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Technical Note 27

Selected Problems of Display and Projection Color Measurement

- Minimum Optical Resolution of a Spectro radiometer for Laser Projection Measurement
- Device Comparability
- Color Mismatch of Monitors

Minimum Optical Resolution of a Spectro radiometer for Laser Projection Measurement

The request for high resolution spectro radiometers becomes more and more popular especially due to the increased use of laser based projections.

In this chapter, it will be investigated which optical resolution (FWHM) is necessary for a spectro radiometer to measure laser projection systems correctly with regard to the luminance and chromaticity.

It can be distinguished between pure RGB lasers and the hybrid type with a blue laser and fluorescence material. Here the most critical case, a RGB laser projector will be investigated.

First of all there will be discussed the definitions for the resolution of a spectro radiometer. There exist three different parameters with respect to the resolution which are sometimes mixed:

The **optical resolution**, also called bandwidth or Full Width at Half Maximum (FWHM), is the real limiting resolution parameter. It describes

- the spectral widening of a very narrow spectral line, e.g. of a laser or a discharge lamp, caused by the optical system of the spectrograph.

The **digital resolution**, also pixel resolution (nm/ pixel), is the spectral bandwidth which falls on one pixel of the spectrograph detector array. It should be at least

- 1/3 of the optical resolution, otherwise it will be the limiting factor.

The **calculated resolution** value is the interpolated step with of the spectral calculation. Typical values used for spectro radiometers are 1 and 5 nm.

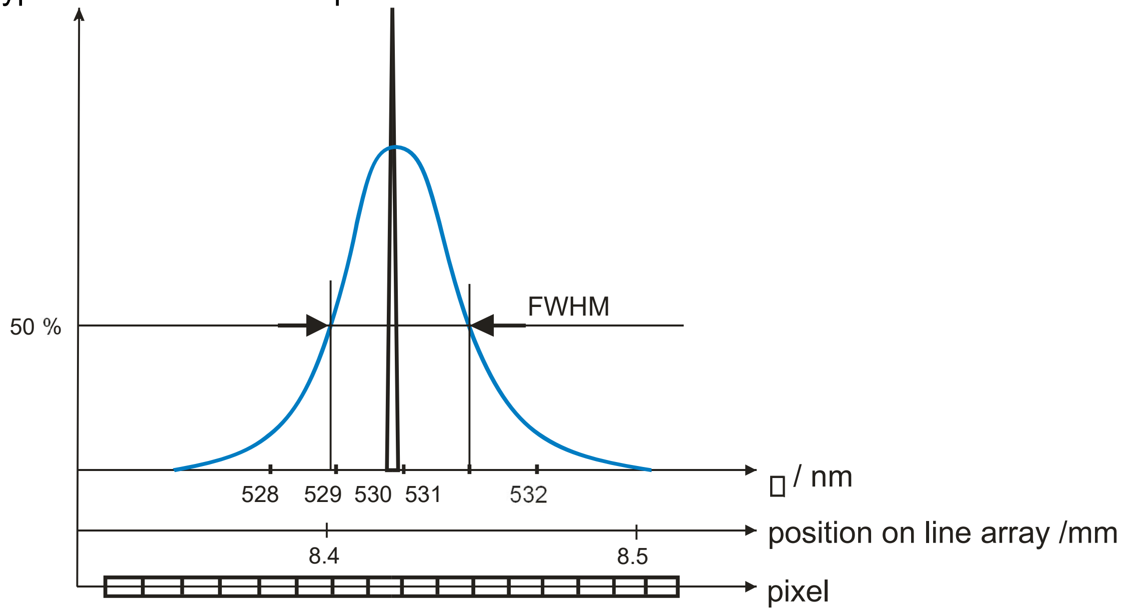
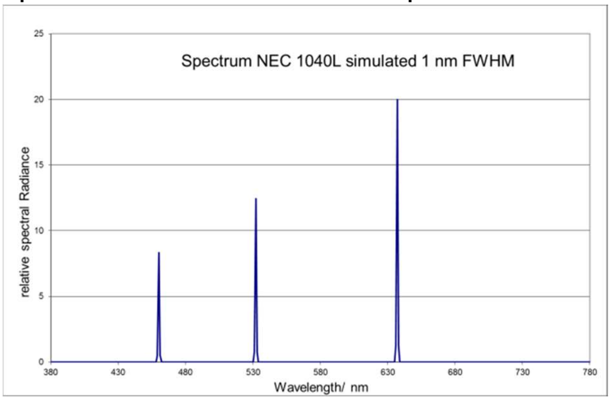
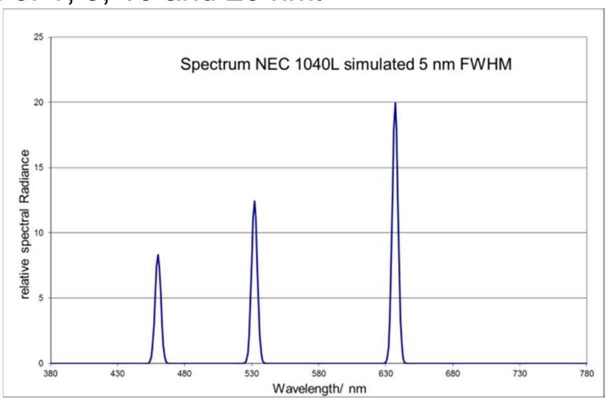


