Advantages of *elementary* and *affine* colour reproduction with *rgb** coordinates

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Version 1.0, http://130.149.60.45/~farbmetrik/ISO_ACR_10.PDF (11 Pages, 500KB)

Abstract

Based on the Report CIE R1-47:2009 *Hue Angles of Elementary Colours* a device independent elementary hue output is proposed for application in image technology. The output is linearized for the eight viewing conditions defined in ISO 9241-306;2008. The eight viewing conditions correspond to eight ambient light reflections on the display surface. Up to now the *rgb*-input colour coordinates in a file are usually interpreted as device coordinates, for example of the standard *sRGB* device according to IEC 61966-2-1. If the *rgb*-input colour coordinates are interpreted as elementary coordinates the hue output is device independent and equal for any display (and printer) device.

If in addition the device in linearized by a linearization method, for example similar to the method in ISO/IEC TR 19797, then for equally spaced *rgb*-input series the output is visually equally spaced in CIELAB, see ISO 11664-4:2008. In this case there is a linear relation between scaled *rgb*-input coordinates which are called *rgb** coordinates and the *LCH** coordinates of CIELAB. The coding efficiency of the standard display device increases by a factor 10 if the *relative rgb** coordinates in the range between 0 and 1 are used. The *affine* transfer is well defined for any device and produces an *affine* reproduction in CIELAB. There is no clipping and no loose of information and the output may therefore be called a trusted output.

1 Introduction

Colour and colour-management standards have several cross-cutting goals: Equally spaced color scales, elementary device colors that are aligned with device-independent scales, coding efficiency, and insensitivity to such factors as quantization error and luminance reflection of the display. Standardization groups of ISO, CIE, and DIN are developing a common RGB profile-connection space to meet these requirements.

This paper shows a part of this development. For example for the *rgb*-input data the start output of a standard *sRGB* device is shown in the CIELAB diagrams ($C^*_{ab,a}$, L^*) and (a^*_a, b^*_a) For equally spaced *rgb*-input data the output colour series are usually not equally spaced in CIELAB, compare Fig. 7. There are large improvements by the linearization method both in device and elementary hue space, compare Fig. 8 and 9.

Colour management according to ISO 15076-1 (ICC-colour management) uses a fixed coding space in the ICC-LAB space which deviates slightly, for example by the normalization to media white, from the CIELAB space. The ICC coding range is between $-127 <= (a^*, b^*)_{ICC} <= 128$ and $0 <= L^*_{ICC} <= 100$ and therefore a cartesian coordinate system is used. The *rgb** coding range is between $0 <= rgb^* <= 1$ and a triangle-cylindric coordinate system is used. This coding increases the efficiency by a factor 10 for the standard *sRGB* with the luminance reflection L_r = 2,5% compared to the reference white, see clause 8.

In addition the *rgb*-hue angle spacing is much more efficient in elementary space compared to the device space. For example the ratio of the smallest and largest *device* hue angle sector is (compare Fig. 12, Part 2):

$\Delta h_{ab,min} / \Delta h_{ab,max} = \Delta h_{ab,V\text{-}M} / \Delta h_{ab,\ C\text{-}V} = 22 / 110 = 0{,}20$

Similar the ratio of the smallest and largest *elementary* hue angle sector is (compare Fig. 12, Part 2):

$\Delta h_{ab,min} / \Delta h_{ab,max} = \Delta h_{ab,C'\text{-}B} / \Delta h_{ab,\ J\text{-}G} = 54 / 70 = 0{,}79$

Therefore there are many ergonomic and large efficiency advantages for the use of the visual *rgb** coordinates.

