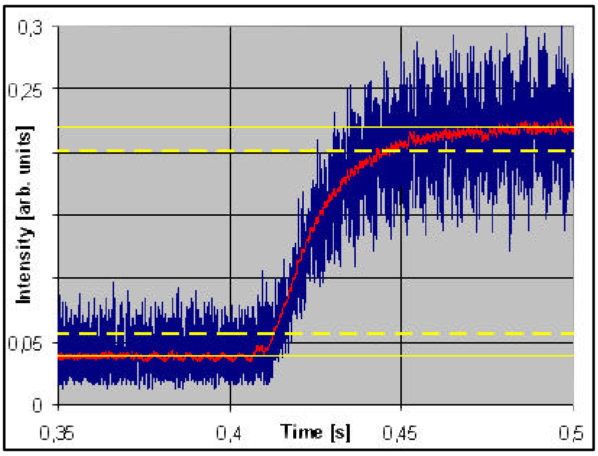
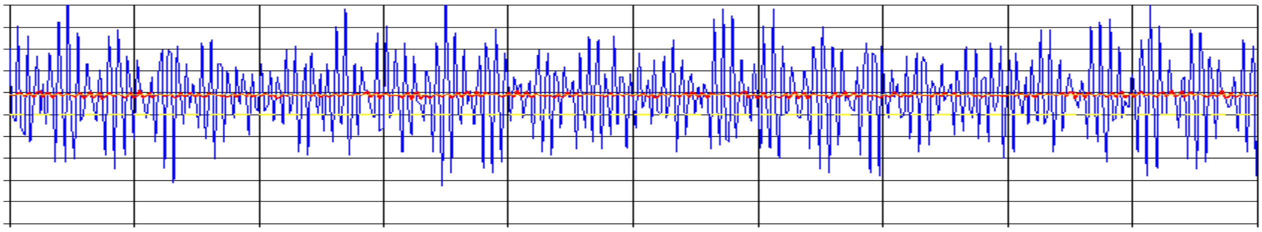
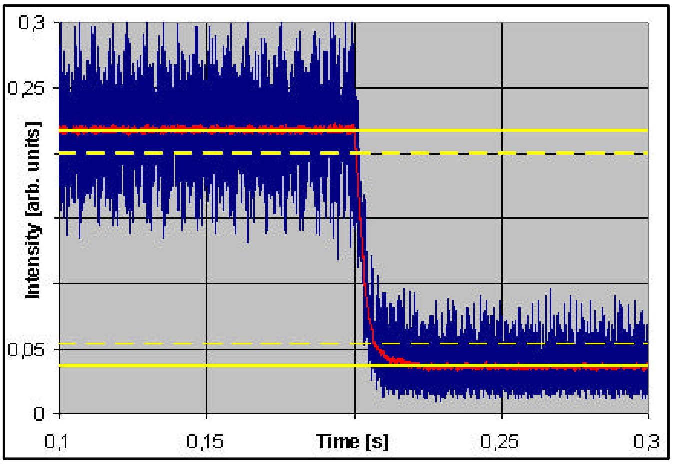


Evaluation of transition times from filtered luminance data



A White Paper

version 5-10/07



Display-Metrology & Systems
D-76135 Karlsruhe
www.display-metrology.com

Summary

The time that elapses between a change o f the electrical driving signal of an electro-optical display in general, and, specifically an LCD, can be measured and characterized in various ways.

This document introduces the terminology with special emphasis on the difference between *image formation time* (according to ISO 13406-2 and ISO 9241-305) and response times, e.g. *gray-to-gray transitions times*.

This document also introduces a procedure for correction of the transition characteristics when a *moving window averaging* process has been applied for removal of periodic luminance modulations as caused e.g. by periodic fluctuations of the backlight unit.

Applicable Standards

The following standard documents describe *terms & definitions* and *procedures for measurement & evaluation* of ***temporal luminance variations*** as induced by changes of the electrical driving conditions of electro-optical displays.

ISO 13406-2

3.4.4	***Image formation time***: time for the relative luminance to change from 10% to 90% and back (the stationary levels are 0% and 100%).
8	Measurements
8.7.21	Image formation time, frame period averaging

Note: ISO 13406-2 is limited to full-swing luminance transitions between WHITE (RGB=255) and BLACK (RGB=0).

ISO 9141-305

6.4	Temporal performance measurements
6.4.1	Temporal luminance variation
6.4.2	***Image formation time***, ripple filtering
6.4.3	***Image formation time between gray-levels*** transitions between 5x5 or 9x9 levels of gray

Note: The term ***image formation time*** always comprises two transitions, one transition from state-1 to state-2 and the inverse transition from state-2 back to state-1.

IEC 61747-6

5.3	***Response times*** (turn-on time, turn-off time, rise time and fall time)

Note: the term ***response time*** is a generic expression indicating the temporal evaluation of a response to a stimulus. There is no authoritative specification of " ***response time***".

Specifically, any transition between two stationary optical states in response to a change of electrical driving conditions can be characterized by two threshold values (e.g. 10% and 90%) in between two stationary levels and the corresponding time periods:

- ***delay time*** (latency), elapsing between the change of driving at t = 0 and the first threshold,
- ***transition time***, elapsing between the first and the second threshold.

The thresholds can be chosen to be different from the usual 10% and 90% (e.g. 1% and 99%). When this is done it must be specified together with the results (e.g. $t_1 - t_{99}$).

