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GRAPHIC TECHNOLOGY – DISPLAYS FOR COLOUR PROOFING – CHARACTERISTICS AND VIEWING CONDITIONS

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Revision history
Draft 1 - Very rough document produced for the TC 130 meeting in San Francisco, 1996
Draft 2 - Incorporation of comments by Prof. K Schlaepfer, produced for the TC 130 meeting in Chicago, 1997
Draft 3 – Revisions following the Chicago meeting, produced for the TC 130 meeting in Sao Paulo, 1997

Notes pertaining to this revision:
It was agreed in Vancouver that due to various other standards activities (ISO 3664, IEC TC 100, CIE Division 8, etc) much of the previous versions of the document was superfluous. A restricted version of that document concentrating on the main display characteristics and recommended viewing conditions only was agreed as being useful. This is the proposed draft for that. It incorporates comments on Draft 3 made by Prof. K Schlaepfer.

INTRODUCTION

The ability to match colour images displayed on colour monitors, to the images produced when the same digital file is rendered by proofing and printing systems is increasingly expected in Graphic Arts. Such systems are commonly referred to as 'soft' proofing systems. Obtaining such a match is not simple and to be fully accurate requires careful control of many aspects of the process. The primary purpose of this International Standard is to make recommendations with respect to the viewing conditions. If this is controlled it is then possible for users to exchange meaningful calibration and characterisation data such that a consistent and, possibly, accurate colour match to the hard copy proof is achieved. This International Standard is primarily based on the needs of Cathode Ray Tube display technology, but it is anticipated that many of the recommendations will be appropriate to newer technologies.

The appearance of a colour image on a colour display is influenced by many physical factors other than controlled ambient viewing conditions. Amongst the most important of these are uniformity, convergence, size and resolution (in order to permit rendition of the proof at close to its normal size and with the finest detail visible on the hard copy at normal viewing distances), freedom from flicker, the opto-electronic calibration of the display and the settings of its display driver software. So, to be acceptable as a proofing system which provides a reasonable level of image quality the display must also exhibit acceptable quality of these properties. In this International Standard, minimum requirements for factors, such as uniformity, convergence, refresh rate, size and spatial resolution are also specified. However, these parameters are subject to improvement as display technology changes or improves and this International Standard should be seen as defining minimum requirements for these. It is assumed that displays used for this purpose will always conform to accepted industry 'standards' for CAD, and generally provide quality levels considered acceptable for this purpose, where they offer an improvement over the specifications herein.

It should be noted that, even for the highest quality of display, the appearance of the displayed image will be limited by the accuracy of the colour transformation used for converting the digital file from its encoded colour space to that required for display purposes. No formal specifications are given for this in this International Standard, although the issues are discussed in an informative Annex, together with recommendations for achieving an acceptable colour transformation.

It should be noted that this International Standard ONLY considers the setting up of colour displays as 'soft' proofing devices. It is primarily directed at applications where the displayed image will be directly compared to a hard copy. It is therefore concerned with modifying the 'hard' and 'soft' controls of the display to enable it to simulate a proof. In this sense it can be looked on as a 'slave' device. However, it is in the interests of a CAD user, where the colour display in a real sense 'originates' the image, to set the display up in a very similar way. This will enable simpler optimisation of the colour transformation to the selected hard copy system used for rendering the image in order to produce an accurate reproduction, if this is an important requirement. However, it is possible to undertake image processing to modify the image when rendered to make it look like the displayed image (colour gamuts permitting) whatever the opto-electronic calibration of the display. This is briefly discussed in the Annex.

GRAPHIC TECHNOLOGY - DISPLAYS FOR COLOUR PROOFING – CHARACTERISTICS AND VIEWING CONDITIONS

1. SCOPE

This International Standard provides recommendations for uniformity, size, resolution, convergence and refresh requirements, luminance levels and viewing conditions for a colour display used to simulate a hard copy proofing system in Graphic Arts.