2 1080 colours including 9x9x9 colour scales for output linearization

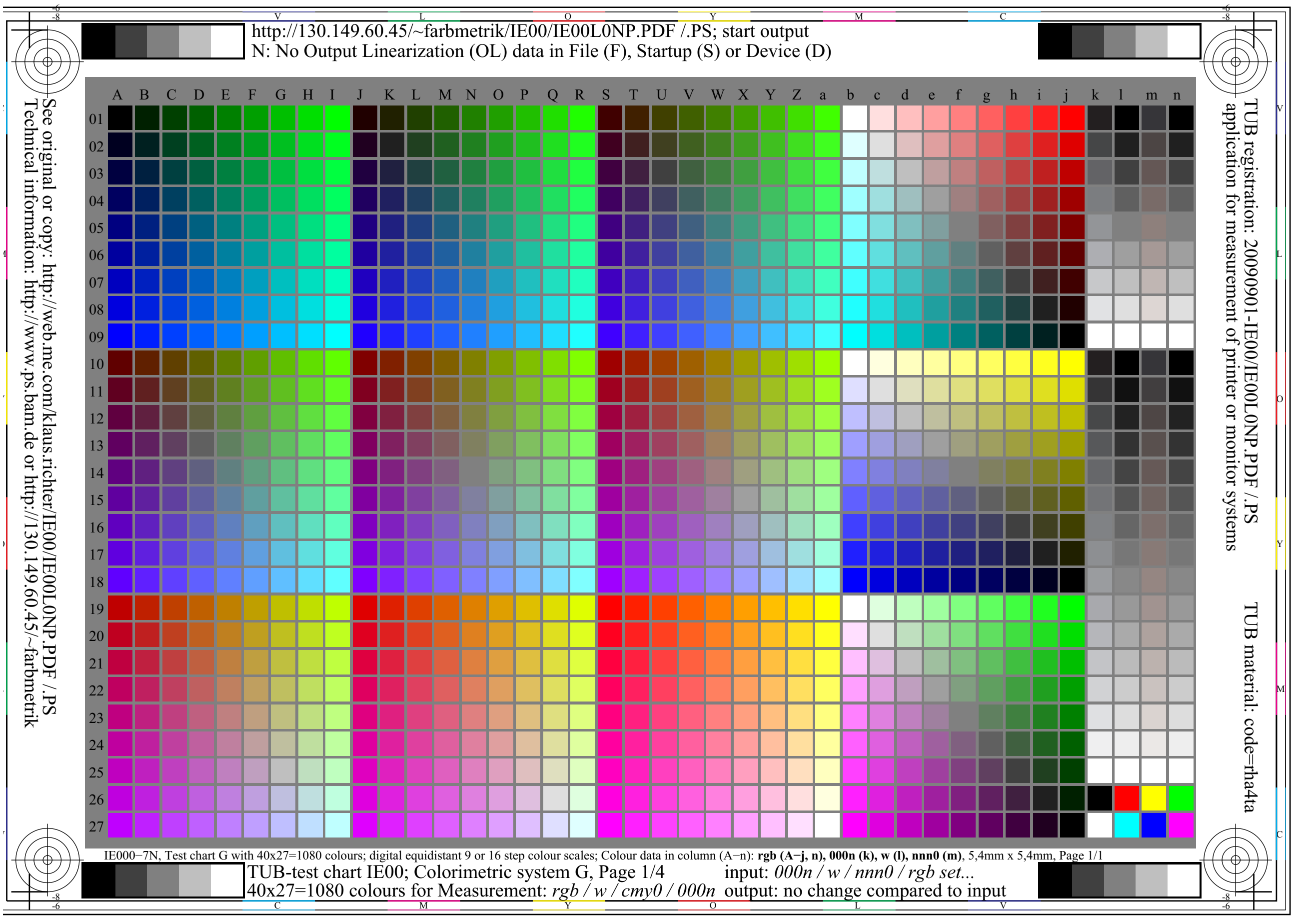


Fig. 1 — Test chart *G* with 1080 standard colours

Fig. 1 shows the test chart *G* (standard **G**rid) with 1080 standard colours. There are 9 step colour series arranged as 9x9x9 = 729 colours in rows A to a and lines 01 to 27. Rows *b* to *j* show opponent colour series for the interpretation

1. *rgb -> olv** as device hues *O - C, Y - V*, and *L - M*
2. *rgb -> rgb** as elementary hues *R - C', J - B,* and *G - M'*.

The rows k to n and lines 01 to 25 show 9 and 16 step achromatic colour series and the lines 26 to 27 show the 8 basic colours (six chromatic colours either *OYLCVM* or *RJGC'VM'* and white *W* and black *N*). The four grey series may be used to measure the repeatability.

For the test chart *G* (Fig. 1) see the URL (4 pages with *rgb*-input data on page 4, 450 KB)
http://130.149.60.45/~farbmetrik/IE00/IE00L0NP.PDF

NOTE 1: For the definition of the six chromatic device colours *OYLCVM* and the six elementary colours *RJGC'BM'* see for example ISO/IEC 15775 and DIN 33872-1.

The test chart G is used to measure the start and linearized output in the device or elementary space and to specify the colorimetric output properties according to ISO/IEC 15775. The rows *b* to *j* are used to measure and calculate the data for Fig. 8 to 10. The rows *A* to *a* are used to calculate the data for the linearized output for the two interpretations *rgb -> olv** and *rgb -> rgb**, compare Fig. 9 and 10.

NOTE 2: The URLs in the frame area of the test charts are active and allow to download the test charts and information.

NOTE 3: The relation between the *olv** and *rgb** coordinates of the device and elementary colours, colour order systems and image technology is described further in ISO/IEC 15775 and by Richter (2010).

3 Output linearization examples

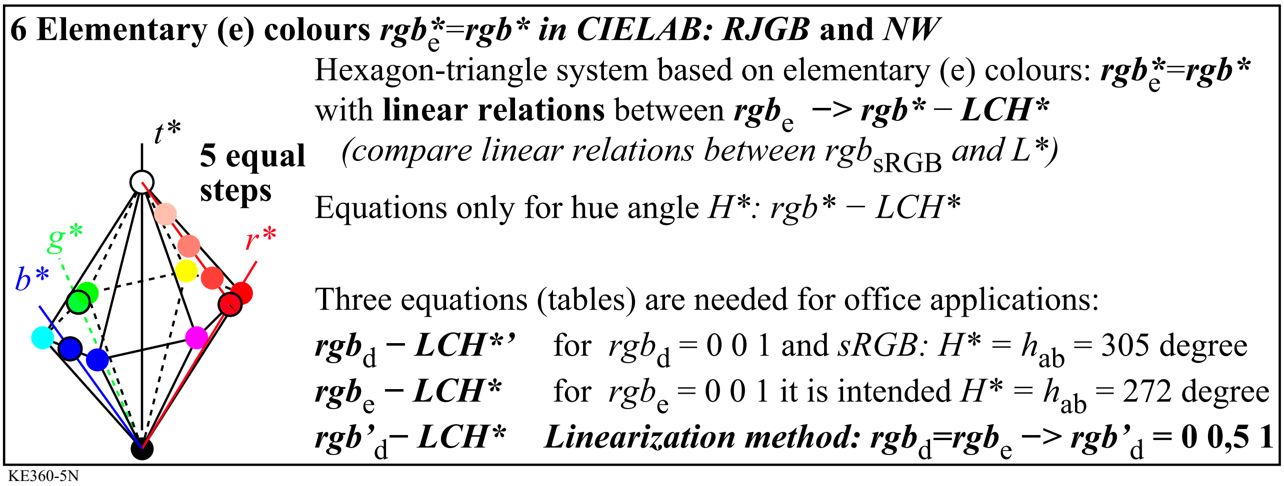


Fig. 2 — Output linearization for device and elementary colours of maximum CIELAB chroma C^*_{ab}

Fig. 2 shows the device and elementary colours of maximum CIELAB chroma C^*_{ab}. If the *rgb*-input data are interpreted as device (d) data, then for the standard sRGB device the CIELAB hue angle h_{ab}=305 degree is produced. This colour is a very reddish blue. By interpretation as elementary (e) data the CIELAB hue angle h_{ab}=272 degree is produced. This is the intended elementary Blue *B*.