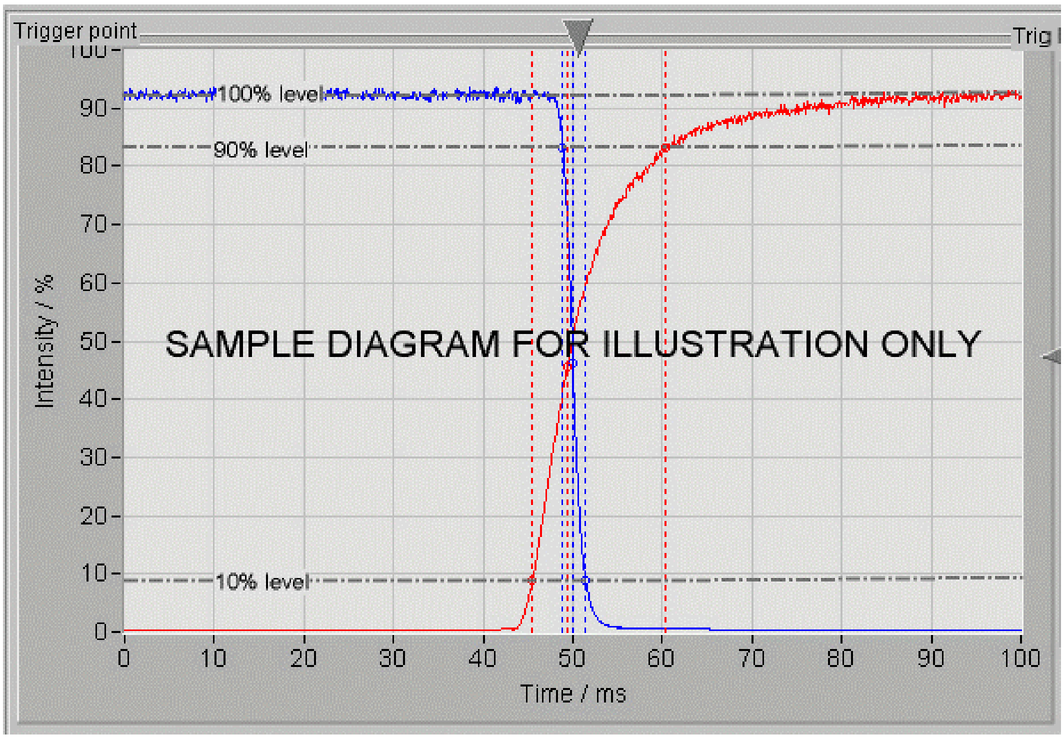
Vesa FPDM-Version 2.0

303-9	Luminance step-response
305	Temporal performance
305-1	Response time

Vesa FPDM Update, May 19, 2005

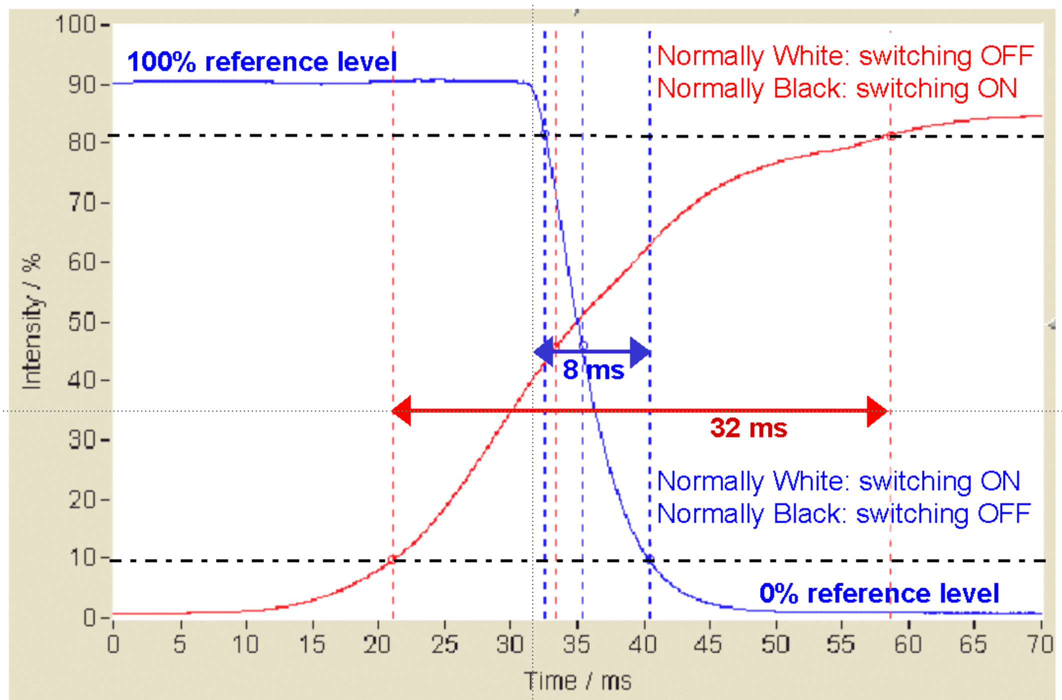
309-1	Moving Egde Blur: Consideration of overshoot and undershoot

General



General case of luminance transitions between two luminance states: transition from bright to dark (blue curve), transition from dark to bright (red curve).

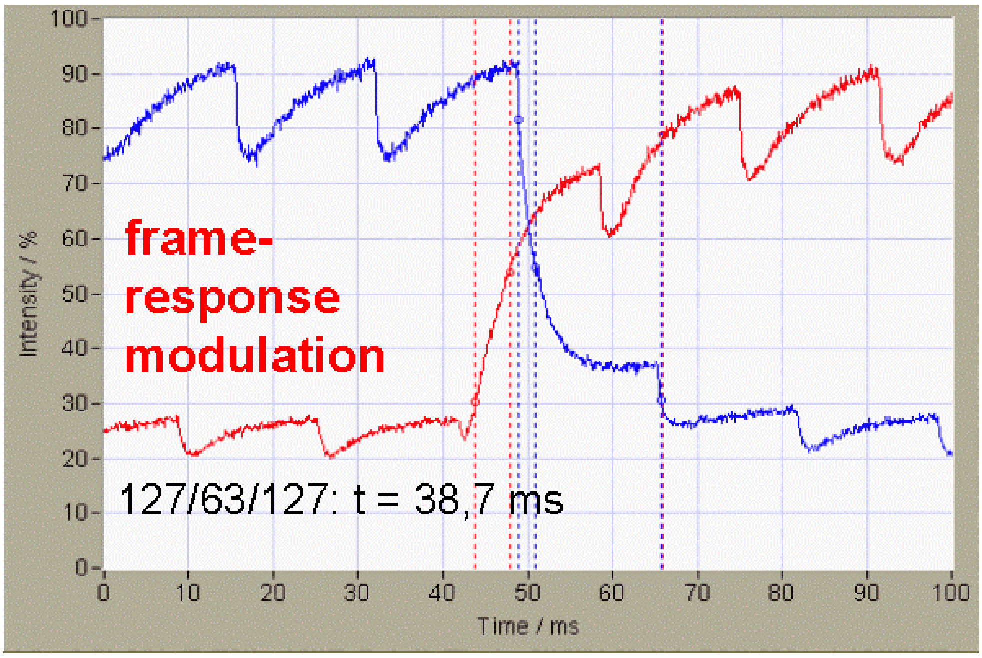
The plateau-levels for t $\rightarrow\infty$ correspond to the 100% and 0% reference levels. The transition times ($t_{10} - t_{90}$) are the time intervals between a change from 10% to 90% or vice versa.