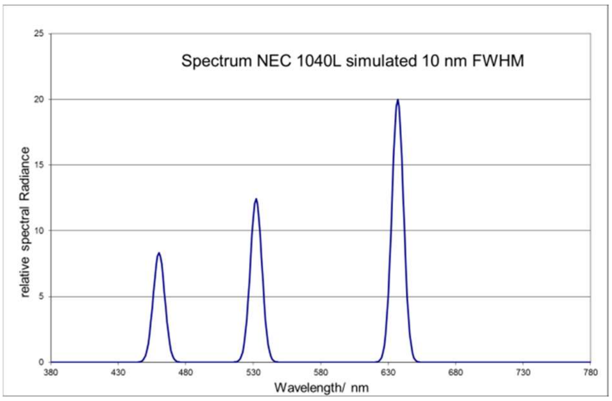
Fig. 1: Different resolution definitions of a peak

Now we will consider a RGB laser projector, e.g. the NEC 1040L. Its light source is a combination of the three laser wavelengths of 460 nm (blue), 532 nm (green) and 637 nm (red).

The following diagrams show simulated white spectra of this projector when detected by a spectro radiometer with an optical resolution of 1, 5, 10 and 20 nm.







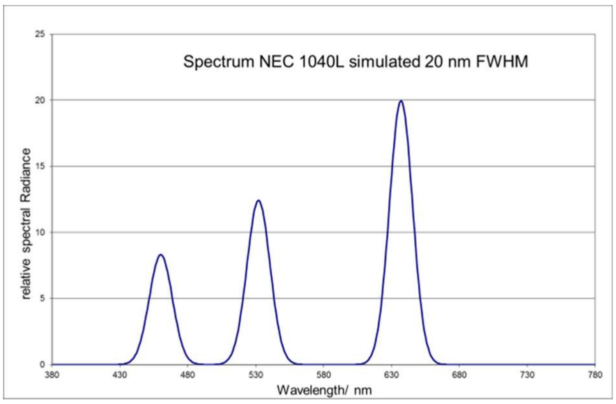


Fig. 2: Simulated projector spectra with different optical resolution

The following diagrams show the x and the y value calculated for the optical resolution of 1 to 20 nm in steps of 1 nm. It can be seen, that both chromaticity values are nearly constant or only slightly changing for an optical resolution of 1 to 4 … 5 nm. Hence a meter with a resolution of 4 … 5 nm is sufficient also for the calibration of laser projectors. But it has to be considered that there are many other influences on the measurement result which overlap this small change (see chapter 2).

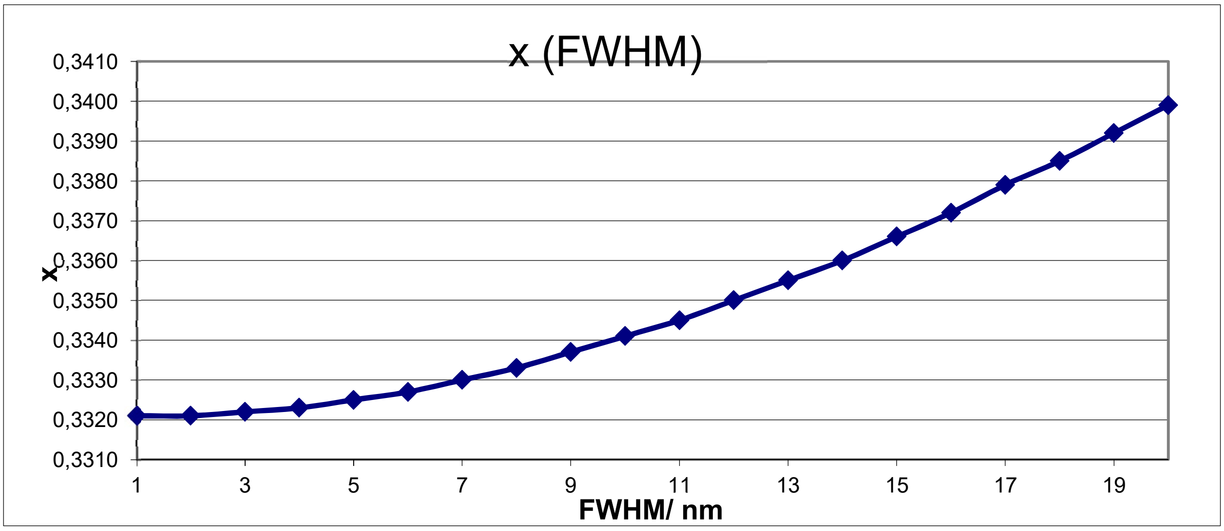


Fig. 3: Dependence of chromaticity x from the optical resolution (FWHM)