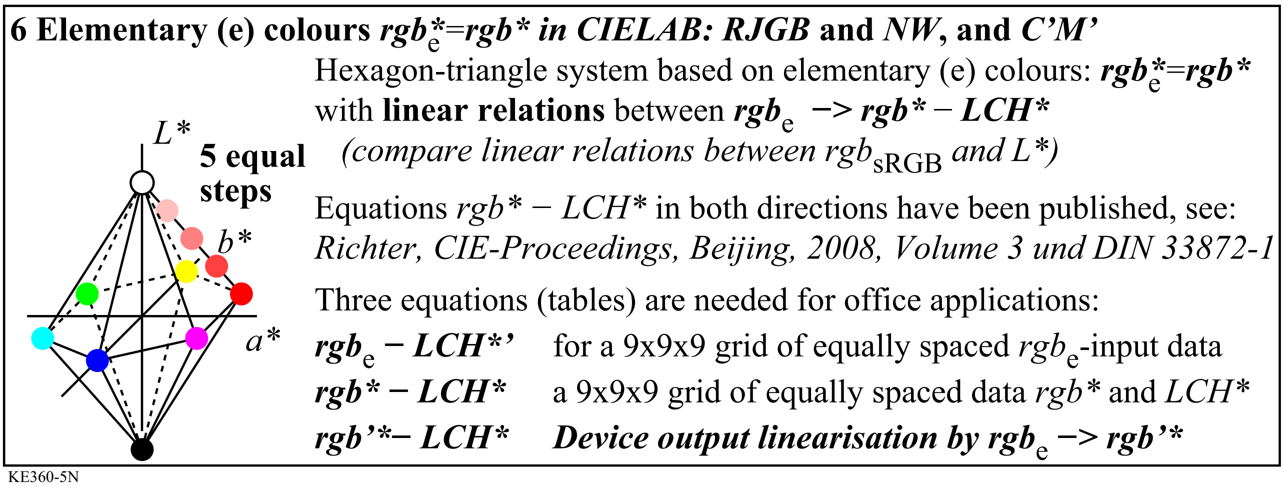


Fig. 3 — 3D-output linearization of any device by a transform rgb_e -> rgb'^* (dash-star)

Fig. 3 shows the 3-dimensional output linearization of any device by a transform rgb_e -> rgb'^*. This is usually a table between 729=9x9x9 and 256x256x256 *rgb*-input entries and the corresponding rgb'^* data. The tables for 8 viewing conditions (luminance reflection L_r = 0% to 40% according to ISO 9241-306, Annex D) can be calculated by a Linearization Method (LM) which is similar to the method of ISO/IEC TR 19797. The use of the tables, for example within the display device (8 output modes), produce an *affine* colour management for 8 viewing conditions. Equally spaced 9 step *rgb*-input data produce equally spaced output data in CIELAB for any of the 8 viewing conditions. This is indicated in Fig. 3 by the red balls for the series White *W* - Red *R*.

The LM uses *relative* CIELAB coordinates and the CIELAB metadata of a 48-step hue circle of maximum chroma for any device. This increases the efficiency of coding by a factor 10 for the standard display device. According to CIE 168 the *sRGB* space fills only 20% of the CIELAB coding space and for the standard luminance reflection 2,5% this gamut reduces to 50%. Therefore relative coordinates increase the efficiency by a factor 10. For more information see clause 8.

4 Measurement and CIELAB data of *LCD* displays for *rgb*-input data and start output

Usually the chromaticity of the *LCD* primaries is constant as function of luminance. Then the CIELAB chroma of the *LCD* primaries increases continuously with the increasing tristimulus value *Y* up to a maximum. For the series between the most chromatic colours and White W the CIELAB chroma decreases to cero

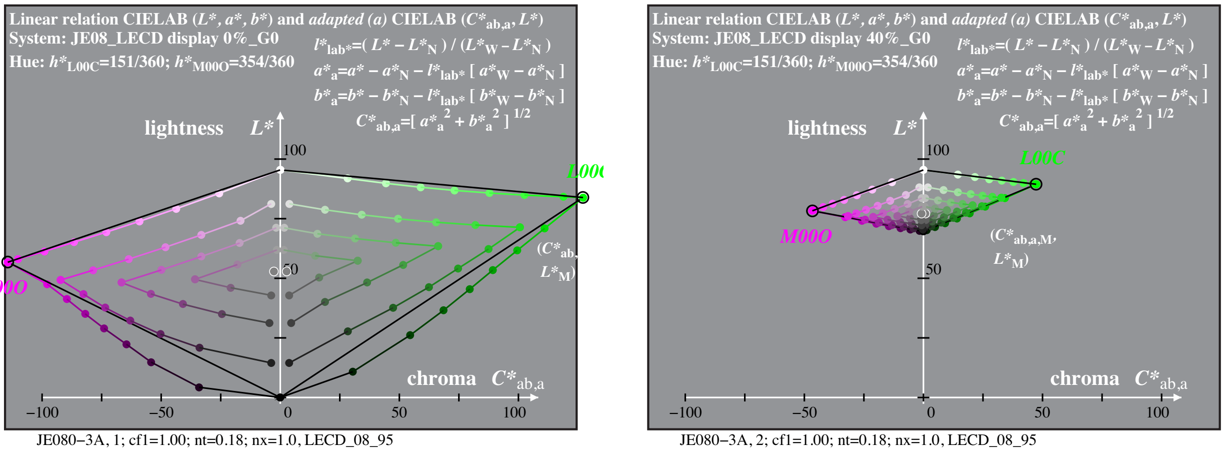


Fig. 4 — Measurement data of a LECD display for L_r=0 and 40% in a CIELAB ($C^*_{ab,a}$, L^*)-plane

Fig. 4 shows the measurement data of a LCD display with LED backlight for L_r=0% and 40% in a CIELAB ($C^*_{ab,a}$, L^*)-plane. The CIELAB chroma is normalized to cero for White *W* and Black *N*. For the luminance reflection L_r=40% which may occur for a data projector in a room with much daylight the colour gamut shrinks by a factor 11. For L_r=40% the mean gray is not any more located in the middle between Black N and White W. The lighter steps have large CIELAB differences and the near black samples show often no CIELAB difference and are not distinguishable.

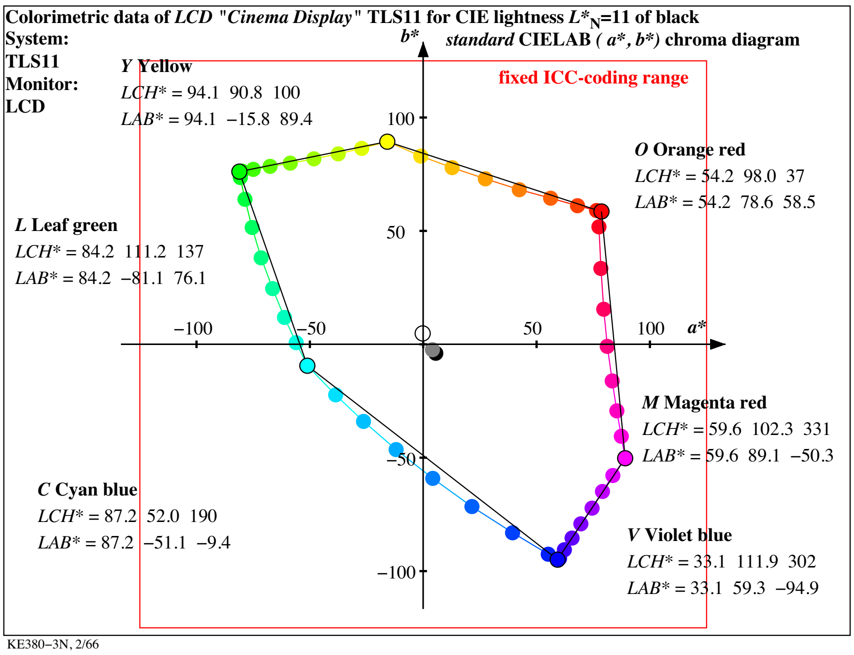


Fig. 5 — Measurement data of a LCD display for L_r=1% (L^*=11) in a CIELAB (a^*, b^*)-chroma plane

