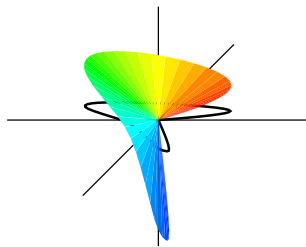


Output Linearization Methods for Displays, Printers, and Offset Print



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At the 2011 CIE Division 8 meeting in South Africa CIE Division 8 *Image Technology* decided the

**Reportership CIE R8-09
Output Linearization Methods for Displays and Printers**

Terms of Reference

Make a report on proposals for the application of output linearization methods. The report may cover the device and elementary hue output of displays and printers.

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Forword

For the newest version of this paper on output linearization which is called here and in the following a white standard document, see

<http://130.149.60.45/~farbmetrik/outlin>

A first version of this white *paper* for a standard document (technical report or other) for discussion appeared in April 2013 for an unofficial meeting of the secretary and members of CIE Division 8 at the CIE anniversary meeting in Paris, see 59 pages 1,3 MB

http://130.149.60.45/~farbmetrik/OUTLIN13_01.PDF.

The present version of this document, dated 2013-12, see 63 pages 1,3 MB

http://130.149.60.45/~farbmetrik/OUTLIN13_02.PDF.

is an improvement by suggestions of different experts. This version fixes some editorial errors and considers the publication CIE R1-57:2013 *Border between luminous and blackish colours*. Annex E discusses the possible application of a device-independent visual *RGB** colour space which may be based on CIE R1-57.

The present version is still for discussion. There is no decision yet how to proceed with this white standard document within CIE, ISO, or IEC.

The new report CIE R1-57:2013 allows to define a completely **device-independent visual *RGB** colour space**. Table 1 of CIE R1-57 includes the data for the **Ostwald optimal colours** of maximum chromatic value C_{AB} and in addition approximately for maximum CIELAB chroma C_{ab}^* . The *Ostwald* colours may serve as reference colours for colour appearance for any human observer.

The *Ostwald* colours appear neither luminous nor blackish. According to the table E.1 in Annex E they form for example a 16 or 48 step hue circle with different luminance factors Y . The largest luminance factor $Y=93$ appears for yellow-green (spectral range of the optimal colour between 495nm and 770nm) and the lowest $Y=7$ (spectral range between 380 and 495nm) for a bluish red. colour In the additive mixture both mix together to White with $Y=100$.

The hue angles and the luminance factors of the Ostwald colours for D65 are very similar to the colours in the *sRGB* colour space. In the *sRGB* colour space for displays according to IEC 61966-2-1 the additive mixture colour *greenish yellow* of the two primaries red ($Y=21$) and green ($Y=72$) has the luminance factor $Y=93$ and the blue primary has the luminance factor $Y=7$, compare Table B.1 of Annex B.

In 2012 ia publication **Colour and Colour Vision - Elementary colours in colour image technology** was published by K. Richter. This paper applies the output linearization methods of this white standard document for the *sRGB* display output, the *offset print* output on different papers, and the *laser printer* output. Many colorimetric results of this publication are included in this white standard document.

Free offset prints of this paper may be ordered by email to klaus.richter@mac.com. For many people the real output is much more impressive compared to the technical matter in this white standard document which is intended for people with a lot of technical knowledge in the colour field.

The paper **Colour and Colour Vision - Elementary colours in colour image technology** is available in different versions for monitor, offset, and printer output,

and in the different languages German, English, French, Spanish, and Italian, see

<http://130.149.60.45/~farbmetrik/color>

Content of K. Richter, Output Linearization Methods for Displays, Printers, and Offset Print

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1 Scope

A digital file with 9x9x9 *rgb* equally spaced input data is used to produce 729 colours on a colour display. The digital file format may be *PostScript* (PS) or *Portable document* (PDF). Within the different file formats the 9 step colour scales are defined by 9 digital values between 0 and 1, for example by 0, 1/8, 2/8 to 8/8 in RGB coordinates. The first output is measured and by the linearization method (LM) of this Technical Report, a visually equally spaced output is produced in relative CIELAB units, for example between the white display and a 48 step hue circle of maximum device chroma for these hues.

This Technical Report produces tables *rgb* -> *rgb*** (dash-star coordinates, compare ISO/IEC 15775) for output in device space and also tables *rgb* -> *rgb*** according to CIE R1-47:2009 for the device independent elementary hue output. The output is linearized for the eight viewing conditions defined in ISO 9241-306 for eight ambient light reflections on the display.

There are tables of output values and graphs for the first and linearized output. This method produces a linear relationship between the linear digital input data and the output data on a visual relative CIELAB scale in any hue plane. The method is applicable for systems that do not have colour management or as a linearization method for devices that could be used as a *setup_state* for colour management. The aim of this method is to produce equal CIELAB spacing. The equal spacing of the steps achieved in the linearization method may be adapted to various purposes. The accuracy of this method is expected to be within $\Delta E^*_{ab}=1$ of CIELAB. However, the standard deviation of ΔE^*_{ab} of colour output on different positions of the display, or on the printer, or in offset print is for example between $\Delta E^*_{ab}=0,5$ (photo printer) and $\Delta E^*_{ab}=5$ (laser printer). For real output the accuracy is therefore device-dependent and in many cases larger than $\Delta E^*_{ab}=1$.

NOTE 1: This Technical Report applies the Technical Report ISO/IEC TR 19797 for output linearization of printer to displays and to the eight luminance reflections L_r between 0 and 40% according to ISO 9241-306, Annex D. Similar as for printers this Technical Report could be used as a *setup_state* for colour management. In addition the affine transformation of Fig. 25 on page 38 is a colour management strategy. It is intended that for example the user can choose one mode of eight for the whole display output similar as in ISO 9241-306.

NOTE 2: The effectivity of the cylindrical and relative triangle coding in hue planes is by a factor 10 more effective compared to the fixed 8-bit coding in the range -128 and 127 for a^* and b^* of CIELAB and 0 and 100 for L^* of CIELAB. The ten times higher effectivity and accuracy of coding is based on data for the *sRGB* color space. CIE 168 shows that the *sRGB* gamut fills 20% of this CIELAB coding gamut. For the standard luminance reflection $L_r=2,5\%$ in the office the *sRGB* gamut fills only 50% of the standard *sRGB* gamut in the dark room.

2 Conformance

A paragraph.

3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

CIE 15:2008, Colorimetry

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

CIE 168:2005: Criteria for the Evaluation of Extended-Gamut Colour Encoding

CIE R1-47:2009, Hue angles of elementary colours, see for download under REPORTS <http://div1.cie.co.at>

CIE R1-57:2013, Border between luminous and blackish colours, see for download under REPORTS <http://div1.cie.co.at>

DIN 33872-1 to 6:2010, Information technology - Office machines - Method of specifying relative colour reproduction with YES/NO criteria, see for download of test charts <http://www.ps.bam.de/33872E>

ISO EN DIN 9241-306:2008, Ergonomics of human system interaction – Part 306: Field Assessment methods for electronic visual displays

ISO 8995; CIE S 008:2002-05, Lighting of indoor work places

ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: CIE Colorimetry — Part 4: 1976 $L^*a^*b^*$ Colour Space (CIELAB)

ISO 15076-1:2005, Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC.1:2004-10

ISO/IEC 15775:1999, Information Technology – Office machines – Method of specifying image reproduction of colour copying machines by analog test charts – Realization and application

ISO/IEC 15775/Amd.1, Information technology – Office machines – Machines for colour image reproduction – Method of specifying image reproduction of colour copying machines by analog test charts – Realization and application – Amendment 1

ISO/IEC TR 19797:2004, Information technology – Office machines – Machines for colour image reproduction – Device output for 16-step colour scales, output linearization method (LM) and specification of the reproduction properties

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, see for download of test charts <http://www.ps.bam.de/24705TE>

SS 019100:1997, Colour notation system, and SS 019102:2004, NCS ATLAS (NCS Colour atlas)

4 Terms and definitions

3.1

Colorimetric data

Three colour data with a defined and simple relation to the standard CIELAB data $LAB^* = L^*, a^*, b^*$ or $LCH^* = L^*, C^*_{ab}, h_{ab}$

NOTE 1: There is a family of colorimetric *standard* CIELAB data LAB^* , of colorimetric *adapted* data LAB^*_a , and of colorimetric *relative* data lab^* , compare table C.1.

NOTE 2: The family of the colorimetric *standard* CIELAB data LAB^* has two equivalent versions $LAB^*LAB^* = L^*, a^*, b^*$ and $LAB^*LCH^* = L^*, C^*_{ab}, h_{ab}$, compare table C.1.

NOTE 3: The family of the colorimetric *adapted* CIELAB data LAB^*_a has two equivalent versions $LAB^*_a LAB^*_a = L^*_a, a^*_a, b^*_a$ and $LAB^*_a LCH^*_a = L^*_a, C^*_{ab}, h_{ab}$, compare table C.1.

NOTE 4: The family of the colorimetric *adapted* data LAB^*_a has a defined and simple relation to the standard CIELAB data LAB^* . The adapted lightness L^*_a is identical to the standard lightness L^* , compare table C.1. In some applications corresponding colour values are necessary which then use the index a, for example the tristimulus values X_a, Y_a, Z_a of the chromaticity values x_a and y_a . For example in Fig. 8 on page 14 the colorimetric *adapted* data LAB^*_a are calculated from the colorimetric *standard* CIELAB data LAB^* and shown as colour samples.

NOTE 5: The family of the colorimetric *relative* data lab^* has many equivalent versions, for example $lab^*lab^* = l^*, a^*_a, b^*_a, lab^*lch^* = l^*, c^*, h^*, lab^*ncu^* = n^*, c^*, u^*$, and $lab^*cmY^*_e = c^*_e, m^*_e, y^*_e$, compare Table B.1. The colorimetric *relative* data lab^* have a defined and simple relation to the colorimetric *adapted* CIELAB data LAB^*_a . For example in Fig C.2 the colorimetric relative data l^*, c^*, h^* are calculated from the adapted CIELAB data L^*_a, C^*_{ab} , and h_{ab} , and are shown as colour samples.

NOTE 6: The colorimetric data LAB^* , LAB^*_a , and lab^* are listed together with the names and abbreviations in table E.1. Additional coordinates, for example colour deepness d^* , brillianthness i^* , and whiteness w^* are not defined in table E.1. The

linear relationship, for example between these coordinates and $lab^*rgb^*_e$ is shown in the paper “Colorimetric supplement to DIN 33872-1 to -6 [1] and in Annex C.

3.2

colorimetric space CIELAB

three-dimensional space for the geometrical representation of colorimetric data with rectangle or cylindrical standard or adapted CIELAB coordinates.

NOTE 1: The colorimetric data may be of the type *rectangle*, for example $LAB^*LAB^* = LAB^*$, $LAB^*_aLAB^*_a = LAB^*_a$ or of the type *cylindric*, for example $LAB^*LCH^* = LCH^*$, $LAB^*_aLCH^*_a = LCH^*_a$

3.3

Colorimetric isometric data

relative CIELAB data lab^*tab^* or lab^*tch^* , for which the calculated colorimetric differences correspond to a high degree with the visual differences.

3.4

Colorimetric isometric space

Three-dimensional space for the geometrical representation of the relative CIELAB data lab^*tab^* or lab^*tch^* , where the differences in the space correlate to a high degree with the visual differences of a device system.

NOTE 1: This space is to a high degree isometric in the sense of perception and shows a high degree of visual uniformity.

NOTE 2: If the coordinates lab^*t^* , lab^*c^* , and lab^*h^* are used, then the three-dimensional visual representation of the 16-step colour series between White W and Black N and the six chromatic colours is a double cone, which is called a Natural Colour Connection Space NCCS

NOTE 3: For any device system the colorimetric data lab^*t^* in the range 0 to 1 are used for the vertical axis, and the colorimetric data lab^*c^* in the range 0 to 1 are used for the horizontal axis. For the 16-step colour series equal visual differences correspond to equal geometric differences.

NOTE 4: Fig. A.3 and A.4 shows colour samples in the colorimetric isometric space of the type cylindrical with the coordinates tch^* .

3.5

Device system colours

Output colours of a device system which are dependent on the hard and software properties including the viewing illumination.

NOTE 1: Examples are reflective colours on a printer, the light colours of a monitor or the projected colours of data projectors.

3.6

Normal colour vision

Vision perception, which can be determined by a colour vision test, and which corresponds to the CIE-2 degree observer according to CIE 15 or DIN 5033.

NOTE: The normal colour vision of an observer is for example tested according to DIN 6160 by the Anomaloscope of Nagel or with *Ishihara* test charts.

3.7

Colour difference

Amount of the perceived difference between two colours.

NOTE: The colour difference ΔE^*_{ab} between two colours is calculated according to ISO 11664-4 with the CIELAB colour difference formula.

3.8

Relative colour difference

Amount of the perceived difference of at least three colours A, B, and C.

NOTE 1: The colorimetric specification of the relative colour differences is given by comparison of the relative colour difference between $A-B$ and $B-C$.

NOTE 2: In the standard series DIN 33872 the relative colour difference of 3-, 5-, 9-, 16-, and 17-step colour series is evaluated visually and/or specified by colorimetry.

3.9

Colour image

visual presentation of colours in a two dimensional arrangement.

NOTE: For example the data of a colour image are defined by 960 times 640 pixels as *rgb* or CIELAB data within a digital test chart.

3.10

Colour image reproduction

Visual evaluation or colorimetric specification of the reproduction of a colour image.

NOTE: For the reproduction for example the *rgb*-data in a digital file are used for the output.

3.11

Relative colour image reproduction

Reproduction of a colour image for which the hue of any colour and the relative colour differences of the arrangement remain constant.

NOTE 1: Equally spaced 17-step colour series in a hue triangle, for example between Black and White, Chromatic and White and Chromatic and Black remain equally spaced by visual evaluation for any output system.

NOTE 2: The relative colour differences of colour images are only slightly dependent by the chromaticity of the illumination compared to large colour data differences of single samples in the office environment. For the office illumination see ISO 8995 and DIN V 18599-4.

NOTE 3: For monitors and data projectors the relative colour differences of colour images are highly dependent on the reflections of the office illumination on the monitor surface and the projection screen, see DIN EN ISO 9241-306. This standard describes methods for output linearization depending on the reflection properties.

3.12

Colour order system

Three-dimensional order of colours by visual and/or colorimetric criteria.

NOTE 1: Examples for the order according to visual criteria are the colour order systems *Natural Colour System (NCS)*, *Ostwald*, *Munsell* and the *Optical Society of America (OSA)*, compare [1].

NOTE 2: Examples for the order according to colorimetric criteria are the colour order systems according to DIN 6164-1 and the *RAL Design System* with a regular cylindrical order in the CIELAB colour space for the CIE standard illuminant D65 and the 10 degree observer, compare [1].

5 Symbols (and abbreviated terms)

PS *PostScript*
PDF *Portable Document Format*

ORS18 **Offset Reflektive System** with lightness $L_a^* = 18$ for Black N
 TLS00 **Television Light System** with lightness $L_a^* = 0$ for Black N
 TLS18 **Television Light System** with lightness $L_a^* = 18$ for Black N (*standard for offset and displays*)

$RYGCBM_d$ Device (d) colours (Colours of the device hue hexagon):
 Red (R_d), Yellow (Y_d), Green (G_d), Cyan blue (C_d), Blue (B_d), and Magenta (M_d)

$RYGBCM_e$ Elementary (e) colours (Colours of the elementary hue hexagon):
 Red (R_e), Yellow (Y_e), Green (G_e), Cyan blue (C_e), Blue (B_e), and Magenta (M_e)

D65 Daylight with correlated colour temperature 6500° Kelvin (CIE 15: standard illuminant)

6 Start and linearized output of RGB displays for standard luminance contrast

6.1 Output of a 16 step device colour circle and definition of elementary colours

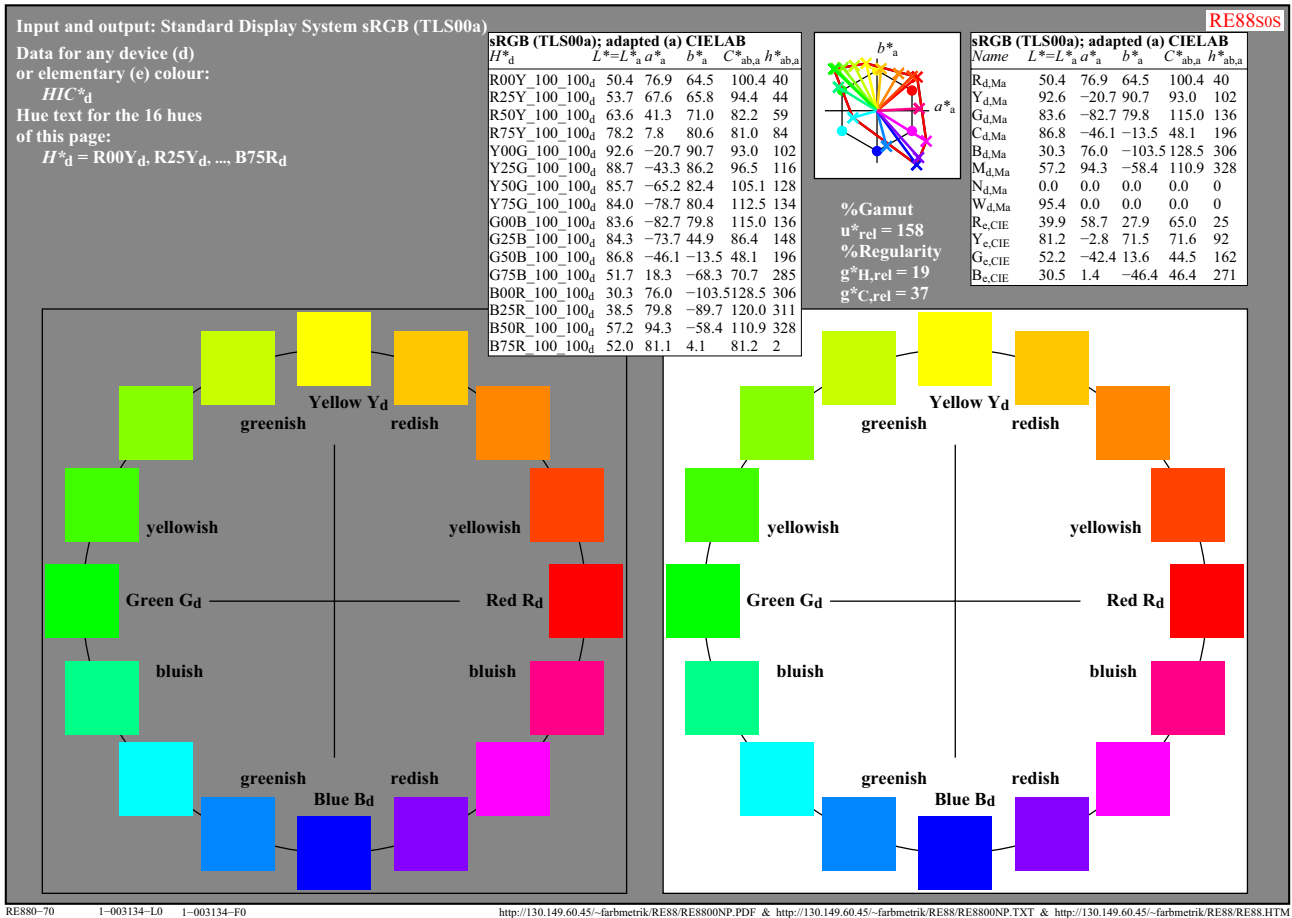


Fig. 1 - Hue circle with 16 colour steps and with device (d) colours

Fig. 1 shows a 16 step hue circle of device (d) colours. The four colours Red R_d , Yellow Y_d , Green G_d and Blue B_d are produced by the rgb_d data $(1, 0, 0)_d$, $(1, 1, 0)_d$, $(0, 1, 0)_d$, and $(0, 0, 1)_d$. The CIELAB data L^* , a^* , b^* , C^*_{ab} and h_{ab} are given in the right table. The hue angles $h_{ab,d}$ 40, 102, 136, 306 belong to the output colours on the standard sRGB display. For comparison the elementary hue angles $h_{ab,e}$ of the CIE test colours 9 to 12 of CIE 13.3 are given. These four colours with the elementary hue angles $h_{ab,e} = 25, 92, 162, \text{ and } 271$ represent the CIE elementary hue angles according to CIE R1-47. The standard deviation of the hue angle is ± 4 for R_e , Y_e , and G_e , and ± 8 for B_e .

Fig. 1 includes a special colour code HIC^*_d , for example $HIC^*_d=R00Y_100_100_d$ for device red. According to DIN 33872-1 the three colour coordinates HIC^*_d are called hue text H^* , Brilliance I^* and Chroma C^* . Brilliance I^* is equal to 100 times the relative brilliance i^* and Chroma C^* is equal to 100 times of the relative chroma c^* .

In addition the CIELAB data L^* , a^* , b^* , C^*_{ab} and h_{ab} are given. For many real applications for black N and white W there is a small difference compared to the ideal values $(a^*_N=0, b^*_N=0)$ and $(a^*_W=0, b^*_W=0)$. Then some

“adaptation” (index a) is necessary for a useful calculation of the hue angles. For the standard (ideal) sRGB device the coordinates $L^*a^*,b^*,C^*_{ab},h_{ab}$ and $(L^*a^*b^*C^*_{ab}h_{ab})_a$ are identical, compare Fig. 9 on page 15 and Annex B on page 54.

Usually for the values $rgb_{_}$ (index $_$ unspecified) the device blue is produced and this colour appears reddish blue. The sRGB hue angle is $h_{ab,d} = 305$. However the elementary hue angle is $h_{ab,e}=272$.

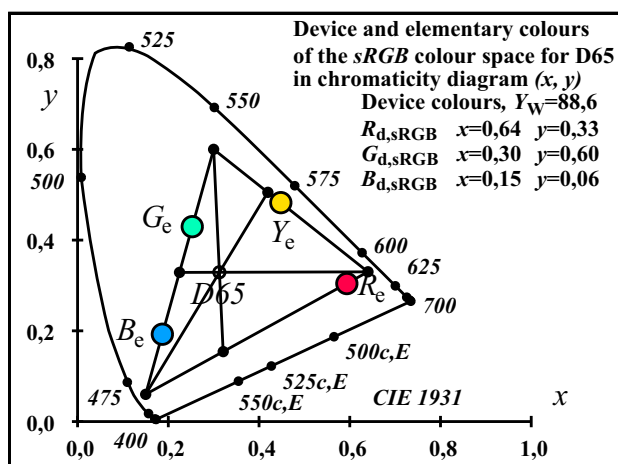
Table 1 - Device colours and elementary colours with visual criteria

Achromatic colours, intermediate colours	Chromatic colours, Elementary colours	Chromatic colours, Device colours
<i>five achromatic colours:</i>	<i>"Neither-nor"-colours</i>	<i>TV, Print (PR), Photo (PH)</i>
<i>N</i> black (French noir)	<i>four elementary (e) colours:</i>	<i>six device (d) colours:</i>
<i>D</i> dark grey	<i>R = R_e red</i>	<i>C = C_d cyan blue (cyan)</i>
<i>Z</i> central grey	<i>neither yellowish nor bluish</i>	<i>M = M_d magenta red (magenta)</i>
<i>H</i> light grey	<i>G = G_e green</i>	<i>Y = Y_d yellow</i>
<i>W</i> white	<i>neither yellowish nor bluish</i>	<i>O = R_d orange red (red)</i>
<i>two intermediate colours:</i>	<i>neither greenish nor reddish</i>	<i>L = G_d leaf green (green)</i>
<i>C_e = G50B_e green-blue</i>	<i>J = Y_e yellow (French jaune)</i>	<i>V = B_d violet blue (blue)</i>
<i>M_e = B50R_e blue-red</i>	<i>neither greenish nor reddish</i>	

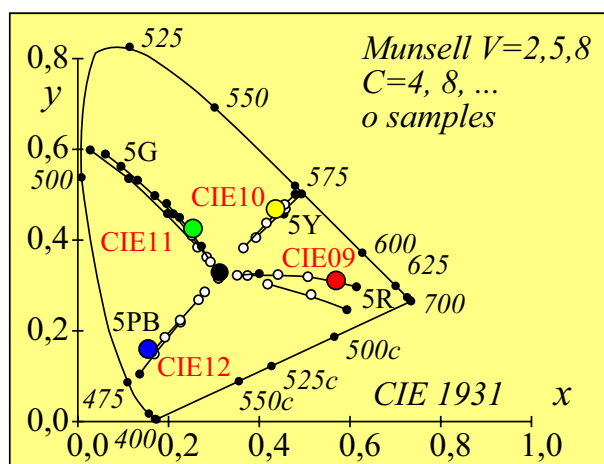
1-003130-L0 1-003130-F0

ME080-10

Table 1 shows the device colours (index d) and the elementary colours (index e) and the visual criteria for the elementary colours. ISO/IEC 15775 uses for example the letters O, L and V instead of R_d, G_d, and B_d which indicate the difference to the letters R, G, and B. However, in this paper we prefer to use the index d or e to distinguish between device end elementary colours or hues.



1-013130-L0 1-013130-F0 RE811-1N/ME491-61



1-003130-L0 1-003130-F0 ME480-30

Fig. 2 - sRGB device colours and elementary colours in the CIE (x,y) chromaticity diagram

Fig. 2 shows the six device colours (black balls) and the four elementary colours which can be produced from these device colours in the CIE chromaticity diagram (left). The four CIE test colours no. 9 to 12 which represent the elementary hues (compare the following) are shown together with the samples of the hues 5R, 5Y, 5G and 5PB of the Munsell colour order system for the three Values V=2, 5, and 8 (approximately L*=20, 50, 80 in CIELAB) (right).

6.2 ISO request to the CIE for an elementary *RGB* system and work results within the CIE

Conclusion 31/2007 ISO TC159/SG4/WG2

Ergonomics – Visual Display Requirements

ISO TC159/SG4/WG realizes that the colour spaces CIELAB and CIELUV of *CIE Division 1* will soon become ISO/CIE standards. In applications we use these CIE colour spaces and *device-dependent* relative RGB colour spaces. For users of visual display systems a *device-independent* RGB colour space is useful. This produces via software the elementary hues Red, Green and Blue for the RGB data 100, 010 and 001 and equally spaced output in CIE colour spaces for equally spaced RGB input. We recommend that *CIE Division 1* study the colorimetric definition of such a space, which can be used in visual display applications.

Remark: We have realized that an example colour space of this type is published in CIE X030:2006, p. 139–144. unanimous vote (Finland, Germany, Japan, Korea, Netherlands, Sweden, USA)

SE380-1

Fig. 3 - Conclusion of ISO TC159/WG4/SC2 for a device-independent RGB colour space

Fig. 3 shows a conclusion of ISO TC159 which includes a request of the ISO committee *Visual Display Requirements* for the definition of the elementary hues by CIE Division 1 Colour and Vision. Different ISO committees have problems with the application of colour in ISO International Standards and Technical Reports. CIE Division 1 is the appropriate body to study the colour problems and to produce guidance.

At the CIE meeting in Stockholm, June 2008, *CIE Division 1* decided to establish the CIE Reportership R1-47 **Hue Angles of Elementary Colours** by *Thorstein Seim (Norway)* in response to the request of ISO TC 159 **Visual Display Requirements** and to present the result at the next CIE meeting in Budapest 2009.

The report **CIE R1-47:2009 Hue Angles of Elementary Colours**

lists in chapter 3.6 the average CIELAB hue angles 26, 92, 166, and 270 of *Miescher, NCS, and the CIE*.

CIE R1-47 recommends to use the CIELAB hue angles **25, 92, 162 and 271** of the CIE test colours no. 9 to 12 according to CIE 13.3 for the four elementary colours R_e , Y_e , G_e , and B_e .

For free download of CIE R1-47 see the CIE Division 1 web site

<http://cie.co.at> under *MINUTES & REPORTS*

SE380-3

Fig. 4 - Decision of CIE Division 1 and Report CIE R1-47 with definition of elementary hue angles

Fig. 4 shows the decision and answer of CIE Division 1 on the request of ISO TC159. The four CIELAB hue angles $h_{ab,e} = 25, 92, 162$ and 271 of the CIE test colours no. 9 to 12 according to CIE 13.3 are proposed for the four elementary colours R_e , Y_e , G_e , and B_e . This is the CIE basis to define the device-independent rgb_e coordinates which produce the visual elementary hues. The report includes the standard deviation of the elementary hue angles. For R_e , Y_e , and G_e the values $h_{ab,e} = \pm 4$, and for B_e the value $h_{ab,e} = \pm 8$ is given. However, for example the standard *sRGB* colour space produces $h_{ab,d} = 305$ and an example printer of a leading printer company $h_{ab,d} = 260$. Both hue angles are outside the visual range $h_{ab,e} = 271 \pm 8$, and in addition the shift is in the display case towards the reddish and in the printer case towards the greenish side. Therefore, if the proposal $h_{ab,e} = 271 \pm 8$ of CIE R1-47 is reached on most devices, this will be a large improvement for users.

One must consider that there are hundreds of *RGB* colour spaces, including the ISO standard spaces *sRGB*, *RIM RGB*, *ROM RGB*, *Adobe RGB*, *ECI RGB*. All are device specific and not related to the visual elementary hue definition of CIE R1-47.

6.3 Output of the elementary colour circle

The output of the elementary colour circle on a standard *sRGB* display needs hue shifts, compare Fig. 32 on page 45. For example the three rgb_d values $(0\ 0\ 1)_d$ (d =device) produce the hue angle $h_{ab,d}=305$ and the three rgb_e values $(0\ 0\ 1)_e$ (e =elementary) produce the hue angle $h_{ab,e}=271$. For a 16 step device and elementary hue circle the hue angles $h_{ab,d}$ and $h_{ab,e}$ are given in the tables of Fig. 1 on page 8 and Fig. 5 respectively. For example for the device hue $Y00G_d$ and the elementary hue $Y00G_e$ the hue angles are $h_{ab,d}=102$ and $h_{ab,e}=92$. The device hue angle $h_{ab,d}=102$ produces a greenish yellow compared to the elementary hue angle $h_{ab,e}=92$ with the standard deviation ± 4 . The colour code $Y00G_{100_{100}_e}$ belongs to the rgb values $rgb_e=(1\ 1\ 0)_e$. The first value $Y00G_e$ is called the hue text, the following two values are 100 times the relative brilliance i^* and the relative chroma c^* . One can use the capital letters $I^* = 100\ i^*$ and $C^* = 100\ c^*$. There are two equations which allow to transform between values of rgb^* and c^* and i^* for both the device and the elementary colours:

$$c^* = \max(rgb^*) - \min(rgb^*)$$

$$i^* = \max(rgb^*)$$

Example: For a greyish red with $rgb^* = (0,75, 0,50, 0,25)$ it is valid $c^* = 0,5$ and $i^* = 0,75$ (compare also Fig. 14 on page 20).

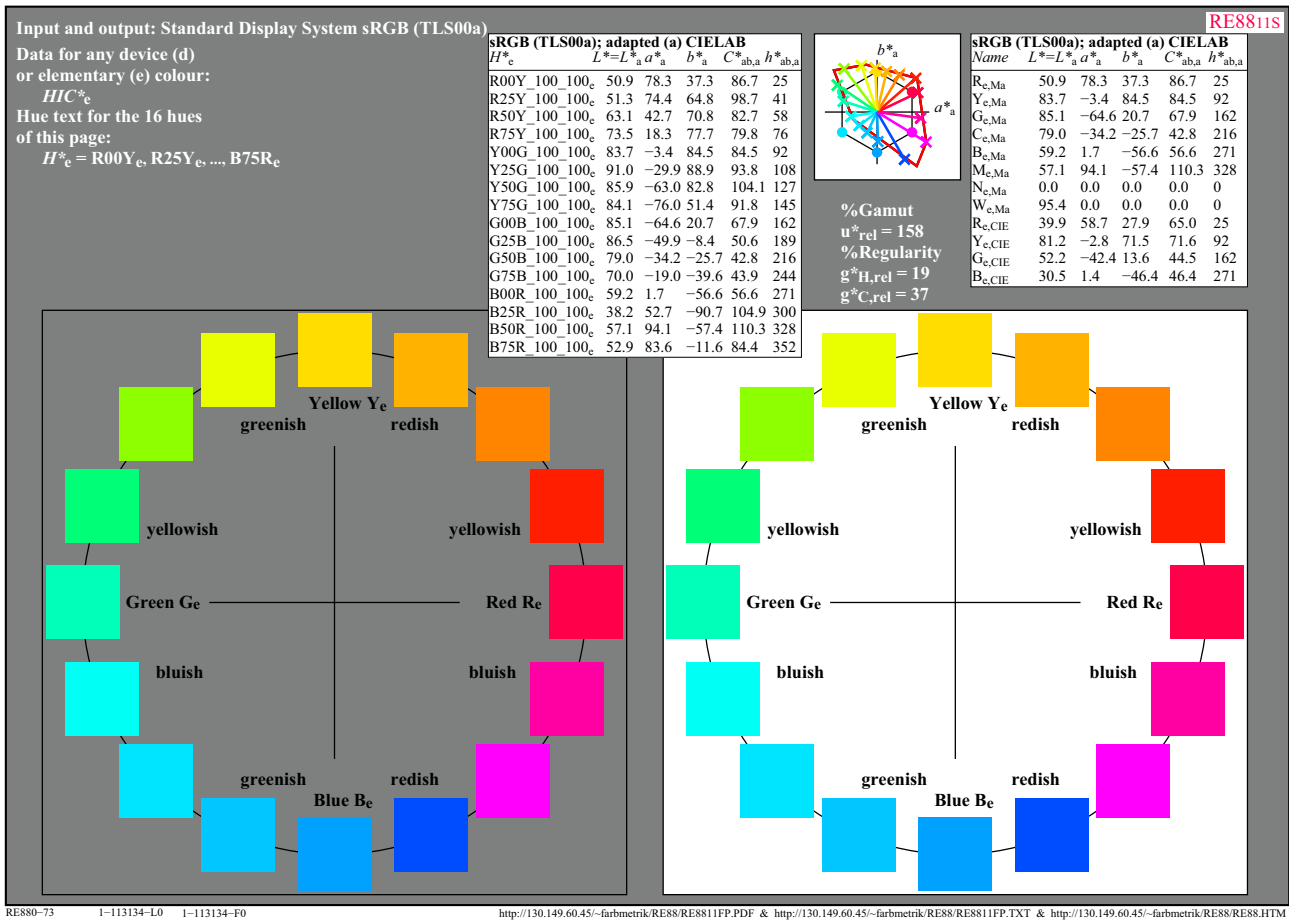


Fig. 5 - 16 step hue circle of elementary (e) colours

Fig. 5 shows a 16 step hue circle which shall produce the elementary colours R_e , Y_e , G_e , and B_e according to the criteria given in the figure. There may be a small visual difference on the grey and white background. One may realize that Yellow $Y_e=Y00G_e$ is darker compared to the next greenish step $Y25G_e$. This is a disadvantage of the *sRGB* display system and not for printers. Both produce a lighter elementary yellow compared to the *sRGB* display.