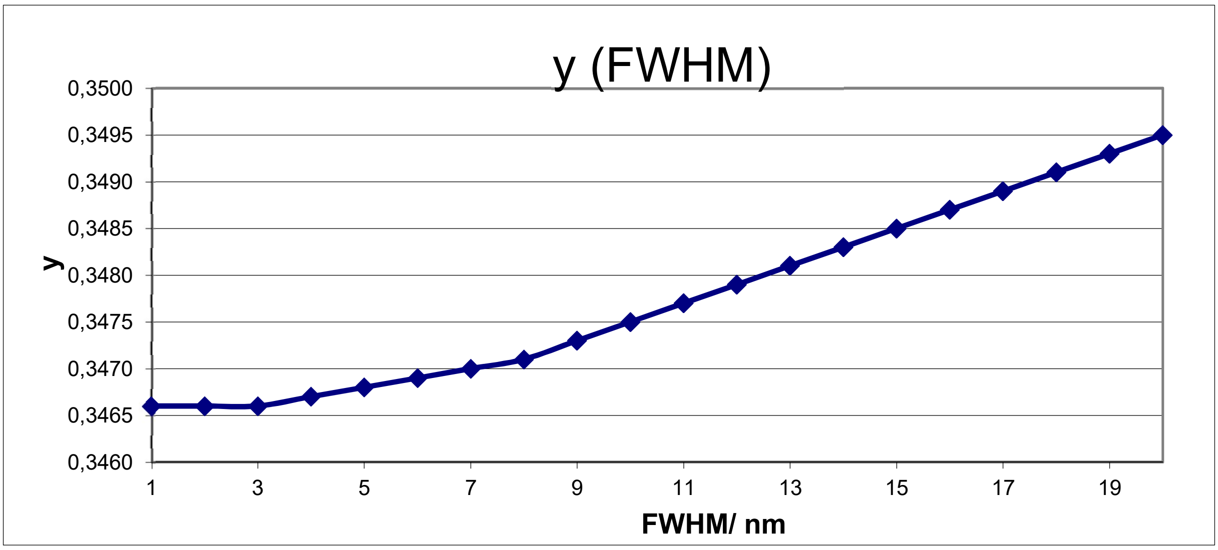


Fig. 4: Dependence of chromaticity y from the optical resolution (FWHM)

The following diagram shows the total xy shift of the same measurements and for the same change of the optical resolution.

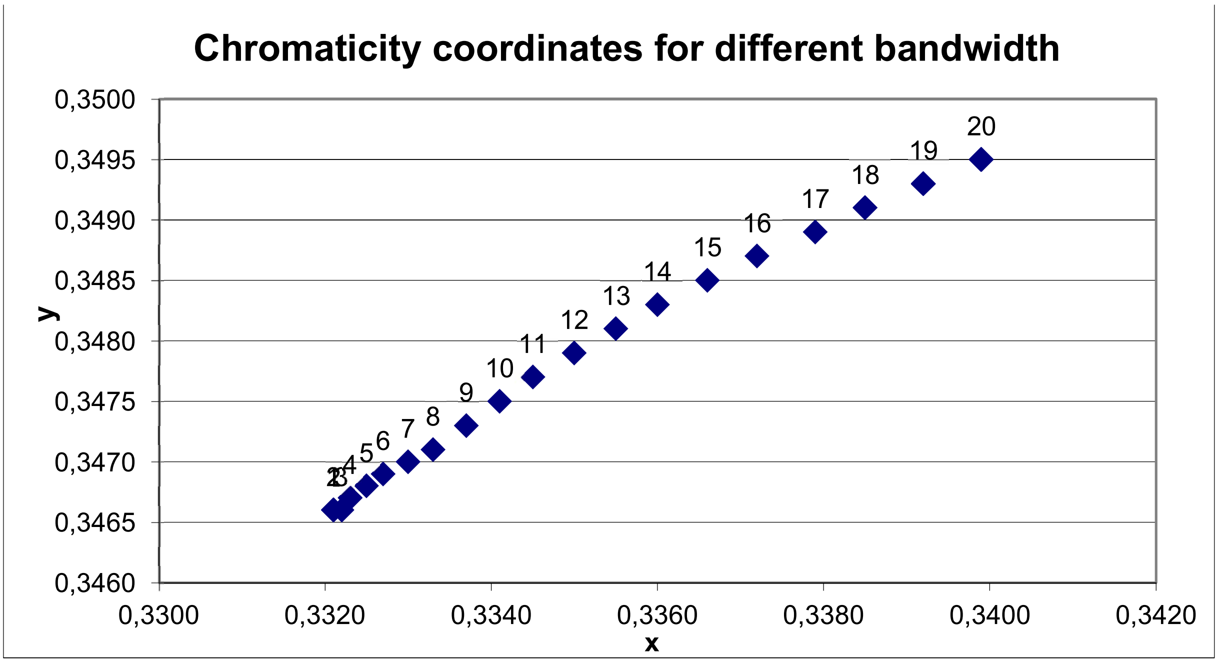


Fig. 5: Dependence of chromaticity xy from the optical resolution (FWHM in nm)

Summarizing: It is not necessary to use a device with a higher optical resolution than 4 … 5 nm for this application.

The same result is valid for non-laser projections and displays.

Device Comparability

There are several devices on the market for the measurement of color of self luminous objects, especially of monitors and projections. They are based either on the tristimulus technique (colorimeters) or on the spectral technique (spectro radiometers).

An often discussed question is the comparability of the measuring results of different devices. It can be distinguished between two levels of comparability: between devices of the same model and between different models, especially between models of different manufacturers. The different models of one manufacturer are often calibrated in the same way and the manufacturer will take care about the comparability of his products, on one side by its measuring uncertainty calculations and on the other side by practical tests.

