewing angles within ±30° and ±45° horizontally, vertically, and diagonally.

The black level, when measured from viewing angles up to ±20° in any direction from the perpendicular axis to the centre of the screen, horizontally and vertically, = Δ*u*′, Δ*v*′ = < 0.01. When measured from viewing angles between ±20 – ±45° horizontally and vertically = Δ*u*′, Δ*v*′ = < 0.02.

1.9 Motion artefacts

Motion blur on FPD screens should be comparable to those of the CRT, or to a degree at which it cannot be detected. Work continues on decreasing the visibility of motion artefacts. Different FPD technologies require different solutions and produce different artefacts. In addition the refresh rate of FPDs may not be at the same rate as the native rate of the image. Care should be taken to ensure that no difference in motion rendition is introduced.

1.10 Screen resolution

The horizontal and vertical pixel counts on the screen must be equal to the number of active samples per line and the number of active lines per frame of TV system for *R*, *G* and *B*, respectively. The desire is to have a one to one pixel mapping without the use of image scalers. In some cases, scaling may be required in order for the image to completely fill the screen End users are advised to determine the characteristics of the scaler before performing any critical evaluation.

1.11 Image scaling, de-interlacing and overscan

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

b) It is desirable that monitors display the image in the native interlace or progressive format that is present on the input interface. De-interlacing of interlace images, if equipped, should be able to be turned off.

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[1] If the colour temperature is designed for either *D*65 or *D*93 only, the other colour temperature must be realized by signal processing. Under these circumstances, 10-bit precision may not be obtained.

c) The default mode should be to 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 often may be one-to-one pixel mapping.

d) Monitors should offer optional programmable overscan/underscan mode of up to 5%.

1.12 Uniformity

The luminance values measured at many points for each luma signal level on the whole screen should meet the following conditions when the signal of the grey level is input: (the maximum measured value – the minimum measured value)/the average value ≤ 0.10. This measurement should be performed at a mid grey level, and white level.

1.13 Mura[2]

Mura should not be visually detected on the screen regardless of reproduced luminance levels or colour saturation. This artefact is not expected to be a problem however in the interest of completeness it is included in this Report.

1.14 Smear[3] (vertical and horizontal crosstalk)

When the input signal has a rectangle of luma signal of value 64 (black) or 940 (100% white) near the centre and has a grey area in its surroundings (see Fig. 2), the difference in luminance between the horizontal and vertical belt-like portions and the other grey portions should not be greater than 0.5%.

1.15 Stability

a) A 30-min warm-up period from a "cold" start should be allowed before any observations or measurements are taken.

b) After this warm-up time, the measurements shall remain within the specifications given for 24 h.

1.16 Screen size

The screen size of the display is at the discretion of users, but may need to be larger (because of the target viewing distance of 3 times picture height) for adequate monitoring of HD. Production spaces are still designed for the same size CRT monitors previously used, because there are often constraints which make moving to larger screen sizes difficult. This may have an impact on the ability to adequately monitor HD quality. It is suggested that screen sizes in the range of 18-32 inches may suite current environments. It is anticipated that larger screen sizes will be required in the future.

1.17 Pixel defects

The ideal situation would be that there are no pixel defects. A more pragmatic approach may that there should be no visible pixel defects. Specific image content may expose pixel defects differently.

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[2] "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.

[3] "Smear" is a term for capturing devices with CCD, and it means the phenomenon that a vertical bright bar occurs when such strong light source as the sun or electric bulbs is shot. In case of CRT monitors, when a much brighter or darker spot than the surrounding area causes vertical or horizontal bars, this phenomenon is also often called as smear. The similar phenomenon is called as "crosstalk" for LCD and "image streaking" for PDP. Here, smear means the phenomenon that the data on one part of the display influences what is displayed elsewhere.

1.18 Ringing

Ringing or overshoots should not be introduced by any processing in the display. Ringing "in the image signal" should be displayed. Monitors should not cut off under- and over-shoots, or sub-black and super-white levels.

1.19 Image sticking (long-term after-image)

The characteristics for image sticking (long-term afterimage**)** on the screen of a FPD should be less than a CRT monitor.

1.20 Interface signal

The input interface should comply with Recommendation ITU-R BT.1120 for both 4:2:2 signals and 4:4:4 signals.