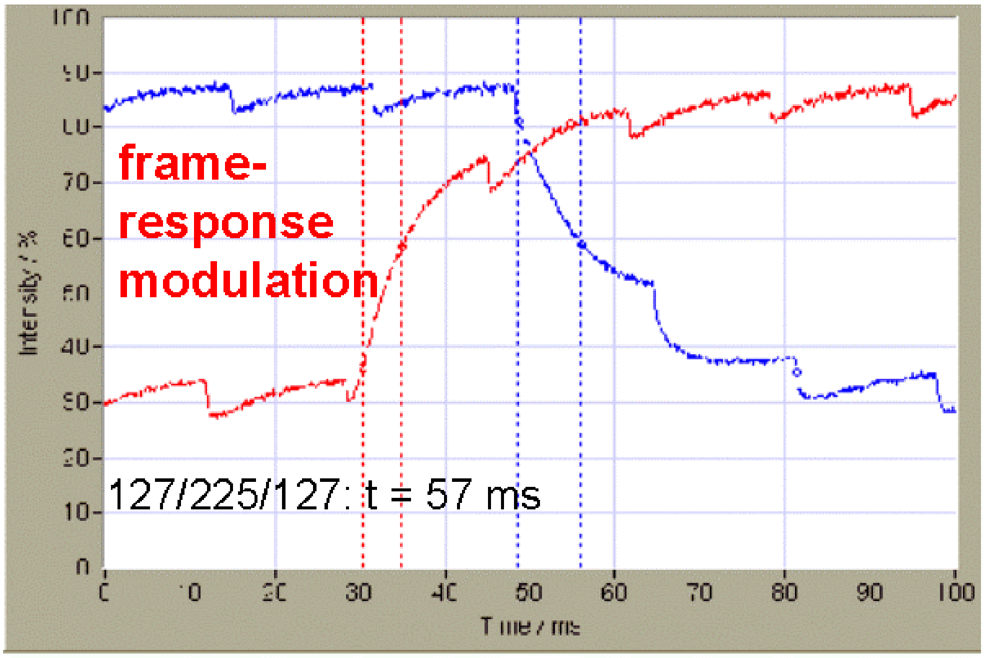


Transition times (t_{10}-t_{90}) determined for two well-behaved transitions (without overshoot and undershoot).

There is also a ***delay time*** (*latency*) between the change of electrical driving conditions and the corresponding optical response.

Artifacts

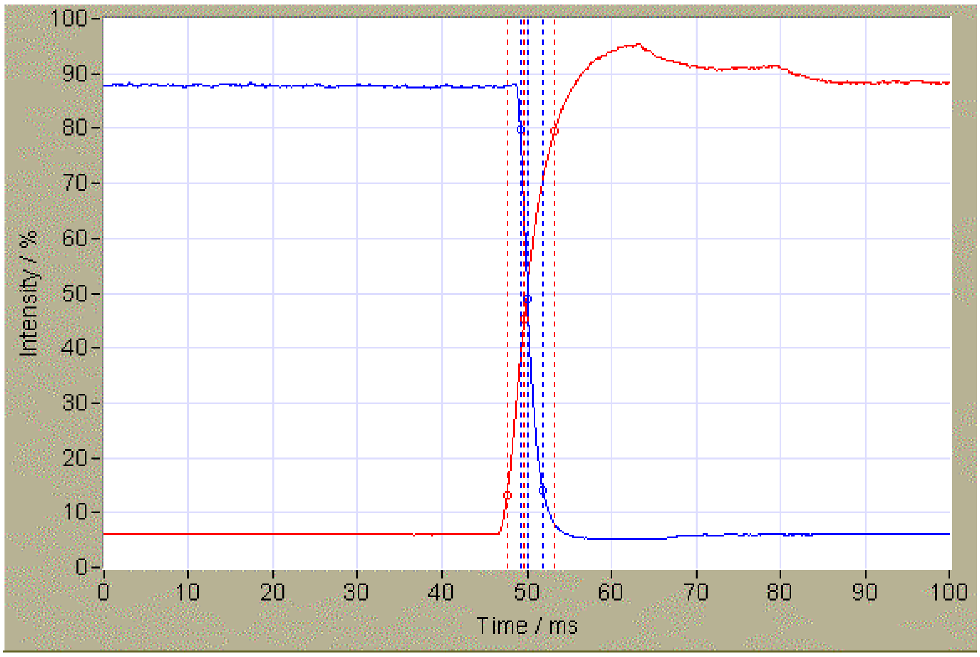




Artifacts caused by refreshing of the screen: *frame response modulations*.

Such luminance modulations make determination of transition times more difficult.

Overshoot and undershoot

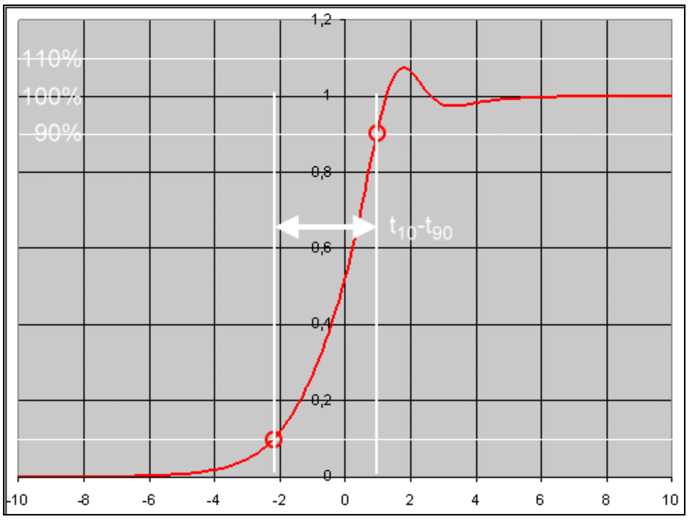


Overshoot caused by insufficiently optimized overdriving parameters and circuit. The respsonse time ($t_{10} - t_{90}$) for the red curve is short, but it takes two frames for the optical respsonse to settle to the stationary state.