The comparison of tristimulus and spectral measuring devices of different manufacturers can produce very different results depending from their parameters. E.g. if the deviation of the spectral responsivity of a colorimeter to the Color Matching Functions (CMF) is too high there will exist significant differences to the readings of a spectro radiometer, where the CMFs are stored in its software. The matching of the colorimeter to the spectro radiometer (profiling) will help, but only for the same shape of spectra.

Additionally, it can be shown already theoretically that differences in parameters of devices of same technology will also result in different readings. Examples for such critical parameters are the optical resolution (see chapter 1) and the stray light behaviour.

More influences are the status of calibration, in case of spectro radiometers for the wavelength axis as for the sensitivity axis as well.

Category	Examples
Measuring equipment general	Tristimulus/ Spectral Device parameters (CMF matching, Resolution, Dynamics, Straylight, Linearity, ...)
Measuring equipment individual	Calibration status of the probes (wavelength, sensitivity)
Individual errors	Warm up time too short Ambient light (reflex) Individual sensitivity

The following test is an example of comparing the measuring results of spectroradiometers (specbos 1211 (JETI), CR-250 (Colorimetry Research) and CS-2000 (Konica Minolta)), measuring a JVC LCD monitor with CCFL backlight. The diagrams show the deviations in Y, x and y of specbos 1211 and CR-250 to the readings of a CS2000 for different settings of the monitor:

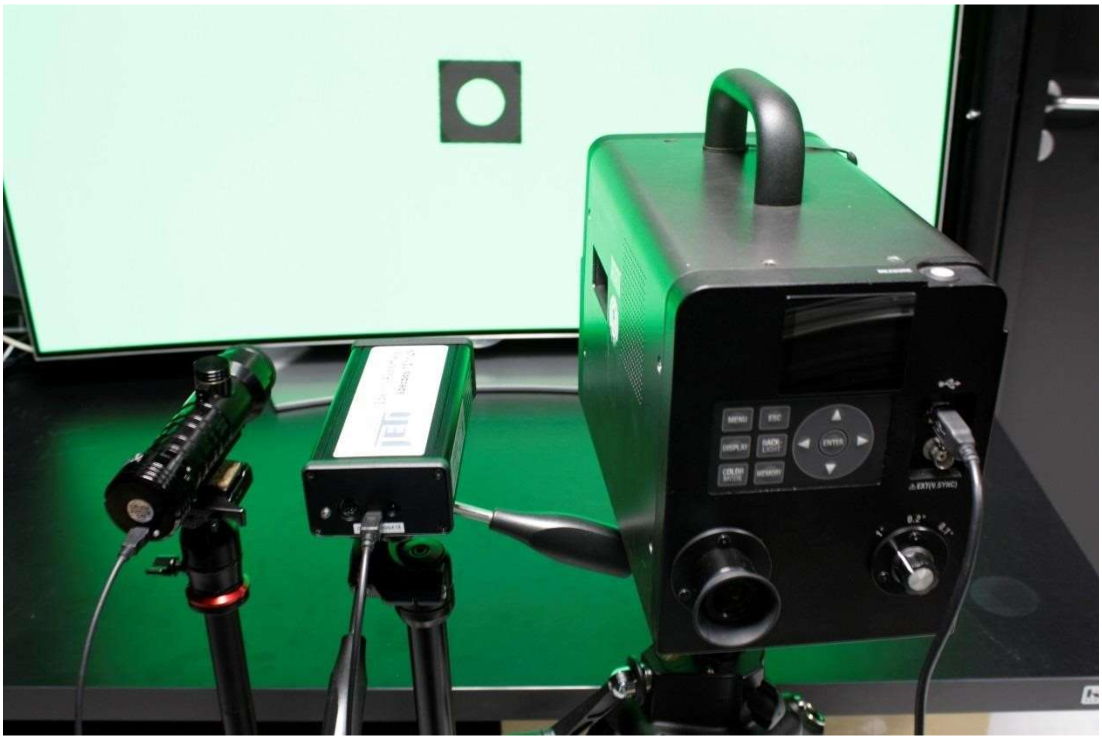


Fig. 6: CR-250, specbos 1211 and CS-2000 in front of an OLED monitor

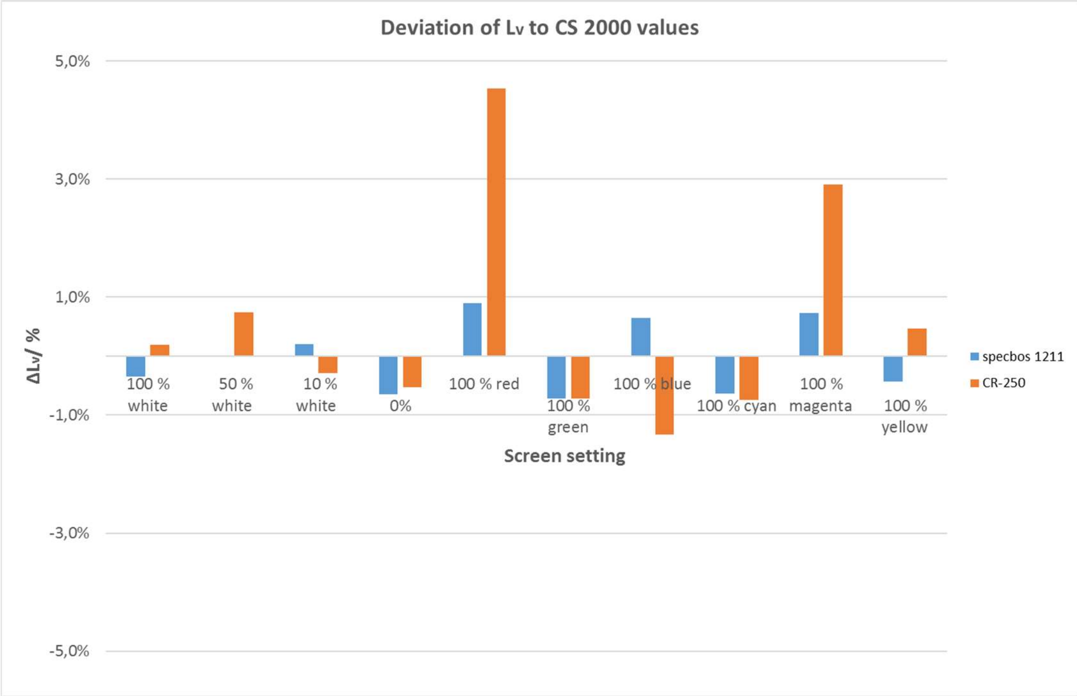


Fig. 7: Deviation of Lv of CR-250 and specbos 1211 readings to CS 2000

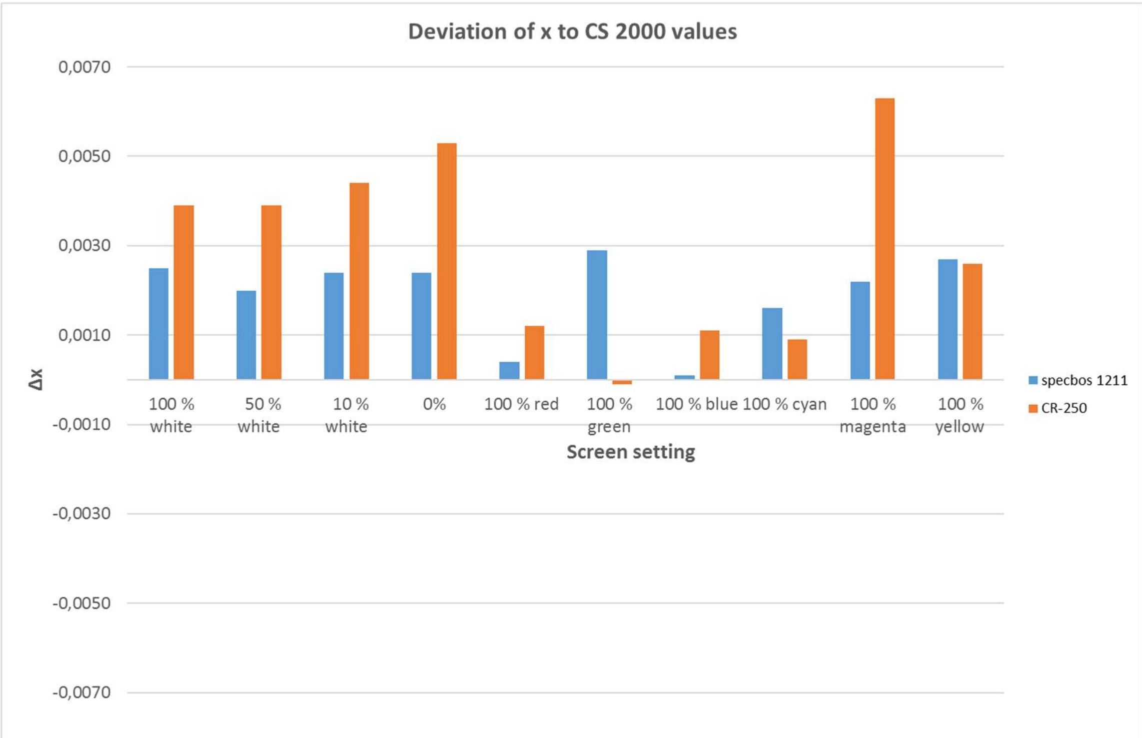


Fig. 8: Deviation of x (above) and y (below) of CR-250 and specbos 1211 readings to CS 2000

All three devices were properly calibrated and individual impacts were carefully avoided during the measurements. It can be seen that the deviation of x and y between the units is around 0.001 … 0.003 with some exceptions. For the white settings this will cause differences in CCT of 150 … 250 K.

The differences in luminance readings are in the range of 1 % with two exceptions.

Other comparisons during previous years show similar results. It can be summarized that the deviation of properly calibrated comparable devices are in the following ranges:

- up to 0.002 .. 0.003 in **xy**
- therefore the differences in **CCT** are up to 150 K
- $\mathbf{L_v}$ in the 1 ... 2 % range

The different readings are mainly caused by differences in
- o Wavelength fit
- o Level calibration
- o Spectrometer parameters (stray light, non linearity, bandwidth ...)