6.4 ISO/IEC request to the CIE for a human visual RGB system and work results within CIE

Resolution Busan 18/2009 of ISO/IEC JTC1/SC28 "Office Equipment"

SC28 Review of the AWG recommendation on jn28n1280 (DIN 33872-1 to 6)

The German proposal included the concept of a human visual RGB. SC28 recognizes the importance of correct understanding of the human visual system and the potential importance and application of this understanding to office equipment and office systems. SC28 welcomes the German plan to continue development of the human visual RGB within **CIE Division 1 and Division 8**.

In addition SC28 welcomes a new proposal from Germany in the future based on this CIE human visual RGB work, potentially in relation to AWG/PWG5 NWI-9

(Office colour space).

unanimous vote (Austria, China, Germany, Japan, Korea, USA)

SE380-5

Fig. 6 - Resolution on a human visual RGB of ISO/IEC JTC1/SC28 Office Equipment

Fig. 6 shows the Resolution *Busan 18/2008* of ISO/IEC JTC1/SC28 *Office Equipment*. An English translation of the German Standard series DIN 33872-1 to 6, see <http://www.ps.bam.de/33872E>, has been discussed in SC28. According to Fig. 7 further ISO processing in SC28 has been stopped until a human visual RGB system is developed within CIE Division 1 and 8.

The German standard series DIN 33872-1 to -6 is addressed to many applications of different specialized ISO committees, for example TC 42 (Photography), TC 130 (Graphic Technology), TC 159 (Displays, compare Fig. 3 on page 10), and ISO TC 171 (Document Management). Only CIE Division 1 has the broader view and is in addition the appropriate International Standard Body for *Colour and Vision*. Therefore it is a German wish to proceed in this area by a CIE Technical Report which in addition may be applied in different ISO committees.

At the CIE meeting in South Africa, June 2011, **CIE Division 1** decided to establish the Reportership **CIE R1-57 Border between Luminous and Blackish Colours** by *Thorstein Seim (Norway)* in response to the resolution 18/2009 of ISO/IEC JTC1/SC28.

In addition **CIE Division 8** decided to establish the Reportership

CIE R8-09 Output Linearization Methods for Displays and Printers by *Klaus Richter (Germany)* in response to the same resolution 18/2009 of ISO/IEC JTC1/SC28.

Both reports **CIE R1-57** and **CIE R8-09** have relations and may appear during 2013 at the CIE web site.

Possible Result: Definition of a device-independent visual RGB^*_e system as response to the request of SC28.

All surface colours define a hue circle of maximum chroma located within the CIE (x,y) chromaticity diagram.

CIELAB chroma C^*_{ab} and lightness L^* of this circle as function of hue h_{ab} serves as reference points of a *device-independent visual RGB^*_e system* (compare the reference C^*_{ab}, L^* hue circle of the *NCS* system).

SE380-7

Fig. 7 - Present Work in CIE Division 1 and 8 to solve the request of ISO/IEC JTC1/SC28

Fig. 7 indicates that a larger step towards a human visual and device-independent RGB^*_e system may be reached in 2013 with the two proposed Reportership Reports CIE R1-57 and CIE R8-09. CIE R1-57:2013 is published and the report CIE R8-09 may be published soon, depending on the decision of CIE Division 8.

In Fig. 6 SC28 has asked Germany to produce the output according to a human visual RGB system. This paper and the report CIE8-09 seem to be a step in this direction. In addition this white standard document allows to realize a lot of the user wishes according to DIN 33872-1 to -6 for display, offset and printer output.

6.5 Standard documents which include input and output linearization and device colours

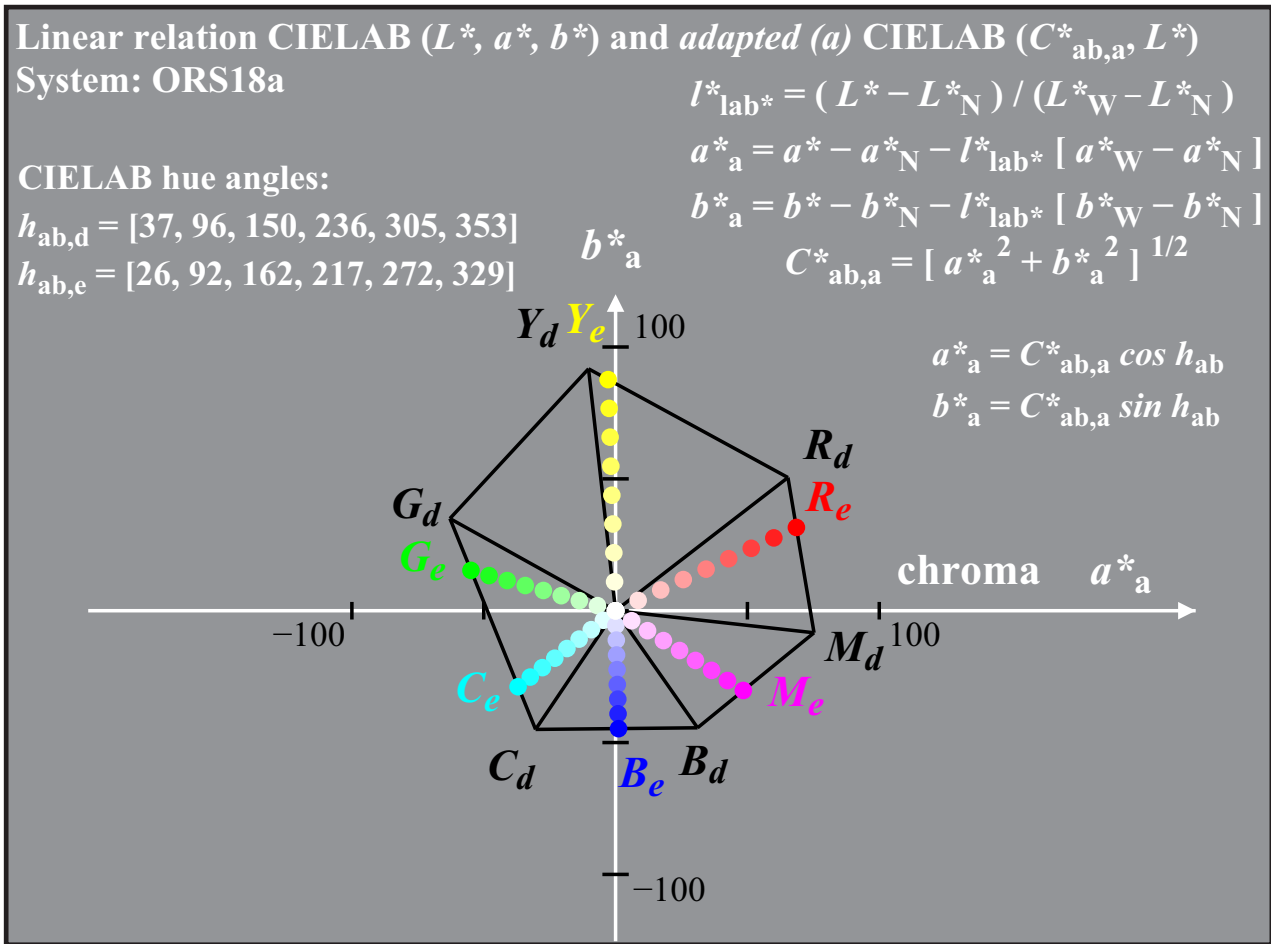
Table 2 - Overview of ISO and DIN documents based on CIE visual and colorimetric differences

Input	Output	Input and output media and applications			Technical Report (TR) or Standard	Method & Test: Linearization	
		Input media	Output media	Application			
–	–	–	–	Basis	ISO/IEC TR 24705	{ DIN 33866–1 DIN 33872–1	
analog	analog	linearized ISO/IEC-file + ISO/IEC-test chart (hardcopy)	Hardcopy	Copier	ISO/IEC 15775	{ DIN 33866–2 JIS X 6933	
analog	digital	ISO/IEC-test chart (hardcopy)	File	Scanner	ISO/IEC TR 24705	DIN 33866–4	
digital	analog	ISO/IEC-test chart (File)	{ Hardcopy Softcopy	{ Printer Display	{ ISO/IEC TR 24705 ISO/IEC TR 24705 ISO 9241–306	{ DIN 33866–3 DIN 33872–2,4 DIN 33866–5 DIN 33872–2,4	
The ISO/IEC-input linearisation method produces an ISO/IEC-file from an ISO/IEC-original scene: Flower motiv with 16 equidistant grey steps, and 14 CIE-test colours according to CIE 13.3 The ISO/IEC-output linearisation method produces from an ISO/IEC-file a linearized display, offset or printer output:							
ISO/IEC-input linearisation method				ISO/IEC-output linearisation method			
Input	Output	Application	Technical Report (TR) or Standard	Input	Output media	Application	Technical Report (TR) or Standard
Original scene + CIE-colours	ISO/IEC-Image File	Reference Image File	ISO/IEC 15775 ISO/IEC TR 24705	ISO/IEC-File	Hardcopy	Printer	ISO/IEC TR 19797 ISO 9241–306 8 viewing conditions CIE R8–09: 2013 device space + device-independent visual RGB*eo space
				ISO/IEC-File	Softcopy	Display	
				ISO/IEC-File	{ Softcopy Hardcopy Hardcopy	{ Display Offset Printer	

I-000000-L SE200-7N

Table 2 shows many International and National Standards and Technical Reports of ISO, IEC, DIN, and JIS. The common basis is the input or output evaluation or colorimetric specification based on CIE colorimetry. It may be the only standard document overview which is highly based on CIE colorimetry in this application field. Most of the standard documents are directed to only one application, for example copiers, scanners, printers, or displays. However there are multifunctional devices (a copier may be at the same time a scanner and a printer) which need in addition separate evaluations or specifications.

Table 2 shows that the intended report CIE R8-09 includes the three *devices display, offset, and printer* in **one** standard document. According to the terms of references of CIE R8-09 (see page 1) the device-dependent colour output is covered, and in addition the **device-independent** elementary colour output is included



SE270-3N

Fig. 8 - Device and elementary colours of standard offset according to ISO/IEC 15775

Fig. 8 shows the device colours $RYGCBM_d$ of standard offset according to ISO/IEC 15775 and the elementary colours $RYGB_e$ which are produced in standard offset for the four elementary hue angles $h_{ab,e} = 25, 92, 162,$ and 271 . In addition the mean hue angles $h_{ab,C_e} = 217 = 162 + (271 - 162) / 2$ and $h_{ab,M_e} = 329 = 271 + (397 - 271) / 2$ are given for C_e and M_e . Most of the so called RGB and $CMYK$ printers use similar device colours compared to offset. The colour difference is about $\Delta E^*_{ab} = 20$ compared to the standard $sRGB$ display colours.

Fig. 8 shows some equation to calculate the CIELAB coordinates with the index a (= adapted). If the CIELAB coordinates of black N (a^*_N, b^*_N) and white W (a^*_W, b^*_W) are all zero (which is not true for standard offset and most printers) then the coordinates with the index a are identical to the coordinates without index. In any case the adapted coordinates (index a) have the values 0 for both the black N and white W . For the calculation of the hue angle this property is necessary.

If the CIELAB (a^*, b^*) coordinates of black N and W are known one can transfer to the adapted coordinates and backwards.

Many CIE data, for example $x, y, X, Y, Z, L^*, C^*_{ab}, h_{ab}$ of the six standard chromatic colours RGB_d and CMY_d and black N and white W are given in Annex B on page 54 for the offset system ORS18 and the television systems TLS00 and TLS18. The system called TLS00 is identical to the standard display system $sRGB$. The system TLS18 has the lightness $L^*_N = 18$ for black N . This lightness corresponds to the CIE tristimulus value $Y = 2,5$.

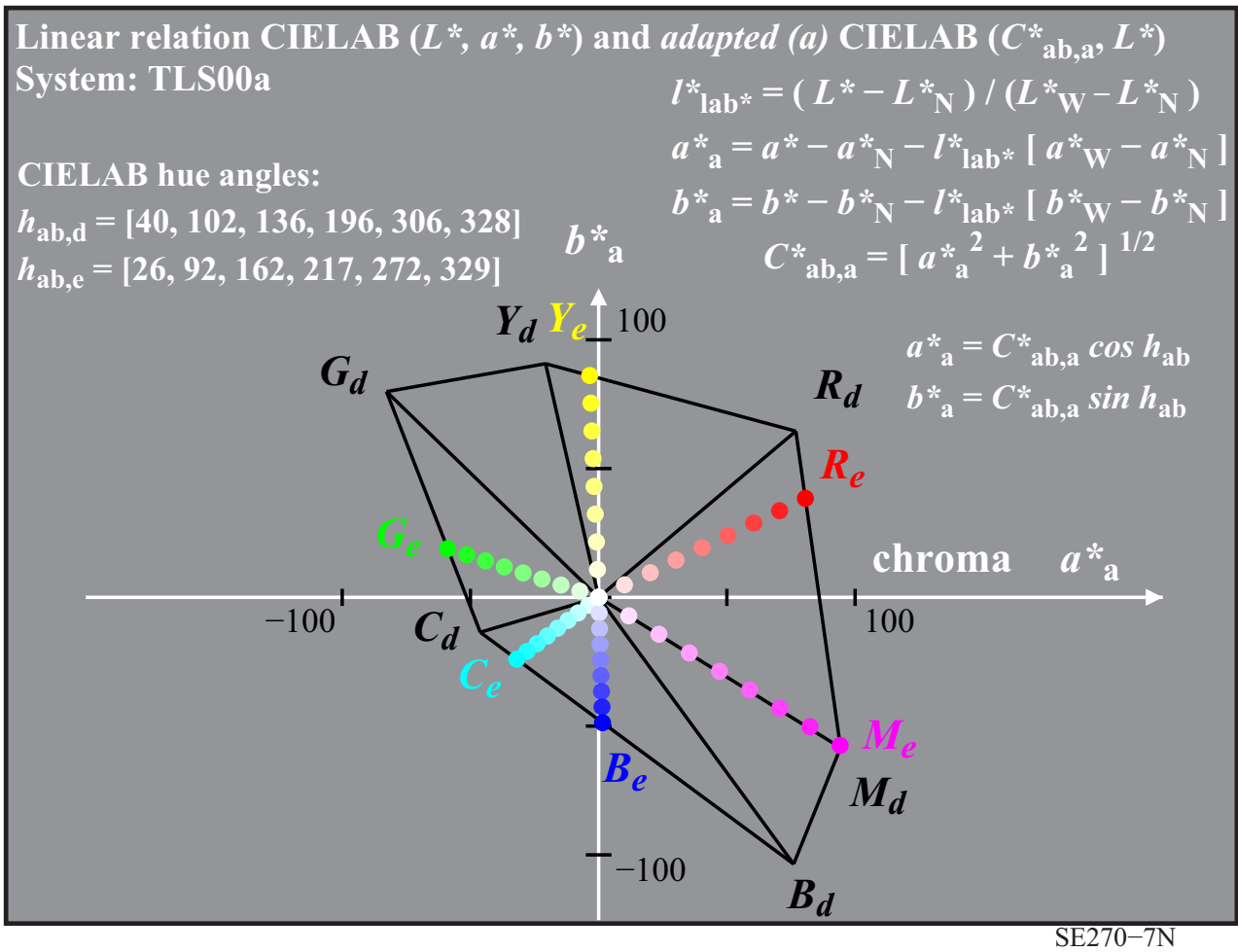


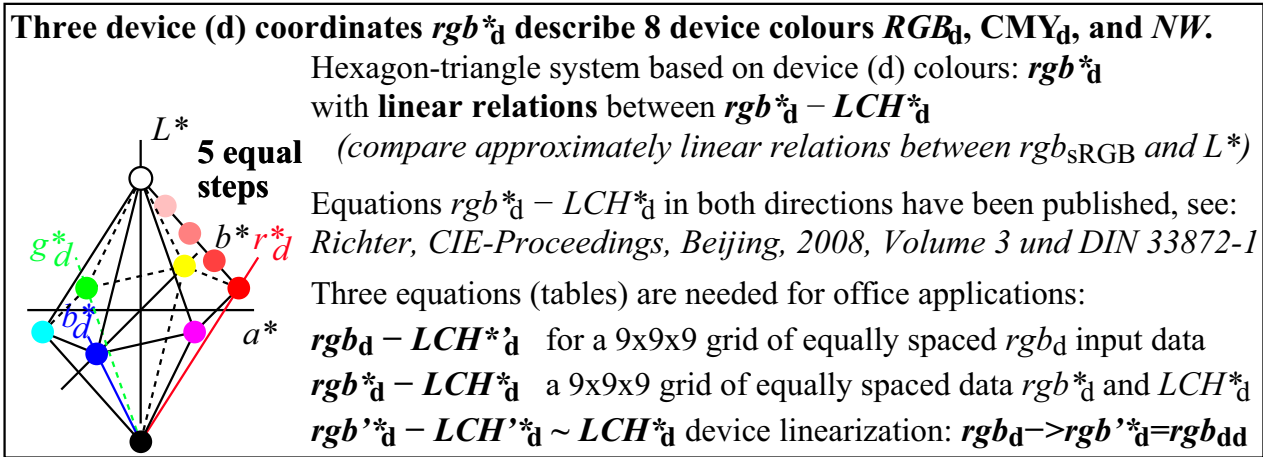
Fig. 9 - Device and elementary colours of the standard sRGB display according to IEC 61966-2-1

Fig. 9 shows the device colours $RYGCBM_d$ of the standard sRGB display according to IEC 61966-2-1. The elementary colours $RYGB_e$ have the four elementary hue angles $h_{ab,e} = 25, 92, 162,$ and 271 . In addition the colours C_e and M_e are shown for the hue angles $h_{ab,C_e} = 217 = 162 + (271 - 162) / 2$ and $h_{ab,M_e} = 329 = 271 + (397 - 271) / 2$.

Fig. 9 shows some equations to calculate the CIELAB coordinates with the index a (= adapted), similar as Fig. 8. The standard sRGB device produces the colours B_d and M_d with a high chroma. This is the case in a dark room without reflection on the display. In offices with a standard luminance reflection of $L_r = 2,5\%$ (CIE tristimulus value $Y = 2,5$ compared to the white reference) the chroma $C^*_{ab,a}$ decreases by about 10% and is still much larger compared to the chroma $C^*_{ab,a}$ of standard offset ORS18a, compare Fig. 8 on page 14.

The different chroma of standard offset ORS18a and the standard display sRGB indicate that a colorimetric reproduction with the same $L^* C^*_{ab} h_{ab}$ values on the display and in print is not possible. A comparison of Fig. 8 on page 14 and Fig. 9 shows similar chroma $C_{ab,a}$ for the elementary blue B_e . However, the lightness L^* on the screen is larger. Both values $(L^* C^*_{ab,a})_e$ are needed for the comparison and the reproduction.

6.6 Colour double cone and basics of output linearization

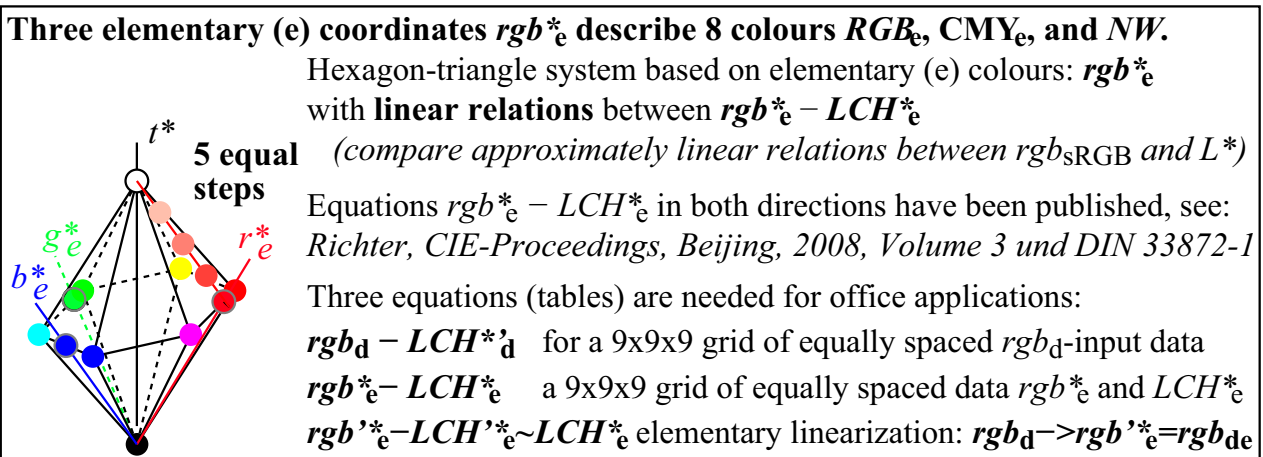


SE201-5N

Fig. 10 - Six chromatic device colours RGB_d and CMY_d , and black N , and white W

Fig. 10 shows the device coordinates rgb^*_d which can describe six chromatic device colours RYG_d and CMY_d , and the achromatic colours black N and white W . They are all located on the border of a three dimensional colour cone with a hexagon basis. Usually display systems use additive mixture of a most chromatic primary, for example red R_d , with different amounts of the opponent colour C_d to produce for example the five step scale between red R_d and white W .

It is the goal to define both equally spaced rgb^*_d coordinates, in this case $rgb_d = (1,00\ 0,00\ 0,00)_d$, $(1,00\ 0,25\ 0,25)_d$, $(1,00\ 0,50\ 0,50)_d$, $(1,00\ 0,75\ 0,75)_d$, and $(1,00\ 1,00\ 1,00)_d$, and equally spaced relative CIELAB coordinates $tcu^*_d = (0,50\ 1,00\ R00Y)_d$, $(0,625\ 0,75\ R00Y)_d$, $(0,75\ 0,50\ R00Y)_d$, $(0,875\ 0,25\ R00Y)_d$, and $(1,00\ 0,00\ R00Y)_d$. The coordinates tcu^*_d are called device triangle lightness t^*_d , device relative chroma c^*_d , and device hue text $u^*_d (=R00Y)_d$ according to DIN 33872-1. For the 5 step colour series between red R_e and white W there is by definition a linear relation between the coordinates rgb^*_d and LCH^*_d . Therefore for any rgb^*_d value the LCH^*_d values can be calculated in both directions, if the LCH^*_d data for the colours of maximum chroma are given. In applications instead of 6 steps 48 steps of a chromatic circle are used.



SE201-7N

Fig. 11 - Six chromatic elementary colours RGB_e and CMY_e , and black N , and white W

Fig. 11 shows the elementary coordinates rgb^*_e which can describe six chromatic elementary colours RGB_e and CMY_e , and the achromatic colours black N and white W . The equations are similar compared to Fig. 10. The coordinates star-dash (*) and dash-star (**) are defined in ISO/IEC 15775 and will be applied in clause 7.4 on page 28. The real data LCH^*_e have for the sRGB display colours an average colour difference $\Delta E^*_{ab} = 0,6$ compared to the intended data LCH^*_e .

Table 3 - Coordinates rgb^*_e and CIELAB $(L^*a^*b^*C^*_{ab}h_{ab})_e$ of a 16 step hue circle and mixture colours

rgb^{}_e and CIE data of a elementary (e) hue circle according to CIE R1-47:2009 for sRGB display L_r =0%*

16 step elementary hue circle with hues: $h_{ab,a,e} = 25.4, 92.3, 162.2, 271.7$

Code	$L^*_{a,e}$	$a^*_{a,e}$	$b^*_{a,e}$	$C^*_{ab,a,e}$	$h_{ab,e}$	rgb^*_e
$R00Y_e = R_e$	50.9	78.1	37.1	86.4	25.4	1.00 0.00 0.00
$R25Y_e$	52.2	71.9	65.2	97.1	42.1	1.00 0.25 0.00
$R50Y_e$	63.1	42.7	70.7	82.6	58.8	1.00 0.50 0.00
$R75Y_e$	72.7	19.7	76.7	79.2	75.5	1.00 0.75 0.00
$Y00G_e = Y_e$	83.6	-3.4	84.2	84.3	92.3	1.00 1.00 0.00
$Y25G_e$	90.8	-31.8	88.5	94.0	109.7	0.75 1.00 0.00
$Y50G_e$	85.9	-63.0	82.7	104.0	127.2	0.50 1.00 0.00
$Y75G_e$	84.1	-76.6	54.1	93.8	144.7	0.25 1.00 0.00
$G00B_e = G_e$	85.1	-64.2	20.5	67.4	162.2	0.00 1.00 0.00
$G25B_e$	87.1	-49.5	-8.4	50.2	189.6	0.00 1.00 0.50
$G50B_e$	79.1	-33.9	-25.6	42.5	217.0	0.00 1.00 1.00
$G75B_e$	70.1	-18.8	-39.1	43.4	244.2	0.00 0.50 1.00
$B00R_e = B_e$	59.3	1.7	-56.0	56.1	271.7	0.00 0.00 1.00
$B25R_e$	38.3	52.5	-90.3	104.4	300.1	0.50 0.00 1.00
$B50R_e$	57.3	94.2	-57.4	110.4	328.6	1.00 0.00 1.00
$B75R_e$	52.5	82.3	-4.2	82.4	357.0	1.00 0.00 0.50

5 step equidistant grey scale: $L^*_e = 0.0, 23.8, 47.7, 71.5, 95.4$

Code	$L^*_{a,e}$	$a^*_{a,e}$	$b^*_{a,e}$	$C^*_{ab,a,e}$	$h_{ab,e}$	rgb^*_e
$N000W_e = N_e$	0.0	0.0	0.0	0.0	0.0	0.00 0.00 0.00
$N025W_e$	23.8	0.0	0.0	0.0	325.3	0.25 0.25 0.25
$N050W_e$	47.7	0.0	0.0	0.0	325.1	0.50 0.50 0.50
$N075W_e$	71.4	0.0	0.0	0.0	325.1	0.75 0.75 0.75
$N100W_e = W_e$	95.4	0.0	0.0	0.0	0.0	1.00 1.00 1.00

SE300-3N, LAB*1a0, adapted=not adapted

rgb^{}_e and CIE data of a elementary (e) hue circle according to CIE R1-47:2009 for sRGB display L_r =0%*

3 colours of the elementary hues $RYGB_e$: $h_{ab,a,e} = 25.4, 92.3, 162.2, 271.7$

Code	$L^*_{a,e}$	$a^*_{a,e}$	$b^*_{a,e}$	$C^*_{ab,a,e}$	$h_{ab,e}$	rgb^*_e
$R00Y_e = R_e$	50.9	78.1	37.1	86.4	25.4	1.00 0.00 0.00
$0,5R_e + 0,5N_e$	25.4	39.0	18.5	43.2	25.4	0.50 0.00 0.00
$0,5R_e + 0,5W_e$	73.1	39.0	18.5	43.2	25.4	1.00 0.50 0.50
$Y00G_e = Y_e$	83.6	-3.4	84.2	84.3	92.3	1.00 1.00 0.00
$0,5Y_e + 0,5N_e$	41.8	-1.7	42.1	42.1	92.3	0.50 0.50 0.00
$0,5Y_e + 0,5W_e$	89.5	-1.7	42.1	42.1	92.3	1.00 1.00 0.50
$G00B_e = G_e$	85.1	-64.2	20.5	67.4	162.2	0.00 1.00 0.00
$0,5G_e + 0,5N_e$	42.5	-32.1	10.2	33.7	162.2	0.00 0.50 0.00
$0,5G_e + 0,5W_e$	90.2	-32.1	10.2	33.7	162.2	0.50 1.00 0.50
$B00R_e = B_e$	59.3	1.7	-56.0	56.1	271.7	0.00 0.00 1.00
$0,5B_e + 0,5N_e$	29.6	0.8	-28.0	28.0	271.7	0.00 0.00 0.50
$0,5B_e + 0,5W_e$	77.4	0.8	-28.0	28.0	271.7	0.50 0.50 1.00

5 step equidistant grey scale: $L^*_e = 0.0, 23.8, 47.7, 71.5, 95.4$

Code	$L^*_{a,e}$	$a^*_{a,e}$	$b^*_{a,e}$	$C^*_{ab,a,e}$	$h_{ab,e}$	rgb^*_e
$N000W_e = N_e$	0.0	0.0	0.0	0.0	0.0	0.00 0.00 0.00
$N025W_e$	23.8	0.0	0.0	0.0	325.3	0.25 0.25 0.25
$N050W_e$	47.7	0.0	0.0	0.0	325.1	0.50 0.50 0.50
$N075W_e$	71.4	0.0	0.0	0.0	325.1	0.75 0.75 0.75
$N100W_e = W_e$	95.4	0.0	0.0	0.0	0.0	1.00 1.00 1.00

SE300-4N, LAB*1a0, adapted=not adapted

Table 3 shows the coordinates rgb^*_e and the corresponding CIELAB data $(L^*a^*b^*C^*_{ab}h_{ab})_e$ for the standard sRGB colour space. On the left side the data are given for a 16 step elementary hue circle and on the right side for mixture colours between the most chromatic colours and both black N and white W . On both sides a 5 step grey scale is added. For the normalization of the data for white W the standard L^*_W data of the standard offset paper according to ISO/IEC 15775 are used ($Y=88,6, L^*=95,4$).

It is very essential to understand the goal of this report which uses the term output linearization. For output linearization a regular double cone forms the colour space with a circular instead of the hexagon basis, and with the coordinates tcu^* to be defined. The next two figures will include some example data and the definitions of this coordinates which can be calculated either from the data rgb^*_e or $(L^*C^*_{ab}h_{ab})_e$.

Table 3 shows the data $L^*_{a,e} = L^*_e$ for the 16 step hue circle. The largest value $L^*_e=90,8$ is reached for $Y25G_e$ and the lowest value $L^*_e=38,3$ for $B25R_e$. The coordinate triangle lightness t^*_e for only the most chromatic colour circle in Table 3 is defined as

$$t^*_e = 0,5 (L^*_e / L^*_{e,M}) \quad (=0,5 \text{ for } L^*_e = L^*_{e,M})$$

For the achromatic colour series the triangle lightness t^*_e is equal to the relative CIELAB lightness L^*

$$t^*_e = (L^* - L^*_N) / (L^*_W - L^*_N)$$

Relative chroma c^* is defined as relative CIELAB chroma C^*_{ab} compared to the chroma $C^*_{ab,M}$

$$c^*_e = C^*_{ab,e} / C^*_{ab,e,M} \quad (=1 \text{ for } C^*_{ab,e} = C^*_{ab,e,M})$$

Therefore the most chromatic colour circle of Table 3 (left) has the coordinates $t^*_e=0,5$ and $c^*_e=1$ for any hue.

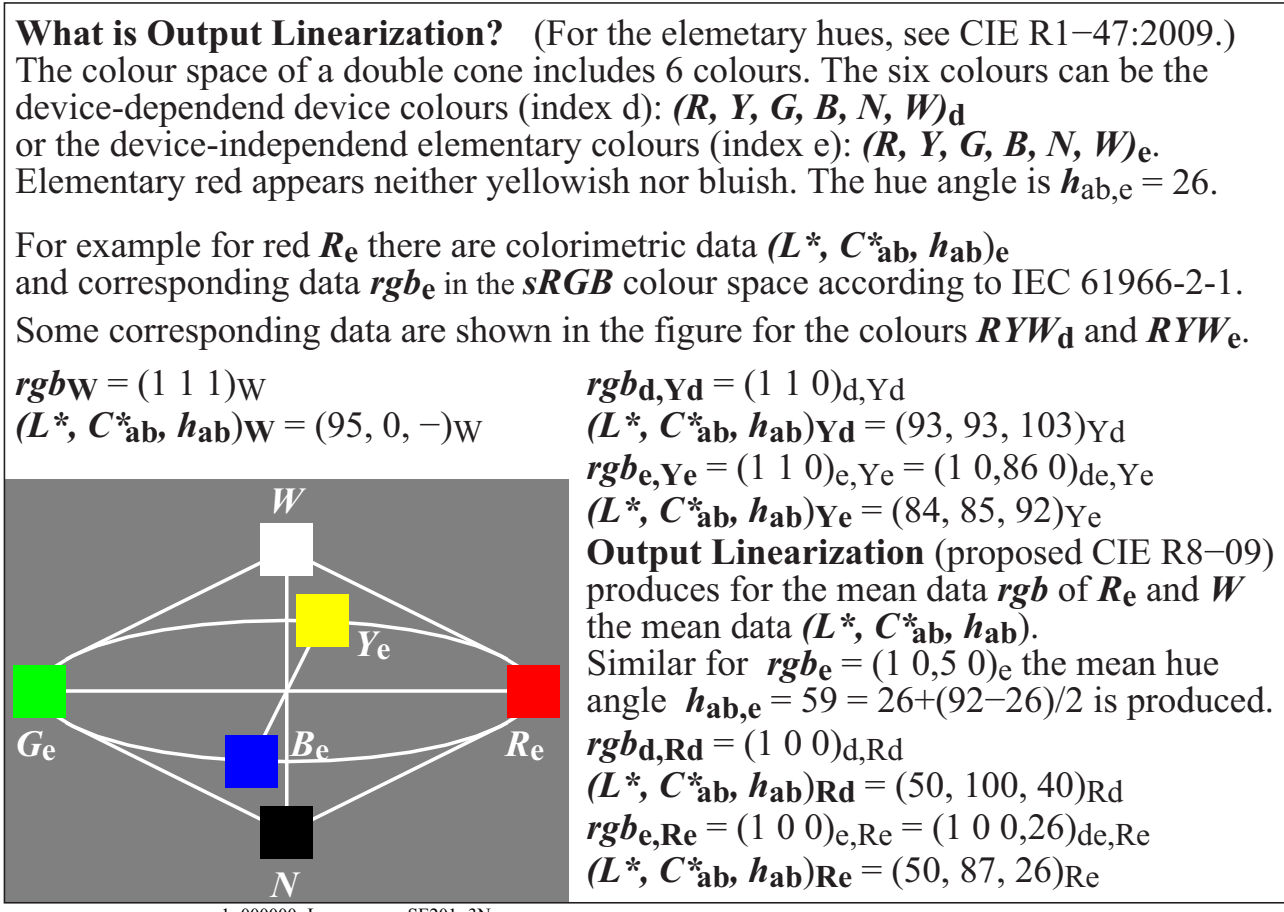


Fig. 12 - Answer of the Question: What is Output Linearization?