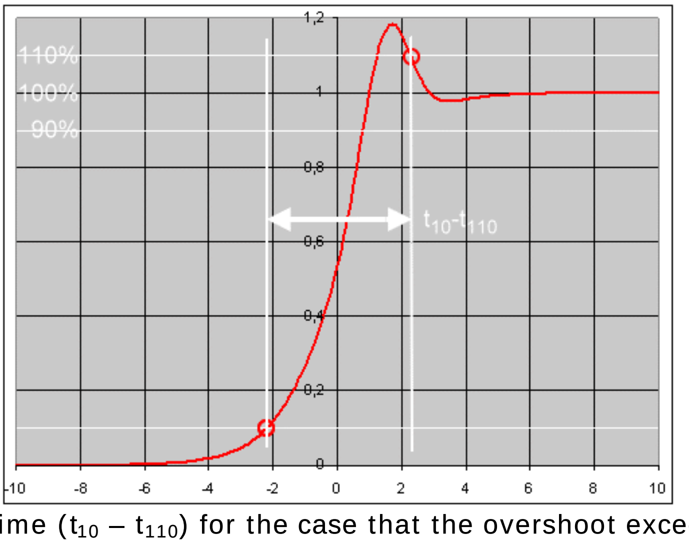
In order to speed up the response of transitions between different levels of gray the overdriving technique has become widespread. However, when the overdriving parameters are not well adjusted overshoot (red curve) or undershoot may occur. These artefacts should not be accepted since they can be avoided by careful design of the overdriving parameters.

Characterization of the steepness of the slope of a transition in the presence of overshoot and undershoot should be carried out corresponding to the principles described in Vesa FPDM 2 Update 050519, page 9. The penalty for overshoot and undershoot in excess of 10% as described there seems to be important to avoid cheating and specmanship.

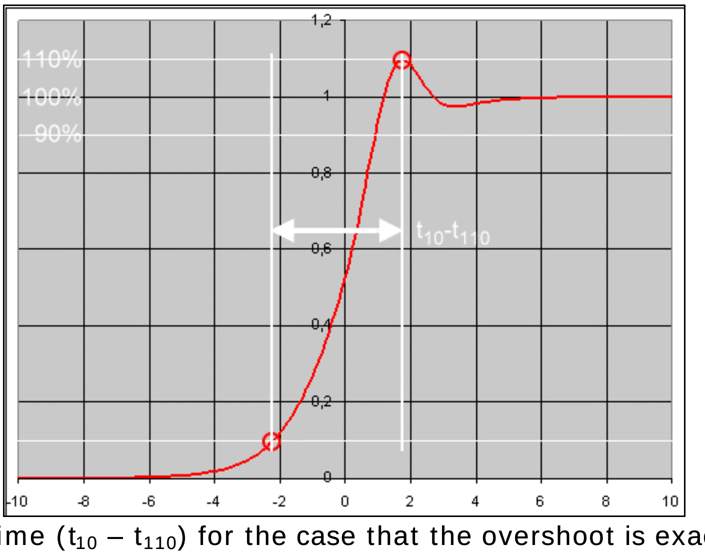
In the attempt to make the transition between a variation of 10% and 90% as fast as possible a large overshoot and undershoot is often accepted by LCD monitor manufacturers. In such cases the slope characteristics ($t_{10} - t_{90}$) become short, but the optical response is far from having settled after that period of time.



Transition time ($t_{10} - t_{90}$) for the case that the overshoot remains below 110%.



Transition time ($t_{10} - t_{110}$) for the case that the overshoot exceeds 110%.



Transition time ($t_{10} - t_{110}$) for the case that the overshoot is exactly 110%.

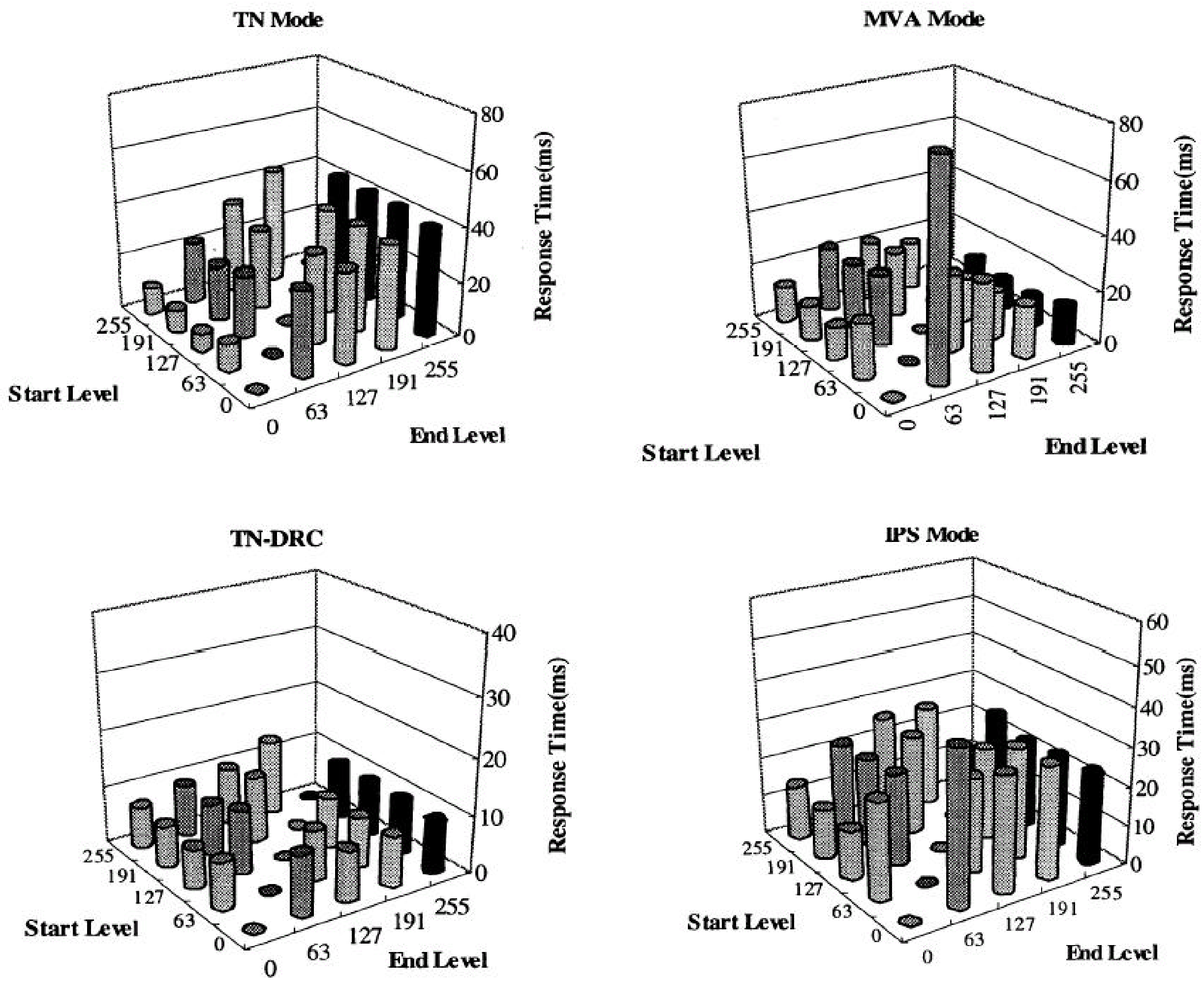
According to this definition there is a pronounced increase of the Transition time when the overshoot is equal to or more than 10%. The same principle applies for the undershoot.