Fig. 5 shows measurement data of a LCD display for L_r=1% (L^*=11) in a CIELAB (a^*, b^*)-chroma plane. The device hue names and the CIELAB data *LAB** and *LCH** are given. The achromatic point shifts slightly but normalization in the adapted CIELAB diagram (a^*_a, b^*_a) will produce the chroma $C^*_{ab,a}$ = 0 for both Black *N* and White *W*. This adaptation is necessary to define the hue in comparison to Black and White.

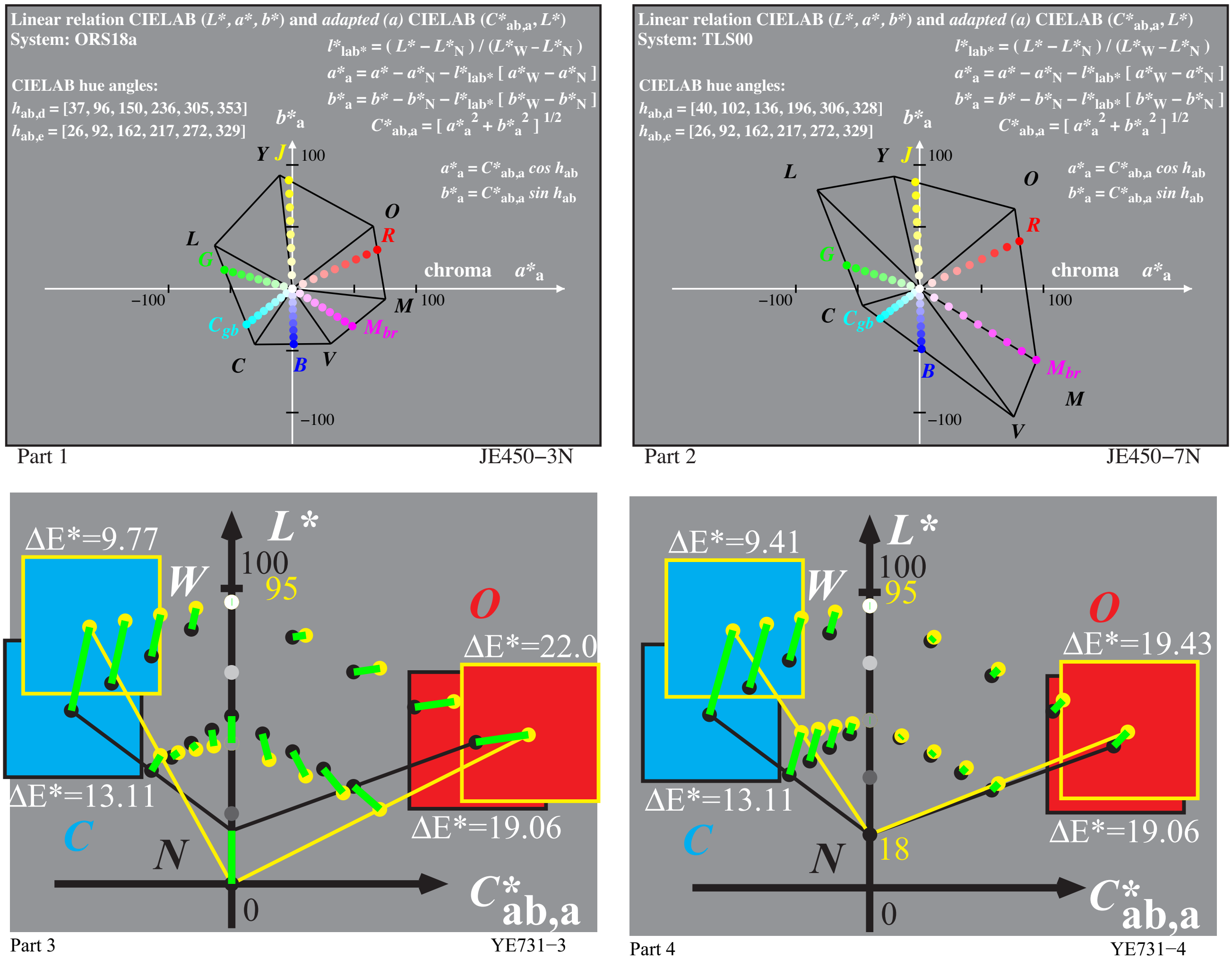


Fig. 6 — Device and elementary colours and affine transformation for three device systems

Part 1 and Part 2 of Fig. 6 show the device and elementary colours in the CIELAB (a^*_a, b^*_a) chroma diagram and *affine* transformations between the standard offset System ORS18 (Part 1) and the standard television systems TLS00 (Part 3) and TLS18 (Part 4). The device colours *OYLCVM* (in black) and hue angles are different. The output of the colours of the elementary colours *RJGB* with the elementary hue angles h_{ab} = 26, 92, 162, and 271 defined in CIE R1-47 is *device independent* and preferred.

Equal hue output is the most important visual property and therefore the application of this property is an ergonomic requirement. In addition in part 1 and 2 the elementary hue output of *RJGB* is reached for the *rgb*-input data (1,0,0), (1,1,0), (0,1,0), and (0,0,1).

Part 3 and 4 of Fig. 6 show the device colours of the system ORS18, TLS00, and TLS18 in the CIELAB $(C^*_{ab,a}, L)$ diagram. The printer colour gamut is fixed (black lines) and the display gamut (yellow lines) depend on the luminance reflection L_r of the display. The CIELAB L^* lightness range is reduced by a factor 0,8 = (95-18)/95 between TLS00 and TLS18. Therefore the colour gamut is reduced to 51% (=$0{,}8^3$) for TLS18 compared to TLS00 (dark room with no luminance reflection on the display surface).