Fig. 12 tries to answer the question: What is output linearization? With Fig. 11 on page 16 it was possible to understand the transfer from the coordinates $L^*C^*_{ab}h_{ab}$ to the double cone coordinates tce^* with a circular basis. For a mean grey and the most chromatic colours the value of the triangle lightness is $t^*_e = 0,5$. For the circle the relative chroma is $c^*_e = 1$. Both the device colours and the elementary colours are located on this circle. However, they have different CIELAB hue angles, for example $h_{ab,Y_d} = 103$ and $h_{ab,Y_e} = 92$.

Fig. 12 shows that there is a linear calculation of the intended CIELAB hue angles. For example the coordinates $rgb_e = (1\ 0,5\ 0)_e$ which belong to the hue $(R50Y)_e$ are in the middle between the data for red and yellow. It is intended that the data $rgb_e = (1\ 0,5\ 0)_e$ produce the CIELAB hue angle in the middle between the hue angles of red R_e and yellow Y_e .

The next figure will give more example data how to transfer between the different coordinates. The user friendly coordinates are based on the request of ISO TC 159 *Ergonomics - Visual Display Requirements* (compare Fig. 3 on page 10).

At the same time a further step seem to be reached towards a human visual RGB^*_e colour space. This development of the CIE Division 1 was requested by ISO/IEC JTC1/SC28 (Fig. 6 on page 12).

6.7 Colour in daily life and definition of user friendly relative colour coordinates

Application of colour in daily life or in Colour Information Technology (IT)	
Design, architecture, art, industrial products Measured for CIE standard illuminant D65	Colour Information Technology Measured for CIE illuminants D65 and D50
colour order system; name and coordinates: <i>RAL Design System (CIELAB)</i> $L^*C^*_{ab}h_{ab}$, lightness, chroma, hue angle <i>Munsell Colour System</i> <i>VCH</i> , lightness (Value), Chroma, Hue text <i>Natural Colour System (NCS)</i> ncu^*_e : relative blackness, relative chroma relative elementary hue text	Device system name and coordinates: Printer system (illuminants D50 or D65): $cm y_d$, content of "cyan, magenta, yellow" Display system (standard illuminant D65): $rgb_d/sRGB_d$, content of "red, green, blue" <i>No user friendly colour coordinates</i> <i>Nearly no connection to colour order systems</i>
<p>Aim: define user friendly connection</p> <p>New: Interpretation of the rgb colour data in the range 0 to 1 as elementary colour data rgb^*_e</p> <p><i>Linear</i> relations between <i>relative</i> and <i>absolute</i> coordinates $lab^*_d - LAB^*_d$ and $lab^*_e - LAB^*_e$ $rgb^*_d - (L^*a^*b^*C^*_{ab}h_{ab})_d$ and $rgb^*_e - (L^*a^*b^*C^*_{ab}h_{ab})_e$ (CIELAB) $rgb_d - cm y_d, rgb^*_d - cm y^*_d$ and $rgb_e - cm y_e, rgb^*_e - cm y^*_e$ ("1-minus"-relation) $rgb^*_d - nce^*_d, rgb^*_d - ncu^*_d$ and $rgb^*_e - nce^*_e, rgb^*_e - ncu^*_e$ <i>relative</i> coordinates lab^*_e: elementary redness r^*_e, greenness g^*_e, blueness b^*_e, blackness n^*_e chroma c^*_d, elementary hue e^*_e, elementary hue text u^*_e</p>	

SE251-3

Fig. 13 - Application of colour in daily life or in colour information technology (IT)

Fig. 13 shows colour coordinates used in daily life in the field of colour order systems, for example the CIELAB coordinates $L^*C^*_{ab}h_{ab}$. There are coordinates used in information technology, for example rgb_d of the sRGB colour space. There seems to be nearly no user friendly colour coordinates in information technology, for example those requested by ISO TC159 Ergonomics - Visual display requirements. The coordinates rgb_e of Fig. 13 and the coordinates $cm y^*_e$ used in offset printing seem to fill this gap. Both are connected by the so called 1-Minus-Relation (1MR) which is based on the three equations

$$c^*_e = 1 - r^*_e \quad m^*_e = 1 - g^*_e \quad y^*_e = 1 - b^*_e$$

It is one main goal of this paper to define more user friendly coordinates for image technology and a user friendly connection to CIELAB and other colorimetric systems based on CIE colour measurement and colour appearance.

Usually the colour considered here are presented either on a white display surround or on a white paper. This presentation mode is called surface colour mode in CIE colorimetry. The standard illuminance on the white paper is 500 lux in offices. For the white standard offset paper with the standard reflection of 88,6% this produces the luminance $L = 142 \text{ cd/m}^2$. The same luminance is possible on many modern sRGB or other devices. There are many real device arrangements where it is hard to answer the question if the output of a test chart is produced by the reflection of light on paper or by the emission of light on a screen.

So we may have surface colour mode either by the reflection of light or by the emission of light. Both are in many cases physically (by measurement) and visually equivalent. In addition there are screen technologies which produce the colours by both the emitting of light in a dark environment, and the reflection of light in sunshine

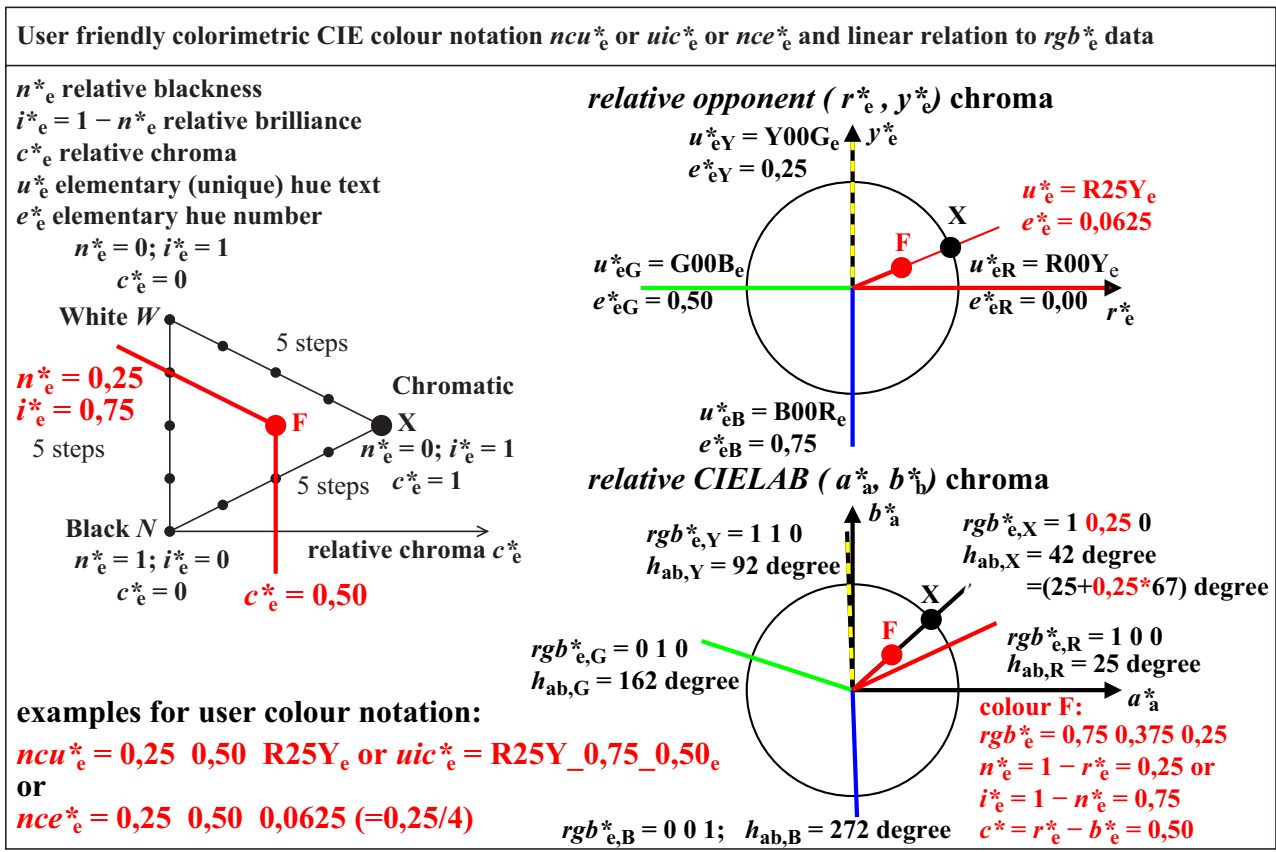


Fig. 14 - User friendly colorimetric CIE colour notations ncu_e^* , uic_e^* or nce_e^*

Fig. 14 shows user friendly colorimetric CIE colour notations ncu_e^* , uic_e^* , and nce_e^* . Some examples show the transfer between the many possible data sets rgb_e^* , ncu_e^* , uic_e^* , and nce_e^* . The CIELAB hue angles for the four elementary colours $RYGB_e$ are given. Instead of the CIELAB coordinates (a_a^* , b_b^*) and the CIELAB hue angle h_{ab} the relative opponent coordinates (r_e^* , y_e^*) and the relative elementary hue e_e^* in the range between 0 to 1 may be used.

On the front cover of the book *Colour and Colour Vision*, see also the next figure, the coordinates rgb_e^* and HIC_e^* are given above and below the samples

It is valid

$$I^* = 100 i^* \text{ and}$$

$$C^* = 100 c^*$$

Then in Fig. 14 the colour notation

$$uic_e^* = R25Y_0,75_0,50_e$$

changes to (*without any comma*)

$$HIC_e^* = R25Y_075_050_e$$

Annex C on page 57 shows these and additional coordinates and their relations.

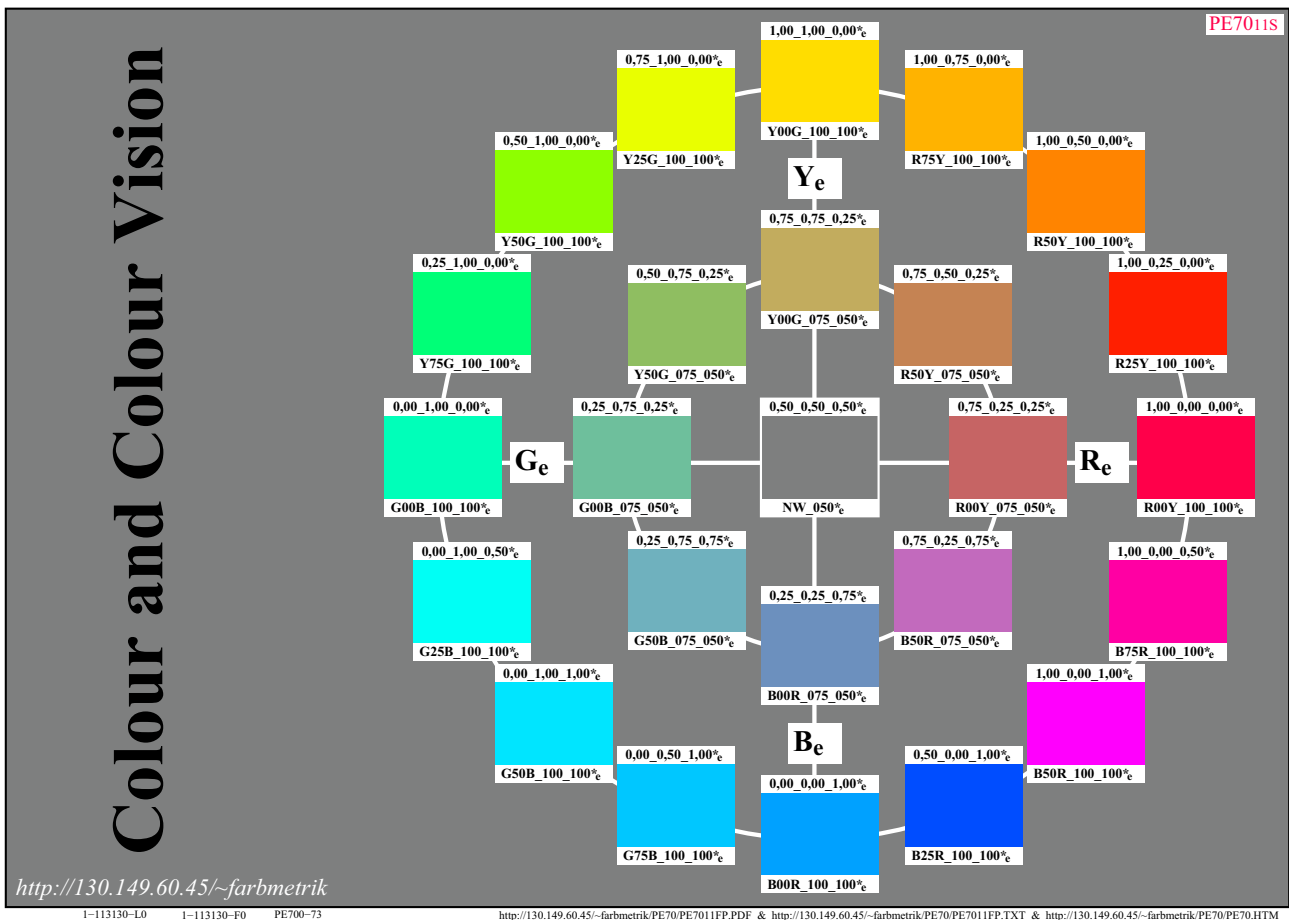


Fig. 15 - Elementary colour circle with 16 samples and colorimetric coordinates rgb^*_e and HIC^*_e

Fig. 15 shows the 16 step elementary colour circle together with the CIE colorimetric coordinates rgb^*_e on the top and HIC^*_e on the bottom. This colour circle is on the top cover of a book and available in offset print. The inner circle has half the CIELAB chroma C^*_{ab} of the outer circle. The grey is in CIELAB lightness L^* in the middle between the lightness L^*_N of black N and the lightness L^*_W of white W .

The four elementary colours shall have the CIELAB hue angles $h_{ab,e} = 26, 92, 162,$ and 271 . The visual test shall clearly show that for example $R25Y_e$ appears yellowish and $B75R_e$ appears bluish.

Output linearization has been used to produce this colour circle on displays, as printer output and offset output.

For the linearized elementary output of the 25 samples and for the standard $sRGB$ display the calculations show an average colour difference $\Delta E^*_{ab,e} = 0,4$ for the outer circle and of $\Delta E^*_{abe} = 0,7$ for the inner circle. The largest difference appears for the sample $Y50G_{050_050_e}$.

The calculated data are available as tables on the page 52 (page 19 of second series) of the file output <http://130.149.60.45/~farbmetrik/RE69/RE69L0FP.PDF>

Measurement of the linearized device and elementary output for the 25 samples, and for the offset output, show between the intended and measured colours the colour differences $\Delta E^*_{ab,dd}=2,0$ and $\Delta E^*_{ab,de}=2,4$, see page 19 (series 1 and 2) of the file output <http://130.149.60.45/~farbmetrik/RE83/RE83L0FA.PDF>

The file outputs show many additional data and figures, for example the device colours on page 8 and the data rgb_{de} and $(L^*a^*b^*C^*_{ab,a})_e$ for the 360 hue angles $h_{ab,e}$ between zero and 360 in steps of $\Delta h_{ab,e}=1$.

6.8 Device and Elementary colour circles

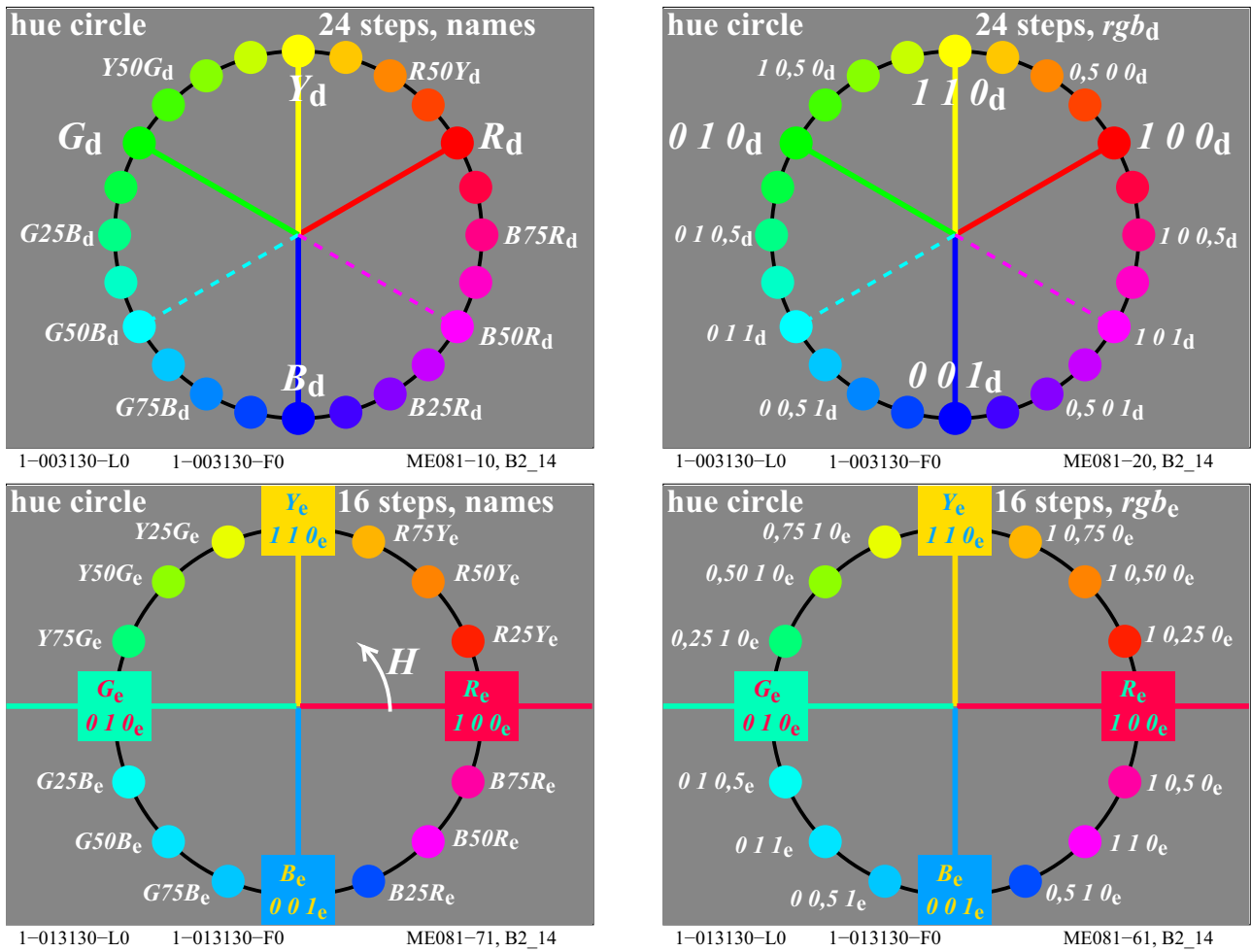


Fig. 16 - Device hue circle with 24 steps and elementary hue circle with 16 steps

Fig. 16 shows two device hue circles with 24 steps on the top. The hue text H_d^* is given on the left side, and the rgb_d data are given on the right side.

Fig. 16 shows two elementary hue circles with 16 steps on the bottom. The hue text H_e^* is given on the left side, and the rgb_e data are given on the right side.

A comparison of the device and elementary hue circle (top and bottom) shows an increase of the hue angle range from 60 to 90 for the sectors R_e to Y_e and Y_e to G_e . This is the lighter side of the colour circle.

At the same time there is a decrease of the hue angle range from 120 to 90 for the ranges between G_d via C_d to B_d , and B_d via M_d to R_d . This is the darker side of the colour circle.

This change is used in the *Natural Colour System NCS* and is appropriate for applications by at least two reasons

- The CIELAB chroma of surface colours is for the darker side between G_e via B_e to R_e roughly half compared to the lighter side. Therefore the ratio colour difference/hue angle difference $\Delta E_{ab}^*/\Delta h_{ab}$ is roughly half for the darker side. Therefore it is appropriate to reduce the hue angle range from 120 to 90 for the darker side and to increase the hue angle range from 60 to 90 for the lighter side.

- in many applications, for example house and wall paintings, clothes and advertising, the lighter colour side is much more important compared to the darker colour side. Therefore the elementary (e) hue scaling by rgb_e^* is more appropriate compared to the present device (d) colour scaling by rgb_d^* .

7 Equivalent relative coordinates *rgb* and *cmymk* for digital and analog colours

7.1 Test chart output with 1080 colours on a displays with different software

By CIE colorimetry and according to the *PostScript Reference Manual* there are many equivalent relative coordinates *rgb* and *cmymk* to describe colours in digital files and the (analog or visual) surface or display colours

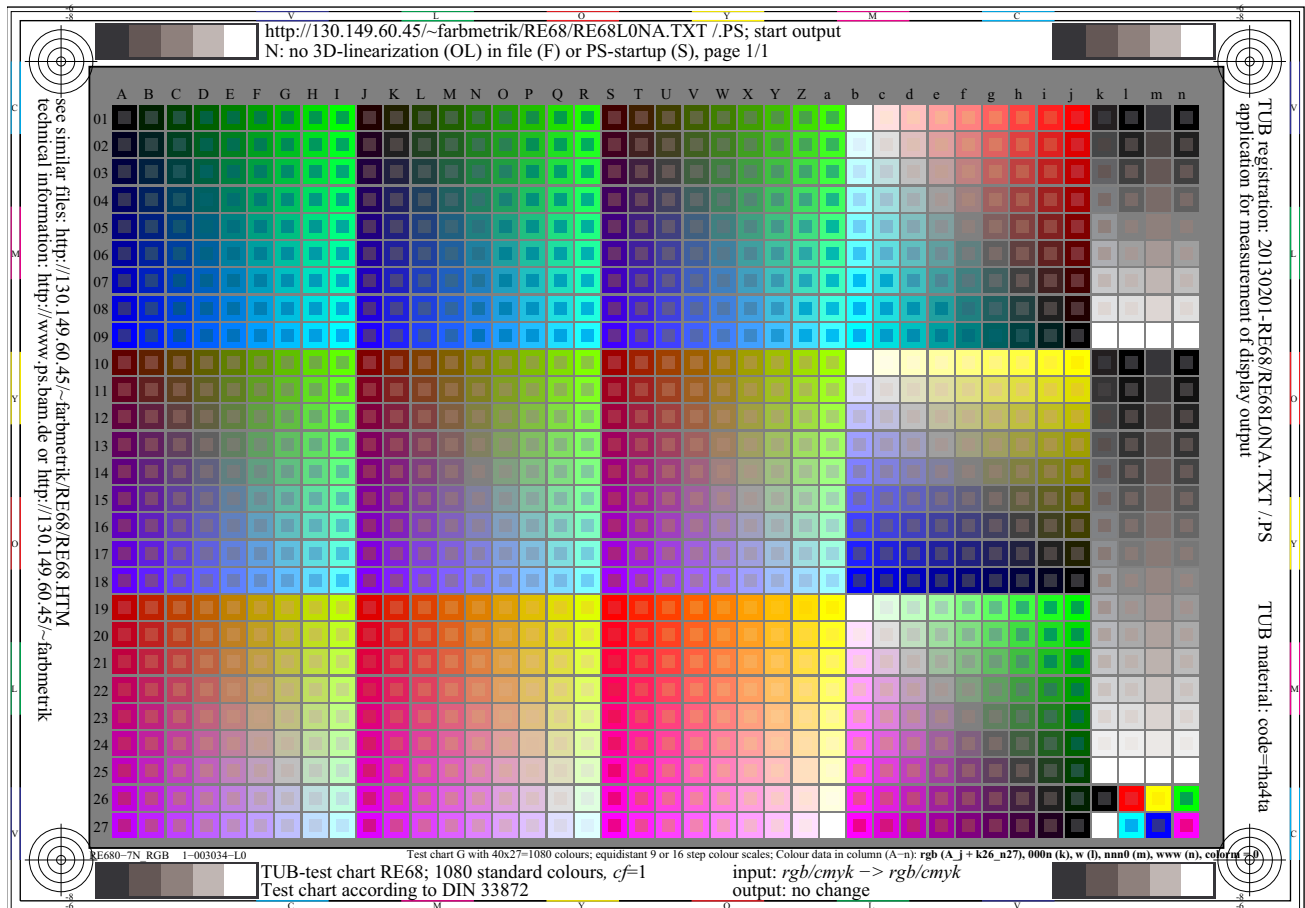


Fig. 17 - Standard colour test chart with 1080 colours defined by *rgb* and equivalent data

Fig. 17 shows a standard colour test chart with 1080 colours. The left 729 (=9x9x9) colours (columns A to a and rows 01 to 27) show a standard grid (Grid G) which is often used for output colour measurement.

The following 243 (=3x9x9) colours (columns b to j, and rows 01 to 27) show opponent colour planes $R_d - C_d$, $Y_d - B_d$, and $G_d - M_d$ with three times the achromatic series in the diagonal.

At least there are 9 step grey scales (columns k to n, rows 01 to 09) and 16 step grey scales (columns k to n, rows 10 to 25) and the six most chromatic device colours and black and white (columns k to n, rows 26 and 27).

There are two equivalent definitions for chromatic colours by two *PostScript* operators:

```
rgb setrgbcolor
cmymk setcmykcolor
```

The output looks usually different and the difference is device-dependent.

The values of *rgb* and *cmymk* are in the range 0 to 1, otherwise a negative value is set to zero, and for values larger 1 the value is set to one. There is the so called 1-Minus-Relation (1MR) between *rgb* and *cymk* which is given by

$$c = 1 - r \quad m = 1 - g \quad y = 1 - b \quad k = n = 1 - w = 0.$$

If the lowest value $w = \min(r, g, b)$ which is called the white value w of the three is larger than zero then the

following relation is equivalent:

$$c = 1 - r - w \quad m = 1 - g - w \quad y = 1 - b - w \quad k = n = 1 - w.$$

There are four equivalent definitions for grey (achromatic) colours with $r=g=b=w$ by the PS operators

- $w w w$ *setrgbcolor*
- $n n n 0$ *setcmykcolor*
- $0 0 0 n$ *setcmykcolor*
- w *setgray*

These definitions are used in the four rows k to n. The output looks usually different and is device-dependent.

7.2 Screen shot of the display output with the software Adobe FrameMaker

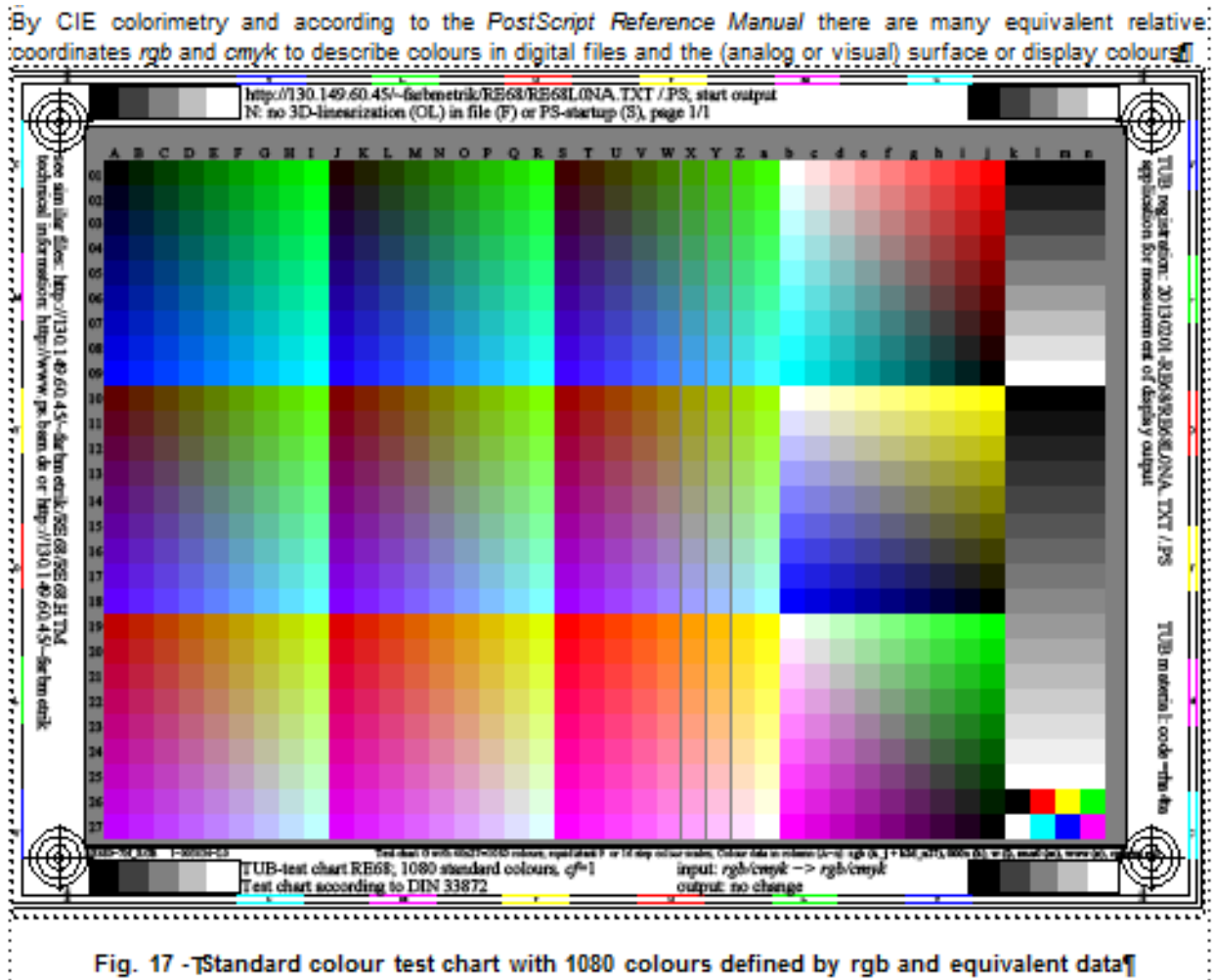


Fig. 17 - [Standard colour test chart with 1080 colours defined by rgb and equivalent data]

Fig. 18 - Screen shot of the 1080 colour output by the software Adobe Frame Maker, compare last page

Fig. 18 shows a screen shot of the output of the 1080 standard colours defined by the four PS operators:

- $r g b$ *setrgbcolor*
- $c m y 0$ *setcmykcolor* (always in addition as the inner square with half of the diameter for any colour)
- $0 0 0 n$ *setcmykcolor*
- w *setgray*

with corresponding values defined by the 1-Minus-Relation. The output is equal with Adobe Frame Maker.

Therefore the display output of Fig. 18 (a screen shot produces a *tiff*-file) is equal. The printer output of Fig. 18 (based on the PDF-file created by the software Adobe Frame Maker Version 8) shows up to four different colour outputs for the four equivalent PS operators, similar as the present software Adobe Reader

The software *Adobe Frame Maker* produces for the four PS operators
 - **equal output** on the screen as intended for the four equivalent PS operators by CIE colorimetry,
 - and a PDF file for later print if requested.

The software *Adobe Reader* produces with the same PDF-file (which includes the four PS-operators)
 - **different device-dependent output on the screen and in print** for the four equivalent PS operators.

It is obvious that a device-independent CIE standard is needed. At present many of the devices produce for values around $cmY_d = (0,45\ 0,32\ 0,32)$ a mean grey and **not** for $cmY_e = cmY_d = (0,5\ 0,5\ 0,5)$. There is a historic basis for the strange cmY_d values. A special offset process has produces for the values $cmY_d = (0,45\ 0,32\ 0,32)$ a mean grey. However, by many reasons grey shall now be produced by the black colorant N (K) only, if the device has a black colorant (and for example the three additional colours CMY).

Note: The software *Preview* of the *Mac* operating system OSX up to Version 10.2 includes the 1-Minus-Relation and has produced equal colour output for equivalent colour definitions. Since Version 10.3 the output is different.

Note: In addition the software *Preview* of the *Mac* operating system OSX changes any PS file to a PDF file by a double click on the PS file. Therefore output linearization is possible with the software *Preview* of the *Mac* operating system OSX without additional software, for example the software *Adobe Distiller* on a *Mac* or on a Windows operating system.