Image formation time between gray-levels

According to ISO 9141-305

6.4 Temporal performance measurements
6.4.1 Temporal luminance variation
6.4.2 Image formation time, ripple filtering

6.4.3 Image formation time between gray-levels 5x5 or 9x9 levels of gray



From: S. Suzuki, et. al., *Response Time Evaluation for LCD Display Modes and its Relationship to Moving Image Perception*, Proc. SPIE, Vol. 4657 (2002)

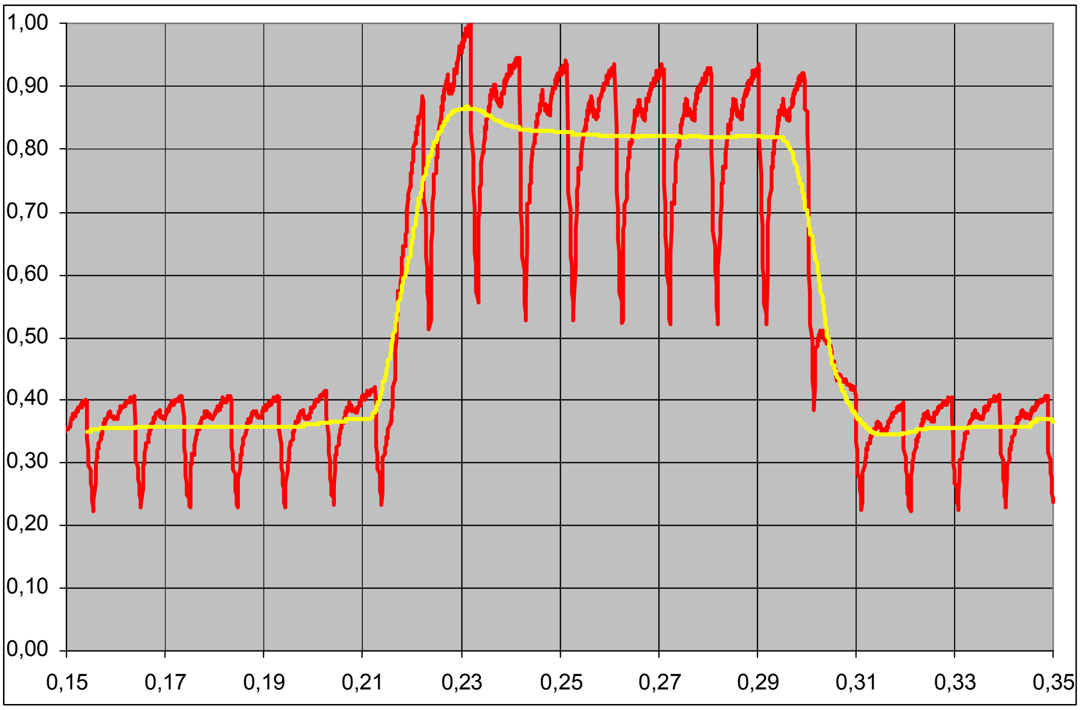
Whenever transitions between a variety of gray levels are evaluated it is good practice not to choose one value which accidentially is the shortest, but instead the set of results should be analyzed with well known statistical means.

The following choices adequately characterize the set of gray-to-gray (g2g) transition times:

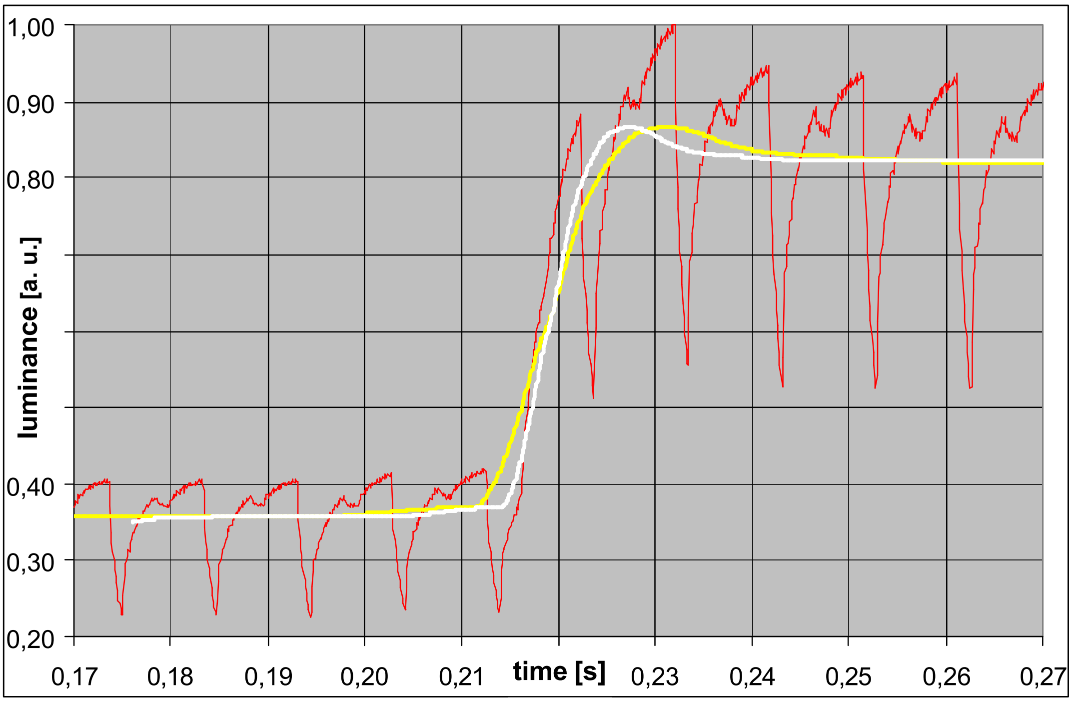
- the complete set of values in matrix form (graphically or numerically),
- mean value together with the standard deviation,
- mean value together with maximum and minimum value,
- median value together with the standard deviation.