NOTE: The specification provided in this International Standard has largely been produced with regard to CRT displays, which is by far the dominant technology in use at the time of preparation. However, displays using other technologies would be expected to at least meet the specification provided herein.

2. NORMATIVE REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3664: Photograpy – Viewing conditions

CIE Publication 122 - 1996: The relationship between digital and colorimetric data for computer controlled CRT displays.

3. DEFINITIONS

For the purposes of this International Standard the following definitions shall apply:

calibration:

characterisation:

convergence:

gamma:

hard copy proof:

interpolation:

opto-electronic transfer function:

profile:

soft copy proof:

tracking:

4. REQUIREMENTS

4.1 Resolution

The display resolution should be such that it is capable of displaying an image of 1280 x 1024 pixels without interpolation. When a test image of the form and dimensions described in 5.1 is displayed, all specified lines shall be visible at a normal viewing distance.

4.2 Size

Displays used for this application should have a diagonal measurement for the displayed image of at least 43cm (17 inches) and the displayed image should be at least 22cm (8.5 inches) high.

4.3 Refresh rate

Displays used for this application should have a refresh rate of at least 80 Hz non-interlaced.

4.4 Uniformity

The display should be visually uniform when displaying a flat white, grey and black image. It is required by this International Standard that when measured as described in 5.2 all values should be within 5% of the luminance of the centre and shall be within 10% of it. However, there should not be areas of significant visual non-uniformity between these areas.

4.5 Convergence

When displaying the grid pattern described in 5.3 all lines shall appear wholly free of colour fringing within the area shown. A small amount of fringing may be accepted outside of this area but is not recommended.

4.6 Ambient illumination conditions

The ambient conditions shall comply with those specified in ISO 3664, although with the lower limits for ambient illumination. The specification in ISO 3664 may be summarised as follows:

- ambient illumination shall have a colour temperature equal to, or less than, that of the display white point;
- the level of illumination when measured at the face of the monitor, or in any plane between the monitor and the observer, shall be less than 64 lux and, preferably, less than 32 lux;
- the user should avoid any sources of reflection or glare;
- a dark, neutral surround shall be provided for the image displayed.

However, for this application, in which comparison to hard copy is assumed, a more restrictive illumination condition is desirable. For such an application the level of illumination shall be less than 32 lux and the surround shall be 10% of the maximum luminance of the screen. It should also be noted that the ISO 3664 requirement means that the colour temperature of the ambient illumination should be less than, or equal to, that of D50. However, for this application the illumination should

approximate D50 (particularly if the level of ambient illumination is towards the high end of the specification).

This specification also adds the additional constraint that the level of illumination when viewing a black screen (i.e. an image defined as R=G=B=0) shall be less than 5% of that obtained when viewing a white screen (i.e. an image defined as R=G=B=255) when measured at the plane of the observer. This additional constraint is to ensure that any reflected glare from the front surface of the display does not significantly reduce the perceived contrast.

4.7 Chromaticity and luminance of the white and black points and tracking

The white of the display (i.e. when R = G = B = 255) should be set to the chromaticity of D50; namely u'=0.2092, v'=0.4881, within a circle of radius 0.01 from this point. The luminance level should be as high as practical with the display technology used but shall be at least 80 cd/m^2 and should be at least 100 cd/m^2.

NOTE 1 - Where the gain in the individual channels cannot be adjusted and the white is achieved by altering look up tables in the driver software it shall be ensured that one of the channels is set to the maximum digital value.

NOTE 2 - Care should be taken not to set the display at luminance levels higher than that recommended by the manufacturer.

The black point shall have a luminance that is less than 1% of the maximum luminance (i.e. a luminance ratio of at least 100 to 1).

The chromaticity of any neutral image (defined by equal digital counts in R, G and B) should be within a radius of 0.01 in u', v' from the chromaticity of the white. However, the chromaticity tolerance may increase linearly with decreasing luminance such that at 10% of the maximum luminance it shall be within a circle of radius 0.03 of the chromaticity of the white point. It is for this luminance that the individual channel offsets should be adjusted where possible.