Table 4 - Equivalent PS operators for grey colours by CIE colorimetry and PostScript

5 steps of grey series black – white ($N_d - W_d$)	Colour space, colour space coordinates and PostScript operator calculations according to ISO/IEC 15775:1999-12											
Linear mixture between black and white in CIELAB colour space	<i>relative</i> CIELAB											
	$lab^*w^*_d$ <i>setgray</i>	$lab^*000n^*_d=000n^*_d$ <i>000n^*_d setcmykcolor</i>				$lab^*cmy0^*_d=cmy0^*_d$ <i>cmy0^*_d setcmykcolor</i>				$lab^*rgb^*_d=rgb^*_d$ <i>rgb^*_d setrgbcolor</i>		
1,00 N_d +0,00 W_d (Black N_d)	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00
0,75 N_d +0,25 W_d	0,25	0,00	0,00	0,00	0,75	0,75	0,75	0,75	0,00	0,25	0,25	0,25
0,50 N_d +0,50 W_d	0,50	0,00	0,00	0,00	0,50	0,50	0,50	0,50	0,00	0,50	0,50	0,50
0,25 N_d +0,75 W_d	0,75	0,00	0,00	0,00	0,25	0,25	0,25	0,25	0,00	0,75	0,75	0,75
0,00 N_d +1,00 W_d (white W_d)	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00

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5 steps of grey series black – white ($N_d - W_d$)	Colour space, colour space coordinates and PostScript operator calculations according to ISO/IEC 15775:1999-12								
Linear mixture between black and white in CIELAB colour space	<i>Standard</i> CIELAB $LAB^*LAB^*_d = LAB^*_d$ <i>LAB^*_d setcolor</i>			<i>adapted</i> CIELAB $LAB^*LAB^*_{a,d} = LAB^*_{a,d}$ <i>LAB^*_{a,d} setcolor</i>			<i>relative</i> CIELAB $lab^*ncu^*_d = ncu^*_d$ <i>ncu^*_d setcolor</i>		
	1,00 N_d +0,00 W_d (Black N_d)	18,01	0,50	-0,40	18,01	0,00	0,00	1,00	0,00
0,75 N_d +0,25 W_d	37,35	0,10	0,80	37,35	0,00	0,00	0,75	0,00	R00Y _d
0,50 N_d +0,50 W_d	56,70	-0,10	2,10	56,70	0,00	0,00	0,50	0,00	R00Y _d
0,25 N_d +0,75 W_d	76,05	-0,50	-3,40	76,05	0,00	0,00	0,25	0,00	R00Y _d
0,00 N_d +1,00 W_d (white W_d)	95,41	-0,98	4,76	95,41	0,00	0,00	0,00	0,00	R00Y _d

SE250-3

Table 5 - Equivalent PS operators for cyan blue colours C by CIE colorimetry and PostScript

5 steps of colour series cyan blue – white ($C_d - W_d$)	Colour space, colour space coordinates and PostScript operator calculations according to ISO/IEC 15775:1999-12		
Linear mixture between cyan blue and white in CIELAB colour space	<i>Standard CIELAB</i> $LAB^*LAB^*_d = LAB^*_d$ LAB^*_d <i>setcolor</i>	<i>relative CIELAB</i> $lab^*cmy0^*_d = cmy0^*_d$ $cmy0^*_d$ <i>setcmykcolor</i>	<i>relative CIELAB</i> $lab^*rgb^*_d = rgb^*_d$ rgb^*_d <i>setrgbcolor</i>
1,00 C_d +0,00 W_d (cyan blue C_d)	58,62 -30,62 -42,74	1,00 0,00 0,00 0,00	0,00 1,00 1,00
0,75 C_d +0,25 W_d	67,82 -23,21 -30,86	0,75 0,00 0,00 0,00	0,25 1,00 1,00
0,50 C_d +0,50 W_d	77,02 -15,80 -18,98	0,50 0,00 0,00 0,00	0,50 1,00 1,00
0,25 C_d +0,75 W_d	86,21 -8,39 -7,11	0,25 0,00 0,00 0,00	0,75 1,00 1,00
0,00 C_d +1,00 W_d (white W_d)	95,41 -0,98 4,76	0,00 0,00 0,00 0,00	1,00 1,00 1,00

SE250-5

Table 4 and Table 5 show equivalent PS operators for grey colour series between black N and white W , and for a 5 step colour series between cyan blue C_d and white W . The output with the four standard PS operators shall be the same by CIE colorimetry and the *PostScript* programming language, see *PostScript Reference Manual*.

7.3 PostScript code which includes the 1-Minus-Relation

Table 6 - PostScript programming code which includes the 1-Minus-Relation

<p>Frame File PostScript Code for 1-Minus-Relation (1MR) to <i>setrgbcolor</i> and line 05 to 07 for change of <i>setgray</i> to <i>setrgbcolor</i> and line 09 to 13 for change of <i>setcmykcolor</i> to <i>setrgbcolor</i></p> <pre> 01 %!PS-Adobe-3.0 EPSF-3.0, 1MR for change to setrgbcolor 02 /1MR-0000 {%BEG procedure 1MR-0000 03 %1MR-Transform of setgray and setcmykcolor to FFM_setrgbcolor 04 05 /setgray {%BEG procedure setgray to setrgbcolor 06 dup dup FFM_setrgbcolor 07 } def %END procedure setgray to setrgbcolor 08 09 /setcmykcolor {%BEG procedure setcmykcolor to setrgbcolor 10 /FFM_k exch def /FFM_y exch def /FFM_m exch def /FFM_c exch def 11 FFM_k 0 eq {1 FFM_c sub 1 FFM_m sub 1 FFM_y sub FFM_setrgbcolor} 12 {1 FFM_k sub dup dup FFM_setrgbcolor} ifelse 13 } def %END procedure setcmykcolor to setrgbcolor 14 15 } def %END procedure 1MR-0000 16 %%Trailer %END 1-Minus-Relation (1MR) to setrgbcolor </pre> <p>Remarks: The FF_PS code includes: /FFM_setrgbcolor {setrgbcolor} bind def Then <i>setgray</i> and <i>setcmykcolor</i> is changed to standard <i>setrgbcolor</i></p>

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Table 6 includes some *PostScript* program code which transfers the three PS operators and their values

- *w setgray*

- *c m y 0 setcmykcolor*

- *0 0 0 k setcmykcolor*

towards the usually used PS operator *r g b setrgbcolor* with the values *r g b* according to the 1-Minus-Relation.

A user with some technical knowledge and for example the software *Adobe Distiller* can apply the 1-Minus-Relation. A user can download the file text 1MR:
<http://130.149.60.45/~farbmetrik/SE34/SE341-3N.TXT>.

The user can copy the PS program text to the "Startup" directory or the "In" directory of the software *Adobe Distiller*. After a new start of the software *Adobe Distiller* the "Startup code 1MR" will change the three PS operators and their values in the intended direction and the output looks equal for equivalent colour definitions.

This method is used within many black and white PS printers which change the three PS operators to the *rgb* PS operator and produce an equal output for the equivalent colour definitions similar as *Adobe Frame Maker*.

However, many colour PS printers produce different colours in the output similar as *Adobe Reader* and often different depending on the version.

Alternative methods are the copy of the file text 1MR at the beginning of a PS file. Then for example the software Mac Preview uses the file text 1MR by a double click of the file to produce a PDF file with the intended change.

The most important application here is the copy of PS code together with the 1080 measurement data of a device at the beginning of a file. The use of the measurement data in the appropriate PS code changes all colour data in the intended direction.

For example this procedure produces a device linearization for the device or the elementary colour output.

7.4 PostScript Frame File code with output linearization method (FF_LM)

Table 7 - Frame File Postscript code (FF_PS) with three loops

Frame File PostScript Code (FF_PS) with three loops (important parts)
*and line 05 (%line 139) to include different transfer PS codes
 and line 20 (%line 239) to include the PS code of an ISO or DIN test file*

```

01 %!PS-Adobe-3.0 EPSF-3.0 SE34LMFF.PS 20110801
02 %%BoundingBox: 0 0 842 595
03
04 %line169 %BEG INCLUDE TRANSFER PS CODES
05
06 %END INCLUDE TRANSFERS PS CODES
07 %%EndProlog
08 gsave
09
10 colorm10f 1 colorm20f {/colormf exch def %colorm10f,colorm20f
11 gsave
12
13 xcolor10f 1 xcolor20f {/xcolorf exch def %xcolor10f,xcolor20f
14 gsave
15
16 xchart10f 1 xchart20f {/xchartf exch def %xchart10f,xchart20f
17 gsave
18
19 %line 239 %BEG INCLUDE TEST FILE PS CODE
20
21 %END INCLUDE TEST FILE PS CODE
22
23 68 MM 1.5 MM moveto
24 (http://130.149.60.45/~farbmetrik/SE34/SE34LMFF.PDF) showde
25
26 showpage
27 grestore
28
29 } for %end for xchartf=xchart10f,xchart20f
30 grestore
31 } for %end for xcolorf=xcolor10f,xcolor20f
32 grestore
34 } for %end for colormf=colorm10f,colorm20f
35 %%Trailer

```

Remarks:

The outer loop 10 to 34 is without and with a Linearization Method
colormf=0 or 1 without and with Frame File Linearization Method (FF_LM)

The middle loop 13 to 31 is for the amount of Room Reflections
xcolorf=0 to 7 for 8 display luminance reflections

The inner loop 16 to 29 is for the amount of ISO test pages
xchartf=0 to 11 for 1 to 12 ISO and DIN test file pages

Inclusion of TRANSFER PS CODE, for example 1MR, DEH, at line 05
 Inclusion of TEST FILE PS CODE, for example ME16 of ISO 9241-306

SE340-7N

Table 7 shows an example PS code with three loops. A similar code is used to produce for example the output of many pages, see the file PS text (9 300 lines!) <http://130.149.60.45/~farbmetrik/RE69/RE69LOFP.TXT>

If one changes the extension from ".TXT" to ".PS" then for example the software *Mac Preview* produces a PDF file with 64 pages within a minute. This file includes according to line 5 of Fig. 23 the 1-Minus-Relation and calculates 1080 measurement data from the *rgb* data according to IEC 61966-2-1. This produces a table with a cloud of 729 rgb_d and corresponding $(L^*a^*b^*C^*_{ab})_d$ data. The CIELAB data fill a double cone with the $L^*C^*_{ab}$ data of a 48 step colour circle as basis.

On the pages 20 to 32 (first series) for the 1080 colours of the standard display the above file shows the tables $rgb^*_d - LCH^*_d$ (intended relation) and the tables $rgb^*_d - LCH^*_d$ (relation with dash-star coordinates for output linearization). The following two coordinates are identical: $rgb^*_d = rgb_{dd}$ (device to device output). The colour difference $\Delta E^*_{ab,d}$ between intended and real output is the difference between LCH^*_d and LCH'^*_d .

On the pages 42 to 64 (second series) for the 1080 colours of the standard display the above file shows the tables $rgb^*_e - LCH^*_e$ (intended relation) and the tables $rgb^*_e - LCH^*_e$ (relation with dash-star coordinates for output linearization). The following two coordinates are identical: $rgb^*_e = rgb_{de}$ (device to elementary output). The colour difference $\Delta E^*_{ab,e}$ between intended and real output is the difference between LCH^*_e and LCH'^*_e .

Both tables are listed in Fig. 10 on page 16 (device output) and Fig. 11 on page 16 (elementary output).

7.5 Hue and colour output and accuracy for the sRGB display colours

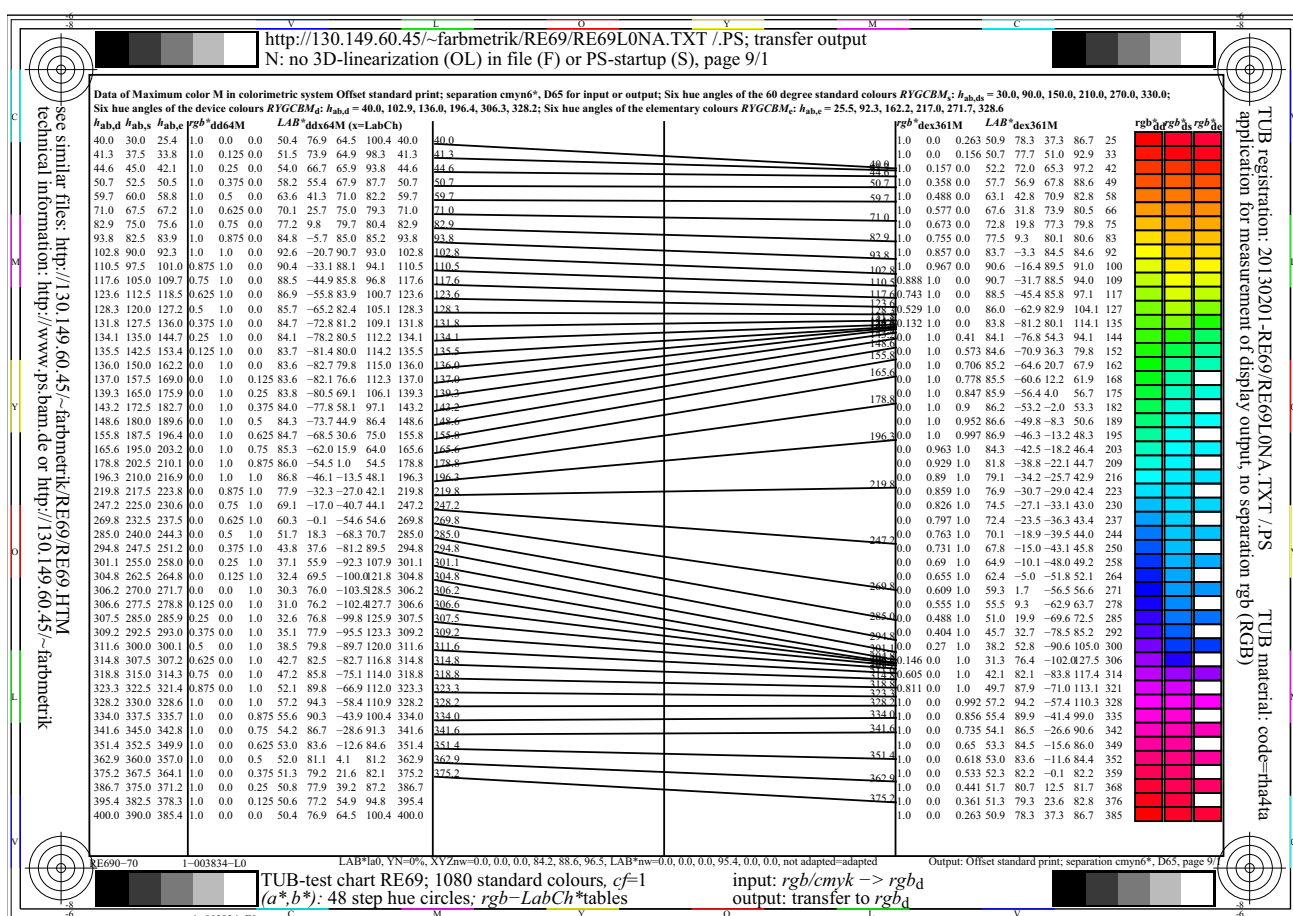


Fig. 19 - *rgb* and CIELAB data of a 48 step hue circle for the device and elementary sRGB colours

Fig. 19 shows *rgb* and CIELAB data of a 48 step hue circle for the device and elementary colours. For the *sRGB* display colours near the hue angle $h_{ab,e}=306$ a large range of rgb_d data with a hue angle range of 30 degree ($h_{ab,d}=300$ to $h_{ab,d}=330$) produce only a small change of the visual rgb_e data with a hue angle range of only 10 degree ($h_{ab,e}=300$ to $h_{ab,e}=310$).

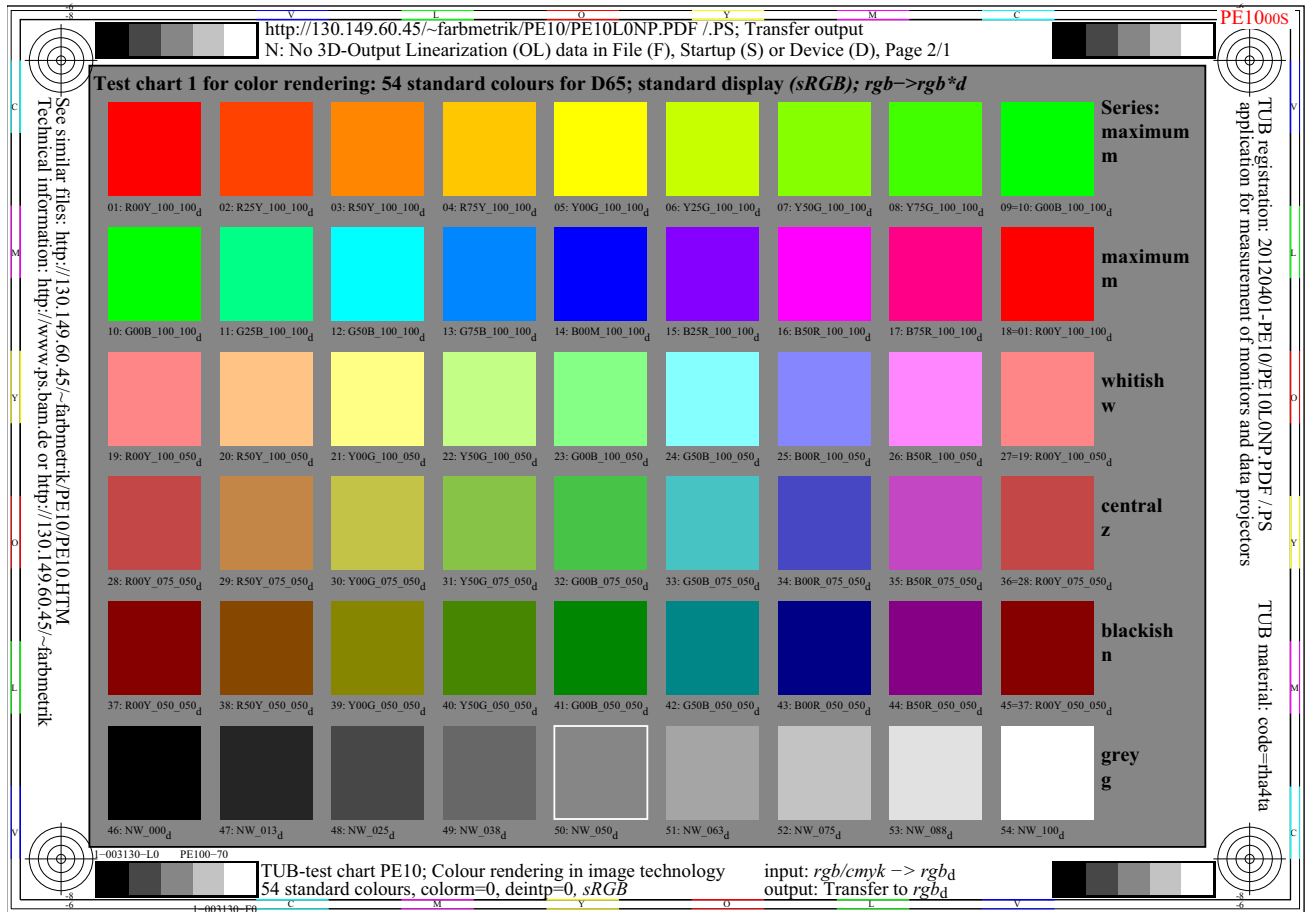


Fig. 20 - HIC^*_d data of a test chart 1 for colour rendering with a 16 step device hue circle

Fig. 20 shows the HIC^*_d data of a test chart 1 for colour rendering with a 16 step device hue circle. In addition there are three 8 step colour circles: whitish, greyish, and blackish. Finally there is a 9 step grey scale.

The first and last colour of the 16 and 8 step colour circles are the same. This reduces difficulties for visual evaluations of the colour differences between the first and last step.

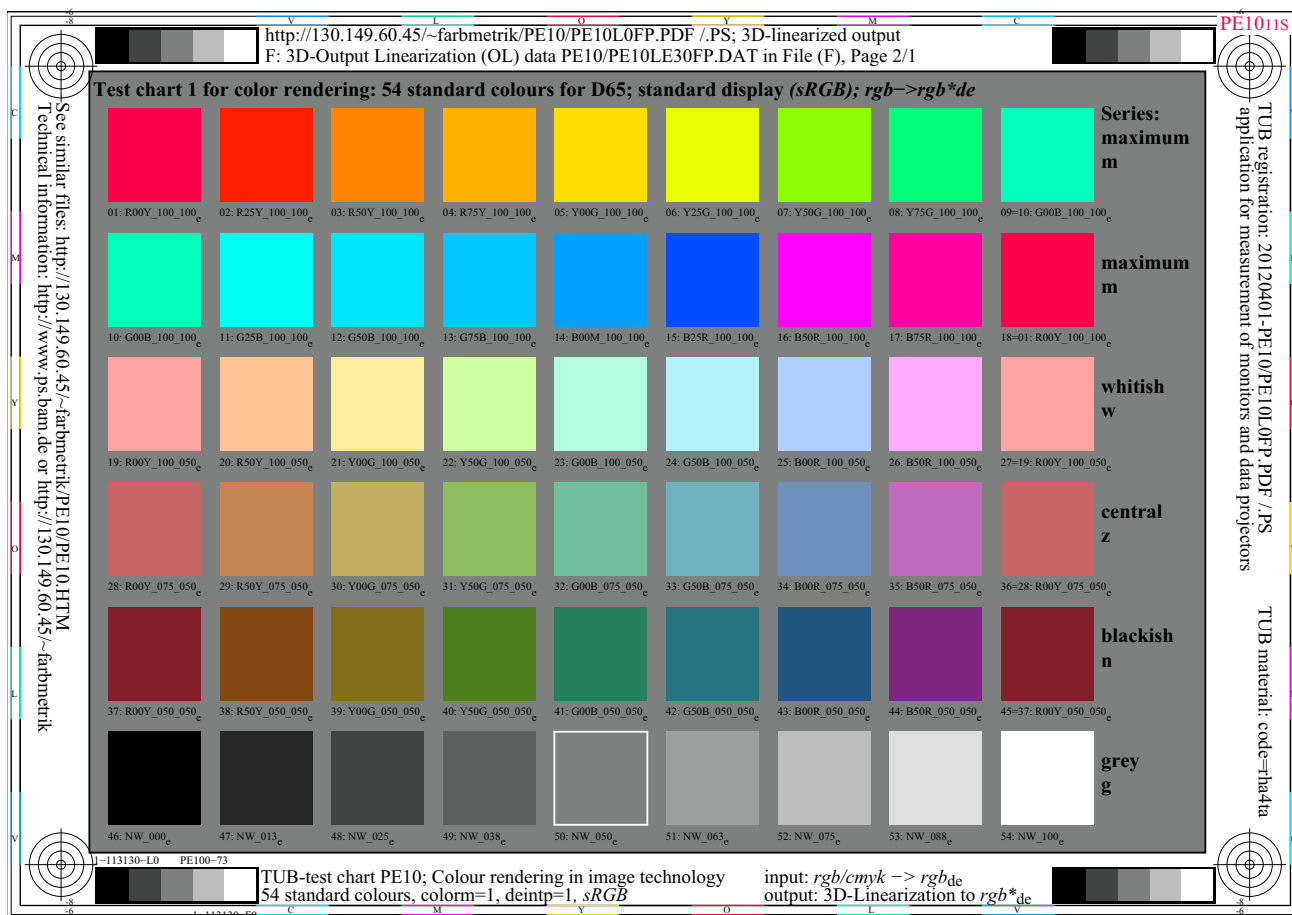


Fig. 21 - HIC^*_e data of a test chart 1 for colour rendering with a 16 step elementary hue circle

Fig. 21 shows the HIC^*_e data of a test chart 1 for colour rendering with a 16 step elementary hue circle.

Table 8 - CIELAB colour differences ΔE^*_{ab} of start and linearized output of the standard sRGB display

Calculation of display output by files and series			Display output transfer and linearization of sRGB display according to IEC 61966-2-1				
files, colour amount, page, and serie			test colours	colour difference ΔE^*_{ab} (real-intended)			
file and output code (d, e, dd, de)	colours	page, serie	content	hue transfer		3D-linearization	
				d (de=0)	e (de=1)	dd (de=0)	de (de=1)
RE69L0NP.PDF (output of d, e) and	57	18, 1 and 2	hue circle	0,9	26,3	0,1	0,4
	53	19, 1 and 2	test chart 1	6,5	21,3	0,8	0,8
	81	28, 1 and 2	plane R-C	7,3	11,2	0,8	0,7
RE69L0FP.PDF (output of dd, de)	81	29, 1 and 2	plane Y-B	8,7	27,1	0,7	0,6
	81	30, 1 and 2	plane G-M	11,4	22,0	0,6	0,6

SE360-1

Table 8 shows the CIELAB colour differences between real and intended colours on a sRGB display for no room light reflection on the display ($L_r=0$). For the 48 steps of a hue circle and the 9 grey steps (57 colours) the CIELAB colour difference is $\Delta E^*_{ab,d} = 0,9$. However, the colour difference is $\Delta E^*_{ab,e} = 26,3$ for the start output of the sRGB elementary colours. These differences are reduced to $\Delta E^*_{ab,dd} = 0,1$ and $\Delta E^*_{ab,de} = 0,4$ by output linearization. The remaining difference is therefore below threshold ($\Delta E^*_{ab}=1$). This is similar for the colours of the test chart 1 for colour rendering. This test chart is shown in Fig. 20 on page 30 for the intended device colour output and in Fig. 21 for the intended elementary colour output. Again the mean difference is below

threshold and similar for the 81 colours in the hue planes *R-C*, *Y-B*, and *G-M* for the two intentions device colour and elementary colour output.

Compared to other output methods the accuracy is by a factor 10 higher, for example compared to ICC colour management according to ISO 15076-1. The reason is the different coding and use of the CIELAB output data of the *sRGB* colour space.

According to CIE 168 the *sRGB* colour space fills only 20% of the CIELAB coding space.

The standard *sRGB* space according to ISO 9241-306 with 2,5% room light reflection fills half of the space defined by no room light reflection.

Therefore the coding of the for example 729 measurement data between -128 to 127 (8 bit) for CIELAB a^* and b^* and between 0 and 100 for L^* produces at least coding errors of $\Delta E^*_{ab}=1$. These errors are here avoided, because only the $L^*a^*b^*$ data of a 48 step colour circle are used with for example two digits after the comma for the three CIELAB data $L^*a^*b^*$.

Similar tables compared to Table 8 on page 31 with the colour differences ΔE^*_{ab} are available

- for different room light reflections on the screen or
- for different *CMY* and *CMYK* printers with only *rgb* input or
- for different *CMY* and *CMYK* printer with the additional *cmyk* input or
- for *CMYK* offset print with *rgb* or *cymk* input.

In these cases the standard deviation of the general colour output plays a larger role and increases the colour differences ΔE^*_{ab} between the intended and the real output.

For example the 6 basic colours *RYGCBM* are 3fold on the test chart with the 1080 colours (Fig. 17 on page 23).

A digital photo printer with *rgb* or *cmy0* input data has shown a standard deviation near $\Delta E^*_{ab}=0,5$.

For two laser printers no. 1 and 2, and offset print, all with *cmyk* input data in the file, the output colour depends often on the colours of the neighborhood and is between $\Delta E^*_{ab}=2$ and 5.

In addition for the laser printer no. 2 with only *rgb* data in the file the very irregular start output produces problems and irregular output, see Fig. 31 on page 44.

Therefore, and in addition, the colour differences ΔE^*_{ab} are dependent on device specific properties of printers and offset print.

The accuracy of the proposed method of output linearization of this paper is given in Table 8 and is below $\Delta E^*_{ab} \leq 1$. This is below the visual threshold.

For displays the value $\Delta E^*_{ab} \leq 1$ is only possible with 14 or 16 bits if the display has a linear luminance output ($\gamma = 1$) as function $r=g=b=w$ data .

If the display output luminance is coded only with 8 bits, then only 16 equal steps are possible which differ by the value $\Delta L^*=6,7$ ($=100/32$), compare the relation between luminance and lightness in Fig. 22 on page 33. This is much higher compared to the threshold lightness $\Delta L^*=1$.

8 Output Linearization for eight luminance contrast ratios C_{Y1} to C_{Y8} of displays

8.1 Equidistant grey scales for standard and different luminance contrast ratios

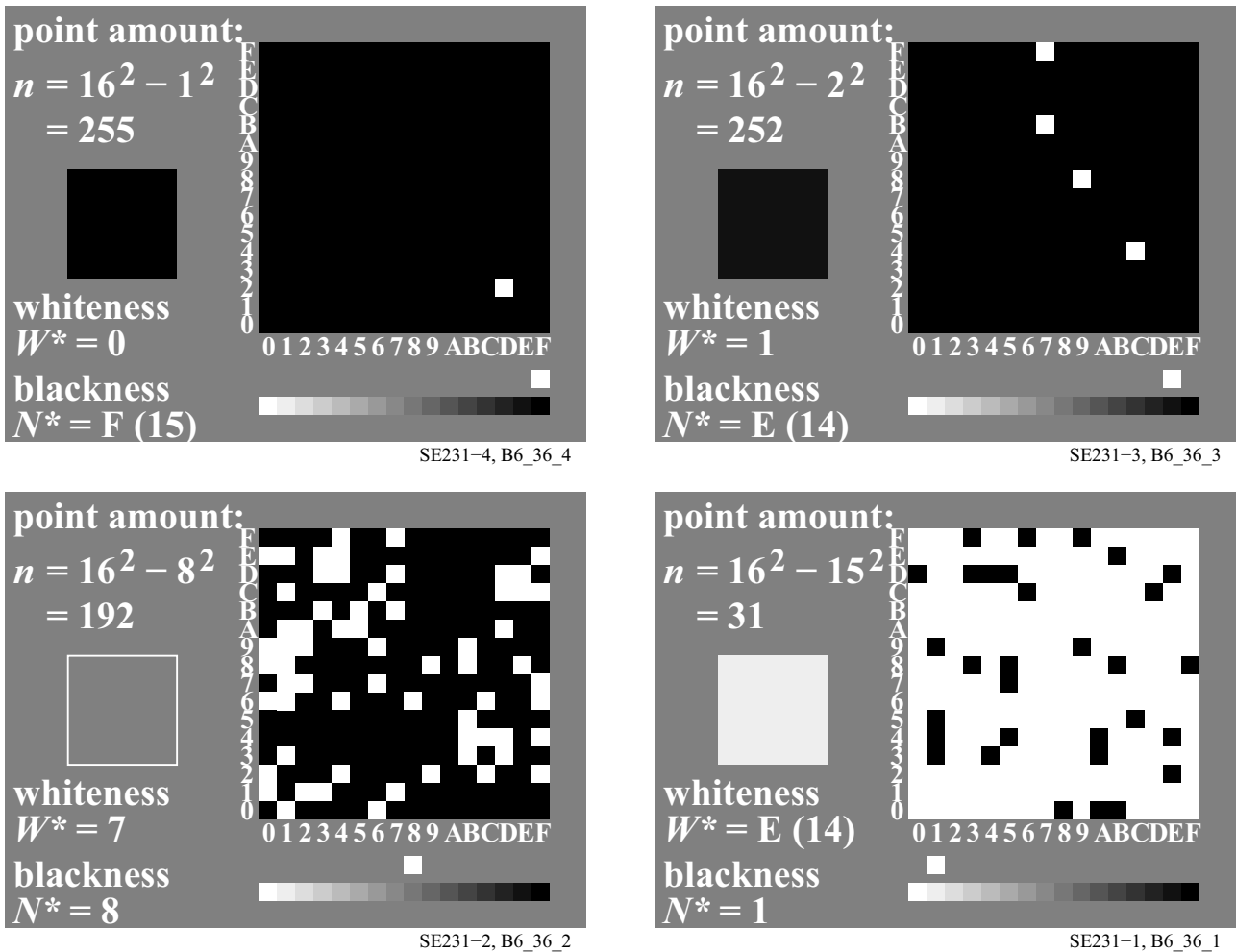


Fig. 22 - Equidistant grey scale with 16 steps

Fig. 22 describes one possibility to produce a visually equidistant grey scale. A square of the size 0,16 mm x 0,16mm is filled by 256 points. These points are again squares of the size 0,01 mm x 0,01 mm. Fig. 22 shows how to use a digital image setter with these properties to produce a grey scale with 16 visual equidistant steps. Black N is produced without any or one point in the black square. The large square has the size of the human visual resolution limit. This limit is often given as 60 lines/cm or 6 lines/mm which leads to a line width of 1/6 mm.

If the 16 step grey scale shall be equidistant, then no or one white point produces black. More points of the amounts 4, 9, 16, 25, ..225, and 256 produce the visual equidistant grey scale. The 16 steps may be described by the hexadecimal number 0,1,...9,A,..D,F, compare the figure. It is important to realize that

- for a grey near the middle (blackness $N^*=8$) 192 (=256-64) points are still black and only 64 white,
- the first two steps near black N differ by an amount of 3 (=4-1) points (blackness F and E),
- the last two steps near white W differ by an amount of 31 (=256-225) points (blackness 1 and 0).