2 User requirements – Functionality of a master monitor (Informative)

Defining master monitor functionality is NOT intended to be a product design, manufacturers are encouraged to design products with features and functionality as they see fit. This list of functional requirements is not intended to be a complete list. These requirements are intended to be guidelines only.

2.1 Input signal format and interface

The input signal format should be HD-SDI interface specified in Recommendation ITU-R BT.1120.

2.2 Display range on display for each input signal

The default aspect ratio should be 16:9, all pixels contained in the pixel matrix 1 920 x 1 080 should be displayed without rescaling.

In some cases, when a 4 × 3 aspect ratio image is carried by the interface, the image should be 1 440 × 1 080 pixels mapped within the 1 920 × 1 080 interface format.

2.3 Selection of display range (scan selection)

Normal (100%) displays all active image area of the input signal.

Over-scan (105%)/under-scan (95%) display format is optional, and should not be used for image evaluation. The over-scan/under-scan programmable functionality may be used to verify consumer viewing conditions.

To perform "underscan display" in a simple way, an adjustable black border is suggested to surround the image. The overscan amount being adjustable, up to 5%.to account for local regional conditions

2.4 Backlight intensity control

When adjusting the monitor luminance, it is preferable to use backlight intensity control rather to use signal level scaling to retain the bit precision. Accordingly, where applicable, it should be possible to change the backlight intensity manually in small increments, and to switch to preset values. It should be possible to change and store the preset values.

When a luma signal of value 940 (100% white) is input, the backlight should be adjustable so that the luminance can be within the range of 100 to 250 cd/m^2.

Some technologies do not use a backlight, in this case the white level should be adjusted to be within the range of 100 to 250 cd/m^2 by the means other than signal level scaling.

2.5 Reference white

*D*65 should be the default value (in some regions *D*93 may be the default setting).

2.6 Black and white/colour display switch

When an input signal is in Y, C_B, C_R, format it should be possible to display the *Y* signal only (black and white display mode). If an input signal is in the *RGB* format, black and white display mode is not required.

Black and white/colour switch should be easily accessible, with minimal disturbance to the displayed image.

2.7 Delay time[4]

The use of FPDs introduces a potential systems design problem. FPDs typically use some form of image processing that may well introduce significant delay before the image is displayed. Different technology, and modes of operation, could introduce delays that are not consistent between manufacturers and or monitors from one manufacturer. Users should be aware that applications requiring accurate switching times or verification of Lip Sync will also need to know the delay time of a monitor. It is suggested that manufacturers indicate the delay time of their master monitor.

2.8 Aspect ratio markers

It should be possible to display the lines to display the positions for 14:9, 13:9 and 4:3, and the line colours should be selectable. The sample numbers defining the borders should comply with Fig. 1.

It should be possible to perform a shadow display for the outside parts of 14:9, 13:9 and 4:3, and the luminance for the shadow parts should be selectable. The sample numbers (Black, Grey, etc.) which define the borders should comply with Fig. 1.

2.9 Safe area markers

As shown in Fig. 2, it should be possible to perform a marker display for the safety zone in full screen display. Users should be able to change the marker position for safety zone from 80% to 100% in increments of 1%, and the current % should be displayed on the screen.

If a signal with aspect ratio of 14:9, 13:9 or 4:3 is displayed, the marker position should be changeable from 80% to 100% in increments of 1%, and the current % should be displayed on the screen.

2.10 Selection of plain colour *R, G, B*

It should be possible to independently display the *R*, *G*, *B*, signals.

2.11 Gain control (*RGB* independent gain control)

The gains for *R*, *G* and *B* should be independently adjustable.