Color Mismatch of Monitors

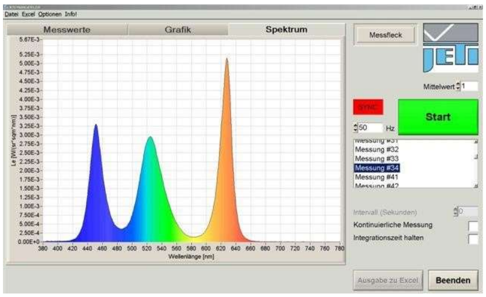
The following is an actual problem in OLED color adjustment: A precise calibration of such display can end with a slightly colored white appearance, mainly with a yellowish shade of color. A similar problem is already known for many years: Two monitors made by different display technologies might appear visually different after calibration. It is very difficult to match displays of different technologies, e.g. an LCD with LED backlight and one with CCFL backlight, to the same visual perception.

Fig. 9: CCFL/ LCD (left) and Plasma monitor (right), both set to same xyY values

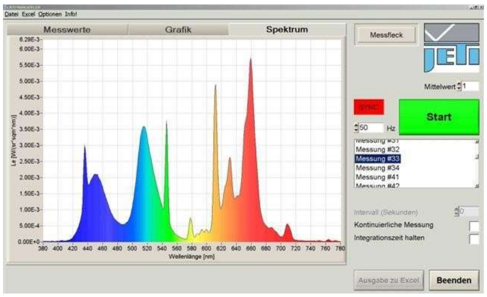
Such problems arise due to the appearance of new display technologies during previous years. There exist two approaches to solve these problems and they will be summarized here:

1. Use other than the CIE 1931 Color Matching Functions (CMF)
2. Use an offset for the xy values

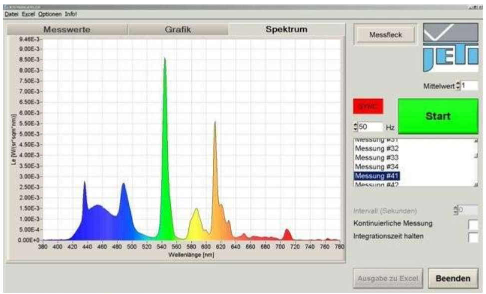
The following figure shows typical white spectra of different display technologies:



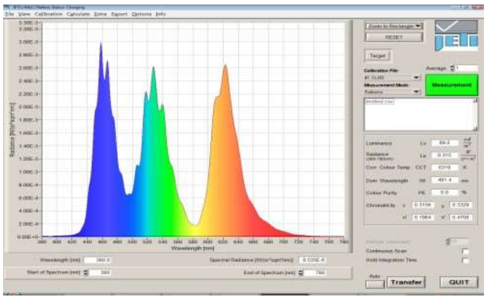
LCD with LED backlight



LCD with CCFL backlight



CRT



OLED

Fig. 10: White spectra of different displays

It can be seen that there are spectra with wide peaks and spectra with wide and narrow peaks.

Possible reasons of the problems are:

- The concept of Color Matching Functions does not simulate the human color vision correctly, e.g. the visual impression of broadband spectra is different than that of spectra with narrow band parts.
- The Color Matching Functions of 1931 do not correctly reproduce the human color vision.

1. New color matching functions

The classical light and color measurement is based on the 2° standard observer of CIE 1931. These data are based on the measurements of two color scientists (W. David Wright and John Guild) and a very limited number of test persons. It quickly became clear that these data did not fully reproduce the visual perception of the human being. So the research on alternate functions started very soon and is continued till today. The only other standardized data are these of the 10° observer of 1964. Due to the fact that the angular subtense of a TV monitor is more close to 10° than to 2° under normal conditions these data work slightly better for the calibration than the 1931 data.

A better approach is to use the data of Judd, modified by Vos (Judd Vos CMFs). If they are appliedd they give a better visual agreement than both classical CIE data, especially when used on an OLED display. 2006/ 2015 the CIE published a new document No. 170 with a data set, which is based on the data of Stiles/ Burch (1959) with a modification by Stockman. They can be calculated for different angles between 2 and 10°, but also for different observer ages.

The CIE 170 data were modified afterwards by Schanda and Csuti (University of Veszprem, Hungary), they shifted values in the blue region by – 6 nm. Recently Polster (TU Ilmenau, Germany) found a better agreement with human color vision for a shift of only – 3 nm. Many of these data can be found here: http://www.cvrl.org

One has to consider that all these data were developed based on experiments with LED illumination, but they can be used for all monitor calibrations too. The following diagrams show several CMFs, separated by $\bar{x}$, $\bar{y}$ and $\bar{z}$.