4.8 Opto-electronic transfer function

The gamma of a CRT display should be in the range 2 to 2.4 for each channel. This shall be measured as described in clause 5. The procedure for defining offset and gain is also specified in clause 5.

NOTE 1 - For device technology other than CRTs the gamma function may be very different from this simple power function. The display driver look up tables should be loaded to achieve this specification.

NOTE 2 – The term gamma has been used here as defined in CIE 122 – 1996. As such it is being used in a quite unambiguous way and, together with the offset and gain, it provides the opto-electronic transfer function of the CRT display. However, traditionally in Graphic Arts, gamma was often defined as the 'best fit' exponent when ignoring offset and gain and this usage should not be confused with the definition here. Some standards (such as IEC 61966-2.1: Default RGB colour space – sRGB) go further and suggest that since the term has been used in various ways they prefer not to use it at all, to avoid possible ambiguity. Those requiring further information on this subject are referred CIE 122 – 1996 and to the paper by Anderson et al, listed in the Bibliography, which includes explanation of some of the terms that have been in common use (including system gamma, monitor gamma and encoding gamma) and how they relate to the definition in CIE 122.

5. TEST PROCEDURES

5.1 Resolution

A test image, consisting of a number of images – each composed of white and black lines of varying resolution as shown in figure 1a - is displayed in various positions and orientations. An example is shown as figure 1b. When viewed at a normal viewing distance (approximately 0.5m) the lines labelled D (which have a spacing of 0.35mm) shall be clearly distinguishable, and those labelled F (which have a spacing of 0.25mm) should be clearly distinguishable, for all images within the central region of the display. (The central region is defined as that within half the linear diagonal distance). Any images outside of this region may have a resolution poorer by 0.05mm.

5.2 Uniformity

The uniformity shall be determined for a flat white, grey and black image. These shall be achieved by displaying a white image, a grey image and a black image as defined below.

- the white shall consist of the maximum value in each of the Red, Green and Blue channels (255 for an 8 bit display);
- the grey shall consist of approximately half of the maximum value in each channel (127 for an 8 bit display), and
- the black shall consist of approximately a quarter of the value in each channel (63 for an 8 bit display).

For each level, 9 points of the image area of the screen shall be measured with a suitably sensitive photometer, as shown in figure 2.

5.3 Convergence

Convergence shall be evaluated using a test pattern as shown in figure 3 and assessed visually.

NOTE: The grid lines of figure 3 should be approximately 2mm in width.

5.4 White point and Black point chromaticity and luminance

Luminance and chromaticity measurements should be made with a spectroradiometer meeting the requirements specified in CIE publication 122. Colorimeters may be acceptable and shall be used if no spectroradiometer is available. However, care should be taken to select a good quality device as discussed in CIE publication 122. If the spectroradiometer or colorimeter does not meet the accuracy required the procedure described in CIE publication 122 should be used to improve the accuracy for the specific display type being measured.

The measurements shall be made in the centre of the screen, at the central point shown in figure 2 and the sampling rate should comply with the requirements of CIE publication 122. The chromaticity of the white should be obtained by measuring a displayed image consisting of the maximum digital value in each channel (255 for an 8 bit device) and adjusting the gain of the individual channel amplifiers. Where no such adjustment is possible the look up tables of the driver software shall be adjusted.

The black point chromaticity shall be measured in a similar way but at a luminance level of 10% of the maximum luminance.

5.5 Opto electronic transfer function and tracking

Following setting of the white and black points the gain, offset and gamma shall be determined as specified in CIE 122 – 1996. The chromaticity should be measured for at least 10 neutral colours (R = G = B), at levels of luminance spanning white to full black, and approximately equally spaced in lightness. From this data the gain, offset and gamma shall be calculated as specified in CIE 122. The resultant data will enable confirmation that the values specified in both 4.7 and 4.8 are being achieved.