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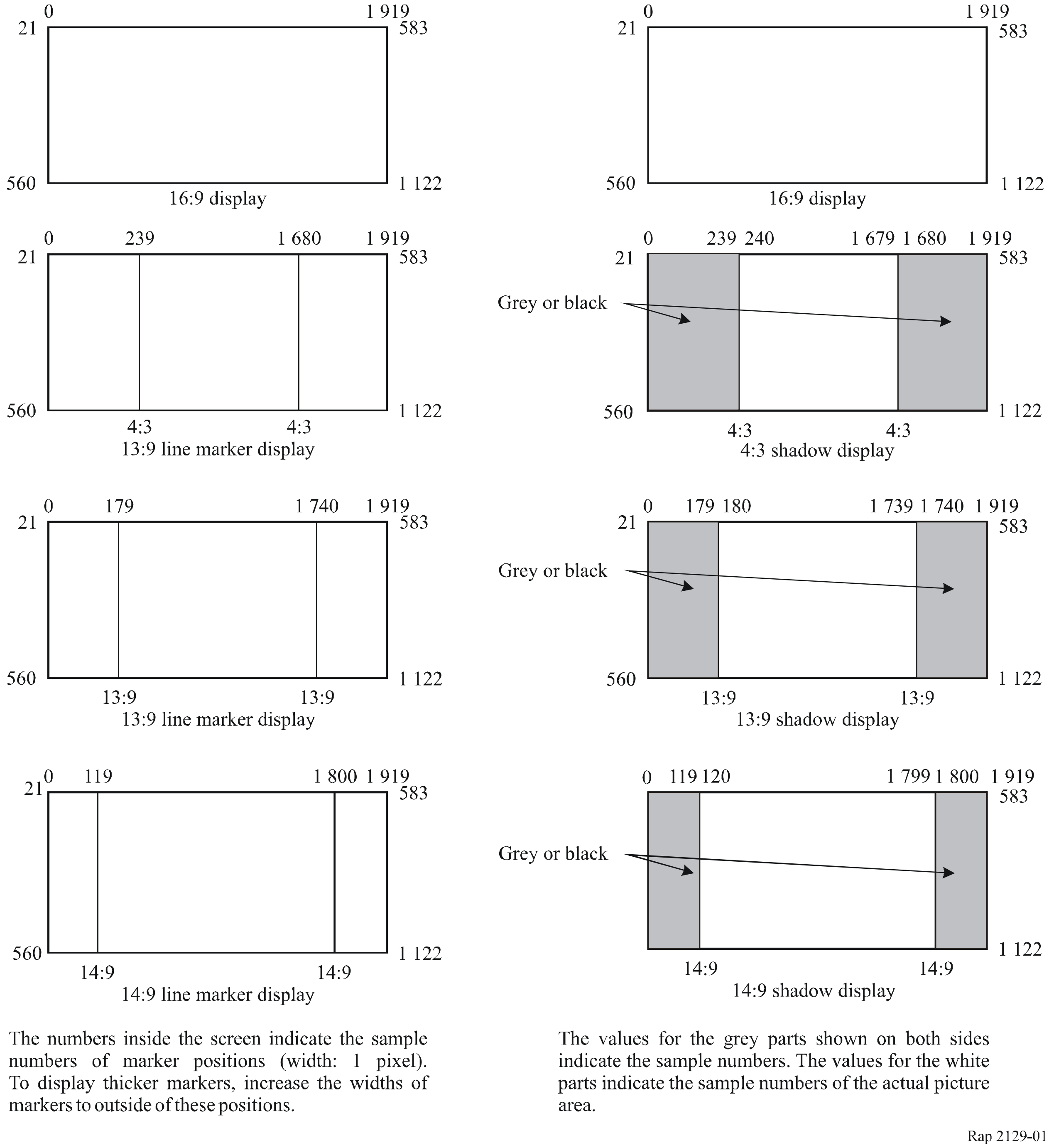
[4] "Delay time" here means the latency between the input signal and the displayed signal, namely "delay time" refers to the period from the time when a signal is input into the input signal terminal of FPD to the time when it is displayed.

FIGURE 1
Border positions in line marker or shadow display



2.12 Bias control (*RGB* independent pedestal (Black level) control)

Where applicable the biases of *R*, *G* and *B* should be independently adjustable.

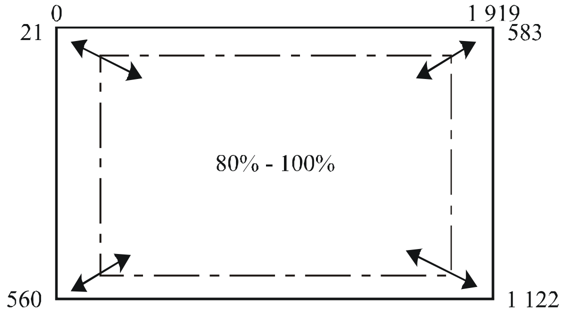
2.13 Brightness control (Black level)

It should be possible to change the brightness settings manually and switch to preset settings. The preset settings should be programmable.