Green lines indicate the colour transfer between the printer and the monitor or vice versa. The transfer is called an *affine* colour transfer. The whole colour solid is used in any case for the transfer. Fig. 6 shows the property that equally spaced input data produce equally spaced output colours. This is a main requirement for a trusted output with no clipping and no loose of information. The *affine* transformations are well defined, for example for the eight luminance reflections according to ISO 9241-306 and for the *sRGB* display output.

5 CIELAB data of standard *sRGB* display for 9 step *rgb*-input data (start output).

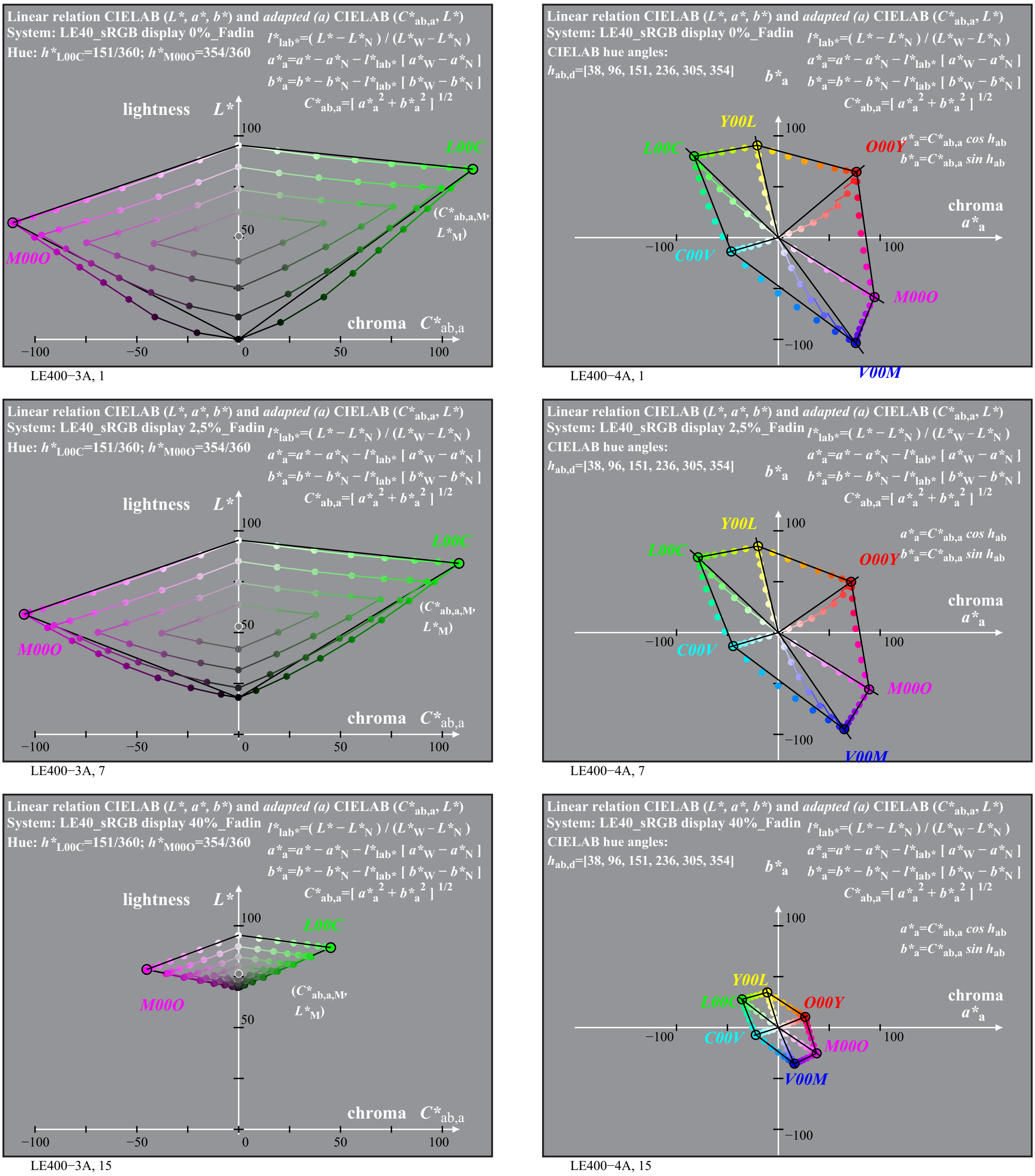


Fig. 7 — Start device colours of *sRGB* device for three luminance reflections L_r = 0%, 2,5%, and 40%

Fig. 7 shows the start device colours of the standard *sRGB* device for the three luminance reflections L_r = 0%, 2,5%, and 40%. For equally spaced *rgb*-input data and according to CIELAB the spacing in not equally spaced in this start output. The mean grey (*rgb* = 0,5, 0,5, 0,5) is not in the middle between black and white for L_r = 2,5% and 40%. There is a hue shift especially for the series White - Orange red O and White - Violet blue V. The colour gamut reduces to 51% for L_r = 2,5% and 9% for L_r = 40%.