In the example the luminance L increase linear with the amount of points. However the lightness L^* which describes the equal visual spacing increase with the square root of the luminance L . It is valid

$$L^* = L^{1/2} - 1 \quad L^*=0, 1, 2, \dots, 15 \text{ (or in hex } 0, 1, 2, \dots, 9, A, \dots, D, F); L = 1, 4, 9, 16, \dots, 225, 256$$

In printing and other applications instead of the lightness L^* the blackness $N^* = 16 - L^*$ is used. In colorimetry the CIELAB lightness in the range between 0 and 100. The tristimulus value Y is linear related to the luminance L and the following CIELAB equation and two approximations are in use

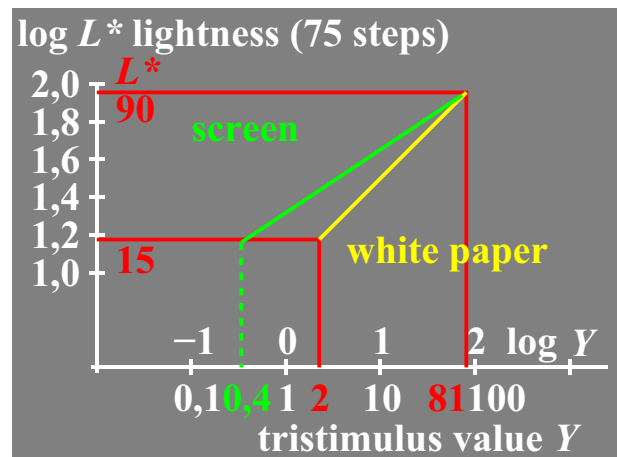
$$L^* = 116 (Y/100)^{1/3} - 16 \text{ with the approximation } L^* = 100 (Y/100)^{1/2,4} \text{ or roughly } L^* = 100 (Y/100)^{1/2}$$

The last formula with the square root (exponent 1/2) is a good approximation for a white surround. The exponent (1/2,4) is used in the *sRGB* colour space according to IEC 61966-2-1 and more useful for a grey surround. The CIELAB formula produces for $Y=2,5$ the lightness $L^*=18$ and for $Y=88,6$ (white standard offset paper) the lightness $L^*=95,4$. Therefore the standard lightness range on standard paper is $\Delta L^*=77,4$ and the luminance contrast is $Y_W:Y_N = 88,6:2,5 = 36:1$. ISO 9142-306 defines this contrast as standard contrast range C_{Y5} . There are 8 luminance contrast ranges $C_{Y8}, C_{Y7}, \dots C_{Y1}$ with the luminance contrast ratios 288:1, 144:1, 72:1, 36:1, 9:1, 4.5:1, 2.25:1. The luminance contrast range C_{Y8} may appear with an emissive display in a dark room with no room light reflection on the display. The luminance contrast range C_{Y1} may appear on a data projector screen within a room illuminated by much daylight.

8.2 Tristimulus value Y , lightness L^* blackness N^* , and equidistant grey scale

sensation scaling functions
lightness L^* and tristimulus value Y
adaptation on surround white: $L^* = 100 (Y / 100)^{1/2,0}$
adaptation on surround gray: $L^* = 100 (Y / 100)^{1/2,4}$
description with CIELAB 1976: $L^* = 116 (Y / 100)^{1/3,0} - 16$
adaptation on surround black: $L^* = 100 (Y / 100)^{1/3,0}$

SE230-2, B6_29



SE230-3, B6_30

colorness		luminous value	
N^*	L^*	$Y = (L^*/10)^2$	$Y = (L^*/10)^3 / 9$
0	90	81 Y_{max}	81,0 $Y_{normalized}$
2	80	64	56,9 (= Y_{paper})
4	70	49	38,1
6	60	36	24,0
8	50	25	13,9
10	40	16	7,1
12	30	9	3,0
14	20	4	0,9
15	15	2,25 Y_{min}	0,4

SE230-4, B6_31

whiteness	black-	tristimulus	coverage
r^*_d	ness N^*	value Y	b
15,15,15	0	81 Y_{max}	0,00
13,13,13	2	64	0,22
11,11,11	4	49	0,41
9, 9, 9	6	36	0,57
7, 7, 7	8	25	0,71
5, 5, 5	10	16	0,83
3, 3, 3	12	9	0,91
1, 1, 1	14	4	0,98
0, 0, 0	15	2,25 Y_{min}	1,00

SE230-6, B6_33

Fig. 23 - Different sensation scaling functions for a white and black surround and example data

Fig. 23 shows different sensation scaling functions for a white and black surround (top left). In the case of output linearization the CIELAB correction below $Y=0,8$ is not necessary. For the standard *sRGB* display according to ISO 9241-306 and the standard offset print according to ISO/IEC 15775 the luminance factor has the value $Y=2,5$ for black. The CIELAB lightness is given in the top right and the bottom left figure. The corresponding value Y of the approximation equations are given as example.

8.3 Definition and data for eight contrast ratios of displays

Table 9 - Contrast steps C_{Y1} to C_{Y8} and luminances for offset paper and data projector displays

Contrast steps C_{Yi} ($i=1$ to 8), CIE tristimulus values Y_W and Y_N according to ISO 9241-306 ¹⁾					
Contrast step C_{Yi} and Y -ratio ($i=1 \dots 8$)	CIE tristimulus values; Ratio $Y_W : Y_N$ of White W and Black N	CIE tristimulus values; Range $Y_{N1} \dots Y_{N2}$	Paper (S) luminance ²⁾ ; Ratio $[cd/m^2]$ $L_{WS} : L_{NS}$	Display (P) luminance ²⁾ ; Ratio $[cd/m^2]$ $L_{WP} : L_{NP}$	application and colour mode at work place; illuminance on display 500 lux or 250/125/62 lux
C_{Y8} 288:1	88,9 : 0,31	0,00 ... <0,46	142 : 142/288	142*36 : 018	display, only 062 lux
C_{Y7} 144:1	88,9 : 0,62	0,46 ... <0,93	142 : 142/144	142*36 : 035	display, only 125 lux
C_{Y6} 72:1	88,9 : 1,25	0,93 ... <1,87	142 : 142/72	142*36 : 071	display, only 250 lux
C_{Y5} 36:1	88,9 : 2,50	1,87 ... <3,75	142 : 142/36	142*36 : 142	display & surface
C_{Y4} 18:1	88,9 : 5,00	3,75 ... <7,50	142 : 142/18	142*18 : 142	display & surface
C_{Y3} 9:1	88,9 : 10,0	7,50 ... <15,0	142 : 142/09	142*09 : 142	display & surface
C_{Y2} 4,5:1	88,9 : 20,0	15,0 ... <30,0	142 : 142/4,5	142*4,5 : 142	display & surface
C_{Y1} 2,25:1 ³⁾	88,9 : 40,0	30,0 ... <60,0	142 : 142/2,25	142*2,25 : 142	display & surface

1) The example is intended for data projectors (P). The standard contrast step (bold) with $L_{WP}=142*36 cd/m^2$ is hard to reach.
 2) 500 lux corresponds to the viewing luminance $L_v=142 cd/m^2$ for a standard white paper with the tristimulus value $Y_W=88,9$.
 3) For the contrast $C_Y=2:1$ the viewing luminances of both the black in the projection and the white standard offset paper are equal (!). Visual fatigue caused by the adaptation luminance ratio 36:1 of the black at the screen and the black at the paper shall be reduced. If for example a grey screen with the CIE tristimulus value $Y_Z=22,2 (=0,25*88,9)$ is used the contrast step C_{Yi} remains constant. Then the luminance ratio of all colours at the screen and the paper has reduced to 9:1. This reduces visual fatigue.

SE531-3N

Table 9 shows in the first column the contrast steps C_{Y1} to C_{Y8} . According to ISO/IEC 15775 for offset print on standard offset paper the **standard** contrast step C_{Y5} is reached (see bold line). The standard output has the contrast value 36:1 which corresponds to the tristimulus value ratio $Y_W:Y_N = 88,6:2,5$ of White and Black. The offset **standard** contrast step C_{Y5} is accepted as a high quality contrast. The silky matte black of offset print has for the CIE 45/0 measuring and viewing geometry the luminance reflection 2,5% ($Y_N=2,5$). Usually all matte blacks of surface colours have a luminance reflection near 4%, so usually the contrast step C_{Y5} may be one step lower.

In offices and at many work places the **standard** illuminance is 500 lux, see ISO 8995-1:2002(E)/CIE S 008/E:2001 — Lighting at Work Places

The standard illuminance 500 lux produces the luminance $142 cd/m^2$ for the white offset paper with the tristimulus value 88,6. Therefore the printed offset black has the luminance $142 cd/m^2$ divided by 36 which is about $4 cd/m^2$.

In Table 9 it is assumed that the standard illuminance 500 lux produces the luminance $142 cd/m^2$ on a white display screen of offset paper. Then for example a data projector must produce a 36 times larger luminance to reach the standard contrast step C_{Y5} of offset paper. At present no data projector reaches these luminances on the white screen. Therefore the visual change as function of contrast step has to be considered. For example the illuminance on the white screen may be reduced to 62 lux instead of 500 lux to reach the larger contrast step, for example by shutters.

Some more information about the eight contrast steps for displays is given in the following

8.4 Start and linearized output of displays for eight different contrast ratios

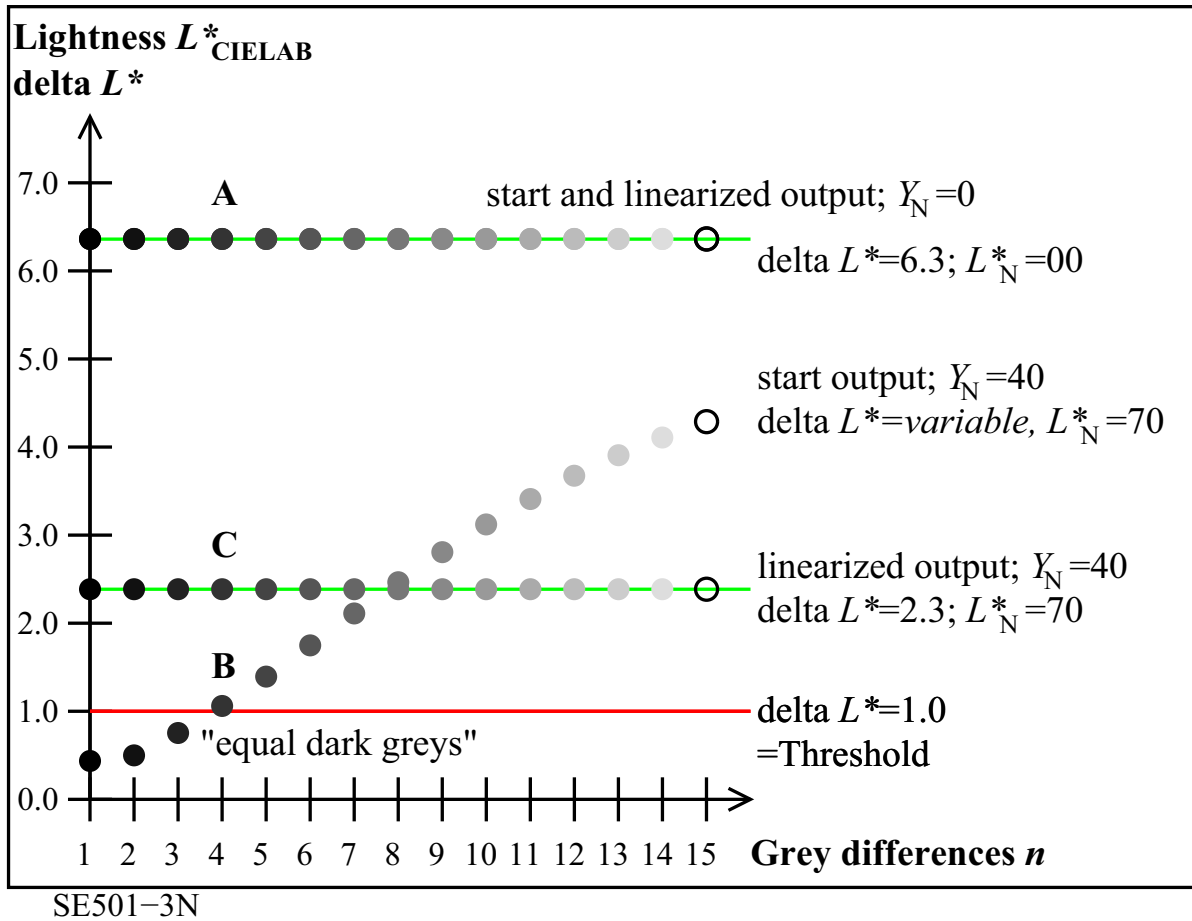


Fig. 24 - Change of 15 sample differences for the tristimulus values $Y_N=0,3$ and 40

Fig. 24 shows the change of 15 sample differences by different luminance reflections at the emissive or data projector display.

In a dark room and for equal colour input values $r=g=b$ of the *sRGB* colour space according to IEC 61966-2-1 the output produces equally spaced grey step with a lightness difference of $\Delta L^*=6,3$. The largest contrast step C_{Y8} is reached.

In Fig. 24 in an office with much daylight the ambient light reflection may produce the tristimulus value $Y_N=40$ for Black N and therefore the lowest contrast step C_{Y1} . In this case the illuminance of the data projector at the screen is about equal compared to the ambient illuminance. In this case four grey differences are below the threshold ($\Delta L^*=1$) and look black.

However, in Fig. 24 a *linearized output* produces 15 equal grey differences with $\Delta L^*=2,3$. Therefore again a 16 step equally spaced grey scale is visible. The grey difference is by about a factor three smaller compared to the dark room condition.

In general equally spaced grey and colour scales in a dark room are not any more equally spaced for different display reflections produced by the ambient light. It can be shown by colorimetry, that an appropriate "Gamma change" produces the intended linearized output for any display reflection.

8.5 Gamma change produces equidistant grey and colour scales for eight contrast ratios

Table 10 - Contrast steps C_{Y1} to C_{Y8} and gamma values for emissive and data projector displays

Contrast steps C_{Yi} ($i=1$ to 8), and absolute and relative Gamma according to ISO 9241–306 ¹⁾					
Contrast step C_{Yi} and Y -ratio ($i=1 \dots 8$)	CIE tristimulus values; Ratio $Y_W : Y_N$ of White W and Black N	CIE tristimulus values; Range $Y_{N1} \dots Y_{N2}$	absolute Gamma G_{Pk} ($k=0$ to 7) for display (P) with $G_{P0}=2,4$ ²⁾ $G_{Pk}=2,4-0,18k$	relative Gamma g_{Pk} ($k=0$ to 7) for display (P) with $G_{P0}=2,4$ ²⁾ $g_{Pk}=G_{Pk}/2,4$	application and colour mode at work place; illuminance on display 500 lux or 250/125/62 lux
C_{Y8} 288:1	88,9 : 0,31	0,00 ... <0,46	$G_{P0} = 2,40$	$g_{P0} = 1,000$	display, only 062 lux
C_{Y7} 144:1	88,9 : 0,62	0,46 ... <0,93	$G_{P1} = 2,22$	$g_{P1} = 0,925$	display, only 125 lux
C_{Y6} 72:1	88,9 : 1,25	0,93 ... <1,87	$G_{P2} = 2,04$	$g_{P2} = 0,850$	display, only 250 lux
C_{Y5} 36:1	88,9 : 2,50	1,87 ... <3,75	$G_{P3} = 1,86$	$g_{P3} = 0,775$	display & surface
C_{Y4} 18:1	88,9 : 5,00	3,75 ... <7,50	$G_{P4} = 1,68$	$g_{P4} = 0,700$	display & surface
C_{Y3} 9:1	88,9 : 10,0	7,50 ... <15,0	$G_{P5} = 1,50$	$g_{P5} = 0,625$	display & surface
C_{Y2} 4,5:1	88,9 : 20,0	15,0 ... <30,0	$G_{P6} = 1,32$	$g_{P6} = 0,550$	display & surface
C_{Y1} 2,25:1 ³⁾	88,9 : 40,0	30,0 ... <60,0	$G_{P7} = 1,14$	$g_{P7} = 0,475$	display & surface

1) The example is intended for data projectors (P) with $G_{P0}=2,4$. Compare IEC 61966–2–1: $G_{P0}=2,4$.
 2) The computer operating system *Apple* has used the value 1,8 until 2010. The change to 2,4 (= *Windows*) is in the wrong direction.
 3) For the contrast $C_Y=2:1$ the viewing luminances of both the black in the projection and the white standard offset paper are equal (!). Visual fatigue caused by the adaptation luminance ratio 36:1 of the black at the screen and the black at the paper shall be reduced. If for example a grey screen with the CIE tristimulus value $Y_Z = 22,2$ ($=0,25*88,9$) is used the contrast step C_{Yi} remains constant. Then the luminance ratio of all colours at the screen and the paper has reduced to 9:1. This reduces visual fatigue.

SE530–3N

The eight contrast steps of Table 10 correspond to different absolute gamma values G_{Pk} ($k=0$ to 7). The absolute gamma value $G_{P0} = 2,4$ is defined for the *rgb* data in the *sRGB* colour space according to IEC 61966-2-1 for no screen reflection in the dark room. The nonlinear data of the *sRGB* colour space which may be named *rgb** according to colorimetry are defined by the equations

$$r^* = r^{(1/2,4)} \quad g^* = g^{(1/2,4)} \quad b^* = b^{(1/2,4)}$$

The value $G_{P0} = 2,4$ in the exponent is called the absolute gamma value. According to Table 10 the value shall be $G_{P0} = 1,86$ for the **standard** viewing condition of the contrast step C_{Y5} . Therefore in this case the modified *rgb** data are defined by the equations

$$r^* = r^{(1/1,86)} \quad g^* = g^{(1/1,86)} \quad b^* = b^{(1/1,86)}$$

It is assumed that the exponent $G_{P0} = 2,4$ of the *sRGB* colour space according to IEC 61966-2-1 is used by the hardware - software workflow. In Table 10 the relative gamma values g_{Pk} ($k=0$ to 7) are defined as

$$g_{Pk} = G_{Pk} / 2.4$$

These values g_P are given at the bottom of any test chart. The graphs on page 3 show approximately the relative gamma values g_{Pk} and the inverse gamma values $1/ g_{Pk}$. For example the relative gamma value $g_{P3} = 0,775$ ($=1,86 / 2,4$) change the linearized output in a dark room ($L_r=0,3$) to a linearized output in the office room ($L_r=2,5$).

8.6 Summary for display output

Table 8 on page 31 shows that the colour differences of the developed linearization method reach the value around $\Delta E^*_{ab} = 0,6$ for both the device and the elementary hue output. This is below threshold defined by $\Delta E^*_{ab} = 1$.

For eight display reflections of the room light a gamma change between 2,4 and 1,14 produces equal output spacing for eight contrast steps defined in Table 10 on page 37.

9 Methods of affine and minimum colour difference output for displays and prints

9.1 Definition of affine colour reproduction between displays and printers or offset print

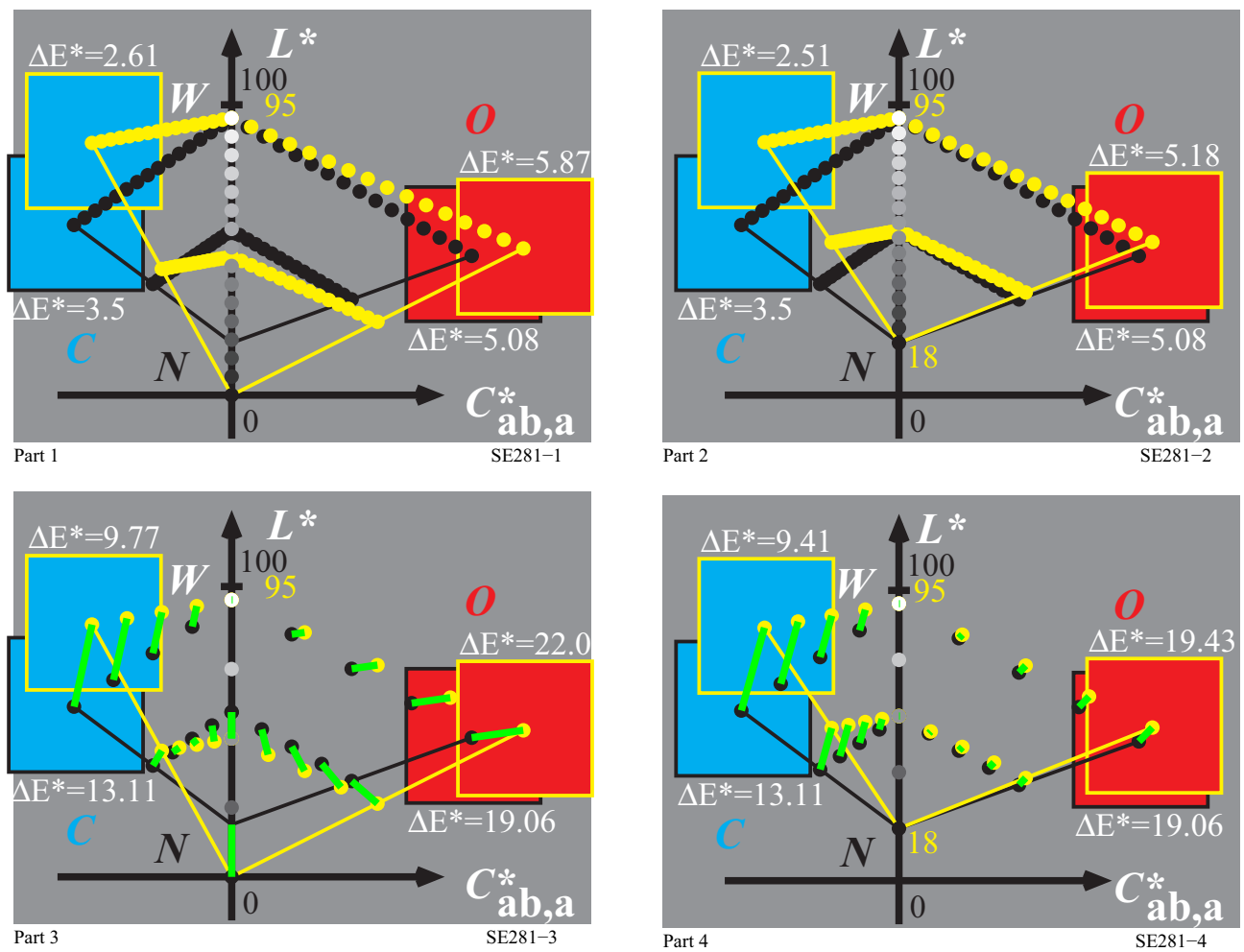


Fig. 25 - Affine (linear) colour transfer between linearized display and printer or offset print output

Fig. 25 shows the affine (linear) colour transfer between the standard linearized display and the offset output. In the top figure (left and right) 16 steps of the display (yellow balls) and printer (black balls) are shown. The display differs by the output of black with the lightness $L^*=0$ (left) and $L^*=18$ (right). The standard lightness $L^*=18$ is defined for standard offset output according to ISO/IEC 15775 and for standard display output according to ISO 9241-306.

The two bottom figures show a complex transfer on the left side and the more simple on the right side. Any colour of the yellow triangle is shifted to a colour of the black triangle. Therefore any colour on the display transfers to a reproducible colour on the printer. The whole triangle gamut of both the display and the printer is used. However, the lightness L^* of all cyan colours on the printer is lower compared to the lightness of the display colours (bottom right).

9.2 Definition for minimum colour difference reproduction between displays and printers

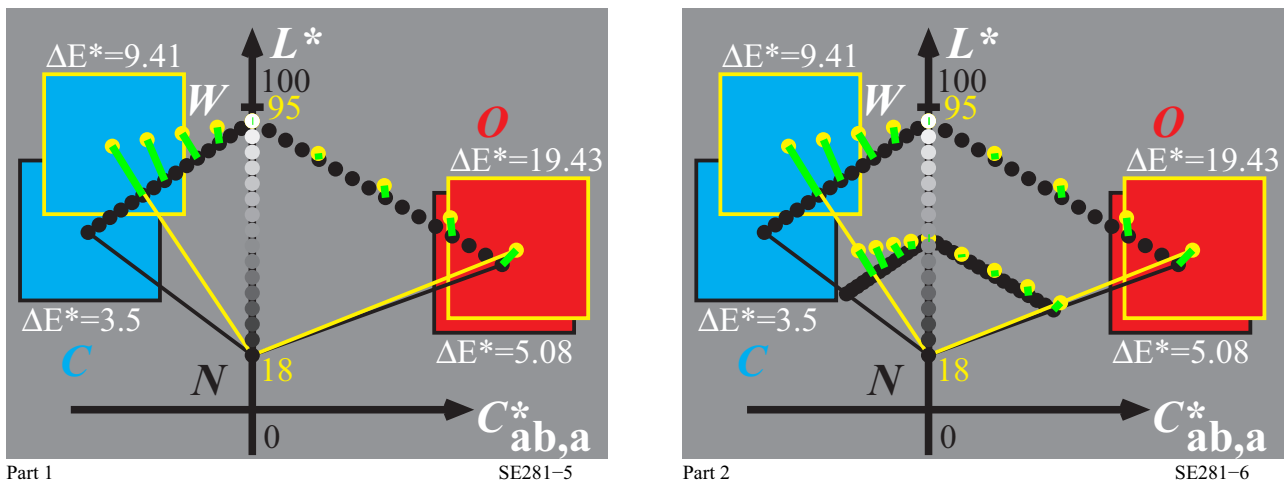


Fig. 26 - “Minimum colour difference” transfer between linearized display and printer output

Fig. 26 shows the “Minimum colour difference” transfer between linearized display and printer output. Again the 16 steps of the display (yellow balls) and printer (black balls) are shown. Both transfers (left and right) show a shift of the light colours. In addition the darker colour series is shifted on the right side. The minimum colour difference ΔE^*_{ab} according to CIELAB is only reached on the left side. However, the “standard” ISO 15076-1 (ICC colour management) allows many proprietary solutions, which many companies use to a high degree. They are all called colour management according to ISO 15076-1.

In Fig. 26 for both cases of the colour transfer any colour of the yellow triangle is shifted to a colour of the black triangle. Therefore any colour on the display transfers to a reproducible colour on the printer.

However, the whole triangle gamut of the printer is **not** used, only about 70% for the cyan hue. Many colours which differ on the display are equal on the printer. There is loss of colour information for about 20% of the light display colours for the cyan hue. However, up to now many printer companies seem to favor this kind of reproduction and use it especially for the so called *RGB* printers with the usual *rgb* input. These printers allow usually only *rgb* data in the files. In case of *cmymk* data in the file there is first a device-dependent and software-dependent change to *rgb* values and then again a change to *cmymk* values within the printer.

In addition some companies produce the output according to company specific “user wishes or preferences” Usually companies produce more light colours compared to the affine reproduction. An example will be shown later in Fig. 31 on page 44

The different device colours, the “Minimum colour difference” criteria, and the company specific consider of user wishes produce colours which are not distinguishable on the printer output for many very different colours on the screen. This may be called a colour chaos in the colour reproduction area. Some colour differences of the 16 step series on the display with a value $\Delta E^*_{ab} = 5$ are in this case reduced below the colour threshold with $\Delta E^*_{ab} = 1$ and are not distinguishable. There is a large variety of outputs on the market..

However, for the affine transfer there is only one solution. The output properties can be evaluated visually for the display or printer output without any measurement equipment, for example with the test charts of DIN 33872-2 to -6, see <http://www.ps.bam.de/33872E>

For the 16 step series the value $\Delta E^*_{ab} = 5$ may vary depending on the display or the printer. Fig. 25 on page 38 shows for the series between white and cyan and white and red the differences between $\Delta E^*_{ab} = 2,51$ and 5,18. (right). Therefore all the steps are visible ($\Delta E^*_{ab} > 1$) on both devices and there is no loss of colour difference information.

10 Start and linearized output of printers with CMY and CMYK device colours

10.1 Linearization of a CMY photo printer with rgb data in the file

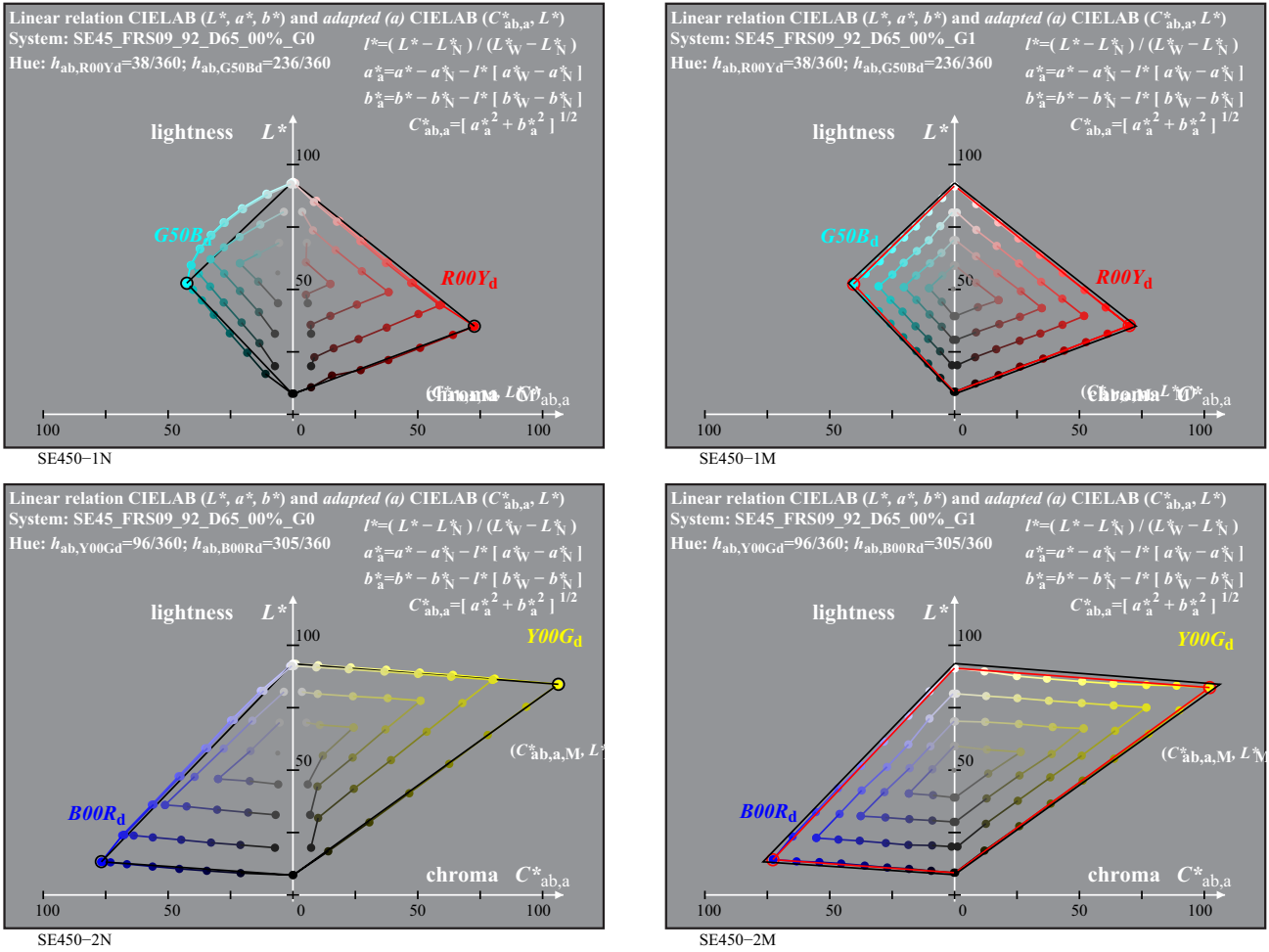


Fig. 27 - Start and linearized output in CIELAB hue planes $R_d - C_d$, and $Y_d - B_d$

Fig. 27 and many of the following figures show the start output on the left side and the linearized output on the right side. The examples in Fig. 27 and Fig. 28 on page 41 are for a photo printer which holds the 1-Minus-Relation. Either the PS operator `rgb setrgbcolor` or `1-r 1-g 1-b 0 setcmykcolor` produce the same output.

The 1-Minus-Relation is for example valid for *Adobe FrameMaker 8 on Windows*. It is for example usually valid for the operating system *Unix*. All the PS figures on the servers

<http://www.ps.bam.de> and <http://130.149.60.45/~farbmetrik>

have been developed with the software *Decwrite* on the operating system *Compac VMS* which holds the colorimetric 1-Minus-Relation. The 1-Minus-Relation was valid for the software *Preview* on the operating system *Mac OSX* until version 10.2 (about 2004). At that time the colour output switched to a colour output which is similar to the output of the software *Adobe Reader*. The output of this software differs according to the version. A larger change in the gamma function appeared between version 3 and 4 (about 2004).

In Fig. 27 the start output (left) of the photo printer produces a colorimetric tint (ΔE_{ab}^* about 5) for many grey steps. The grey axis is defined by the CIELAB data (a_W^* , b_W^*) of white and (a_N^* , b_N^*) of black and differs only slightly from the intended zero values for all these data.

In Fig. 27 the linearized output (right) of the photo printer produces a regular spacing within the hue planes $R_d - C_d$ and $Y_d - B_d$. The grey scale is equally spaced in L^* . The grey scale is now achromatic and in that case

printed by the CMY photo colorants. All the plots of Fig. 27 are based on real measurements of the start and linearized output. The colour difference between the intended and real colour is near the value $\Delta E^*_{ab}=0,5$.