2.14 Contrast control (*RGB* gain control)

It should be possible to change the contrast settings manually and switch to preset settings. The preset settings should be programmable.

FIGURE 2
Display range of safety zone (80-100%)



Safety zone display with 16:9 display

Rap 2129-02

2.15 Auto set-up

The monitor should offer some form of Auto or semi auto set-up functions that can be operator initiated, the intent being that a large number of monitors will match one to another.

3 Guide to measurement techniques – (Informative)

The suggested measurement methods may vary from this text depending upon the test instrument that is being used. Moreover in many cases only subjective observations may be made. End users should be aware that many adjustments to an FPD may differ to adjustments made to a CRT, the manufacturers recommendations should be followed.

3.1 Base line conditions

As a base line, measurement is performed in a dark room after a 30 min or longer warm up time. Measurement should be conducted in a dark room for the following reasons:

a) locations where master monitors are used, are dark; and

b) measurements can be made with minimal influence from the surrounding light.

3.2 Input signal

The digital signal values should be a minimum of 10-bit decimal representation as defined in Recommendation ITU-R BT.709. The “signals” shown below refer to “digital signals” at the specified value. Care should be taken when selecting measuring equipment because there are variations in accuracy (variation included in the measurement data, limit value of measurement, etc.), depending on the measuring method.

3.3 Peak luminance/all-white luminance

Measurement method – (Luminance meter) Input a flat field signal of Y level 940 (100% white) and C_B, C_R value 512, and use the measurement equipment to measure the luminance of the screen in the dark room.

Reason

While the peak luminance/all-white luminance is defined as that corresponding to a signal of Y value 940 and C_B, C_R value 512, the luma signal through value 941 to 1 019 can be used as video data, normally overshoot and undershoot area. Accordingly, FPD should be adjusted so that the video can be displayed with the grey scale tracking maintained even when the luminance is over the peak luminance/all-white luminance.

3.4 Black

Measurement method – (Luminance meter)

Input a flat field signal of Y value 64 (Black) and C_B, C_R value 512, and use the measurement equipment to measure the luminance of the screen in the dark room.

Adjustment method

Measurement for this item must be conducted after adjustment of the display using the PLUGE test signal specified in Recommendation ITU-R BT.814.

Where applicable, automatic backlight intensity should be disabled during this measurement.

3.5 Contrast ratio

Measurement method – (Luminance meter)

The measured FPD is adjusted so that the luminance of 100% white on the screen equals 100 cd/m^2. Brightness of the display is adjusted using the PLUGE test signal and the set up procedure specified in Recommendation ITU-R BT.814.

The contrast ratio measurement signal specified in Recommendation ITU-R BT.815-1 and use the measurement equipment to measure the luminance displaying 100% white (Y value 940) on the screen, and that corresponding to the black value (Y value 64). (C_B, C_R values are set to 512). Contrast ratio is the ratio of luminance values, Black and White.

Where applicable, automatic backlight intensity should be disabled during this measurement.

3.6 Gamma characteristics

Measurement method – (Tristimulus meter or spectroradiometer)

The method of measurement between tradition CRT and FPD is the same. However the adjustment procedure for different display technologies may be quite different from that of a CRT. Users are recommended to use the manufactures adjustment procedure.

3.7 Tone reproduction

Measurement method – (Luminance meter)

For luminance range from 1 to 100 cd/m^2

Deviation from grey should not be visible for luminance below 1 cd/m^2

Another suggested method is to change the Y value of the signal by 1 LSB in 10-bit decimal representation (with the C_B, C_R value set to 512). Use the measurement equipment to check that the measured luminance value changes according to the Y value of the signal.

3.8 Colour gamut

Measurement method – (Tristimulus meter or spectroradiometer)

Measured chromaticity coordinates of the displayed images of the input signals corresponding to the primary colours described in Recommendation ITU-R BT.709 is basically used to express the colour gamut, although some additional means are required to measure whole «three-dimensional» colour gamut.