Luminance modulations caused by backlight

When the backlight intensity is adjusted via PWM, luminance modulations are added to the transitions of the display in the frequency range 100 Hz < f_{mod} < 1000 Hz.



Luminance transitions of an LCD-monitor with additional luminance modulations caused by the backlight unit. Blue-curve: raw data, red lines: local maxima and minima of luminance modulations, yellow curve: raw data after filtering with moving window (averaging). With of filter window = period of backlight modulation. Here: t_{10}-t_{90} = t_{mod} = $1/f_{mod}$ = 9,6ms.

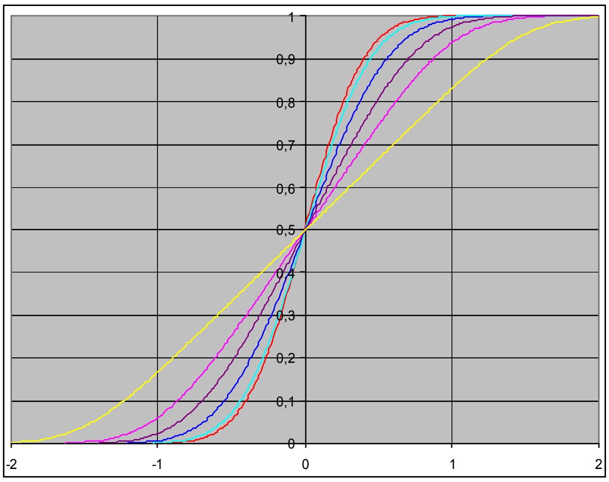


The white curve is what we finally want to obtain: backlight modulation removed by convolution, slope of transition compensated for unwanted effect of convolution (i.e. reduction of steepness of slope).

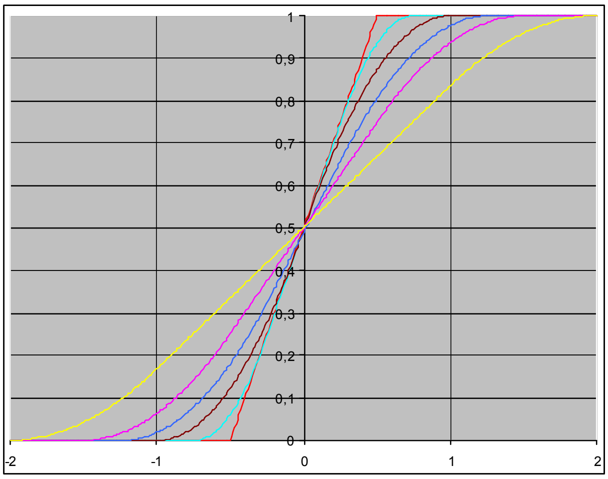
In order to compensate for the effect of the moving window average on the steepness of the transition, three kind of functions have been examined:

- cumulative Gaussian target functions,
- initially linear slope target function, and
- sigmoid target functions.

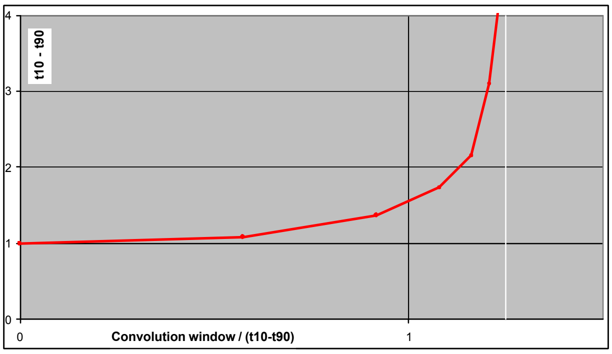
The variation of the factor about which the steepness of the slope of the transition is decreased (i.e. the value of (t_{10}-t_{90}) is increased) is quite independent of the nature of the function chosen for modeling of the transition between two states as illustrated in the diagrams below.



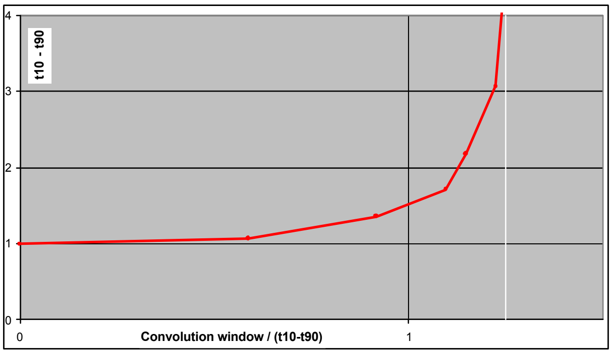
Cumulative Gaussian function and its convolutions (width of convolution window 0,5, 1, 1,5, 2 and 3).



Initially linear slope function and its convolutions (width of convolution window 0,5, 1, 1,5, 2 and 3).



Decrease of steepness of transition versus ratio of (t_{10}-t_{90}) and width of convolution window for the Gaussian functions.