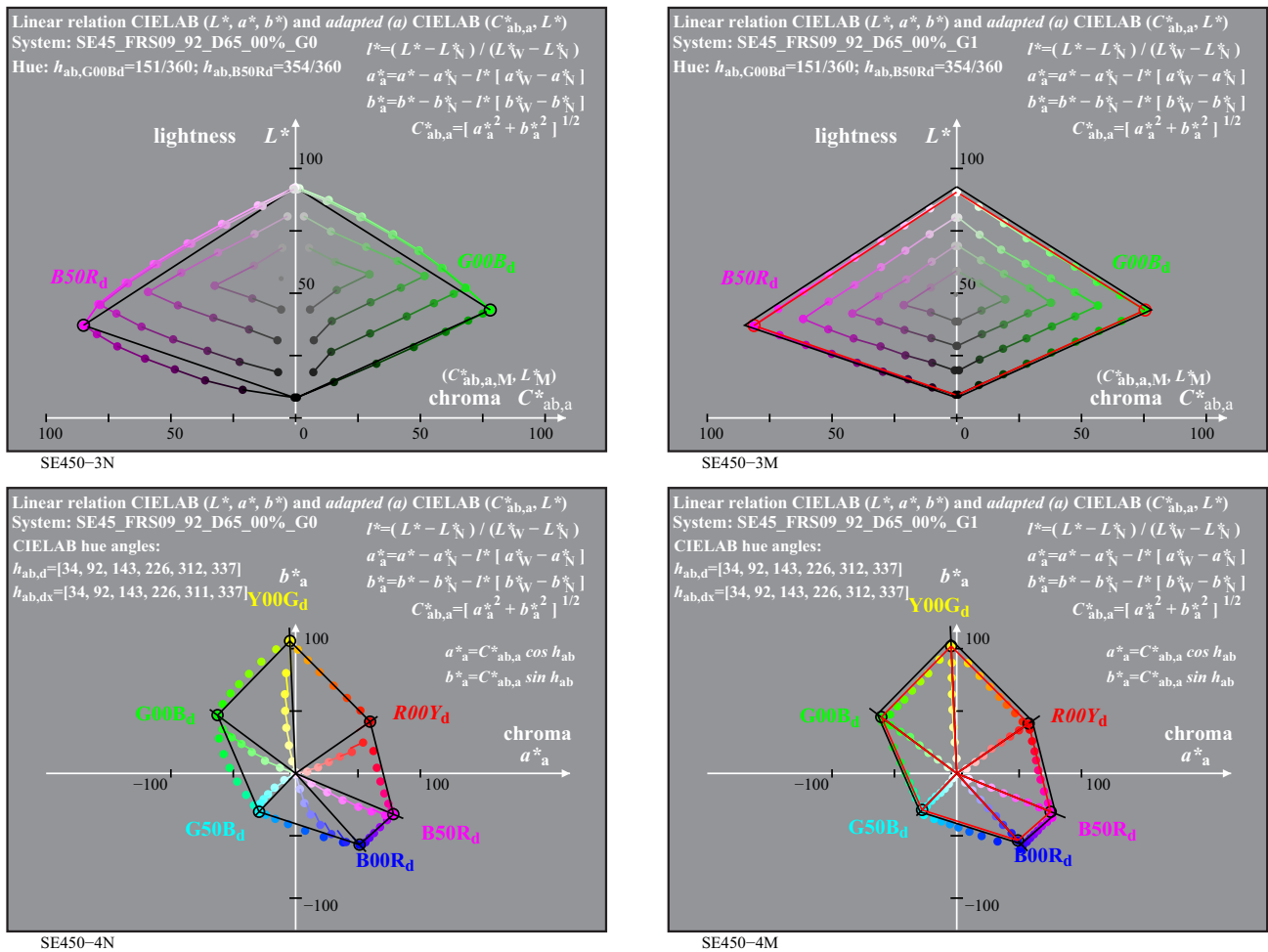


Fig. 28 - Start and linearized output in CIELAB hue planes $G_d - M_d$, and for hue circle

Fig. 28 shows again the start output on the left side and the linearized output on the right side for the photo printer. The two top figures for the hue plane $G_d - M_d$ show similar properties compared to Fig. 27 on page 40.

The two bottom figures show the six series between white and the most chromatic colours in a CIELAB (a^* , b^*) diagram. The start output shows some change of the CIELAB hue angle h_{ab} . The linearized output shows the samples on straight lines as intended.

NOTE: In Fig. 28 it was intended to produce the colours on a hexagon, for examples on a line between Y_d and G_d in the diagram (a^* , b^*). For the present software versions of the output linearization the possible maximum chroma is produced for any hue angle. Instead of 6 device hues a 48 step colour circle is used as reference for the colours of maximum chroma. For example this chroma is between Y_d and G_d larger compared to the black connecting line between Y_d and G_d .

10.2 Linearization of a *CYMK* laser printer no. 1 with two transfers *rgb - cmyk* in the file

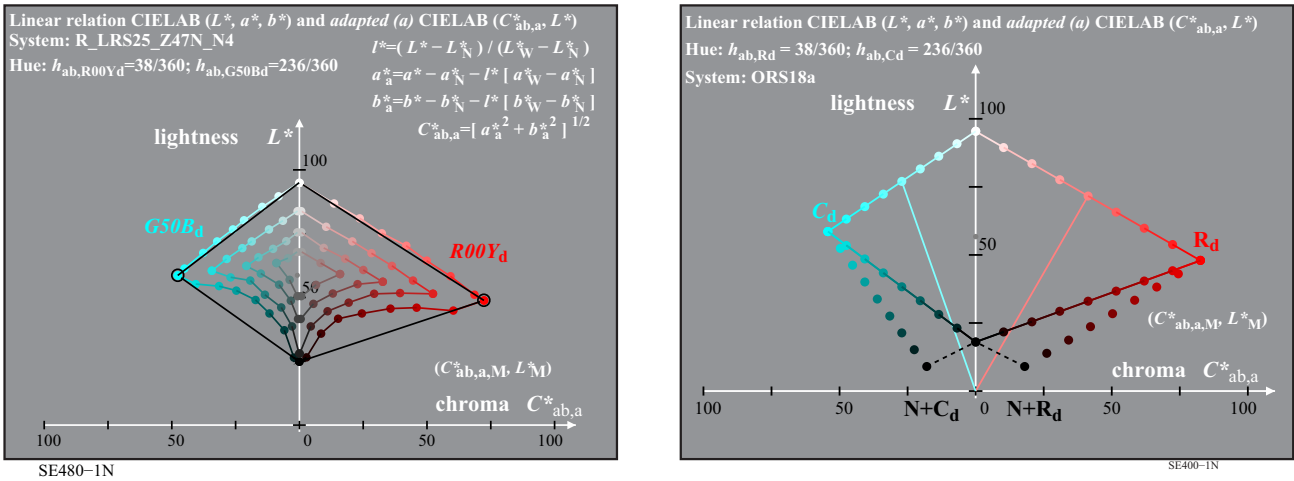


Fig. 29 - Two start outputs with the separations *cmyn4** and *cmyn5** on a *CYMK* laser printer

Fig. 29 shows start outputs with the separation methods *cmyn4** and *cmyn5** for a *CYMK* laser printer with *cmyk* data in the file. There are many methods to transfer *rgb* data in the file to *cmyk* data in the file. CIE colorimetry and PostScript define the 1-Minus-Relation which transfers the PS operator *rgb setrgbcolor* to the PS operator *cm y k setcmykcolor*.

For the most chromatic colours it is valid $c=1-r$, $m=1-g$, $y=1-b$, and $k=0$.
 For all colours it is valid $w=\min(r\ g\ b)$, $c=1-r-w$, $m=1-g-w$, $y=1-b-w$, and $k=w$.

The value w is subtracted from the original three values *cmy*. This method is called under colour removal and has the property that for all grey colours with $r=g=b$ only black is used for the print. Therefore the printed black (for example in colour figures) is always printed only by the black colorant. This reduces the printing costs compared to the overprint of three colorants to produce black.

However, Fig. 29 (left) shows that many dark chromatic colours can not be printed. This unwanted case is avoided in Fig. 29 (right). Here different amounts of black between 0 and 100% are printed on top of R_d or C_d . However this output produces a black with a reddish tint or cyan tint. Both colours have a lightness lower compared to the lightness of the black colorant and in addition there is a gap near black N produced by only the black colorant.

For the intention to produce all the colours up to the triangle line between black N (only) and R_d or C_d , there is the following solution. For example if 50% cyan and 50% black are overprinted the result is a whitish cyan. There explanation is as follows. If 50% cyan is printed then 50% of the white paper is now cyan. If in addition 50% of black is printed, then 25% is cyan, 25% is black, 25% is overprint cyan and black, and 25% is still white. The result is a shift of the output colour $0,5(C_d+N_d)$ towards the white point.

For example this shift towards white can be avoided if for example 50% cyan and 75% black are overprinted which reduces the shift towards white. According to Fig. 29 some shift towards white is allowed because the colours are below the line R_d-N or C_d-N for complete overprint.

Instead of the colour separation *cmyn4** defined by the 1-Minus-Relation the colour separations called *cmyn5** and *cmyn6** have been used for output separation in this report. The lines R_d-N and C_d-N are reached by the start output of the fixed transfer *rgb -> cmyn5** of this laser printer with a *cmyk* input channel.

The start and linearized output properties of such a printer will be discussed in the following.

10.3 Linearization of a *CYMK* laser printer no. 1 with a special transfer *rgb - cmyk* in the file

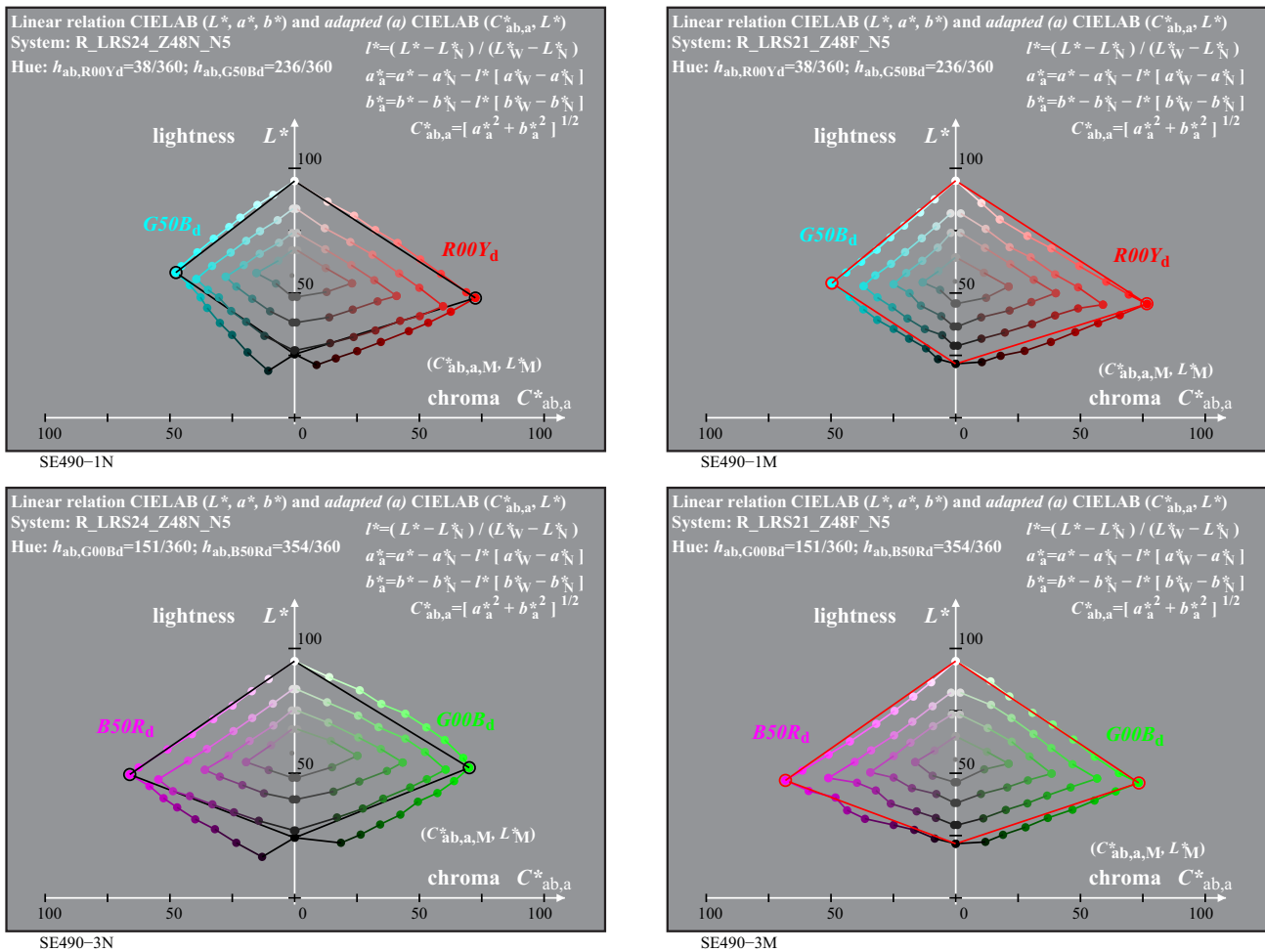


Fig. 30 - Two start and linearized outputs $R_d - C_d$ and $G_d - M_d$ with the separation *cmyk5**

Fig. 30 shows two start and linearized outputs in the hue planes $R_d - C_d$ and $G_d - M_d$ on a *CYMK* laser printer with *cmyk* data in the file.

The *cmyk* data in the file are computed by a fixed separation equation called *cmyk5**. This equation transfers the *rgb* data in the file to *cmyk* data, and for example all data with $r=g=b$ to only a $k=w$ value.

This equation *cmyk5** is different compared to the separation *cmyk4** which can not produce the output colours on the line $R_d - N$ and $C_d - N$, compare Fig. 29 on page 42 (left).

The output shows a reasonable spacing. However there is some more scatter compared to the photo printer in Fig. 27 on page 40 and Fig. 28 on page 41.

In addition the lightness L^* of black is near $L^*=24$ instead of $L^*=9$ for the photo printer.

10.4 Linearization of a CMYK laser printer no. 2 with only rgb data in the file

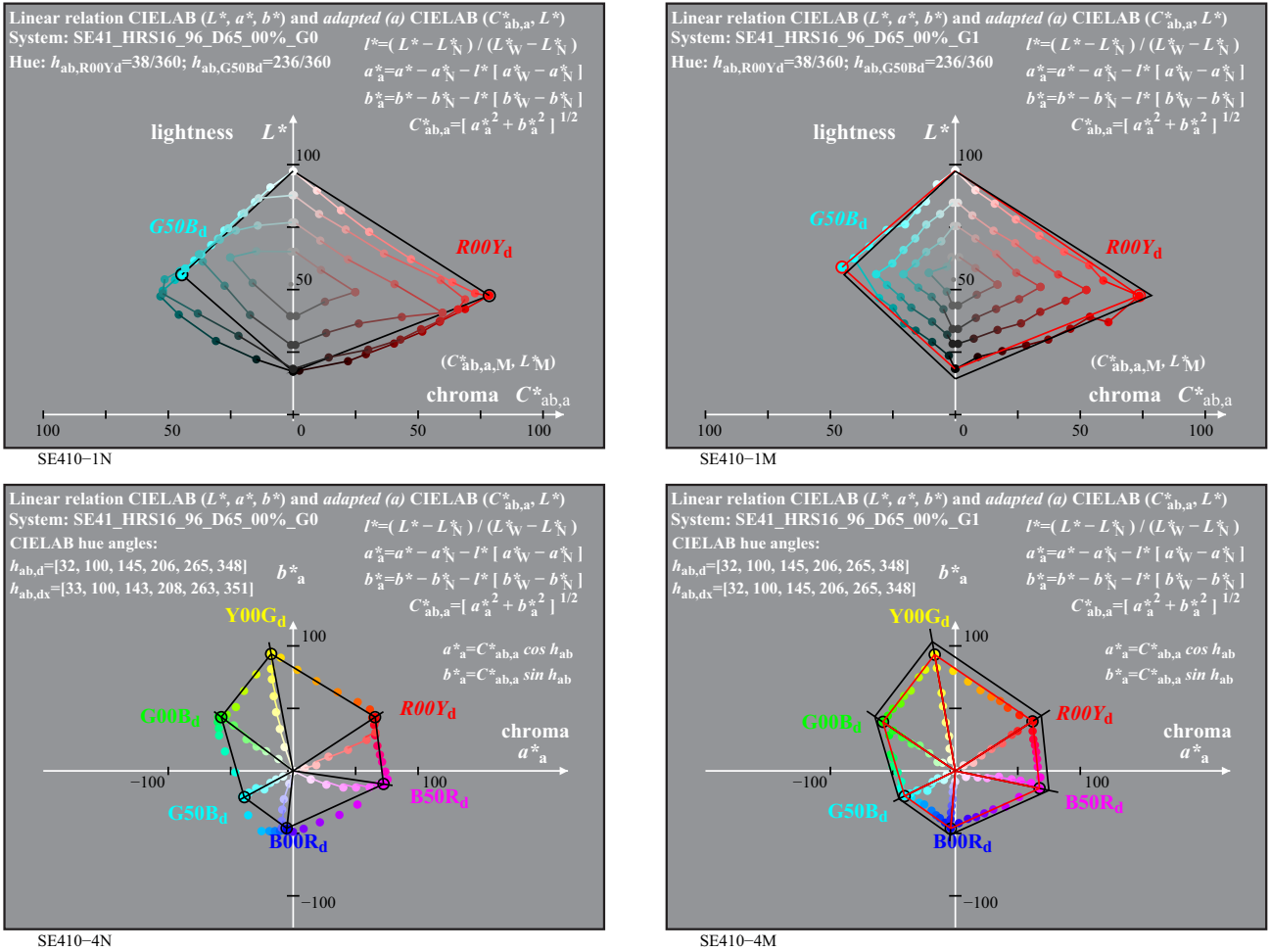


Fig. 31 - Start and linearized output in hue plane $R_d - C_d$ and in CIELAB diagram (a^*_a, b^*_a)

Fig. 31 shows the start and linearized output of a low cost *PostScript* laser printer of a leading printer company. This *Postscript* printer has two input channels for *rgb* and *cmymk* data in the file.

For equivalent *rgb* and *cmymk* data in the file the output is very different, see for example the output of page 1 of the test chart with 1080 colours in Fig. 17 on page 23.

In addition Fig. 31 shows an example output similar to the output of many *RGB* printers on the market. For many different *rgb* data in the test chart file with the 1080 colours the output colours appear equal, for example for the light cyan colours. This property is expected by the *minimum colour difference method* of Fig. 26 on page 39.

10.5 Hue transfer of a CMYK laser printer no. 2 with only rgb data in the file

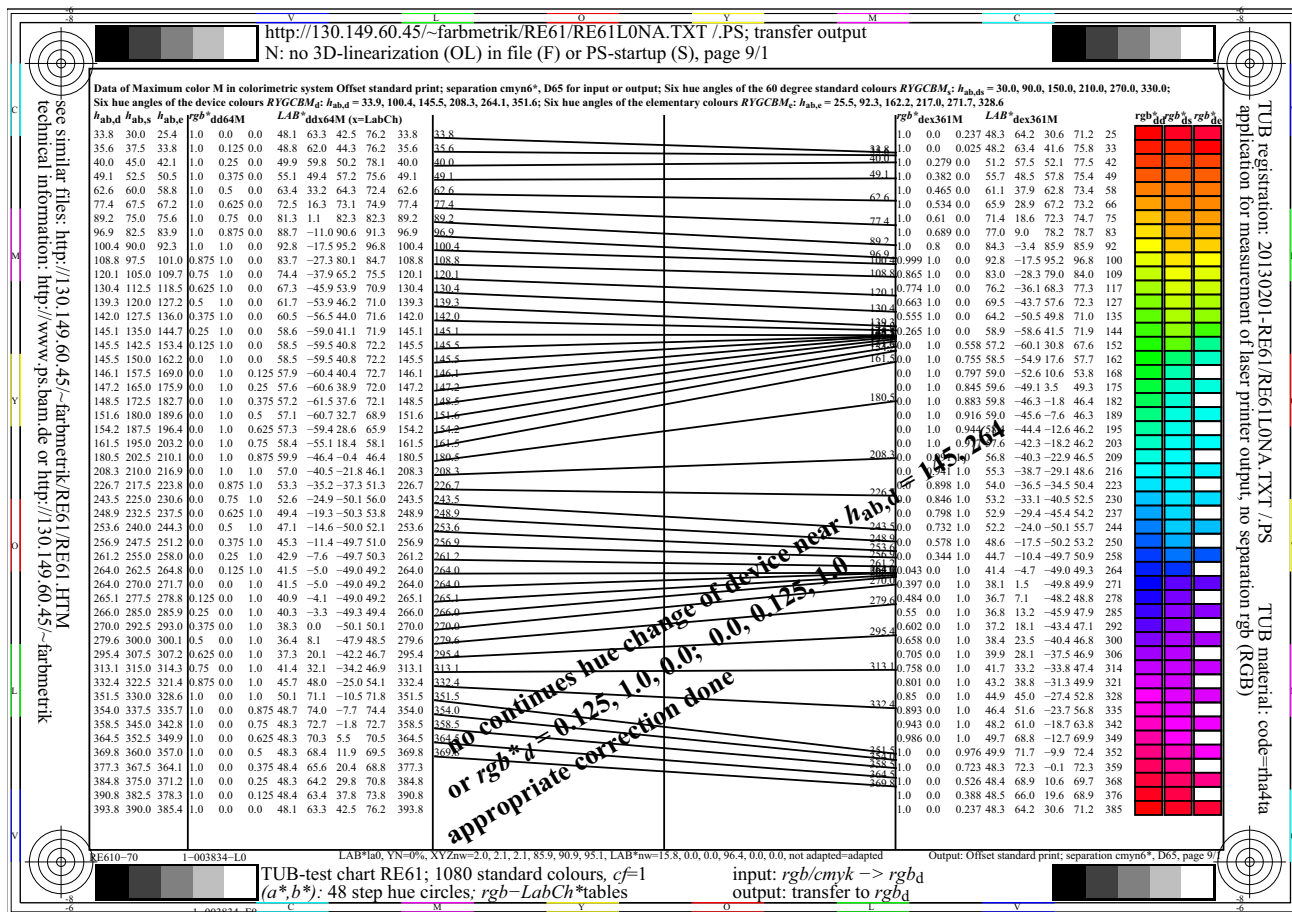


Fig. 32 - rgb and CIELAB data of a 48 step hue circle of a laser printer with only rgb data in the file

Fig. 32 shows the rgb - and CIELAB data for the standard 48 step hue circle of a CMYK laser printer no. 2. Only rgb data are used in the file. This is now the common method to describe colours in files, on the desktop, and in the internet. Column 2 includes 48 different rgb input values in the file with a continues spacing of eight steps, for example between $rgb_{d,R}=(1\ 0\ 0)_d$ and $rgb_{d,Y}=(1\ 1\ 0)_d$. The 48 steps are distributed in the standard file with the 1080 colours. For the position see for example the page 18 of the file <http://130.149.60.45/~farbmetrik/RE69/RE69L0FP.PDF>

In column 2 for any rgb data set one of the three rgb data has the value 0 and another the value 1. This indicates that the 48 steps produce the maximum (M) chroma which is possible with this printer. Real measurement data in CIELAB of the output are included in column 2. Usually there is a continues change of the CIELAB hue angle for a continues change of the rgb data. However, the laser printer 2 shows some hue changes backwards near $rgb_d=(0, 125\ 1)_d$ and $rgb_d=(0\ 0, 125\ 1)_d$. In addition a large range of rgb input values produce nearly the same hue output colours near $h_{ab,e}=152$ (roughly near G_e with $h_{ab,e}=162$), and near $h_{ab,e}=264$ (roughly near B_e with $h_{ab,e}=271$), and near $h_{ab,e}=33$ (roughly near R_e with $h_{ab,e}=26$). Therefore many steps of the output circle look very similar, and in addition near the elementary colours R_e , G_e , and B_e .

The intention of this report is to produce an equally spaced colour circle output between the four elementary colours $RYGB_e$. The hue angles $h_{ab,e}$ of this circle are known, see the values in third column between $h_{ab,e}=25$ towards $h_{ab,e}=385 (=25)$. The data in column 2 include a continues hue change $h_{ab,d}$ of the device colours and the corresponding rgb_d and $(L^*C^*_{ab})_d$ data. For the $h_{ab,e}$ data listed in column 3 the corresponding rgb_e and $(L^*C^*_{ab})_e$ data are calculated by linear interpolation. Pages 7 to 16 of the file <http://130.149.60.45/~farbmetrik/RE69/RE69L0FP.PDF> include the corresponding data for $h_{ab,e}$ between 0 and 360 degree which allow a fast calculation for any hue

angle of any *rgb* data. The indices *dd* (= device to device hue) and *de* (=device to elementary hue) and *M* (maximum chroma) are used for the *rgb* and $L^*a^*b^*C^*_{ab}h_{ab}$ data of the two colour circles in column 2 and 3.

10.6 Hue transfer of CMYK laser printer no. 2 with a transfer *rgb* -> *cmymk* data in the file

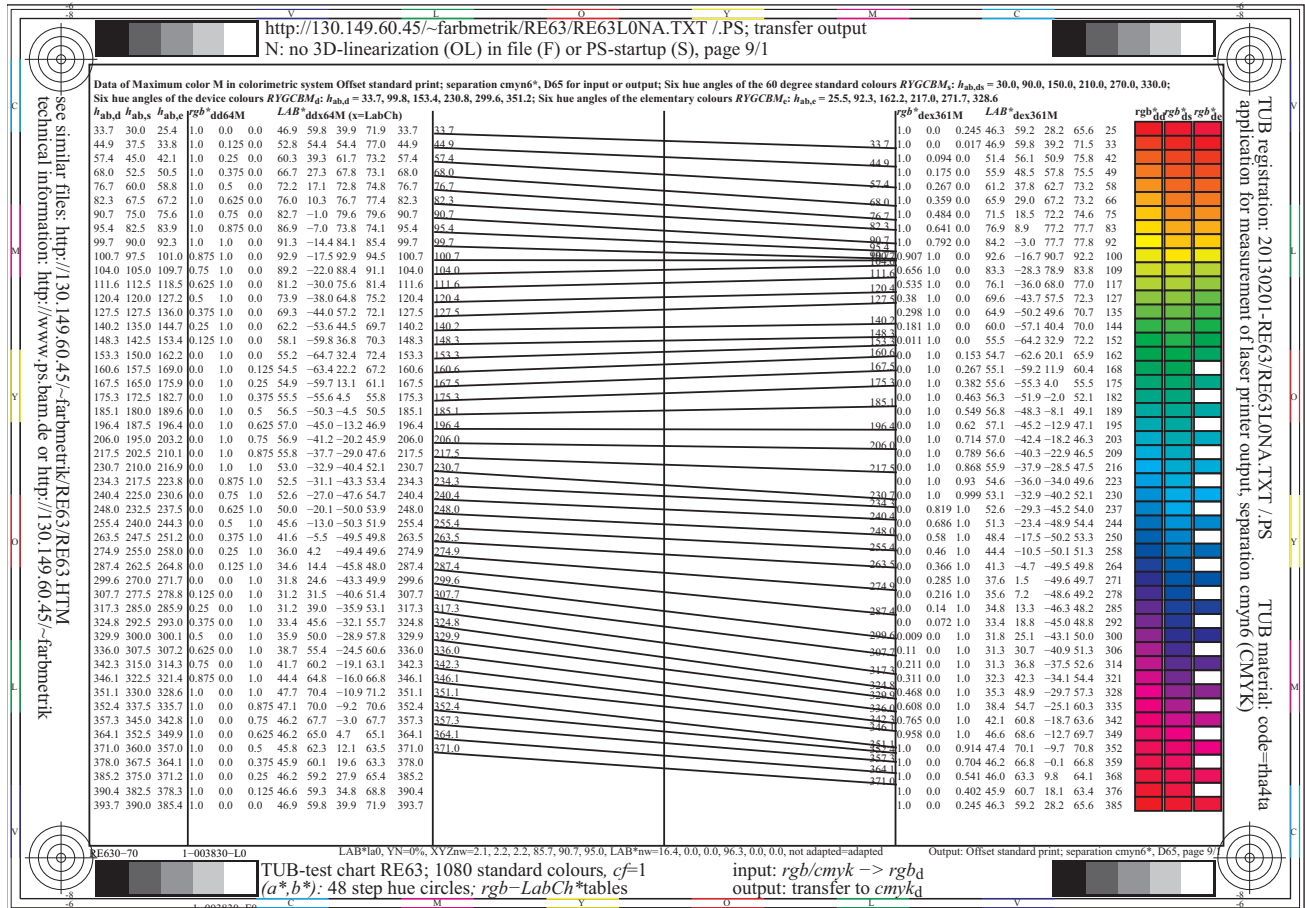


Fig. 33 - *rgb* and CIELAB data of a 48 step hue circle with *cmym6** separation

Fig. 33 shows the *rgb*- and CIELAB data of the CMYK laser printer no. 2 for the standard 48 step hue circle. Now the *rgb* data in the file have been changed by the separation method *cmym6** to *cmymk* data. This method uses complete under colour removal and therefore the grey scale is only printed by the black colorant.

Fig. 32 on page 45 and Fig. 33 shows the hue circle output of the same laser printer no. 2 which look very different. Fig. 32 on page 45 is based on only *rgb* data in the file and Fig. 33 is based on a fixed transfer of *rgb* to *cmymk* data within the file or by the *Frame File Linearization Method* (FF_LM), see Table 7 on page 28. The hue output is much more regular except near $h_{ab,e}=100$ (roughly near \bar{Y}_e with $h_{ab,e}=92$). The interpolation methods for the calculation of the rgb_{de} and $(L^*a^*b^*C^*_{ab})_{de}$ data as function of $h_{ab,e}$ are the same in Fig. 32 on page 45 and Fig. 33. A higher accuracy of the intended hue is expected because of the much more regular spacing of the start output as function of $h_{ab,e}$.

The intended larger hue angle differences Δh_{ab} for the dark output area between green via blue towards red is indicated by producing only every second step in colour in this region, see the last vertical colour circle. The lines in Fig. 33 show a trend for the intended larger hue angle difference of the dark output area between green via blue towards red. This already helps to produce a colour circle similar to an elementary colour circle which is visually equally spaced.

10.7 Summary for start and linearized printer output

There are printer on the market with the same output for *rgb* and *cmky* data according to the 1-Minus-Relation. It is hard to linearize at least some of the *CMYK* printers of the market with only *rgb* input data in the file and no transfer to *cmky* data within the file. However, this is the usual use of many of the printers which usually have no *cmky* input channel.

For any *PostScript* printer there is according to the PS Reference Manual a *cmky* input channel. Here a user can change the *rgb* data in the file by different methods, for example by the Frame File Linearization Method (FF_LM). FF_LM changes the *rgb* data at least of any figure of this paper towards *cmky* data usually at the moment of the device output. The result is a linearized output which fulfills all the user wishes of DIN 33872-2 to -6.

11 Start and linearized output for *CMYK* offset print

11.1 Hue transfer of *CMYK* offset print with transfer *rgb* -> *cmky* in the file

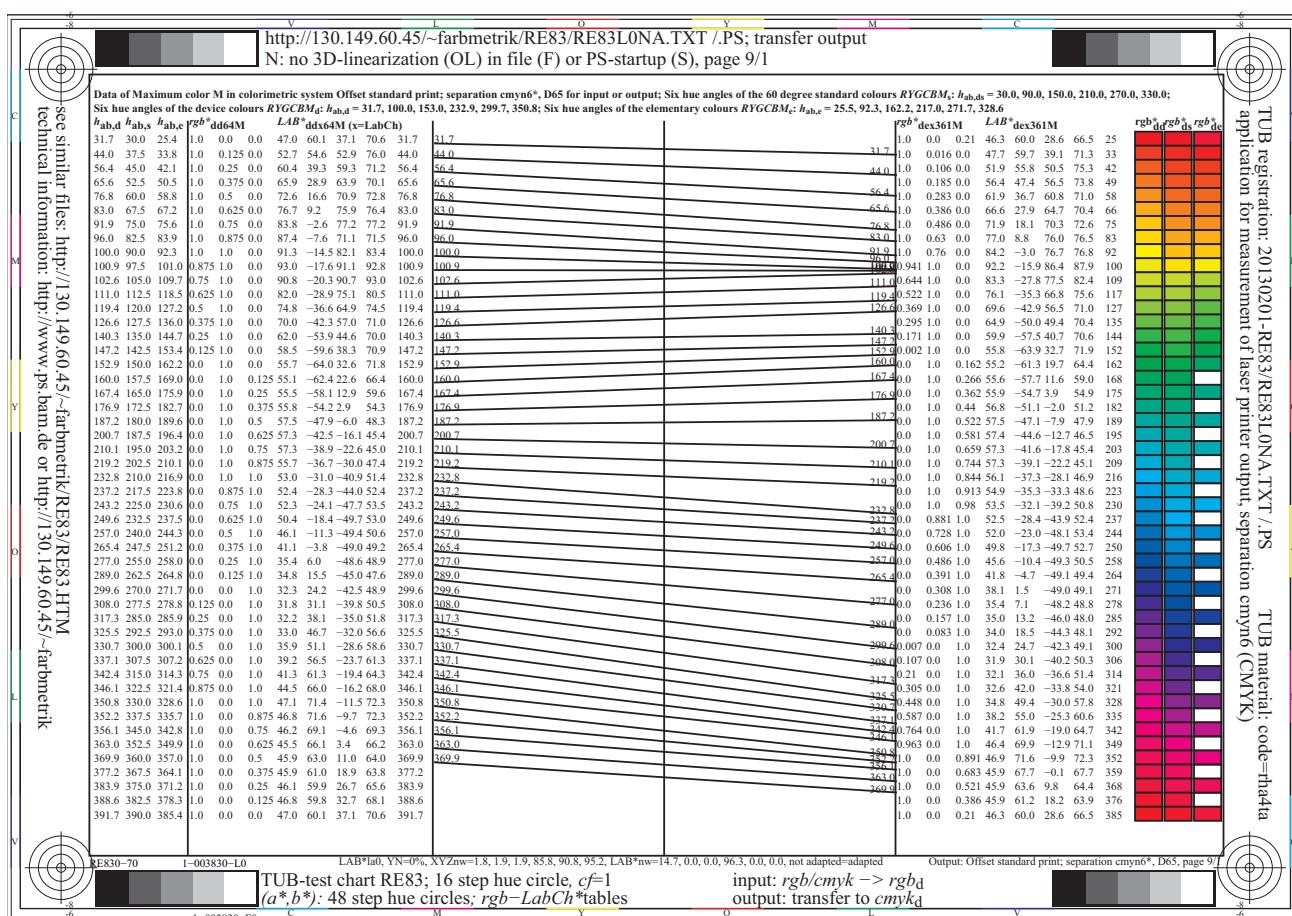


Fig. 34 - *rgb* and CIE LAB data of a 48 step hue circle for the device and elementary offset colours

Fig. 34 shows the *rgb*- and CIE LAB data of the *CMYK* offset print for the standard 48 step hue circle. Similar as in Fig. 33 on page 46 the *rgb* data in the file have been changed by the separation method *cmy6** to *cmky* data. This method uses complete under colour removal and therefore the grey scale is only printed by the black colorant.