6 CIELAB data of standard *sRGB* display linearized in device space *(rgb -> olv*)*

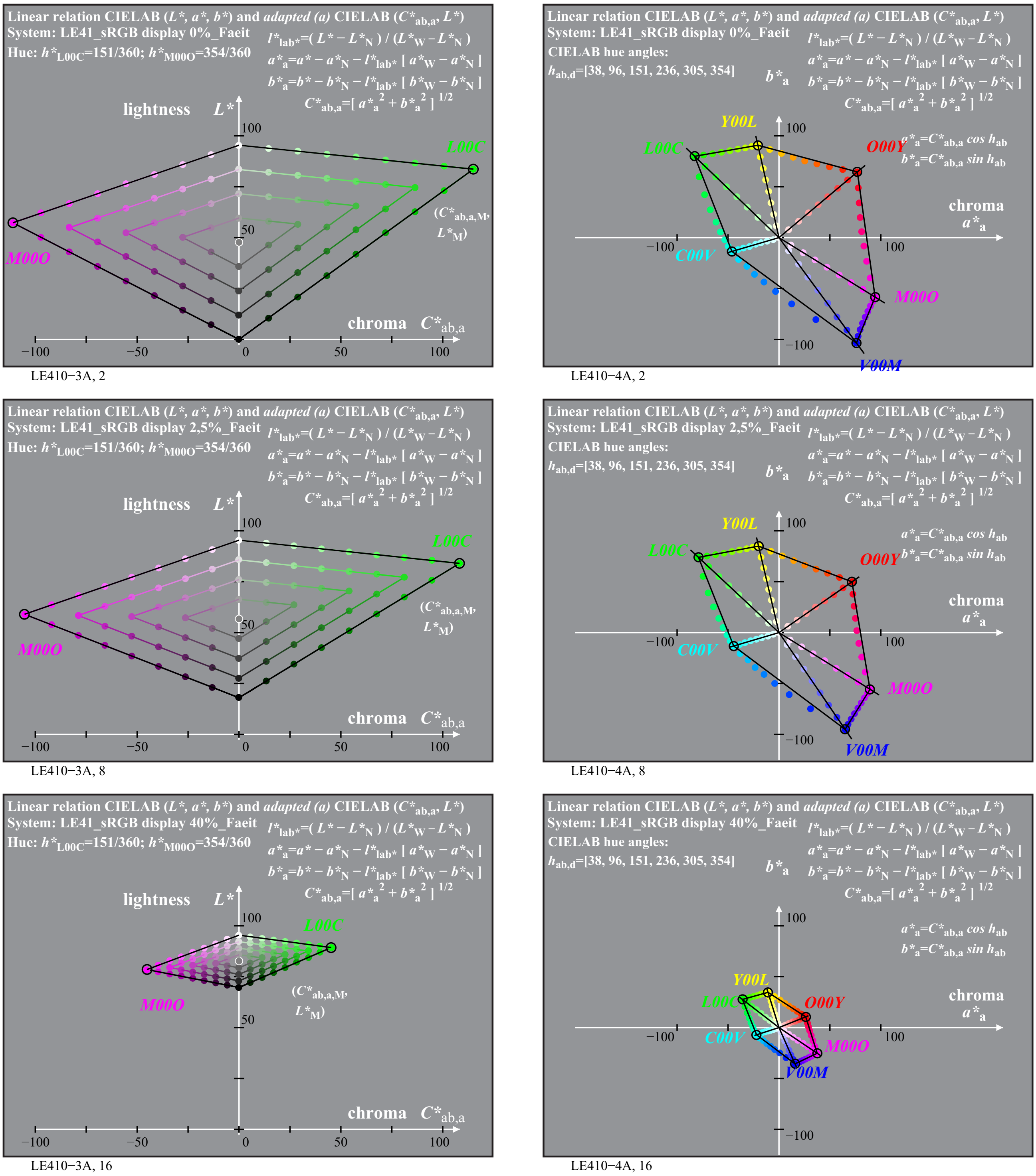


Fig. 8 — Linearized device colours of *sRGB* device for luminance reflections L_r = 0%, 2,5%, and 40%

Fig. 8 shows the linearized device colours of the standard *sRGB* device for the three luminance reflections L_r = 0%, 2,5%, and 40%. For equally spaced *rgb*-input data and according to CIELAB there is now the equally spaced linearized output. The mean grey (*rgb* = 0,5, 0,5, 0,5) is always in the middle between black and white for L_r = 2,5% and 40%. There is no hue shift including the series White - Orange red O and White - Violet blue *V*, compare Fig. 7. Again the colour gamut reduces to 51% for L_r = 2,5% and 9% for L_r = 40%.