3.9 Colour temperature (White point)

Measurement method – (Tristimulus meter or spectroradiometer)

Input a signal of Y value 283, 502, 721 and 940 (C_B, C_R value 512) use the measurement equipment to measure the colour temperature. Adjustments to modify the colour temperature setting of a FPD may differ significantly to that of a CRT. Manufacturers recommendations should be followed.

3.10 Viewing-angle dependency

Measurement method – (Luminance meter, Tristimulus meter or spectroradiometer)

For the measurement of the viewing-angle dependency of reproduced colours, input full screen signal with the colour coordinates of the Macbeth chart. Measurement angles in addition to the front measurement should be Colour ±45° horizontally, vertically, diagonally, and luminance ±45° horizontally, vertically, diagonally.

For the measurement of the viewing-angle dependency of luminance-drop and black-level colour shift, use reference white and black signals, respectively.

3.11 Motion blur

Measurement method

The degree of motion blur should basically be evaluated by visual inspection.

There still remains some concern in using MPRT values[5]. MPRT[6] values are sited in this technical Report for information only.

3.12 Resolution

Reason

On a master monitor, it is desired to display an image without rescaling, a one to one pixel mapping of the display device and the source image is recommended.

3.13 Uniformity

Measurement method – (Tristimulus meter or spectroradiometer)

Input a series of flat field signals consisting of Y value 283, 502, 721 and 940 (C_B, C_R value 512) and use the measurement equipment to measure the luminance values at 50 to 40 000 points on the screen. Use these measured values to calculate the following formula; (the maximum measured value – the minimum measured value)/the average value.

3.14 Mura

Measurement method

At this point there is no objective measurement simple subjective observations are all that is possible.

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[5] MPRT is the abbreviation for Moving Picture Response Time. The blur on the FPD is influenced not only by response time of the FPD but also by hold time. (Even if the response time is 0, a blur is caused by a hold- display.) MPRT is the calculation method of obtaining blur values which are proportional to perceived motion blur values based on two parameters (response time and hold time). There are products that automatically measure MPRT values.

[6] Since the MPRT value for CRT is approximately 3 to 4 ms, if the MPRT value for FPD is 4 ms, it can be judged that there is no problem on motion blur. It is not proven that MPRT can be used for evaluating the motion blur for FPD screen. One option has been expressed in SOMEYA J. [2005] Correlation between Perceived Motion Blur and MPRT Measurement. SID 2005 Digest, p. 1018-1021.

3.15 Vertical and horizontal crosstalk[7]

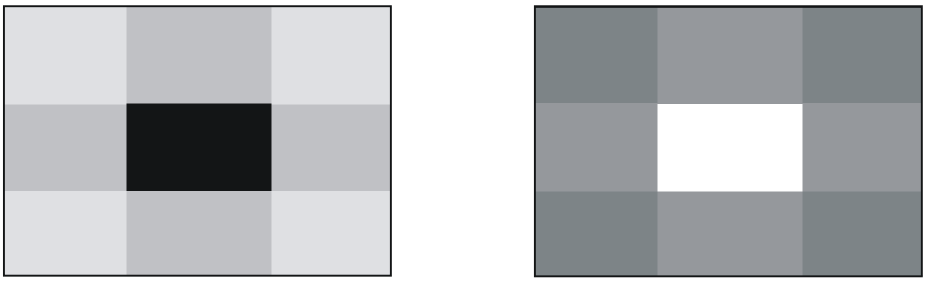
Measurement method

Measurement for this item must be conducted after adjustment of the display using the PLUGE test signal specified in Recommendation ITU-R BT.814.

Evaluate by visual inspection if the difference in luminance between the horizontal and vertical belt-like portions and the other grey portions is detectable when the input signal has a rectangle luma signal of value 64 (Black) or value 940 (White) (area ratio of window signal: 4 to 25% to the screen) near the centre and has a grey surrounding area. Since a luminance difference may occur depending on the rectangle size, it is preferable to evaluate by visual inspection by changing the rectangle size.

With regard to the signal value of grey area surrounding the white window, adjust the grey surrounding area to the following values *Y* value 64, 152, 239, 327, 414, 502 and grey area surrounding the black window: *Y* value 502, 590, 677, 765, 852, (the C_B, C_R channel value should be 512), observations should be made to determine if any modulation of the grey area is detectable.