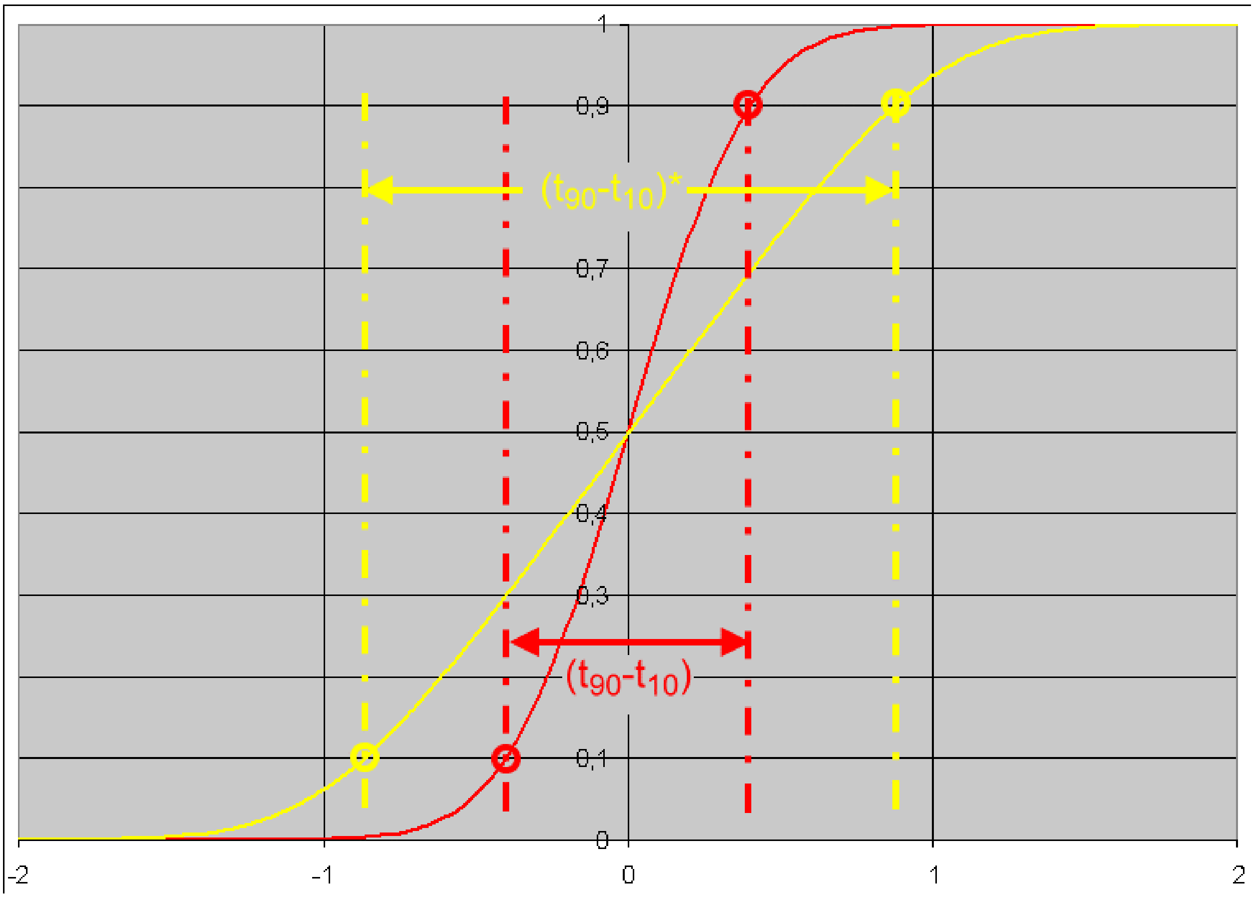


Decrease of steepness of transition versus ratio of (t_{10}-t_{90}) and width of convolution window for the initially linear slope function.

The original curves (red curves, prior to convolution) are adjusted to have a steepness (t_{10}-t_{90}) of 0,8. With increasing width of the convolution window also the slope steepness decreases and thus the value of (t_{10}-t_{90}) increases.

For widths of the convolution window above 4 the ratio of convolution window width to slope width (t_{10}-t_{90}) approaches a limiting value of 1/0,8 = 1,25.

Transition characteristics



The **red curve** represents (an ideal case of) a transition before any numerical treatment (e.g. convolution), its slope being characterized by the flatness (1/steepness) $(t_{90} - t_{10})$.

After convolution, the yellow curve is obtained featuring an increased flatness (i.e. reduced steepness), characterized by the parameter $(t_{90} - t_{10})^*$.

The factor about which the steepnes is reduced by convolution is given by

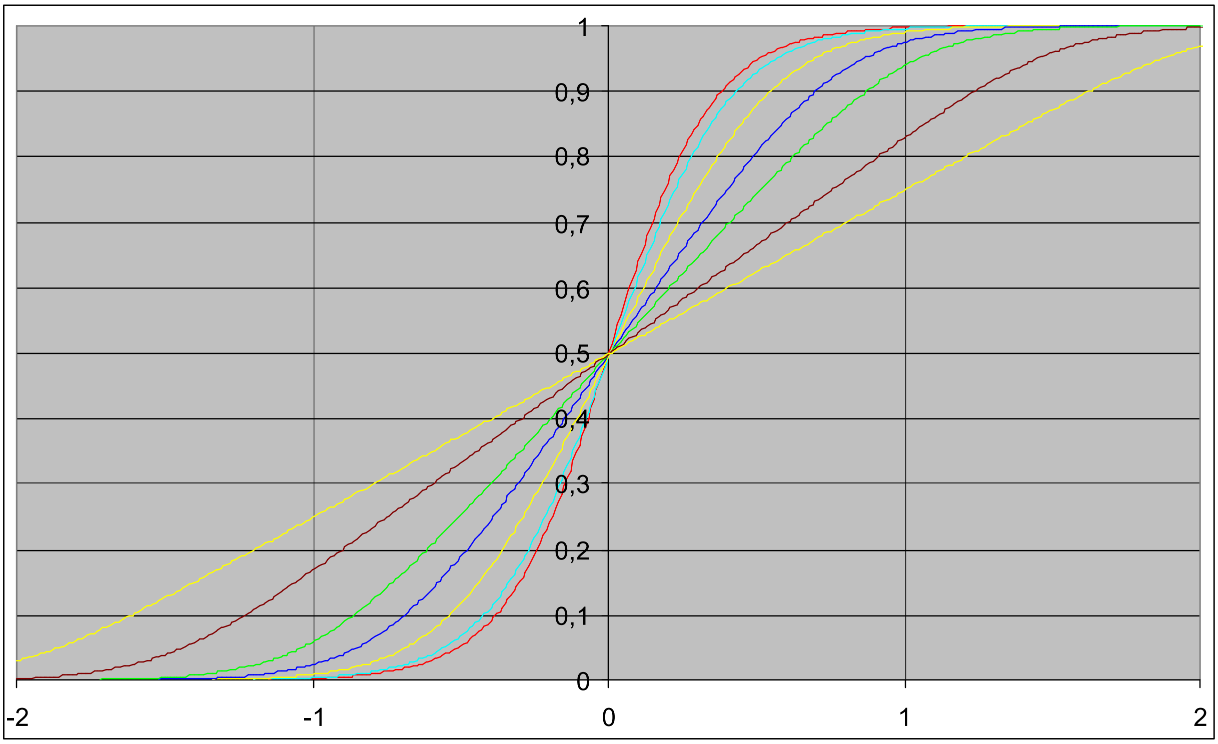
$$f_C = \frac{(t_{90} - t_{10})}{(t_{90} - t_{10})^*}$$

This factor is a function of the width of the convolution window, w, related to the flatness of the original transition, $(t_{90} - t_{10})$.