Figure 1a - Resolution target

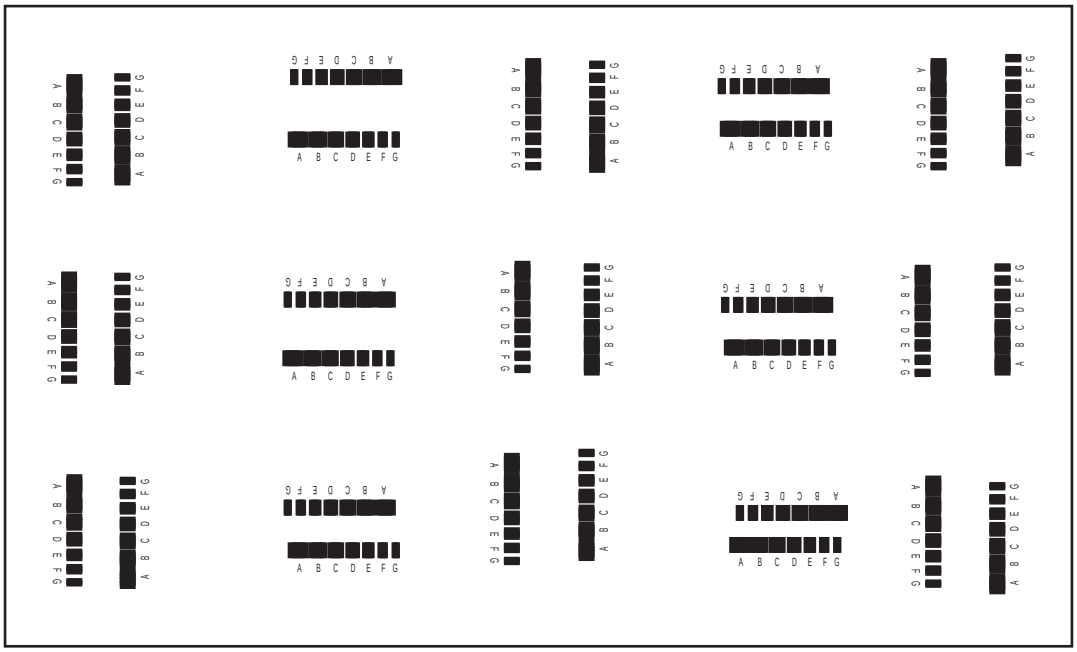
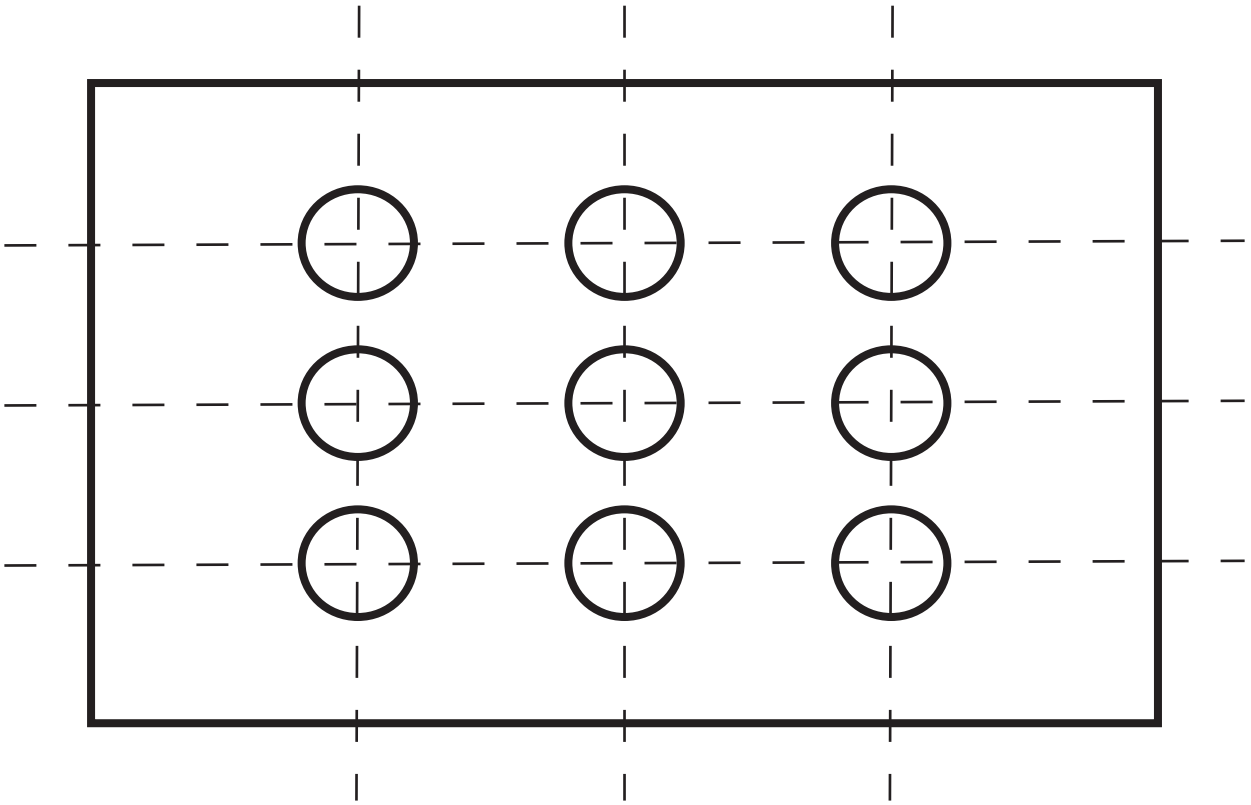