7 CIELAB data of standard *sRGB* display linearized in elementary space *(rgb -> rgb*)*

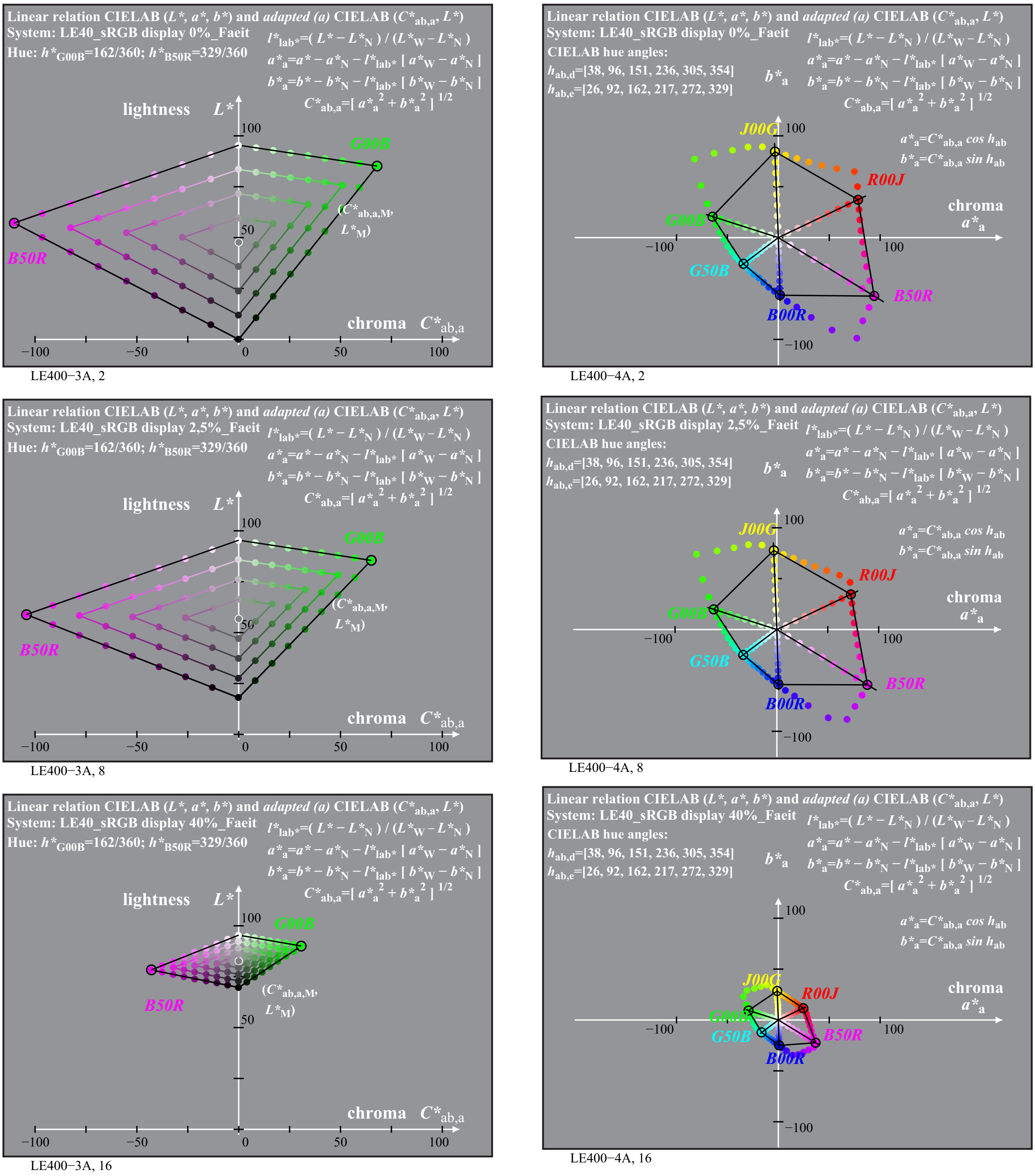


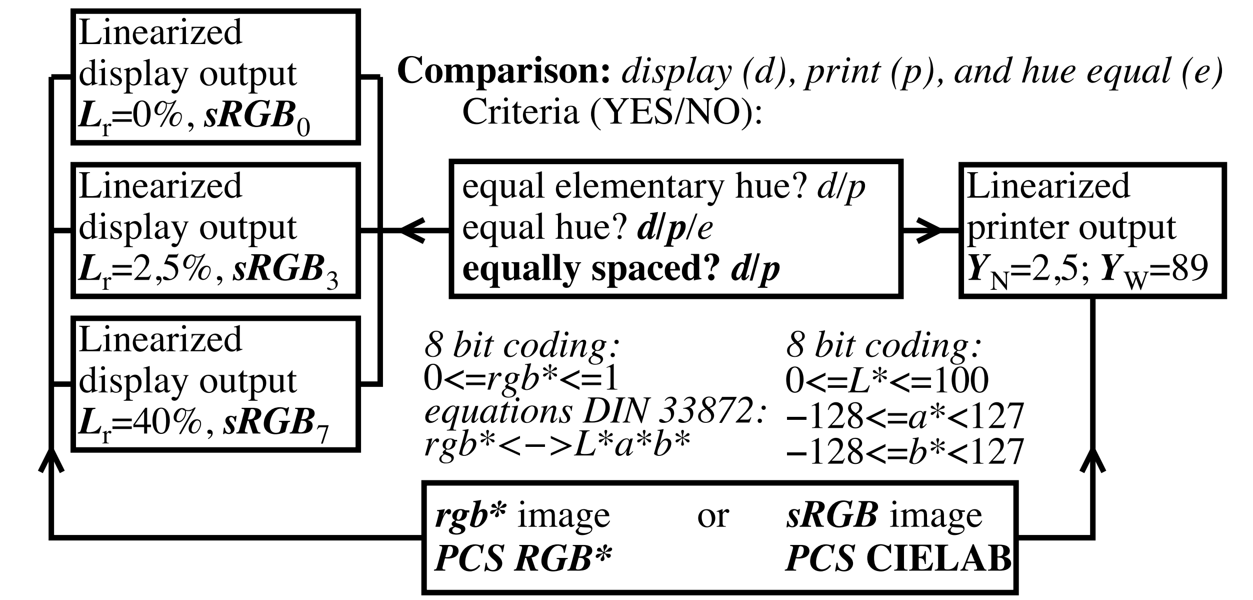
Fig. 9 — Linearized elementary colours of *sRGB* device for luminance reflections L_r=0%, 2,5%, and 40%

Fig. 9 shows the linearized elementary colours of the standard *sRGB* device for the three luminance reflections L_r = 0%, 2,5%, and 40%. For equally spaced *rgb*-input data and according to CIELAB there is now the equally spaced linearized output. The mean grey (*rgb* = 0,5, 0,5, 0,5) is always in the middle between black and white for L_r = 2,5% and 40%. There is no hue shift including the series White - Red *R* and White - Cyan blue *C'*, compare Fig. 7. Again the colour gamut reduces to 51% for L_r = 2,5% and 9% for L_r = 40%. Fig. 9 shows the preferred device independent elementary hue output of this paper and according to CIE R1-47.

8 High coding efficiency with elementary *rgb** coordinates

In image technology for colour coding usually the 8bit-*rgb* coding in the range 0 <= rgb_{8bit} <= 255 is used. This data range corresponds to the range 0 <= *rgb* <= 1.

ISO 15076-1 defines a fixed coding range, compare Fig. 5, which uses for ICC-LAB chroma the range -128 <= a^*_{ICC}, b^*_{ICC} <= 127 and for ICC-LAB lightness the range 0 <= L^*_{ICC} <= 100. The *sRGB* space which is defined for the luminance reflection L_r = 0% fills only 20% of this fixed coding space according to CIE 168.



Luminance reflection L_r	*rgb** coding efficiency e_{3D}	CIELAB Lightness L^*_N	L^*_W	relative Lightness l_r= $(L^*_W-L^*_N)/95$	3D-Colour Gamut size $g_{3D} = [\, l_r]^3$	CIE coding efficiency e_{3D}(CIE 168)
0%	1,00	0	95	1,00	1,00	0,20 *(sRGB)*
2,5%	1,00	18	95	0,81	0,53	0,10
40%	1,00	70	95	0,26	0,02	0,004

KE231−3N,

Fig. 10 — High coding efficiency with *rgb elementary colour coding**

Fig. 10 shows that a high coding efficiency with *rgb** elementary colour coding is produced. For the standard *sRGB* display the efficiency increases by a factor 10. For the luminance reflection L_r=40% the increase is about a factor 200. This increase can be realized if the 48 step hue circle of the device is used as reference for the elementary colour coordinates *rgb**. One can interpret this data as metadata which are used for the application of the display device. The metadata are fixed for any device and can be measured in CIELAB.

If the *Profile Connection Space (PCS) RGB** is used, then the coding efficiency has the value 1,00 for the three luminance reflections L_r = 0%, 2,5%, and 40%. If the PCS CIELAB is used, then the coding efficiency reduces from the value 0,2 to 0,004.

Therefore for the PCS *RGB** the coding efficiency has a constant value 1 for all display luminance reflections L_r. Therefore especially for displays with the standard luminance reflection according to ISO 9241-306 at office work places, and for data projectors with much ambient light, the colour management according to ISO 15076-1 (ICC colour management) has a much lower efficiency. Therefore the application of ICC colour management, for example for the *softcopy - hardcopy comparison*, is less appropriate for L_r=2,5%.