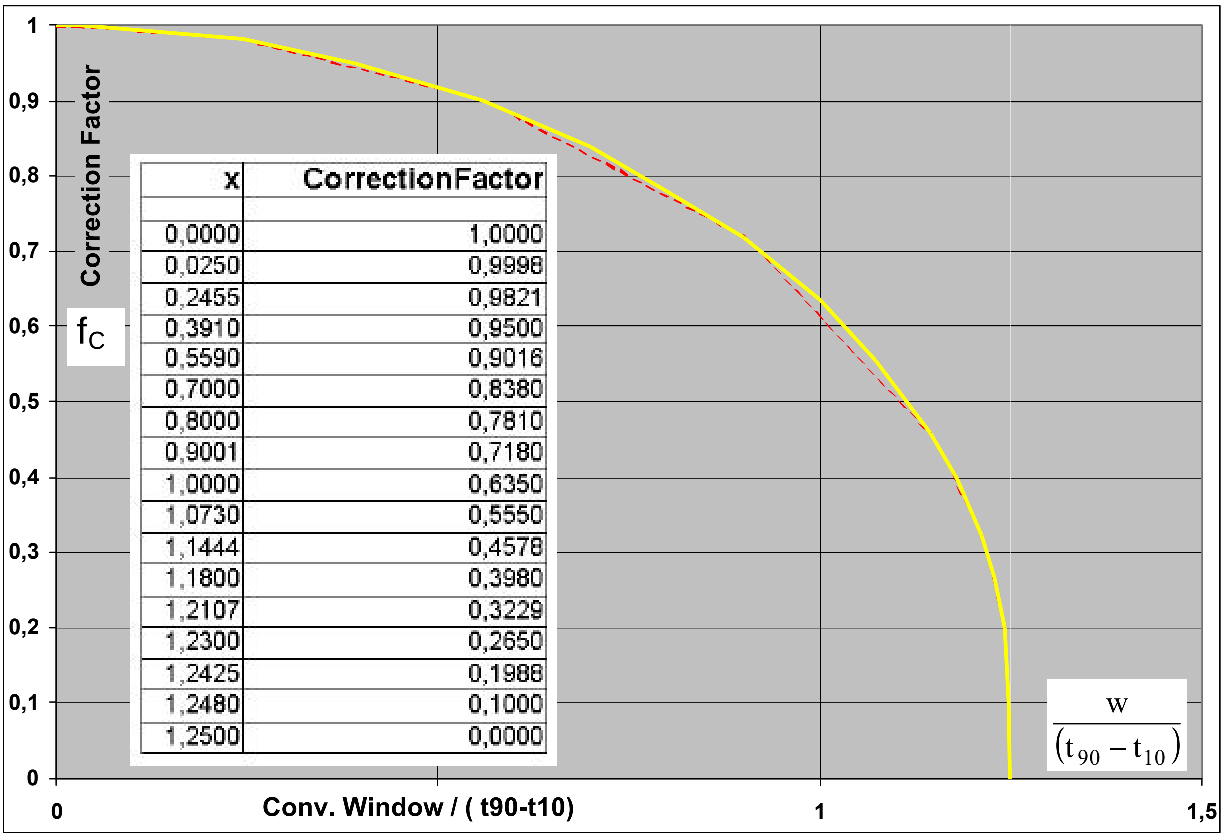
$$f_C = \frac{(t_{90} - t_{10})}{(t_{90} - t_{10})^*} = f\left(\frac{w}{(t_{90} - t_{10})}\right)$$

For case of the steepness of the original transition $(t_{90} - t_{10})$ approaching zero (i.e. $w >> (t_{90} - t_{10})$ as is the case for a step transition), the correction factor also goes to zero.

Sigmoid target functions



A sigmoid function (red curve) is used as a *model function* for the temporal transition between two luminance states (stationary gray levels). The other curves are resulting from convolutions with rectangular windows of width 0,5, 1, 1,5, 2, 3, 4 and 5 (yellow curve).



x	CorrectionFactor
0,0000	1,0000
0,0250	0,9998
0,2455	0,9821
0,3910	0,9500
0,5590	0,9016
0,7000	0,8380
0,8000	0,7810
0,9001	0,7180
1,0000	0,6350
1,0730	0,5550
1,1444	0,4578
1,1800	0,3980
1,2107	0,3229
1,2300	0,2650
1,2425	0,1988
1,2480	0,1000
1,2500	0,0000

Graphical representation of the **correction factor for the steepness** ($t_{10} - t_{90}$) as a function of the width of the convolution window normalized to the period ($t_{10} - t_{90}$).

Example

LCD transition times ($t_{10} - t_{90}$) are typically in the range of 10ms (with overdriving 2ms – 20ms) and convolution windows in the range of 10ms to 1ms (100Hz to 1000Hz backlight modulation).

We take the data shown in the diagrams of page 7 as a numerical example. With a 104 Hz backlight modulation and a transition period ($t_{10} - t_{90}$) of 9.7 ms after convolution to remove the backlight modulation we obtain for the ratio [convolution window / (t_{10}–t_{90})] a value of 0.9897 for which we read the correction factor from the diagram above as ~0.635.

For the corrected transition period ($t_{10} - t_{90}$) we have to multiply 9.7ms with 0.635 to obtain 6.16ms instead of 9.7ms.

Extreme case: for an infinitely fast transition (ideal step response), the period ($t_{10} - t_{90}$) after convolution approaches 0,8*the width of the convolution window and thus the ratio (width of convolution window)/($t_{10} - t_{90}$) $\rightarrow$ 1,25. For values close to 1,25 it becomes increasingly difficult to determine the correction factor (increasing uncertainty).

From the evaluations of the sigmoid curves we obtain a correction factor of 0,100 for a value of the ratio (width of convolution window)/($t_{10} - t_{90}$) = 1,248.

Due to uncertainties and variations in measurement and evaluation of ($t_{10} - t_{90}$) and the increasing steepness of the curve when approaching the limiting value of 1,25, variations in this region are "amplified" and the thus values above x = (width of convolution window)/($t_{10} - t_{90}$) = 1,24 should be used and specified with caution.

Outlook and further work

Work is currently in progress to analytically separate the periodic component (e.g. flicker, frame-response and backlight modulation, etc.) from the transition. This will be an additional approach for evaluation of the transition times ($t_{10} - t_{90}$) without convolution and thus avoiding the limitations of the approach described here.