Figure 1b - Recommended layout of resolution targets

Figure 2 - Positions for measurment of uniformity



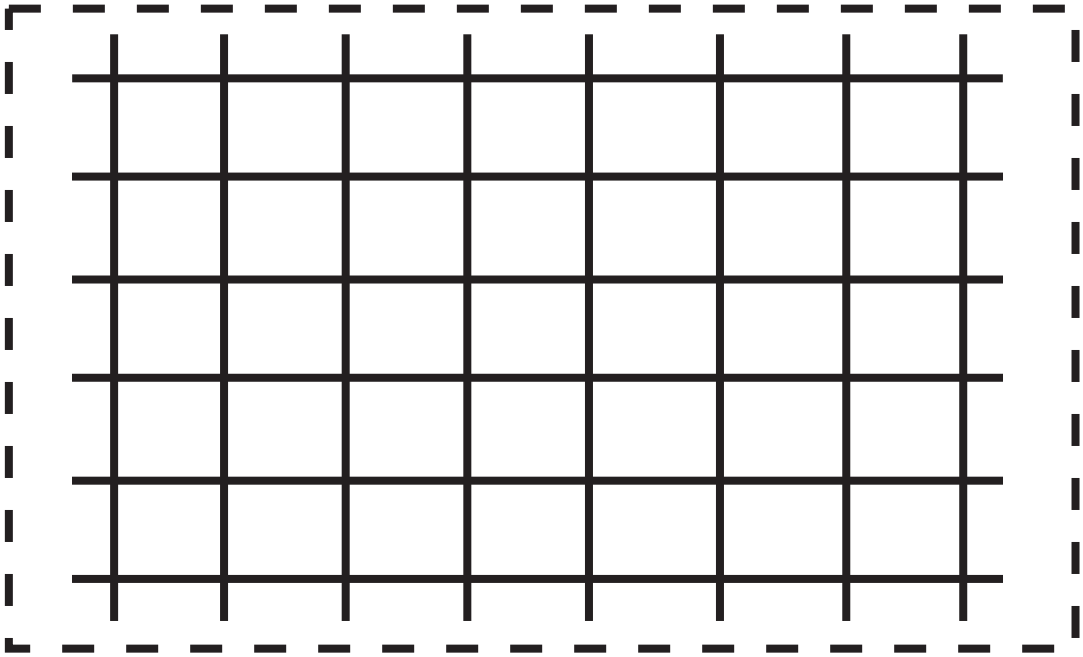


Figure 3 - Grid pattern for assessment of convergence

Annex A (informative)
Characterisation and Calibration

A.1 Matching colour between 'hard' and 'soft' proofs

Even when the display meets the requirements of this International Standard it does not guarantee that an image displayed on the display will match the colour of the same image produced on the hard copy. To achieve a colour match it is necessary to provide a colour transformation such that the colour data format in which the image is encoded can be transformed into that required by the colour display and the hard copy system. Thus, if an image is encoded in a CIE colour space, or in some arbitrary RGB or CMYK format, it will be necessary to transform it to provide a colour match between the proofs. This transformation will normally be achieved by means of a colour management system (possibly based on the use of ICC profiles). However, for information, the principles which this software may well employ for achieving this are discussed below

For colour CRT displays the colour mixing required to produce a colorimetric match to any colour may be defined as a simple linear transformation of the tristimulus values with a correction for gain, offset and gamma as discussed in CIE Technical Report, CIE Publication 122 - 1996. Other non-linear effects, such as cross-talk and internal flare, can usually be ignored for the quality of CRT displays used for this application. If this is not so it will be necessary to modify the transformation calculation, as discussed in CIE Publication 122 - 1996. It should be noted that without the correction for gain and offset the function for gamma will normally be more than a simple power function correction, to take account of the non-linearity required in such a correction, particularly at low luminance levels. However, when parameters for gain and offset are included a simple power function usually provides an acceptable model.

It should also be noted that the simple model described in the previous paragraph may not be applicable to colour LCD flat panel displays. In particular the gamma function characteristic familiar to users of CRT displays may quite different for LCD displays in which it may well not be a constant. At the present time it is unlikely that such displays can meet some of the criteria defined in this International Standard (particularly luminance