9 Application example for eight viewing conditions as eight display modes

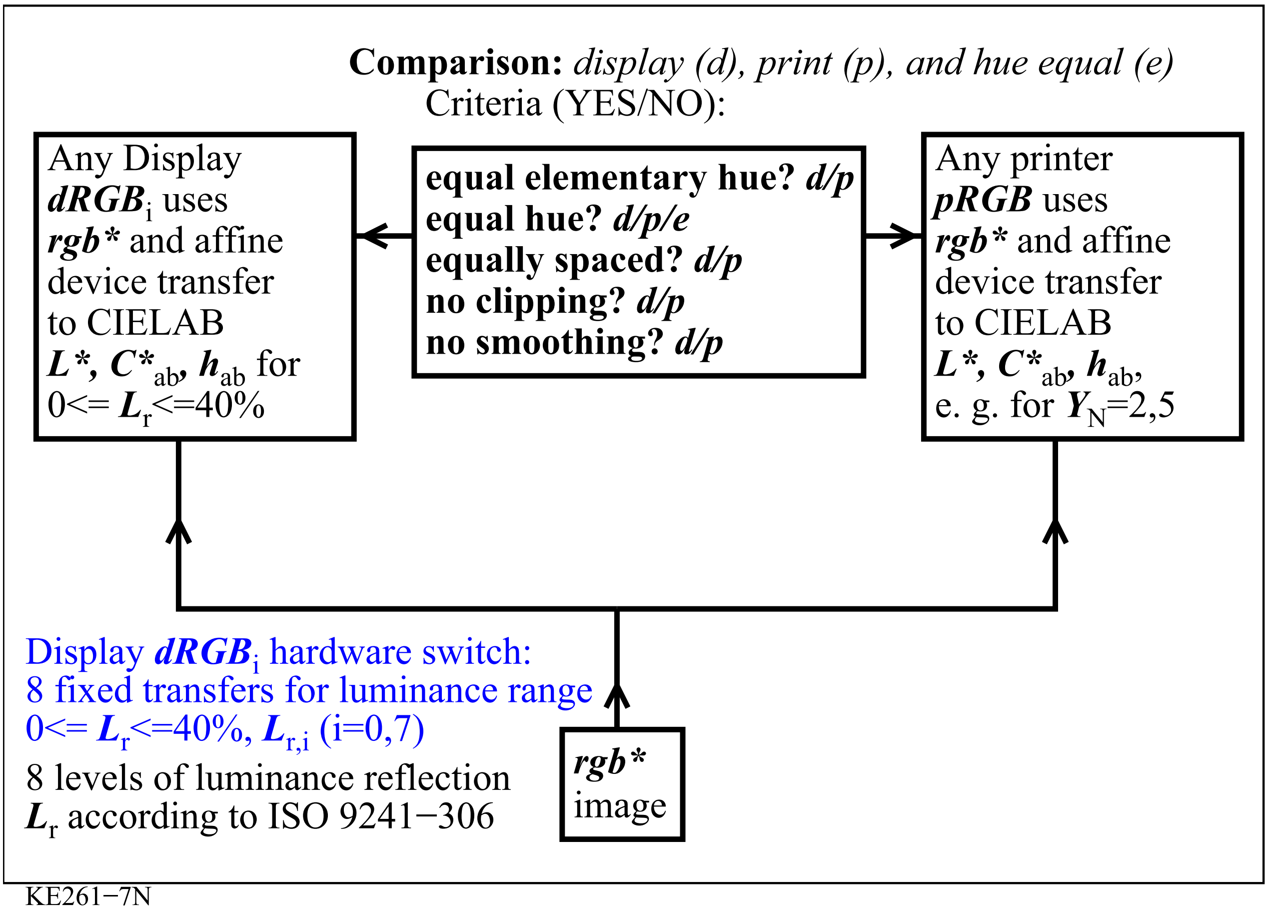


Fig. 11 — Application of eight *affine* colour transformations *rgb* -> *rgb' for eight viewing conditions**

Fig. 11 shows the application of eight *affine* colour transformations *rgb* -> *rgb'** for eight viewing conditions. The transformations are well defined for any device. Fig. 2 and 3 explains the no*tation ('* = dash-star)* and the method to calculate these transformations. Fig. 9 shows the output for an *sRGB* device in the elementary hue planes *B50R* and *G00B*. In addition the CIELAB (a^*_a, b^*_a) chroma diagram shows the hue planes *R00J* and *G50R*, and *J00G* and *B00R*.

At office work places there are colour and visibility changes with the luminance reflection. The user wishes not only to linearize a file output, for example of the test chart file according to ISO 9241-306, Annex D, see

http://www.ps.bam.de/ME16/10L/L16E00NP.PDF

The whole display output shall change according to the ambient light. A possible solution is given in Fig. 12 which shows the workflow interpretation *rgb* -> *rgb** and *rgb**-output linearization for eight luminance reflections L_r = 0, 0,6, 1,2, 2,5, 5, 10, 20, and 40%.

Eight *rgb* -> *rgb'** data tables of Fig. 11 may be used for output linearization within the devices. This shall produce a linearized output on the display for eight luminance reflections and the elementary hues, the equal intermediate hues, the equal spacing and no clipping. A similar output linearization method is possible for printers.

Software solutions are also possible, see the ISO-test chart according to ISO 9241-306 (1,8 MB, 16 pages).
http://www.ps.bam.de/ME15/10L/L15E00FP.PDF

In addition annex D of ISO 9241-306 includes an example for a software solution.

10 References

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CIE 17.4:1983, International lighting vocabulary, 4th ed. (Joint publication IEC/CIE)

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ISO/IEC TR 24705:2005, Information technology – Office machines – Machines for colour image reproduction – Method of specifying image reproduction of colour devices by digital and analog test charts

DIN 33872-1 to -6:2010-11 (in print), Information technology - Office machines - Method of specifying relative colour reproduction with YES/NO criteria - Part 1: Classification, terms and principles - Part 2: Test charts for output properties - Testing of discriminability of 5 and 16 step colour series - Part 3: Test charts for output properties - Testing of equality for four equivalent grey definitions and discriminability of the 16 grey steps - Part 4: Test charts for output properties - Testing of equality for two equivalent colour definitions with 5 and 16 step colour series- Part 5: Test charts for output properties - Testing of elementary hue agreement and hue discriminability - Part 6: Test charts for output properties - Testing of the equivalent spacing and of the regularchromatic spacing. For the test charts according to DIN 33872-1 to -6 see http://www.ps.bam.de/33872E

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