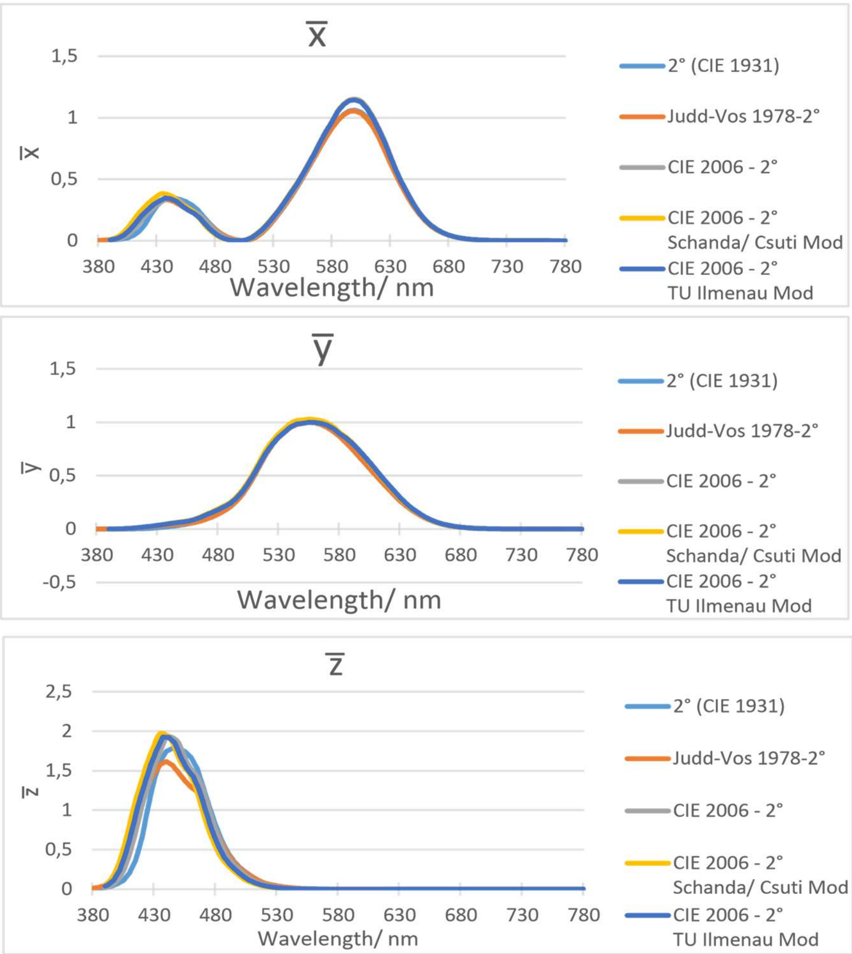


Fig. 11: Comparison of different Color Matching Functions

The software **JETI LiVal** includes the following observer functions:

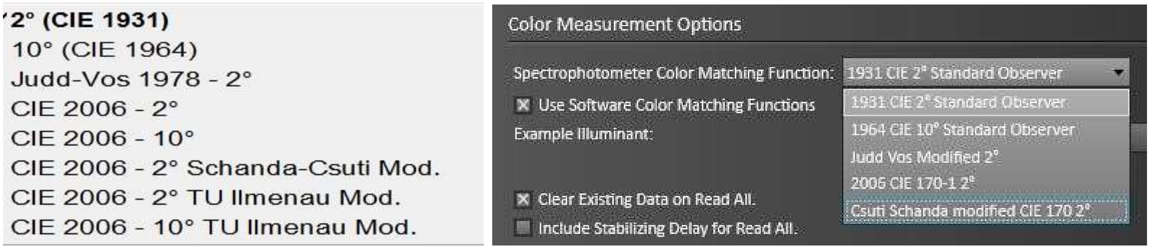


Fig. 12: JETI LiVal and CalMAN Observer settings

The application of a CMF changes the shape of the color diagram slightly:

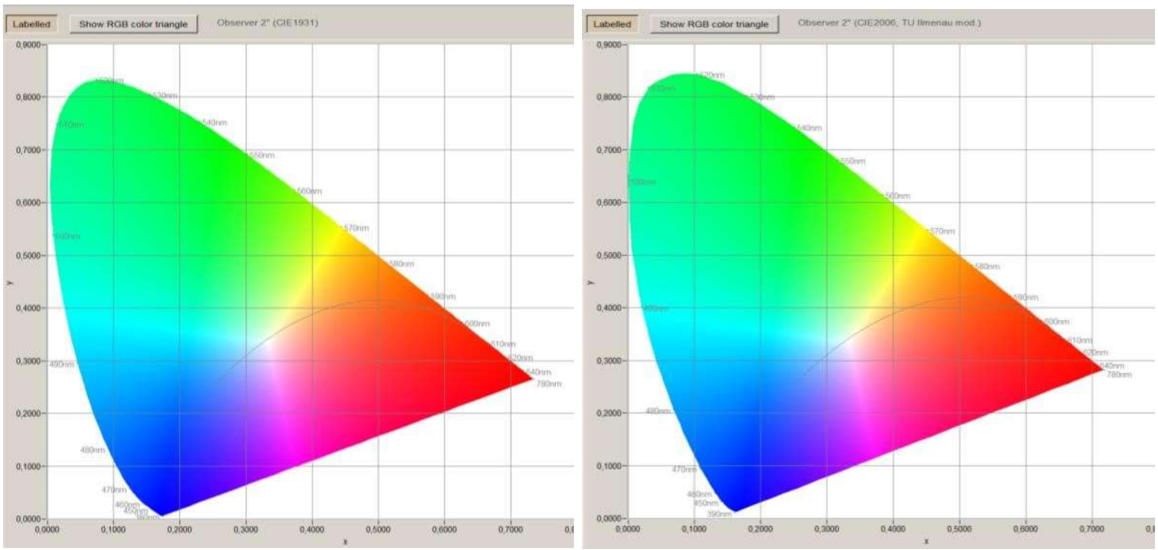


Fig. 13: xy color diagram based on CIE 1931 (left) and Polster (TU Ilmenau) 2°(right)

Tests of several users showed the new CMFs are helpful for a better calibration of monitors, but they don´t fully solve the problem. It is also not clear yet, which data are the best ones for all applications. Currently the user has to proceed his own tests.