level and uniformity) and so they would be excluded for the application defined herein. Furthermore, no general recommendations are available for the opto-electronic transfer characteristics of such displays. However, if the technology matures to the point where they meet all criteria, apart from the simple opto-electronic transfer characteristic described above, they can be included within this International Standard by analogy.

It should also be noted that viewing conditions significantly affect colour appearance and so when comparing different media, in which the viewing conditions may differ and the physical stimulus characteristics differ also, a colorimetric match does not always accurately predict a perceived colour match. This makes it difficult to specify absolute colorimetric target values and tolerances for both print and display unless viewing conditions are tightly specified and the colorimetric values modified to take account of the influence of these conditions. In certain conditions of viewing of the display and proof a good colour appearance match is often obtained when the tristimulus values of the colours displayed match those of the proofs. In general this will be approximately true for the viewing conditions of display and proof defined in ISO 3664 and clause 4.6 of this International Standard, PROVIDING THE IMAGE ON THE DISPLAY IS SURROUNDED BY A WHITE BORDER OF THE CHROMATICITY OF THE SUBSTRATE, APPROXIMATELY 1” IN WIDTH. This also helps in the simulation of the proof. It is also necessary to use the print viewing conditions from ISO 3664 which define a lower level of illumination (viewing conditions P2) if the display and proof are to be compared. If such conditions are assumed a simple measure of colour

difference, for a range of colours, will usually prove fairly effective in assessing characterisation accuracy. However, in general, the eye should be used as the final arbiter in assessing the colour match between a soft and a hard copy proof and the colour transformation modified accordingly.

If the ambient conditions do not meet those specified in this International Standard, and particularly if excessive viewing flare is present, the colour management software will have to modify tone and colour reproduction accordingly and a colorimetric match will not be obtained. In such a situation the use of a colour appearance model, such as CIECAM97s, with appropriate parametric constants selected for the conditions used, may prove effective in calculating the colour transformation.