Fig. 34 and Fig. 33 on page 46 look very similar. Many printer manufacturers use inks and toners which have roughly similar spectral reflection curves compared to the inks used in standard offset print. Therefore the conclusions for the laser printer no. 2 and offset with *rgb* data in the file and the separation method *cmy6** in the file are similar. In most cases the user wishes according to DIN 33872-1 to -6 are fulfilled by output

linearization and the use of the 1-Minus-relation. A visual user test with Yes/No criteria is sufficient and effective. No measuring equipment is needed.

The accuracy of the printer output, and of the standard offset output depends on different factors. Any output of the standard offset process is usually proofed at least by four 5 step colour scales. This visual evaluation or colorimetric specification uses equally spaced *cmymk* data between white and $CMYN_d$ in the test file. If there are visual differences for the offset print output, then the offset machine is usually adjusted to reach this goal. Therefore to a high degree the start offset output of the 16 step series is already visually equally spaced. Fig. 20 on page 30 shows the 54 colours of the test chart 1 for colour rendering. For this test chart the colour differences between the intended and measured colours are $\Delta E^*_{ab,dd}=2,0$ and $\Delta E^*_{ab,de}=2,4$, see page 19 (series 1 and 2) of the file

<http://130.149.60.45/~farbmetrik/RE83/RE83L0FA.PDF>

11.2 Summary for offset print output and comparison with printer output

For offset print the linearization is very successful., and fulfills to the user wishes according to DIN 33872-1 to -6, see for example the prints of the booklet *Colour and Colour Vision* by K. Richter (2012). A visual user test with Yes/No criteria is sufficient and effective. No measuring equipment is needed.

The accuracy of the printer and standard offset output depends on different factors.

Any output of the standard offset process is usually proofed at least by four 5 step colour scales. The *cmymk* data between white and the colours $CMYN_d$ are equally spaced in the file and shall produce equal CIELAB and visual differences. If there are unequal visual differences for the offset print output, then the offset machine is usually adjusted to reach this goal.

Therefore to a high degree the start offset output of the 16 step series is already approximately visually equally spaced. Fig. 20 on page 30 and Fig. 21 on page 31 show the 54 colours of the test chart 1 for colour rendering. For this test chart the colour differences between the intended and measured colours are $\Delta E^*_{ab,dd}=2,0$ and $\Delta E^*_{ab,de}=2,4$, see page 19 (series 1 and 2) of the file

<http://130.149.60.45/~farbmetrik/RE83/RE83L0FA.PDF>

We have measured the standard deviation, for example for the 6 colours RGB_d and CMY_d which are repeated three times at different places of the test chart with the 1080 colours.

Both *CMYK* laser printers no. 1 and 2 show a standard deviation around $\Delta E^*_{ab}=4$, and similar to offset. This seems the main reason that for the *CMYK* laser printer no. 2 the colour differences between the intended and measured colours are similar to offset with the values $\Delta E^*_{ab,dd}=2,1$ and $\Delta E^*_{ab,de}=2,4$, see page 19 (series 1 and 2) of the file

<http://130.149.60.45/~farbmetrik/RE63/RE63L0FA.PDF>

12 Device output properties and linearization methods

12.1 Device output for printers and offset machines

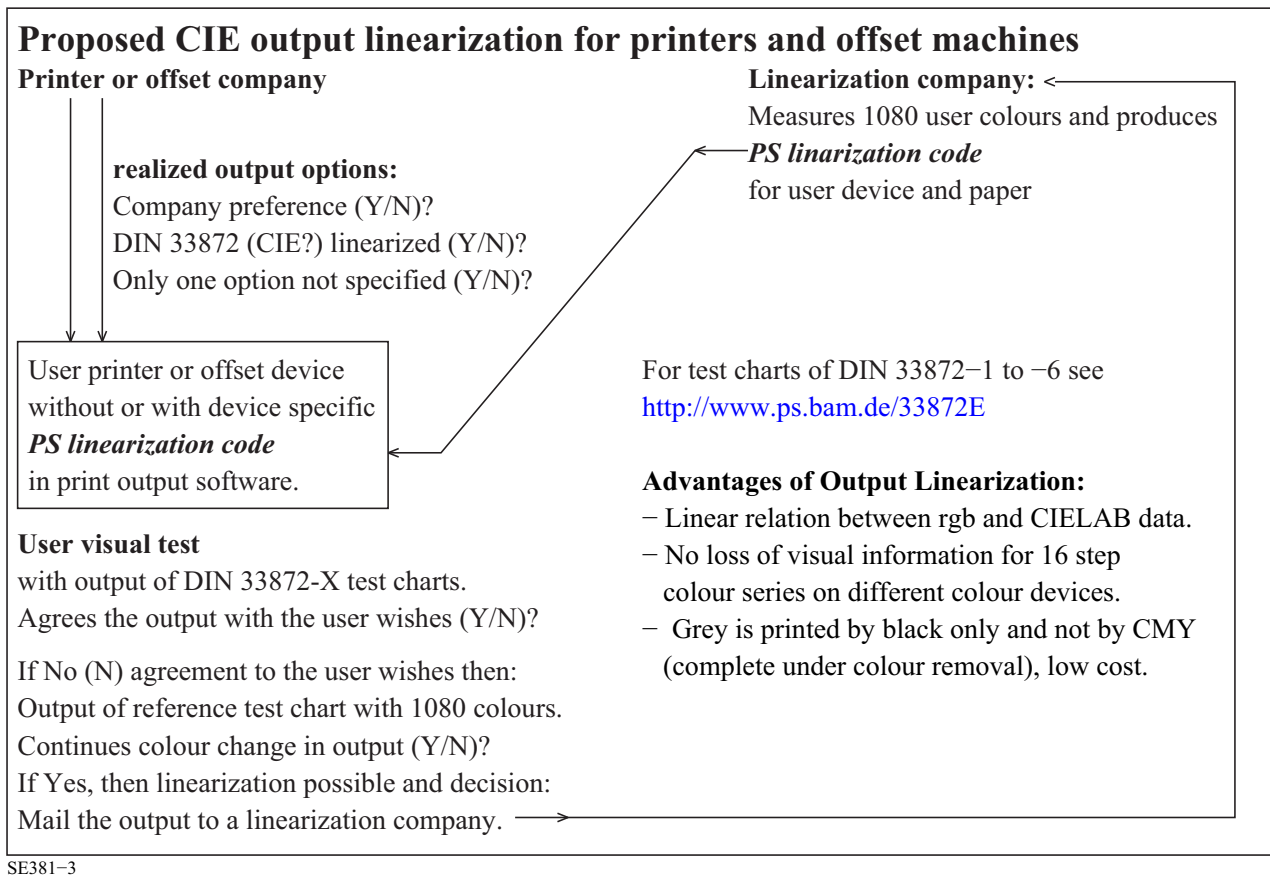


Fig. 35 - Proposed CIE output linearization for printers and offset machines

Fig. 35 shows one possible realization of a proposed CIE output linearization method. A user tests the output of the *RGB* or *CMYK* printer of a printer company, for example with the test charts according to DIN 33872-2 to -6. Usually the visual criteria will show if the user wishes of DIN 33872 are fulfilled or not. For the test charts and corresponding questions for the output see <http://www.ps.bam.de/33872E>

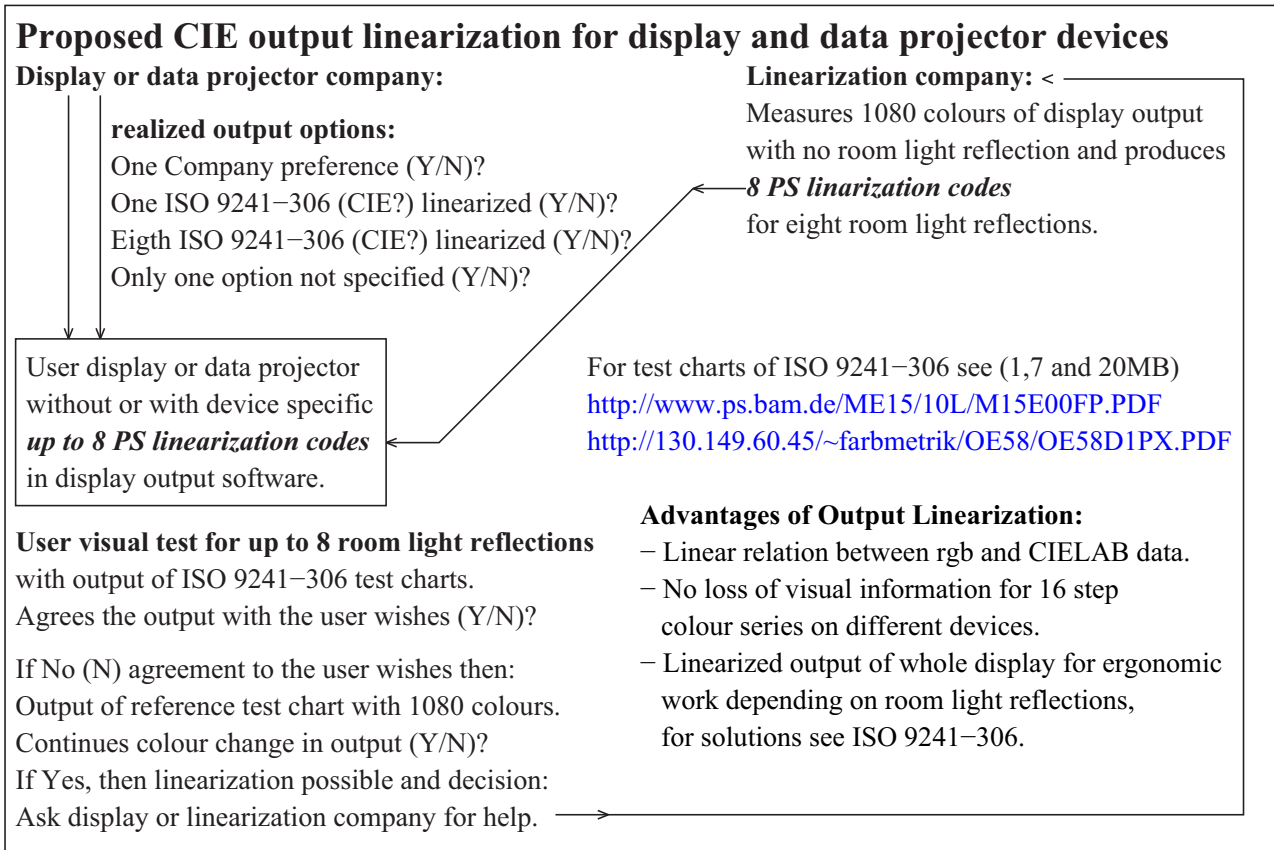
If there is no agreement with one or more user wishes the user may ask the printer or offset company for help.

If there is no help some user may have the possibility to measure the 1080 colours of the test chart output and may apply the Frame File Linearization Method (FF_LM). Then the user has to copy the 1080 measurement data and the DIN 33872-X test file in PS format to the appropriate places in the Frame File, see Table 7 on page 28. An output of this file usually solves the user wish.

If the user has no possibility to measure the output color or has a low technical knowledge the user may send the paper output of the 1080 colours to a *Linearization Company*. He may get back a *Frame File* which includes the measurement data. The user or the *Linearization Company* can include the test chart according to DIN 33872-X. An output of this file usually solves the user wish. If the user wish is solved then the user may pay for the help of the Linearization Company. He can use a Frame File to solve the problems for any user PS file. A PS file can be exported usually from any application.

However, there are limitations. Only the three operators *rgb setrgbcolor*, *w setgray* and *cmymy setcmykcolor* in the PS files are supported up to now. The output according to the user wish which includes the 1-Minus-Relation is expected for any PS files according to DIN 333872-X and any PS file of this paper.

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SE381-7

Fig. 36 - Proposed CIE output linearization for displays and data projector devices

Fig. 36 shows one possible realization of a proposed CIE output linearization method. A user tests the output of a display or data projector company, for example with the test charts according to DIN 33872-2 to -6. Usually the visual criteria will show if the user wishes according to DIN 33872-X are fulfilled or not. For the test charts and corresponding questions for the output see <http://www.ps.bam.de/33872E>

The procedure is similar compared to Fig. 35 on page 49.

In addition the user or the linearization company may produce a file according to the *Frame File Linearization Method (FF_LM)* which includes a loop for the eight standard room light reflections according to ISO 9142-306.

Depending on the reflection of the room light on the emissive display or the data projector display only one of the eight output pages shows the equal spacing of the 16 step series.

There are two files one for the black and white output and another for the colour output. There are Yes/No criteria for the visual evaluation of the output.

For a display output in black and white use the standard file according to ISO 9241-306, Annex D (16 pages, 1,7 MB)
<http://www.ps.bam.de/ME15/10L/L16E00NP.PDF>

For a display output in colour use the proposed standard file according to ISO 9241-306, Annex E (24 pages, 16 MB)
<http://130.149.60.45/~farbmetrik/OE58/OE58D1PX.PDF>

13 Summary

CIE R1-47:2009 Hue Angles of Elementary Colours defines the CIELAB hue angles $h_{ab,e}=26, 92, 162,$ and 272 with a standard deviation of about ± 4 for the four elementary (e) colours $RYG_e,$ and ± 8 for $Be.$

According to *ISO TC159/SC4/WG2 Ergonomics - Visual Display Requirements* the four rgb^*_e -data sets $(1\ 0\ 0)_e,$ $(1\ 1\ 0)_e,$ $(0\ 1\ 0)_e,$ and $(0\ 0\ 1)_e$ shall produce the four elementary hue angles $h_{ab,e}.$

Fig. 15 on page 21 shows a symmetric hue circle with this property. For example elementary red R_e is defined visually as neither yellowish nor bluish, and has the rgb^*_e data $(1\ 0\ 0)_e.$ Red R_e is produced by the device to elementary (de) colour data $rgb_{de}=(1\ 0\ 0,26)_{de}.$ There is only one well defined device-dependent transfer between any data rgb^*_e and $rgb_{de}.$ The star (*) indicates that there is a linear relation between the hue angle $h_{ab,e}$ and the data $rgb^*_e.$ Therefore for the intermediate colour between R_e and Y_e the hue angle has the value $h_{ab,R50Ye}=59$ $[=26+(92-26)/2],$ and is produced by the data $rgb^*_e=(1\ 0,5\ 0)_e.$

Fig. 27 on page 40 shows similar properties in a device hue plane red-cyan (R_d-C_d) for a start and the linearized output. For example there is a linear relation between $rgb^*_d=(0\ 0\ 0)_d$ for black N and $(1\ 0\ 0)_d$ for R_d and the CIELAB-data $(L^*C^*_{ab})_d$ of both colours. In addition there is a linear relation between the CIELAB-data $(L^*C^*_{ab})_{d1}$ and $(L^*C^*_{ab})_{d2}$ of for example

- a display and a printer
- a device for two CIE standard illuminants
- a device for two CIE standard observers.

The transfer between two output possibilities is called an affine transfer. An example is given in Fig. 25 on page 38.

There are different output linearization methods, for example

- within a PS file
- with a PS frame file
- with a PS Startup Distiller directory
- with a PS In-Out Distiller directory
- with a device link profile

In any of these cases a transfer of the data rgb is calculated for example between the rgb data in a file and

- the rgb_{dd} data (dd =device to device colour) or
- the rgb_{de} (de =device to elementary colour)

in the same file for the output. The calculations are done within and during the workflow.

For example for the standard *sRGB* display with a display luminance reflection of $L_r=2,5$ the accuracy of the linearization method is usually 10 times higher compared to the method of ISO 15076-1 (ICC colour management). The table shows some results for two test charts and 81 colours of the three device hue planes $R_d-C_d,$ $Y_d-M_d,$ G_d-M_d and the elementary hue planes $R_e-C_e,$ $Y_e-M_e,$ G_e-M_e

For the standard *sRGB* display and **with output linearization** Table 8 on page 31 shows the mean colour difference $\Delta E^*_{ab}=0,6$ between the intended and real colours for any colour set. This value is below threshold ($\Delta E^*_{ab}=1$).

For example, and for comparison, the colour difference **without output linearization** is $\Delta E^*_{ab}=11,4$ for the 81 colours in the device hue plane $G_d-M_d,$ and $\Delta E^*_{ab}=26,4$ for the intended elementary hue circle of 48 steps together with a nine step grey scale.

The **device-independent elementary hue output** of this report is a step towards a visual human RGB^*_e colour space requested from *ISO/IEC JTC1/SC28 Office Equipment* to be developed within the CIE Division 1 and 8, see Fig. 6 on page 12.

The recent report CIE R1-57:2013 seem to define a next step for output linearization, compare Annex E.

Annex A

Definition and differences of *standard* and *relative* CIELAB data

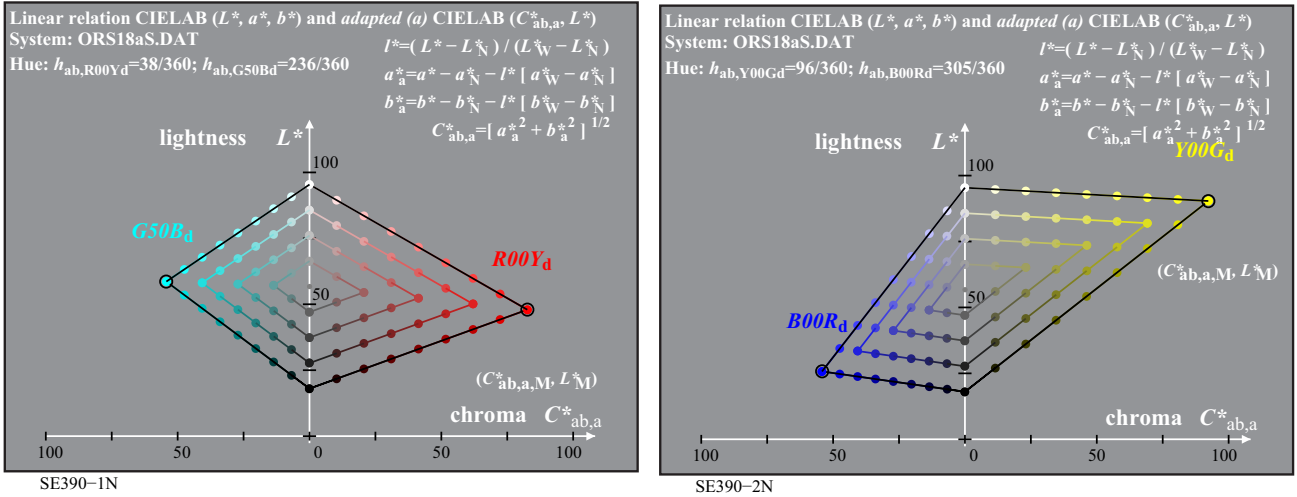


Fig. A.1 — Colour samples of ORS18a of hues R-C and Y-B in the adapted CIELAB diagram ($C^*_{ab,a}, L^*$)

Fig. A.1 shows examples for the calculation of colorimetric data from the standard CIELAB data and shows the colour samples of 9 step colour series at the border and the grey scale. The colours of the hue planes R_d-C_d and Y_d-B_d are shown in the cylindrical adapted CIELAB diagram ($C^*_{ab,a}, L^*$). The colorimetric adapted CIELAB data ($C^*_{ab,a}, L^*$) and h_{ab} are calculated from the standard CIELAB data L^*, C^*_{ab} , and h_{ab} or L^*, a^*, b^* . The coordinates relative lightness I^* , and adapted chroma a^*_a, b^*_a , and C^*_{ab} are defined in the figure.

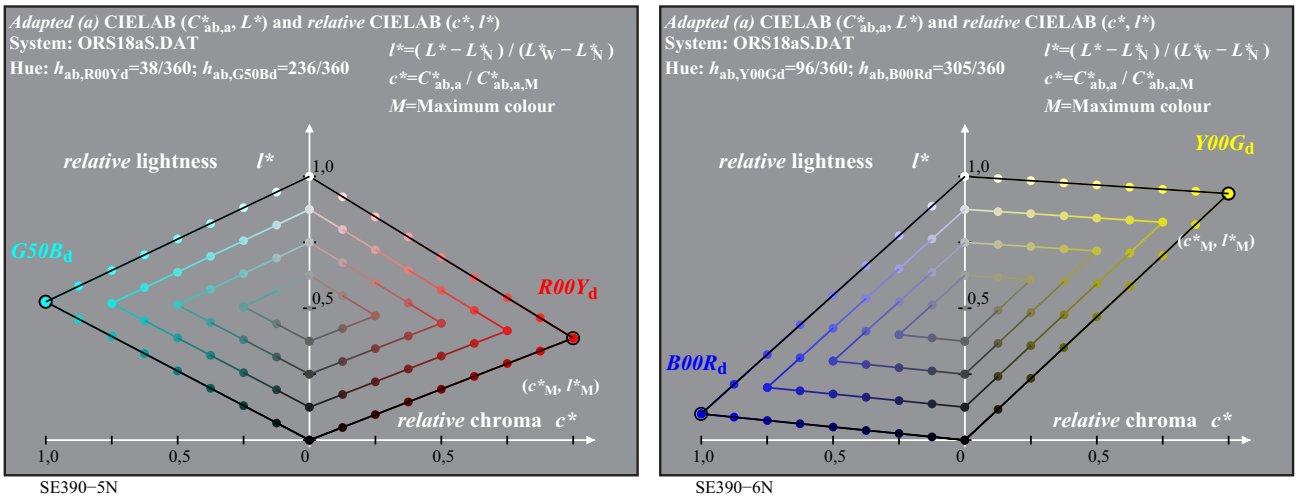


Fig. A.2 — Colour samples of ORS18a of the hues R-C and Y-B in the relative CIELAB diagram (c^*, I^*)

Fig. A.2 shows the same samples as in Fig. A.1. The colours of the hue planes R_d-C_d and Y_d-B_d are shown in the cylindrical relative CIELAB diagram (c^*, I^*). The coordinates relative chroma c^* and relative lightness I^* are defined in the figure. The calculation of the colorimetric adapted CIELAB data ($C^*_{ab,a}, L^*$) and h_{ab} is already given in Fig. A.1.

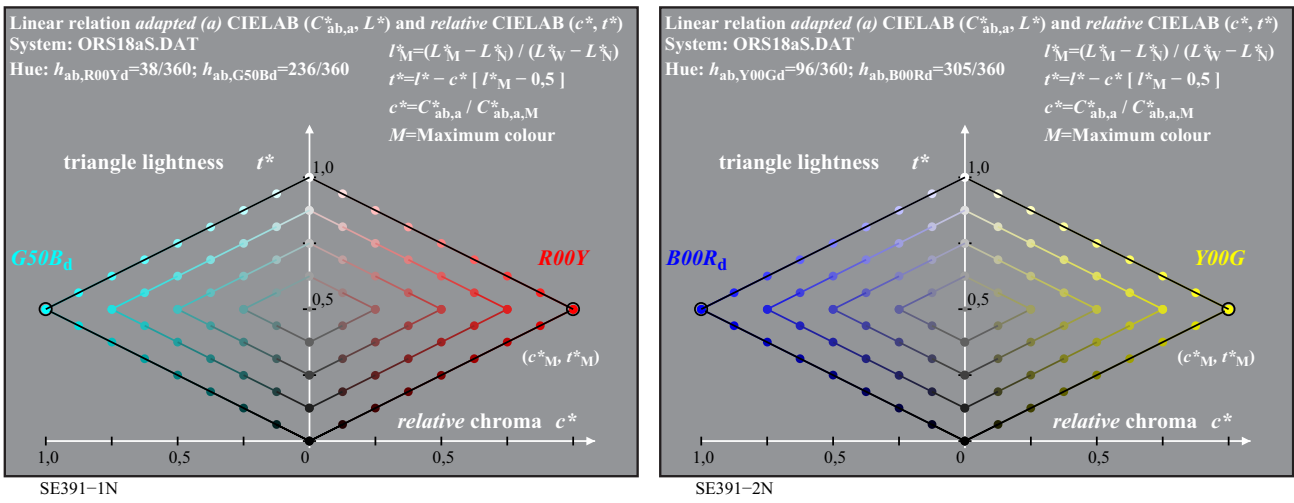


Fig. A.3 — Colour samples of ORS18a of the hues R-C and Y-B in the relative CIELAB diagram (c^*, t^*)

Fig. A.3 shows the same samples as in Fig. A.1 and A.2. The colours of the hue planes R_d-C_d and Y_d-B_d are shown in the cylindrical relative CIELAB diagram (c^*, t^*). The coordinates relative chroma c^* and triangle lightness t^* are defined in the figure. The calculation of the colorimetric adapted CIELAB data ($C_{ab,a}^*, L^*$) and h_{ab} is already given in Fig. A.1.

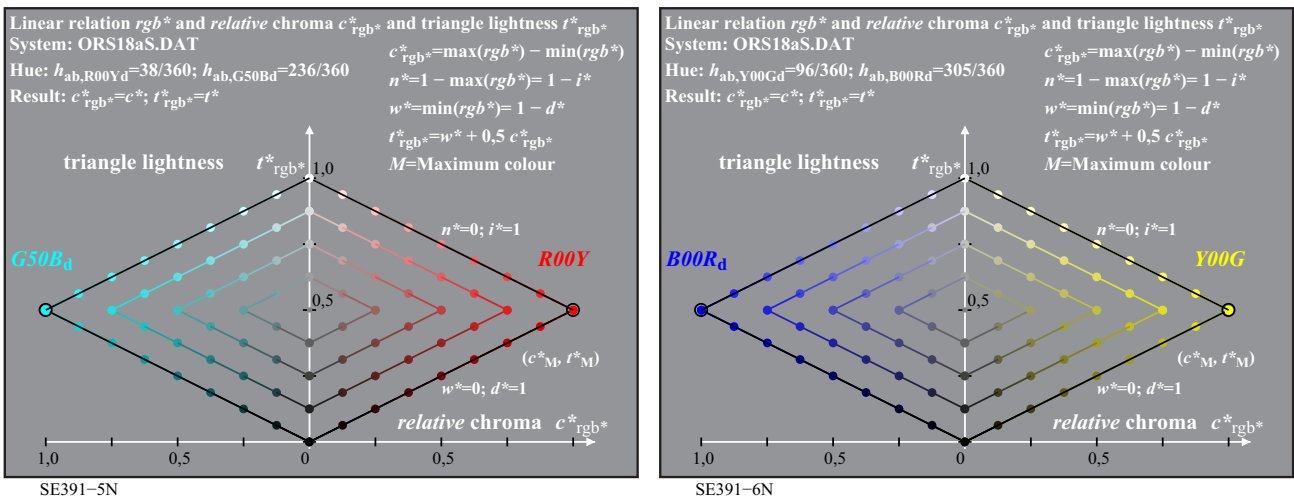


Fig. A.4— Colour samples of ORS18a of the hues R-C and Y-B in the relative CIELAB diagram (c^*, t^*)

Fig. A.4 shows the same samples as in Fig. A.1 to A.3. The colours of the hue planes R_d-C_d and Y_d-B_d are shown in the cylindrical relative CIELAB diagram (c_{rgb}^*, t_{rgb}^*). The coordinates relative chroma c_{rgb}^* and triangle lightness t_{rgb}^* are defined in the figure. The index rgb indicates that the calculation is done from the three rgb values and not from the CIELAB data.

The calculated the relative chroma c^* and the triangle lightness t^* which is calculated from the CIELAB data is identical to the relative chroma c_{rgb}^* and the triangle lightness t_{rgb}^* which is calculated from the rgb -input data for linearized output systems, for example according to ISO/IEC TR 19797:2004. For the hue angle here the CIELAB hue angle h_{ab} is given. However, the standard hue angles $h_{rgb} = 30, 120$ and 170 for red, green and blue and based on the rgb values are also possible. For the calculation of the hue angles h_{rgb} from the rgb data see DIN 33872-1.

Annex B

Standard and relative CIELAB data of the standard sRGB and offset device

Table B.1 — CIELAB data of 8 basic colours $X = RYGBM$ of the monitor TLS00 ($Y_N = 0$; $Y_W = 100$)

Basic television colour or mixture colour for D65 CIE data for $Y_W=100$	chromaticity		tristimulus values ($Y=100,00$ for white D65)			Standard CIELAB data LAB^*_d ($L^*=100,00$ for white; $L^*=0,00$ for black)				
	x_d	y_d	X_d	Y_d	Z_d	L^*_d	a^*_d	b^*_d	$C^*_{ab,d}$	$h_{ab,d}$
<i>three additive mixture colours: television colours acc. to ITU-R BT.709-3</i>										
C_d cyan (cyan blue)	0,225	0,329	53,91	78,74	106,97	91,11	-48,08	-14,12	48,12	196
M_d magenta (magenta red)	0,321	0,154	59,29	28,48	96,99	60,32	98,23	-60,82	110,97	328
Y_d yellow	0,419	0,505	77,00	92,78	13,85	97,14	-21,56	94,48	93,07	103
<i>three additive basic colours: television colours acc. to ITU-R BT.709-3</i>										
R_d red (orange red)	0,640	0,330	41,24	21,26	1,93	53,24	80,08	67,20	100,42	40
G_d green (leaf green)	0,300	0,600	35,76	71,52	11,92	87,74	-86,18	83,18	115,04	136
B_d blue (violet blue)	0,150	0,060	18,05	7,22	95,05	32,30	79,19	-107,85	128,52	306
<i>achromatic colours:</i>										
W -	-	-	-	-	-	-	-	-	-	-
$W1$ (white monitor, 100%)	0,313	0,329	95,05	100,00	108,90	100,00	0,00	0,00	0,00	0
N (black monitor, 0,00%)	0,313	0,329	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
$N0$ -	-	-	-	-	-	-	-	-	-	-

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For the standard television monitor TLS00 with the lightness $L^* = 0$ for Black N and $L^*_W = 100$ for White W (see ISO/IEC 15775) table B.1 shows the CIE chromaticities x and y , and the CIE tristimulus values X , Y , and Z , and the standard CIELAB data $LAB^* = L^*, a^*, b^*$ or $LCH^* = L^*, C^*_{ab}, h_{ab}$ according to CIE 15. The chroma components a^*_N and b^*_N as well as a^*_W and b^*_W are all equal and zero. This is valid for the standard device.

Table B.2 shows the normalization to the lightness $L^*_W = 94,5$ for the White W of ORS18. Table B.1 shows the normalization $L^*_W = 100$ of White W . The normalization to $L^*_W = 94,5$ allows to compare the CIELAB data of White W for print and television colours and is equal to the normalization of ISO 9241-306 and ISO/IEC 15775. Part 1 of Table B.2 shows the lightness $L^*_N = 0$ for Black N for the standard television monitor TLS00. The Table B.1 includes the CIE chromaticities x and y , the CIE tristimulus values X , Y , and Z , and the CIELAB data $LAB^* = L^*, a^*, b^*$ or $LCH^* = L^*, C^*_{ab}, h_{ab}$ according to CIE 15. The chroma components a^*_N and b^*_N as well as a^*_W and b^*_W are all already equal to zero.

Part 1 of Table B.2 shows the lightness $L^*_N = 18$ for Black N . This standard lightness $L^*_N = 18$ may be produced by the luminance reflection of the room light on the monitor surface. Mate surfaces produce about 5% surface reflection, silk mate about 2,5%, and highly glossy about 1,5% for the 45/0 degree CIE measurement geometry. For the room illuminance $E=500$ lux according to ISO 8995 the luminance at the working area is 142 cd/m^2 .

Table B.3 shows the standard and adapted CIELAB data for the standard offset system ORS18 according to ISO/IEC 15775. The tristimulus value of black N is $Y=2,5$ and for white W it is $Y=88,6$.

Many LCD monitors produce a luminance for white around 160 cd/m^2 . If this display surface has the properties of a silky glossy surface then the reflection is around 2,5% and it may be valid $Y=2,5$ for the tristimulus value. For example in offices there are large differences of the luminance reflection and therefore ISO 9241-306 defines the standard reflection 2,5% and seven other reflections between 0% and 40% at work places. The last worst case appears for data projectors, and if the luminance reflection of the projector and the room light are approximately equal on the projection display.