Of course the new CMFs cannot be used with colorimeters which are designed to reproduce the CIE 1931 data. But in this case approach 2 can be used.

2. Offsets for xy values

This approach is easier and concerns the white and gray settings of the display only.

The SMPTE document RP 2080-2:2014 recommends an offset for LED backlighted LCDs of -0.006 for x and of – 0.011 for y. These values are based on tests with the Judd Vos data. For CRTs and plasma displays it is recommended to use the original CIE 1931 data.

Sony recommends specific offset values for the equalization of different monitor types. The following table shows an example:

When equalizing to BVM-E/F, PVM, PVM-A (OLED)

Probe types	Device to be measured		
	BVM (CRT), LMD (LCD), LMD-A (LCD)	BVM-L (LCD)	BVM-E/F, PVM, PVM-A (OLED)
i1Pro/ i1Pro2	(xref + 0.006, yref + 0.011)	(xref + 0.006, yref + 0.007)	(xref, yref)
CA-310*2	(xref + 0.006, yref + 0.011)	(xref + 0.006, yref + 0.007)	
CA-210*2	(xref + 0.006, yref + 0.011)	(xref + 0.006, yref + 0.016)	
CS-200*3	(xref + 0.006, yref + 0.011)	(xref + 0.006, yref + 0.007)	
PM5639/06	(xref + 0.001, yref + 0.011)	(xref + 0.001, yref + 0.007)	
PR-655/ PR-670	(xref + 0.006, yref + 0.011)	(xref + 0.006, yref + 0.007)	
K-10	(xref + 0.002, yref + 0.011)	(xref + 0.002, yref + 0.004)	
specbos 1211	(xref + 0.006, yref + 0.011)	(xref + 0.006, yref + 0.007)	

Fig. 14: Example for offset data recommended by Sony (others are available) More information can be found here: https://pro.sony.com/bbsccms/assets/files/cat/mondisp/solutions/Monitor_AutoWhiteAdjustment_manual.pdf

The following figure shows a shifted white point for the calibration in CalMAN. Instead of the original D65 values slightly shifted xy data obtained by the Judd Vos modification can be used. Additionally, it is possible to use own xy data.

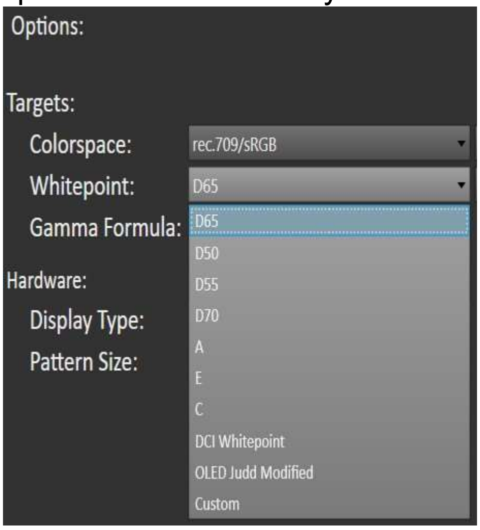


Fig. 15: White point setting in CalMAN

One can see that there is a multitude of possibilities and it is necessary to proceed own tests to find the best result for the application in hand.

Sometimes it is necessary to match two displays of different technologies to the same colors. The problem of different visual color appearance arises especially when two monitors are placed side by side. If they are located at different positions it is much more difficult for the average observer to see a difference, because the eye proceeds an adaption for each viewing situation (“white balance”).

The following procedure based on an xy offset was presented by Flanders Scientific:

1. Decide which of the two displays will serve as the primary reference (we will call this Monitor A). This reference device should be calibrated to a known standard.
2. Generate a flat white field test patch to both monitors. (90% white is recommended).
3. Provide a way for the color of the white field test patch to be adjusted ONLY on the secondary monitor (we will call this Monitor B). The best approach will vary depending on equipment in use, but can be as simple as adjusting RGB Gain controls on the unit.
4. Adjust Monitor B to perceptually match Monitor A on this one solid test patch.
5. After a perceptual match between the two is obtained use a color analyzer to measure the white point on Monitor B. Note this value for later use.
6. Profile Monitor B using LightSpace CMS (or CalMAN). If you obtained your perceptual match by adjusting gain controls on Monitor B make sure to set those back to default before profiling.
7. Once your profile is complete create your 3D calibration LUT as you normally would in LightSpace CMS (or CalMAN), with this one exception: instead of using the default target white point enter the x,y chromaticity values in the source window that you noted in step 5. This will generate a custom perceptual match 3D LUT for use on Monitor B.

This approach ensures that the matched monitor get a regular calibration procedure as well. It gives a better performance than just shifting the white balance. More details can be found here:

http://flandersscientific.com/tech-resources/PerceptualColorMatchingUsingLightSpaceCMS.pdf