NOTE 1 - If the image shown on the display is to be directly compared to a transparency viewed under ISO 3664 conditions, rather than as a simulation of a printed reproduction of that transparency, it is preferable if the white border described earlier is removed. However, it is then not a soft proof as defined in this International Standard.

NOTE 2 - If the displayed image is to be viewed as a simulation of the printed reproduction, but is to be compared directly to a transparency, it should be noted that the conditions for viewing a transparency image specified in ISO 3664 are not practical because of the high level of luminance specified for transparencies. For this application a non-standard transparency illumination condition is normally required, typically of about 25% of the standard value. However, all other attributes should conform to those specified in ISO 3664.

In order to characterise the monitor a colour management system is recommended that permits the chromaticity of the display's phosphors; the offset, gain and gamma components of the opto-electronic transfer function and corrections for viewing conditions to be input as separate variables. The chromaticity of the phosphors may be measured directly and the offset, gain and gamma may be determined as described in CIE publication 122. Corrections for ambient flare may also be based on measurement of this parameter, if necessary, as discussed in CIE publication 122. However, an empirical approach (which simply modifies the gamma function) is often more satisfactory.

The procedure recommended to assess the match between a 'soft' proof and a 'hard' proof is to use the images described in clause A.4. These should be rendered onto hard copy and also displayed on the 'soft' proofing device. The resultant images may then be measured and the colour differences calculated. If the conditions described in this International Standard have been used it should be expected that the average difference will be less than 2 ΔE_{94} units. However, if it has proved necessary to incorporate additional corrections for the viewing conditions used this is likely to be greater, and no value can be specified.

A.2 Colour Gamut

The gamut of colours which may be reproduced on the display should be such that it totally encloses that specified by the primary AND secondary colours produced by the inks specified in the appropriate part of ISO 12647 for which the display is required to provide a proof. Although not strictly accurate the following simple procedure for evaluating this is usually acceptable:

1. A 'plan' view of the print gamut is formed by a hexagon joining the chromaticities of the primary and secondary colours;
2. The print gamut defined in step 1 should be enclosed by the display gamut when that is plotted as a triangle joining the chromaticities of the phosphors in a chromaticity diagram;
3. The display and print gamuts should also be defined, when plotting Lightness as a function of Chroma, for the six hue angles defined by the primary and secondary colours of solid areas of the print. These gamut plots may be defined as simple triangles joining the white and black points with the highest chroma colour at that hue, obtainable with each system. The print gamut should be enclosed by the display gamut for every hue angle. (A reasonable approximation to the

highest chroma colour is usually obtained by simply measuring the solid ink colours and the display colour that produces the correct hue when at least one digital value is set to 255 and another to 0).

This procedure can be summarised as follows:

- From the tristimulus values of the substrate, solid primary and secondary colours and black ink specified in the appropriate part of ISO 12647 calculate the chromaticity co-ordinates (u'v'), Lightness (L*), Chroma (C^*_{uv}) and hue angle (h_{uv}) for each, normalised such that the substrate has L* of 100. Use the chromaticity co-ordinates of the primary and secondary colours to define a hexagon in the u',v' chromaticity diagram.
- Measure the chromaticity co-ordinates (u'v') of the display primaries by defining colour patches in which each of R, G, and B are set to 255 and the remaining two values are set to zero. Use these to define a triangle in the chromaticity diagram which should enclose the hexagon defined in the previous paragraph.
- Assuming additive colour mixture calculate the Lightness and Chroma of the highest chroma display colours with the same hue angle as those of the primary and secondary ink colours normalised such that the white of the display has an L* of 100. Also calculate or measure the Lightness of the black. Use these values to define a triangle by plotting L* against Chroma for each of the six hue angles. Do the same for the ink colours. For each hue angle the triangle formed from the display colours should enclose that formed from the inks.

In practice there are usually colours achievable on the print that cannot be reproduced on the display. Thus some sort of gamut mapping will usually be desirable. When this is required it will be necessary for the colour management system to combine this with the display characterisation. In such a situation a simple measure of colour difference, for a range of colours, will not be adequate for assessing characterisation accuracy as suggested above. A subjective assessment will prove necessary.