Table B.2 — Standard and relative CIELAB data LAB* and lab* of television monitors TLS00 and TLS18

Basic television colour or mixture colour for D65 TLS00(a) for Yw=88,6	chromaticity			tristimulus values (Y=88,6 for white D65)			adapted= standard CIELAB data LAB*d (L*=95,4 for white; L*=0,00 for black) L*a,d=L*d a*a,d=a*d b*b,a,d=b*d C*ab,d				relative CIELAB data lab*d (L*=93,4 for white; L*=0,00 for black)										
	x _d	y _d	z _d	X _d	Y _d	Z _d	L*	a*	b*	C*ab,d	h _{ab,d}	r*	g*	b*	n*	c*	h*	e*	u*	v*	
three additive mixture colours: television colours acc. to ITU-R BT.709-3																					
C _d cyan (cyan blue)	0,225	0,329	—	47,67	69,76	94,78	86,88	-46,17	-13,56	48,12	196	0,00	1,00	1,00	0,00	1,00	0,545	0,578	G31B	0,50	
M _d magenta (magenta red)	0,321	0,154	—	52,53	25,24	85,93	57,30	94,35	-58,42	110,97	328	1,00	0,00	1,00	0,00	1,00	0,912	0,875	B50R	0,50	
Y _d yellow	0,419	0,505	—	68,22	82,20	12,27	92,66	-20,70	90,75	93,08	103	1,00	1,00	0,00	0,00	1,00	0,286	0,289	Y15G	0,50	
three additive basic colours: television colours acc. to ITU-R BT.709-3																					
R _d red (orange red)	0,640	0,330	—	36,54	18,84	1,71	50,50	76,92	64,54	100,42	40	1,00	0,00	0,00	0,00	1,00	0,111	0,056	R22Y	0,50	
G _d green (leaf green)	0,300	0,600	—	31,68	63,36	10,56	83,63	-82,77	79,90	115,04	136	0,00	1,00	0,00	0,00	1,00	0,378	0,406	Y62G	0,50	
B _d blue (violet blue)	0,150	0,060	—	15,99	6,40	84,22	30,39	76,06	-103,58	128,52	306	0,00	0,00	1,00	0,00	1,00	0,851	0,825	B29R	0,50	
achromatic colours:																					
W (ideal white, 100,00%)	0,313	0,329	—	95,05	100,00	108,90	100,00	0,00	0,00	0,00	0	1,05	1,05	1,05	0,00	0,00	0,00	0,00	—	1,05	
W1 (white monitor, 88,6%)	0,313	0,329	—	84,21	88,60	96,49	95,41	0,00	0,00	0,00	0	1,00	1,00	1,00	0,00	0,00	0,00	0,00	—	1,00	
N (black monitor, 0,00%)	—	—	—	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0	0,00	0,00	0,00	1,00	0,00	0,00	0,00	—	0,00	
N0 (ideal black, 0,00%)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

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Basic television colour or mixture colour for D65 TLS00(a); Yw=88,6 +2,5	chromaticity			tristimulus values (Y=88,6 for white D65)			adapted= standard CIELAB data LAB*d (L*=95,4 for white; L*=18,01 for black)				relative CIELAB data lab*d (L*=93,4 for white; L*=18,01 for black)										
	x _d	y _d	z _d	X _d	Y _d	Z _d	L*	a*	b*	C*ab,d	h _{ab,d}	r*	g*	b*	n*	c*	h*	e*	u*	v*	
three additive mixture colours: television colours acc. to ITU-R BT.709-3																					
C _d cyan (cyan blue)	0,228	0,329	—	48,71	70,30	94,79	87,14	-44,44	-13,14	46,32	196	0,00	1,00	1,00	0,00	1,00	0,546	0,578	G31B	0,50	
M _d magenta (magenta red)	0,321	0,162	—	53,43	27,04	86,23	59,01	89,33	-55,69	105,26	328	1,00	0,00	1,00	0,00	1,00	0,911	0,875	B50R	0,50	
Y _d yellow	0,414	0,497	—	68,67	82,33	14,67	92,74	-20,06	84,97	87,30	103	1,00	1,00	0,00	0,00	1,00	0,287	0,289	Y15G	0,50	
three additive basic colours: television colours acc. to ITU-R BT.709-3																					
R _d red (orange red)	0,600	0,330	—	37,89	20,82	4,41	52,76	71,63	49,87	87,29	35	1,00	0,00	0,00	0,00	1,00	0,097	0,036	R14Y	0,50	
G _d green (leaf green)	0,301	0,581	—	33,18	64,08	13,00	84,01	-79,02	73,94	108,20	137	0,00	1,00	0,00	0,00	1,00	0,380	0,411	Y64G	0,50	
B _d blue (violet blue)	0,161	0,079	—	17,93	8,73	84,57	35,47	64,92	-95,08	115,12	304	0,00	0,00	1,00	0,00	1,00	0,845	0,822	B28R	0,50	
achromatic colours:																					
W (ideal white, 100,00%)	0,313	0,329	—	95,05	100,00	108,90	100,00	0,00	0,00	0,00	0	1,05	1,05	1,05	0,00	0,00	0,00	0,00	—	1,05	
W1 (white monitor, 88,6%)	0,313	0,329	—	84,21	88,60	96,49	95,41	0,00	0,00	0,00	0	1,00	1,00	1,00	0,00	0,00	0,00	0,00	—	1,00	
N (black monitor, 2,52%)	0,313	0,329	—	2,40	2,52	2,74	18,01	0,00	0,00	0,00	0	0,00	0,00	0,00	1,00	0,00	0,00	0,00	—	0,00	
N0 (ideal black, 0,00%)	—	—	—	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0	-0,19	-0,19	-0,19	1,19	0,00	0,00	0,00	—	-0,19	

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Table B.3 — Standard and relative CIELAB data LAB* and lab* of offset ORS18 according to ISO/IEC 15775

Basic offset colour or mixture colour for D65 ORS18 with YW=88,6	chromaticity		tristimulus values			Standard CIELAB data LAB*				
	x _d	y _d	X _d	Y _d	Z _d	L* _d	a* _d	b* _d	C* _{ab,d}	h _{ab,d}
<i>three subtractive basic colours: printing colours acc. to ISO 2846-1</i>										
C _d cyan (cyan blue)	0,165	0,234	18,74	26,62	68,54	58,62	-30,62	-42,74	55,59	234
M _d magenta (magenta red)	0,459	0,235	33,06	16,90	22,01	48,13	75,20	-6,79	75,51	355
Y _d yellow	0,441	0,500	68,06	77,10	9,03	90,37	-11,15	96,17	96,82	97
<i>three subtractive mixture colours: # DIN 33866-colours; ISO reference paper</i>										
R _d red (orange red)	0,608	0,338	30,13	16,75	2,28	47,94	65,31	52,07	83,53	39
G _d green (leaf green)	0,253	0,556	8,71	19,18	6,62	50,90	-62,96	36,71	72,89	150
B _d blue (violet blue)	0,216	0,140	7,17	4,65	21,41	25,72	31,45	-44,35	54,38	305
<i>achromatic colours: # calculated by linear chroma extrapolation in the CIELAB colour space</i>										
W1 (ideal white#, D65)	0,320	0,339	94,41	100,00	100,83	100,00	-1,07	5,06	5,17	0
W (ISO paper, D65)	0,320	0,339	83,68	88,60	89,47	95,41	-0,98	4,76	4,86	0
N (black printing colour)	0,312	0,325	2,42	2,52	2,81	18,01	0,50	-0,46	0,69	0
N0 (ideal black#, D65)	—	—	0,02	0,00	0,12	0,00	0,84	-1,68	1,89	0

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Basic offset colour or mixture colour for D65 ORS18a with YW=88,6	chromaticity		tristimulus values			adapted CIELAB data LAB* _{a,d}					relative CIELAB data lab* _a										
	x _{a,d}	y _{a,d}	X _{a,d}	Y _{a,d}	Z _{a,d}	L* _{a,d}	a* _{a,d}	b* _{a,d}	C* _{ab,a,d}	h _{ab,a,d}	r* _a	g* _a	b* _a	n* _a	c* _a	h* _a	e* _a	u* _a	v* _a		
<i>three subtractive basic colours: printing colours acc. to ISO 2846-1</i>																					
C _d cyan (cyan blue)	0,161	0,228	18,79	26,62	71,32	58,62	-30,34	-45,01	54,30	236	0,00	1,00	1,00	0,00	1,00	0,656	0,669	G67B	0,50		
M _d magenta (magenta red)	0,454	0,232	33,08	16,90	22,90	48,13	75,28	-8,36	75,74	354	1,00	0,00	1,00	0,00	1,00	0,982	0,931	B72R	0,50		
Y _d yellow	0,439	0,494	68,47	77,10	10,48	90,37	-10,26	91,75	92,32	96	1,00	1,00	0,00	0,00	1,00	0,268	0,264	Y05G	0,50		
<i>three subtractive mixture colours: # DIN 33866-colours; ISO reference paper</i>																					
R _d red (orange red)	0,605	0,336	30,15	16,75	2,90	47,94	65,39	50,52	82,63	38	1,00	0,00	0,00	0,00	1,00	0,105	0,047	R18Y	0,50		
G _d green (leaf green)	0,249	0,548	8,72	19,18	7,07	50,90	-62,83	34,96	71,91	151	0,00	1,00	0,00	0,00	1,00	0,419	0,461	Y84G	0,50		
B _d blue (violet blue)	0,215	0,140	7,14	4,65	21,44	25,72	31,10	-44,40	54,22	305	0,00	0,00	1,00	0,00	1,00	0,847	0,822	B28R	0,50		
<i>achromatic colours: # calculated by linear chroma extrapolation in the CIELAB colour space</i>																					
W1 (ideal white#, D65)	0,313	0,329	95,05	100,00	108,92	100,00	0,00	0,00	0,00	0	1,05	1,05	1,05	0,00	0,00	0,00	0,00	—	—	1,05	
W (ISO paper, D65)	0,313	0,329	84,21	88,60	96,48	95,41	0,00	0,00	0,00	0	1,00	1,00	1,00	0,00	0,00	0,00	0,00	—	—	1,00	
N (black printing colour)	0,313	0,329	2,40	2,52	2,74	18,01	0,00	0,00	0,00	0	0,00	0,00	0,00	1,00	0,00	0,00	0,00	—	—	0,00	
N0 (ideal black#, D65)	—	—	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0	-0,19	-0,19	-0,19	1,19	0,00	0,00	0,00	—	—	-0,19	

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Annex C Relation of standard and relative CIELAB coordinates

C.1 Terms and definitions of special colorimetric data

In addition to the terms and the definitions of clause 3.1 *Colorimetric data* the maximum colours M of maximum chroma C^*_{ab} of a standard 48 step hue circle and their mixtures are defined. The families of the different colorimetric data of clause 3.1 are now given in Table C.1 and subdivided in Table C.2.

C.1.2

Colorimetric data of maximum colours M of a device system

Three colour data of a 48 step hue circle including the colorimetric linear mixture colours of two neighboring colours C .

NOTE 1: In the standard CIELAB-chroma diagram (a^*, b^*) and in the *adapted* CIELAB-chroma diagram (a^*_a, b^*_a) the maximum colours M create a closed figure by the 48 steps, and in the *relative* CIELAB-chroma diagram (a^*_r, b^*_r) a circle

NOTE 2: For many applications the adapted maximum colours M_a of a 256 step hue circle (8bit) are appropriate for fast colorimetric transfers. Such a table for 360 CIELAB hue angles h_{ab} usually includes the corresponding *rgb*-input data, the CIELAB $L^*, a^*, b^*, C^*_{ab}, h_{ab}$ data and other data for fast transformations between device or device coordinates rgb_{dd} and device to elementary coordinates rgb_{de} .

C.2 Colorimetric data of Maximum colours M in table form

Table C.1 — Examples of colorimetric data of maximal colours M of a device system

Colorimetric data of maximum colours M of a device (d) or elementary (e) system					
colorimetric name	family	family member	coordinate kind	coordinate (compare CIELAB $L^*, C^*_{ab}, h_{ab}, a^*, b^*$)	coordinate name
<i>standard</i> CIELAB	LAB^*	$LAB^*LCH^*_M$ or $LAB^*LAB^*_M$	cylindrical or kartesic	$L^*_M = LAB^*L^*_M$ $C^*_M = LAB^*C^*_{ab,M}$ $H^*_M = LAB^*h_{ab,M}$ $A^*_M = LAB^*a^*_M$ $B^*_M = LAB^*b^*_M$	lightness chroma hue angle red green chroma yellow blue chroma
<i>adapted</i> CIELAB (a)	LAB^*_a	$LAB^*_aLCH^*_{a,M}$ or $LAB^*_aLAB^*_{a,M}$	cylindrical or kartesic	$L^*_{a,M} = LAB^*_aL^*_{a,M}$ $C^*_{a,M} = LAB^*_aC^*_{a,M}$ $H^*_{a,M} = LAB^*_aH^*_{a,M}$	adapted lightness ($= L^*_M$) adapted chroma adapted hue angle ($0 \leq H^*_{a,M} \leq 360$)
<i>relative</i> CIELAB (r)	lab^*	$lab^*lch^*_M$ or $lab^*lab^*_M$	cylindrical or kartesic	$l^*_M = lab^*l^*_M$ $c^*_M = lab^*c^*_M$ $h^*_M = lab^*h^*_M$	relative lightness relative chroma relative hue ($0,00 \leq h^*_M \leq 1,00$)

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Table C.2 — Examples of colorimetric data and linear relationship

Colorimetric <i>standard</i> CIELAB data and linearly related <i>adapted</i> and <i>relative</i> CIELAB data					
colorimetric name	family	family member	coordinate kind	coordinate (compare CIELAB $L^*, C_{ab}^*, h_{ab}, a^*, b^*$)	coordinate name
<i>standard</i> CIELAB	LAB^*	LAB^*LCH^* or LAB^*LAB^*	cylindrical or kartesian	$L^* = LAB^*L^*$ $C^* = LAB^*C_{ab}^*$ $H^* = LAB^*h_{ab}$ $A^* = LAB^*a^*$ $B^* = LAB^*b^*$	lightness chroma hue angle red green chroma yellow blue chroma
<i>adapted</i> CIELAB (a)	LAB_a^*	$LAB_a^*LCH_a^*$ or $LAB_a^*LAB_a^*$	cylindrical or kartesian	$L_a^* = LAB_a^*L_a^*$ $C_a^* = LAB_a^*C_a^*$ $H_a^* = LAB_a^*H_a^*$	adapted lightness (= L^*) adapted chroma adapted hue angle ($0 \leq H_a^* \leq 360$)
<i>relative</i> CIELAB (r)	lab^*	lab^*lch^* or lab^*lab^* or lab^*tch^* or lab^*tab^*	cylindrical kartesian cylindrical kartesian	$l^* = lab^*l^*$ $c^* = lab^*c^*$ $h^* = lab^*h^*$ $a_r^* = lab^*a_r^*$ $b_r^* = lab^*b_r^*$ $t^* = lab^*t^*$	relative lightness relative chroma relative hue relative a-red green chroma relative b-yellow blue chroma relative triangle lightness
		lab^*nch^* or lab^*nce^* or lab^*ncu^* or lab^*tce^* or lab^*try^*	triangle-cylindrical triangle-cylindrical triangle-cylindrical cylindrical kartesian	$n^* = lab^*n^*$ $c^* = lab^*c^*$ $h^* = lab^*h^*$ $e^* = lab^*e^*$ $u^* = lab^*u^*$ $r^* = lab^*r^*$ $y^* = lab^*y^*$ $t^* = lab^*t^*$	relative blackness relative chroma relative hue relative elementary hue text relative elementary hue relative r-red green chroma relative j-yellow blue chroma relative triangle lightness
		$lab^*rgb_d^*$	kartesian	$r_d^* = lab^*r_d^*$ $g_d^* = lab^*g_d^*$ $b_d^* = lab^*b_d^*$	relative device red relative device green relative device blue
		$lab^*cmy_d^*$	kartesian	$c_d^* = lab^*c_d^*$ $m_d^* = lab^*m_d^*$ $y_d^* = lab^*y_d^*$	relative device cyan relative device magenta relative device yellow
		$lab^*rgb_e^*$	kartesian	$r_e^* = lab^*r_e^*$ $g_e^* = lab^*g_e^*$ $b_e^* = lab^*b_e^*$	relative elementary red relative elementary green relative elementary blue
		$lab^*cmy_e^*$	kartesian	$c_e^* = lab^*c_e^*$ $m_e^* = lab^*m_e^*$ $y_e^* = lab^*y_e^*$	relative elementary cyan relative elementary magenta relative elementary yellow

Annex D

Automatic colour measurement of output colours on displays

The standard test chart G with 1080 colours in Fig. 17 on page 23 needs to be measured automatically within less than one hour. For printer output this is possible with an *xy*-colour measuring equipment, for example of the companies *Gretag Macbeth* or *XRite*. In the paper case the output of the test chart G with 1080 colours on standard paper is used. For display output the following two *PDF* files produce 57 and 1080 colour pages for the display measurement. A file for the output of 48 hue steps and 9 grey steps produces the following output page no. 1



Fig D.1 — Display output for colour measurement of a 48 step hue circle and 9 grey steps

Fig. D.1 shows the first page of the display output for colour measurement of a 48 step hue circle and the 9 grey steps. A continuous number between 1 and 57, and for example the device hue text u_d^* ($= R00Y_d = o00y$), and the *rgb*-input data ($= 1\ 0\ 0$)_d are given (bottom left). For the 57 colours see the following URL (57 pages, 60 KB):

<http://130.149.60.45/~farbmetrik/SE59/SE59L0NP.PDF>

For the 1080 standard colours see the following URL (1080 pages, 1,8 MB):

<http://130.149.60.45/~farbmetrik/SE60/SE60L0NP.PDF>

Both files are useful for the separate measurement of colours and if no automatic measurement is available.

For automatic measurement the 1080 colours are produced one by one and measured. A computer program has been developed for the computer operating system *Windows* (installed on a *Macintosh* computer) by J.

Witt for the *high precision colorimeter C1210* of the company *LMT Lichtmesstechnik (Berlin)* at the *Federal Institute for Material Research and Testing (BAM, Berlin)*.

Note: The computer program menu is in German, for example *Starte Messprogramm* is used instead of *start measurement program*.

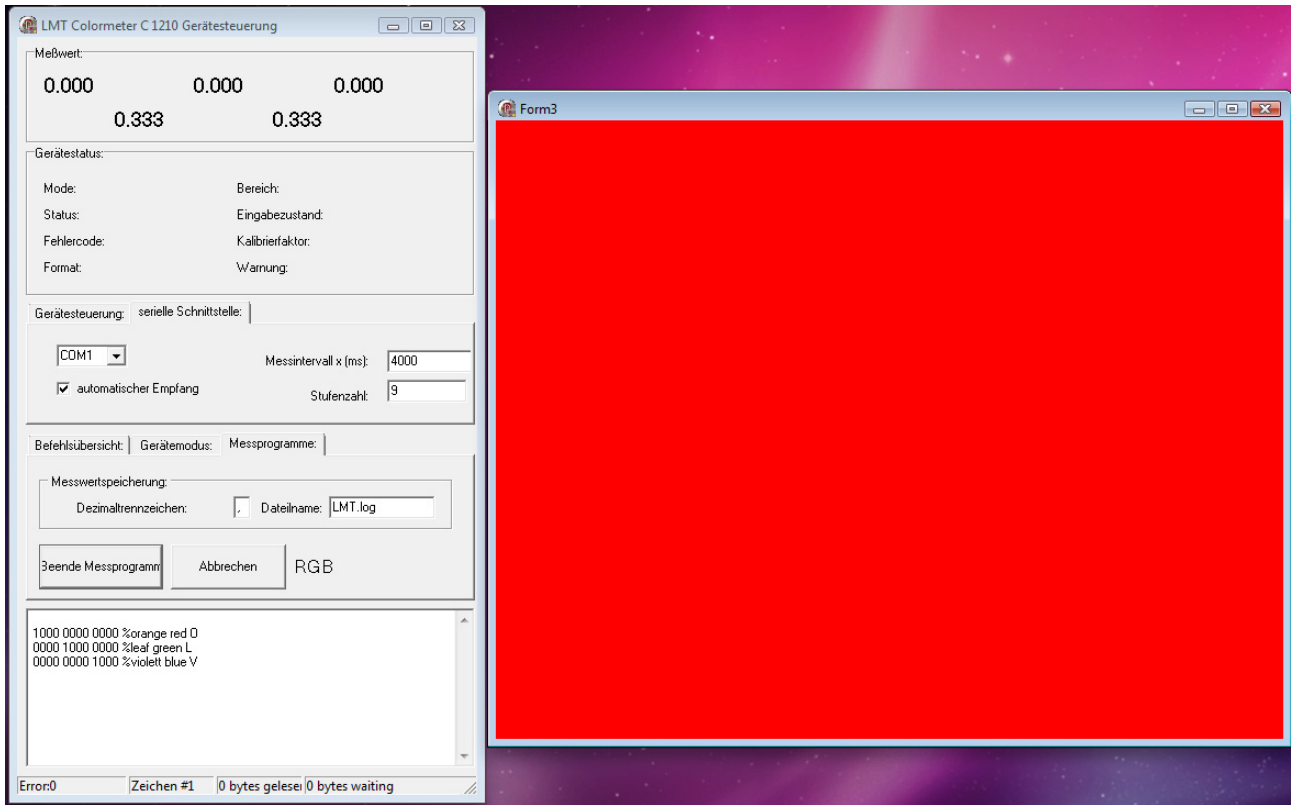


Fig. D.2 — Automatic colour measurement of 1080 standard colours with a colorimeter

Fig. D.2 shows an example output for the automatic colour measurement of 57 or 1080 standard colours with a colorimeter. The colour measurement produces the CIE chromaticity coordinates x , y and the illuminance E in lux (proportional to the tristimulus value Y). It takes about 5s for one colour measurement and therefore it takes about 1,5 hours to measure the 1080 standard colours of Fig. 17 on page 23 (Test chart Grid G).

The program menu allows to measure for example 9x9x9 steps automatically (as indicated by the number 9). If by the technology *copy and paste* the *rgb*-input data (for example 57, or 1080 data) are included in the rectangle at the bottom, then this *rgb*-input data are used to produce and measure the colours in the right window. In the example the device colour R_d (Orange red O) with the *rgb*-input data sequence *1000 0000 0000%Red* R_d (Orange red O) is measured.

If an external data projector, for example a VGA device, is connected to the computer, then the colours in the projection can be measured.

The measurement data of for example 1080 colours appear in a file *LMT.log*. These data are included for example in lines 672 to 1753 of the *PS* file (download the *PostScript* file with ".TXT" instead of ".PS")

<http://130.149.60.45/~farbmetrik/SE61/SE61L0NP.PDF>

The output pages 1 and 2 of the corresponding *PDF* file shows the *rgb*-input data (slightly changed by the 8bit *rgb*-input coding which are necessary for output on most displays). In addition the CIE chromaticities x , y and

the tristimulus values Y_m is shown which is not normalized. The value of Y_m is equal to the illuminance E in lux. On page 2 the measurement value is 365 lux for White W (no.1074).

The eight last colours in Fig. 17 on page 23 are the achromatic colours Black N (no. 1073) and White W (no. 1074) and the six colours $RCYBGM_d$ produced for the input values $(1\ 0\ 0)_d$, $(0\ 1\ 1)_d$, $(1\ 1\ 0)_d$, $(0\ 0\ 1)_d$, $(0\ 1\ 0)_d$, $(1\ 0\ 1)_d$, (no. 1075 to 1080).

On page 1 and 2 the rgb -input data and the measured x , y , Y_m (measured in lux) data are shown. On page 3 and 4 the rgb -input data and the measured x , y , Y_n data are shown. The tristimulus value Y_n is normalized to 100 for white W (colour no. 1074).

In a similar file the CIE XYZ and $L^*C^*_{ab}h_{ab}$ are calculated (4 pages, 225 KB)

<http://130.149.60.45/~farbmetrik/SE62/SE62L0NP.PDF>

The pages 1 and 2 of the file output show the CIE data with the standard normalization $Y=88,6$. The output of the pages 3 and 4 show the data $rgb^*=rgb_{dd}$ which are necessary to produce the intended CIE data $(L^*C^*_{ab}h_{ab})_d$. These data have been calculated by the 3D output linearization method.

Annex E

Device-independent visual RGB* colour space

This Annex E considers the recent publication of the report CIE R1-57:2013 *Border between luminous and blackish colours*.

Table E.1 — The colorimetric coordinates of the Ostwald colours for CIE standard illuminant D65

rgb*_e and CIE data of a elementary hue circle according to CIE R1-47 for Ostwald colours															
<i>XYZ, xy, YAB, and Lab* data for relative spacing of elementary hue h_{ab} of CIELAB</i>															
16 step elementary hue circle with intended elementary hues: h_{ab} = 25.4, 92.3, 162.2, 271.7 of CIELAB															
	X	Y	Z	x	y	A	B	C _{AB}	h _{AB}	L*	a*	b*	C* _{ab}	h _{ab}	rgb -> rgb* _{oe}
R00Y=R_{oe}	66.0	41.1	20.9	0.515	0.321	26.9	9.5	28.5	19.5	70.3	70.9	33.4	78.4	25.2	1.00 0.00 0.00
R25Y_{oe}	64.0	41.5	6.4	0.571	0.371	24.5	15.5	29.0	32.3	70.5	65.1	71.4	96.6	47.6	1.00 0.25 0.00
R50Y_{oe}	62.6	41.7	1.0	0.593	0.396	22.8	17.7	28.9	37.8	70.7	61.2	106.3	122.7	60.0	1.00 0.50 0.00
R75Y_{oe}	71.1	58.7	0.1	0.546	0.451	15.3	25.5	29.7	59.0	81.1	35.2	137.3	141.7	75.6	1.00 0.75 0.00
Y00G=Y_{oe}	76.8	83.9	1.3	0.473	0.517	-2.9	36.0	36.1	94.7	93.4	-5.9	141.9	142.0	92.3	1.00 1.00 0.00
Y25G_{oe}	65.9	89.6	6.7	0.406	0.552	-19.2	36.3	41.1	117.8	95.8	-39.4	113.6	120.3	109.1	0.75 1.00 0.00
Y50G_{oe}	43.7	79.6	8.1	0.332	0.605	-31.9	31.4	44.7	135.4	91.5	-77.3	101.2	127.3	127.3	0.50 1.00 0.00
Y75G_{oe}	26.4	67.7	12.4	0.247	0.635	-38.0	24.5	45.2	147.1	85.9	-113.0	78.6	137.7	145.1	0.25 1.00 0.00
G00B=G_{oe}	21.8	61.8	31.6	0.189	0.536	-36.9	14.2	39.5	158.8	82.8	-119.5	57.9	125.4	162.3	0.00 1.00 0.00
G25B_{oe}	27.8	58.9	81.5	0.165	0.349	-28.1	-6.9	28.9	193.9	81.2	-86.9	-13.9	88.0	189.1	0.00 1.00 0.50
G50B_{oe}	25.6	45.4	108.7	0.142	0.252	-17.5	-23.7	29.5	233.5	73.1	-61.3	-46.1	76.7	216.9	0.00 1.00 1.00
G75B_{oe}	20.2	29.3	108.4	0.128	0.185	-7.6	-30.6	31.5	256.0	61.0	-33.4	-66.8	74.7	243.4	0.00 0.50 1.00
B00R=B_{oe}	18.4	18.7	107.7	0.127	0.129	0.6	-34.9	34.9	271.0	50.4	3.3	-84.8	84.9	272.2	0.00 0.00 1.00
B25R_{oe}	18.0	8.8	105.2	0.136	0.067	9.5	-38.2	39.4	284.0	35.7	64.2	-108.5	126.1	300.6	0.50 0.00 1.00
B50R_{oe}	61.7	26.3	99.4	0.329	0.14	36.7	-28.3	46.3	322.3	58.3	112.5	-65.8	130.3	329.6	1.00 0.00 1.00
B75R_{oe}	71.2	40.6	51.0	0.437	0.249	32.5	-2.6	32.6	355.2	69.9	83.6	-7.1	83.9	355.1	1.00 0.00 0.50
5 step equidistant grey scale with intended lightness: L* = 0.0, 25.0, 50.0, 75.0, 100.0															
N000W=N0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00 0.00 0.00
N025W	4.1	4.4	4.8	0.312	0.329	0.0	0.0	0.0	77.5	25.0	0.0	0.0	0.0	0.0	0.25 0.25 0.25
N050W	17.5	18.4	20.0	0.312	0.329	0.0	0.0	0.0	55.3	50.0	0.0	0.0	0.0	0.0	0.50 0.50 0.50
N075W	45.8	48.2	52.5	0.312	0.329	0.0	0.0	0.0	21.0	75.0	0.0	0.0	0.0	0.0	0.75 0.75 0.75
N100W=W95.0	100.0	100.0	108.8	0.312	0.329	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	1.00 1.00 1.00

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Table E.1 shows the colorimetric coordinates of the Ostwald colours for a 16 step elementary hue circle and a 5 step grey scale, see Table 1 of CIE R1-57:2013.

In Table E.1 in general the CIELAB chroma C*_{ab} is much larger compared to the data in Table 3 on page 17 for the sRGB colour space. An exception is the red colour R00Y_e with the chroma C*_{ab,oe}=78,4 compared to C*_{ab,sRGBe}=86,4. However, because Red of the sRGB display is chosen outside the Ostwald colour gamut and has a larger chroma compared to the Ostwald colour, then the opponent colour has a much lower chroma C*_{ab} compared to the Ostwald colour. One can expect that the sum of the chroma of the opponent colours in the sRGB colour space (86,4+42,5=128,9) is less compared to the sum of the chroma of the opponent colours in the Ostwald colour space (78,4+76,7=155,1). For highest colour contrast the display manufacturers and printer companies may try to fill the Ostwald colour gamut to reach the highest chromatic image contrast.

Table E.1 uses special rgb*_{oe} data (Index oe for the Ostwald (o) elementary (e) colours). Again a linear relation between any CIELAB data and these rgb*_{oe} data may be used in both directions, compare Table 3 on page 17 (left and right). However, the rgb*_{oe} data have now a visual definition and the values are related to visual appearance.

For example, if one of the three rgb^*_{oe} data has the value 1, then the colour appears neither luminous nor blackish according to CIE R1-57. Therefore any of the colours in Table E.1 has the relative blackness $n^*_o=0$, (or brilliance $i^*_o=1$), and the relative chroma $c^*_o=1$. The relative elementary hue e^* (an Index o is not necessary) changes by the value $\Delta e^*=0,0625$ for one step of the 16 step colour circle. It is for example $e^*=0,00$ for R_{oe} , $e^*=0,25$ for Y_{oe} , $e^*=0,50$ for G_{oe} , and $e^*=0,75$ for B_{oe} ,

If one compares the colour triangles based on Table E.1 with the triangles in Fig. 25 on page 38 then in general any device triangle (of the *sRGB* display, of the offset print, or of a laser printer) is smaller compared to the triangle of the *Ostwald* colours.

For applications it may be appropriate to adapt the tristimulus values of the *Ostwald* colours to the tristimulus values $Y=88,6$ for white and $Y=2,5$ for black of both standard offset and displays according ISO/IEC 15775 and ISO 9241-306. In general the *Ostwald* triangles are much larger compared to the application triangles. Therefore one can expect that any surface colour will have rgb^*_{oe} data between zero and 1, and in addition with a *linear relation* to the CIELAB data for all surface colours in both directions.

If the CIELAB data are outside the *Ostwald* gamut then still there is a *linear relation* in both directions, However, in this case for example one of three rgb^*_{oe} data has a value larger one, and this may happen for fluorescent red colours. In applications a larger colour gamut can be used, if for example wide gamut rgb^*_{oe} data with values between $-0,5$ and $1,5$ are allowed. This seems to be useful for highlight and/or fluorescent colours.

An example for the calculation of the rgb^*_{oe} data for the given data $(L^*, C^*_{ab}, h_{ab})_{o,Ye}$ and $(L^*, C^*_{ab}, h_{ab})_{sRGB,Ye}$ of yellow Ye will explain the linear relation between rgb^* , nce^* , and CIELAB data: Table E.1 on page 62 includes the following data of the elementary (e) yellow of the *Ostwald* (o) colour:

$$(L^*, C^*_{ab}, h_{ab})_{o,Ye} = (93,4 \ 142,0 \ 92,3).$$

The corresponding rgb^* data in the device-independent visual RGB^* colour space are $rgb^*_{o,Ye} = (1 \ 1 \ 0)_{o,Ye}$. Table 3 on page 17 includes the following data for the elementary (e) yellow of the *sRGB* display colour:

$$(L^*, C^*_{ab}, h_{ab})_{sRGB,Ye} = (83,6 \ 84,3 \ 92,3)$$

The corresponding rgb^* data in the device-dependent *sRGB* colour space are $rgb^*_{sRGB,Ye} = (1 \ 1 \ 0)_{sRGB,Ye}$

It is first intended to calculate the relative chroma c^* and relative blackness n^* for the elementary yellow of the *sRGB* display in the visual RGB^* colour space.

$$\begin{aligned} c^*_{o,Ye} &= C^*_{ab,sRGB,Ye} / C^*_{ab,o,Ye} \\ &= 84,3 / 142,0 = \mathbf{0,59} \end{aligned}$$

$$\begin{aligned} n^*_{o,Ye} &= 1 - 100 C^*_{ab,o,Ye} / [C^*_{ab,sRGB,Ye} (100 - L^*_{o,Ye}) + L^*_{sRGB,Ye} C^*_{ab,o,Ye}] \\ &= 1 - 100 \cdot 93,4 / [84,3 (100 - 93,4) + 83,6 \cdot 142,0] = \mathbf{0,25} \end{aligned}$$

The data are used to calculate the data $rgb^*_{o,Ye}$ in the device-independent visual RGB^* colour space: We use the general equations $c^* = \max (rgb^*) - \min (rgb^*)$ and $n^* = 1 - \max (rgb^*)$. Therefore the maximum value of $rgb^*_{o,Ye}$ is 0,75. The difference to the lowest $rgb^*_{o,Ye}$ value is 0,59. The **triple solution** for the *sRGB*-yellow with

$$(L^*, C^*_{ab}, h_{ab})_{sRGB,Ye} = (83,6 \ 84,3 \ 92,3) \text{ is } nce^*_{o,Ye} = (0,25 \ 0,59 \ 0,25) \text{ and } rgb^*_{o,Ye} = (0,75 \ 0,75 \ 0,16)$$

The colour coordinates nce^*_{oe} are the mostly used colour coordinates in the area of art, design, and architecture, compare the *Swedish Natural Colour System NCS*. The coordinates rgb^*_{oe} , which are now applied for the area of image technology, are connected by linear equations to nce^*_{oe} . In addition the coordinate systems of both areas are connected with the CIELAB coordinates of colorimetry..

In addition the example shows a weak point of the *sRGB* colour space. The blackness $n^*_{oe} = 0,25$ of the elementary yellow Y_e of *sRGB* displays is too large for many users in the area of art, design and architecture.