FIGURE 3
Crosstalk measurement



3.16 Stability

Measurement method

Following a 30 min "warm up time" the master monitor should retain desired setting for at least 24 h without needing any readjustment.

3.17 Pixel defects

Measurement method

The measurement of a pixel defect is frequently conducted with the measurement equipment that measures light intensity using a CCD and determines if there is any pixel defect from the difference between the measured value and peripheral pixel luminance level detection.

A visual observation of the display using a flat field grey signal may prove to be the most practical approach at this time.

3.18 Ringing

Measurement method

Using any fast rise time signal, visually observe the displayed image for "ringing".

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[7] Crosstalk is the phenomenon that display data influence other display area on a part of display. A much brighter or darker spot than the surrounding area causes vertical or horizontal bars, which is similar to camera smear. The term «Crosstalk» is used for this phenomenon in LCD, and «Image streaking» is used in PDP.

3.19 Image sticking (long-term afterimage)

Measurement method

For example, after displaying the specific pattern continuously for six hours, change to the grey signal of level 10% or 20%, then judge whether the previous pattern can be detectable on the screen.

If the pattern is detectable, measure how long it takes to disappear.

Appendix A

Note – These are the findings of one industry body and are included in this Report for information. Additional verification of some values stated in this Report are underway.

Television has evolved to give pleasing results in a viewing environment described by colour scientists as “dim surround”.

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 that the end-to-end or “system” gamma for consumer viewing environment is approximately 1.2, i.e. definitely not linear.

The system gamma can be expressed as:

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

* Opto-electrical transfer function.

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. 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 × 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 is not changing, and the OETF gamma cannot change (for compatibility reasons and for the continuation of an optimal perceptual coding characteristic), the EOTF gamma must also remain at 2.35, regardless of which new physical display device is used to implement it.

Appendix B

Note – These are the findings of one industry body and are included in this Report for information. Additional verification of some values stated in this Report are underway.

The requirement for "gamma characteristics" is as follows:

The gamma characteristics (electro-optical transfer characteristic) of the display should be equivalent to those of a reference CRT.

It is useful to know the gamma characteristics which the CRT master monitor has for understanding the actual condition described above as requirement for gamma characteristics.

Figures 4 and 5 show the measurement results on gamma characteristics of CRT master monitor under the two conditions, namely luminance on the screen at level 64 is 0.01 cd/m^2 and 0.1 cd/m^2, and each figure has two graphs, one is drawn on logarithmic axis and the other on linear axis and both show the same measurement result.

These graphs show that a CRT monitor changes the gamma characteristic (gamma index)[8] depending on the luminance value on the screen at the level of 64. In case of luminance on the screen at level 64 is 0.01 cd/m^2, gamma index is about 2.4 to 2.6, and in case of 0.1 cd/m^2, gamma index is about 2.2.

[8] The gamma characteristic above may be expressed "input-output characteristic" because the original gamma characteristic of "Cathode-Ray Tube" itself doesn't change. However, the adjustment of "Contrast" and "Brightness" of the CRT monitor changes the range of the so-called gamma curve which corresponds to the levels 64 to 940 of the input signal. This seems to be the reason why it appears the so-called gamma characteristic of a CRT monitor changes depending on the luminance value on the screen at the black level.

FIGURE 4

Measurement result of the gamma characteristic (input-output characteristic) of a CRT master monitor