A.3 Calibration

In order to retain the validity of a characterisation it is necessary to calibrate the display at regular intervals. This involves measurement of the white point and opto-electronic transfer function to ensure they are consistent with those obtained at the time the characterisation was established. The white may be corrected as necessary by adjusting the gain of the individual channel amplifiers or the look up tables of the driver software.

The opto-electronic transfer function may be corrected by adjustment of the offset and gain of the individual channel amplifiers (or the contrast and brightness controls if the three channels are suitably balanced). Where this adjustment does not prove adequate the look up tables of the driver software may be adjusted to achieve the desired result, or the characterisation will need to be re-computed.

A.4 Inter-site Calibration

To ensure consistency, and aid communication between different sites, it is useful to communicate the absolute tristimulus values required from the characterisation software. Display profiles may then be edited to achieve these results if necessary. The colours specified below will be beneficial in this definition. Providing that similar viewing conditions are used at the various sites, as specified in this International Standard, this will then ensure that the images displayed between the various sites are similar.

Where images exist in CMYK form, which are to be output directly without colour management, the following colour patches should be used. Those defined as 5%, 20%, 40%, 70% and 100% values of CMY and all equal overprints of the 40% and 100% colours (i.e. 23 colours in all). For the black ink the same halftone areas should be used; plus 0%, 40% and 100% over every combination of 'grey'. The grey will be determined from the grey balance data in the appropriate part of ISO 12647 when the cyan is defined by the values above. (This produces another 20 colours). The substrate will also be included (producing 44 colours in total). Each of these patches should be defined as images and displayed using the colour transform defined for that display

The series of colour patches should be displayed sequentially in the centre of the screen at a size sufficient for the measuring device selected. To provide an acceptable match between 'soft' proofing systems the characterisation software should produce the chromaticity and relative Lightness required for each colour patch within the tolerance of 2 ΔE_{94} units. If the display and viewing condition conform to this International Standard the tristimulus values of the reference colours will be normally be identical to those of the hard copy system.

Where images are defined in the system in some tristimulus form (e.g. RGB, L*a*b* or XYZ) and 'soft' proofing is obtained by combining profiles, the situation is rather more complex. (In the ICC terminology such a proofing system is obtained by combining the perceptually rendered print output profile with its inverse colorimetric profile and the display colorimetric profile). To evaluate the consistency between devices a reference test image needs to be used, defined in the tristimulus space in which the data is encoded. This will then need to be rendered on each of the displays, using the colour transform defined for that display.

It is more complex than the above procedure insofar as there are a number of possible encoding spaces and because the data will need transforming prior to output to the hard copy as well as the display. The former means that it is not possible to easily define colour target values (as was done for CMYK above) and the latter means that the hard copy output profile needs to also be incorporated in the display colour transform. The choice of hard copy output profile at each site depends upon the workflow but it will normally be necessary to take one as the reference in this procedure.

The procedure recommended is to use the scanned image that was used to characterise the image capture device and set up the colour transform into the encoding space (e.g. the IT8.7/1 or IT8.7/2 target). This image can be obtained from one site and then be provided to every site that requires agreement. It can be displayed on each 'soft' proofing system and a selection of patches measured. Where the IT8.7/1 or IT8.7/2 target is used the following patches are recommended - Rows A, C, E, G, I, K and L of columns 13, 14, 15, 16, 17, 18 and 19. Each patch should be centred on the display and enlarged by zooming prior to measurement. Tolerances should be similar to those described above (i.e. 2 ΔE_{94} units).

Alternatively, the various sites can agree a range of colour encoding values – approximately perceptually uniformly distributed throughout colour space – to produce the test image.

Annex B (informative)
Bibliography

ISO 9241-1:1992. Ergonomic requirements for office work with visual display terminals (VDTs) – Part 1: General Introduction

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