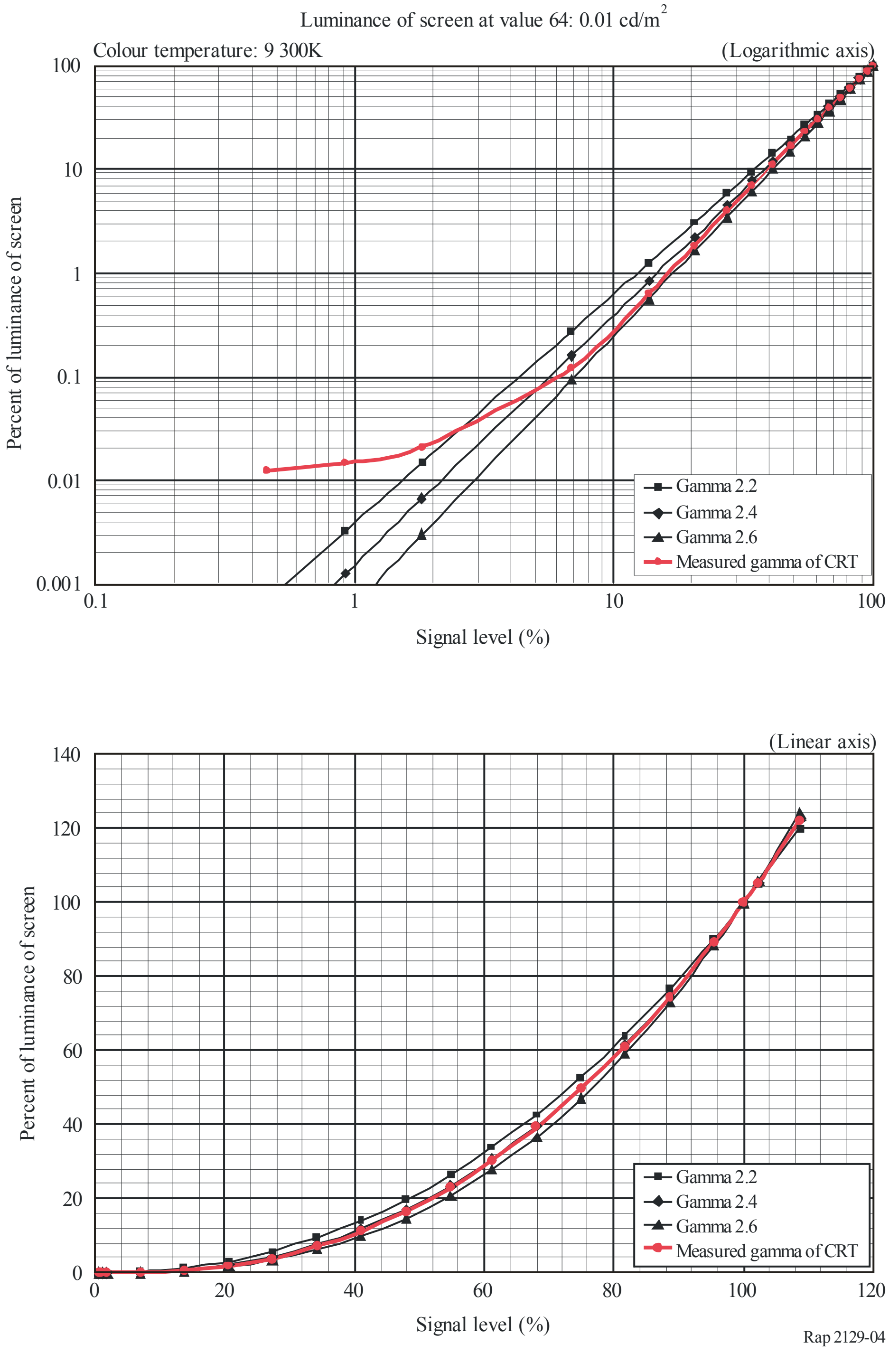
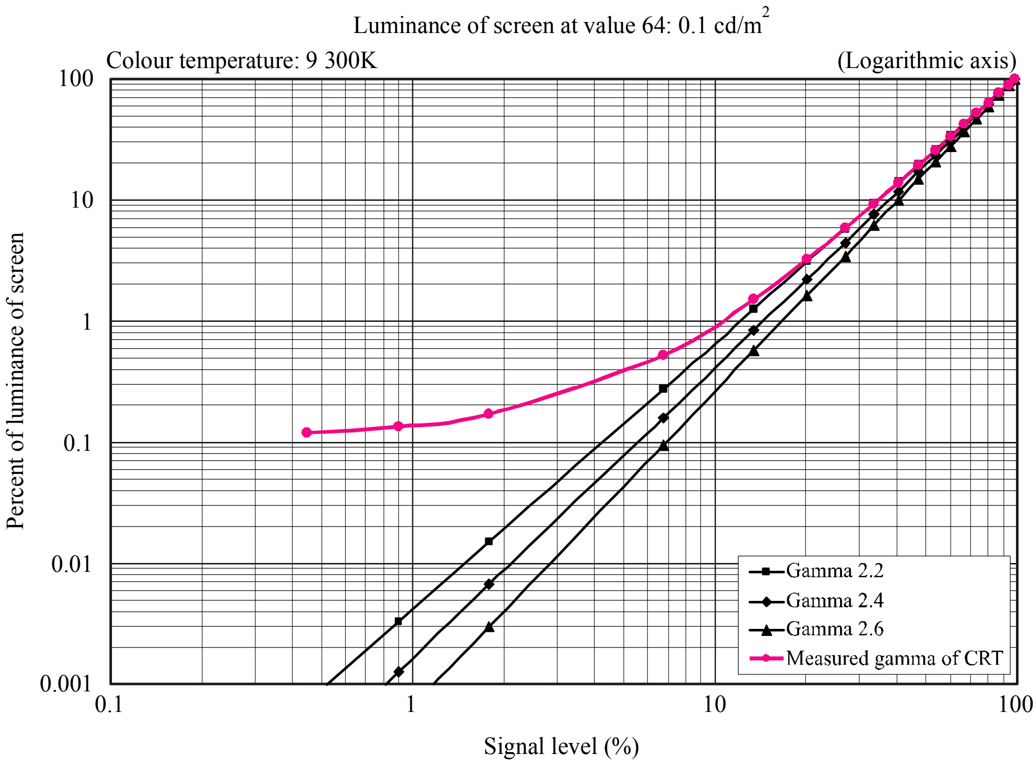
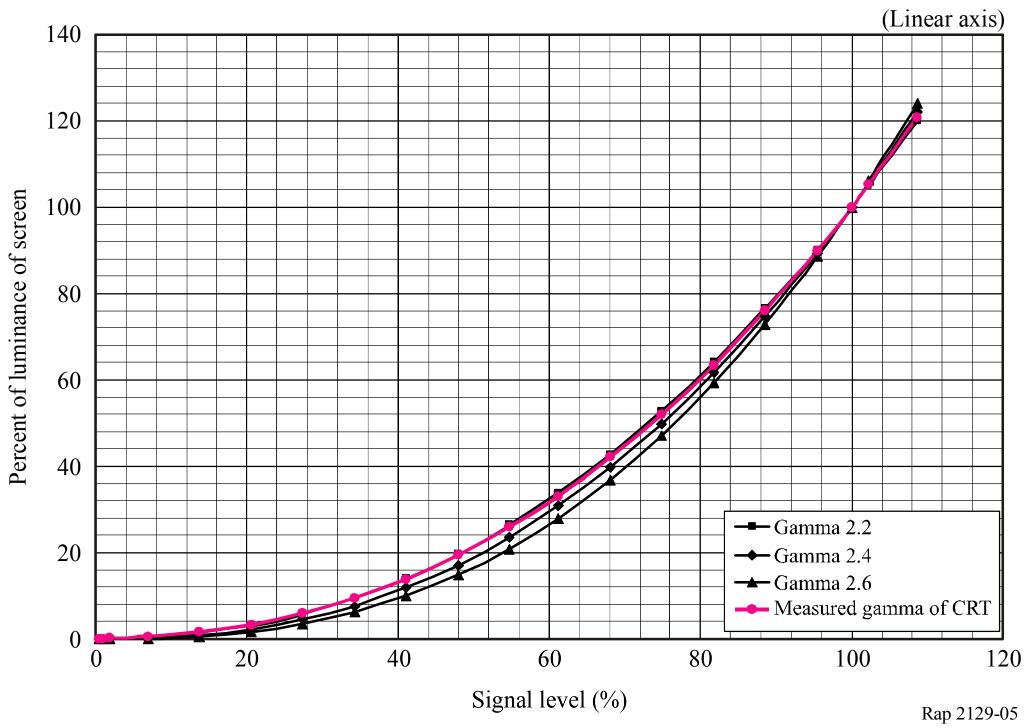


FIGURE 5

Measurement result of the gamma characteristic (input-output characteristic) of a CRT master monitor





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Appendix C

Illustration of the direction and the four planes in measurement