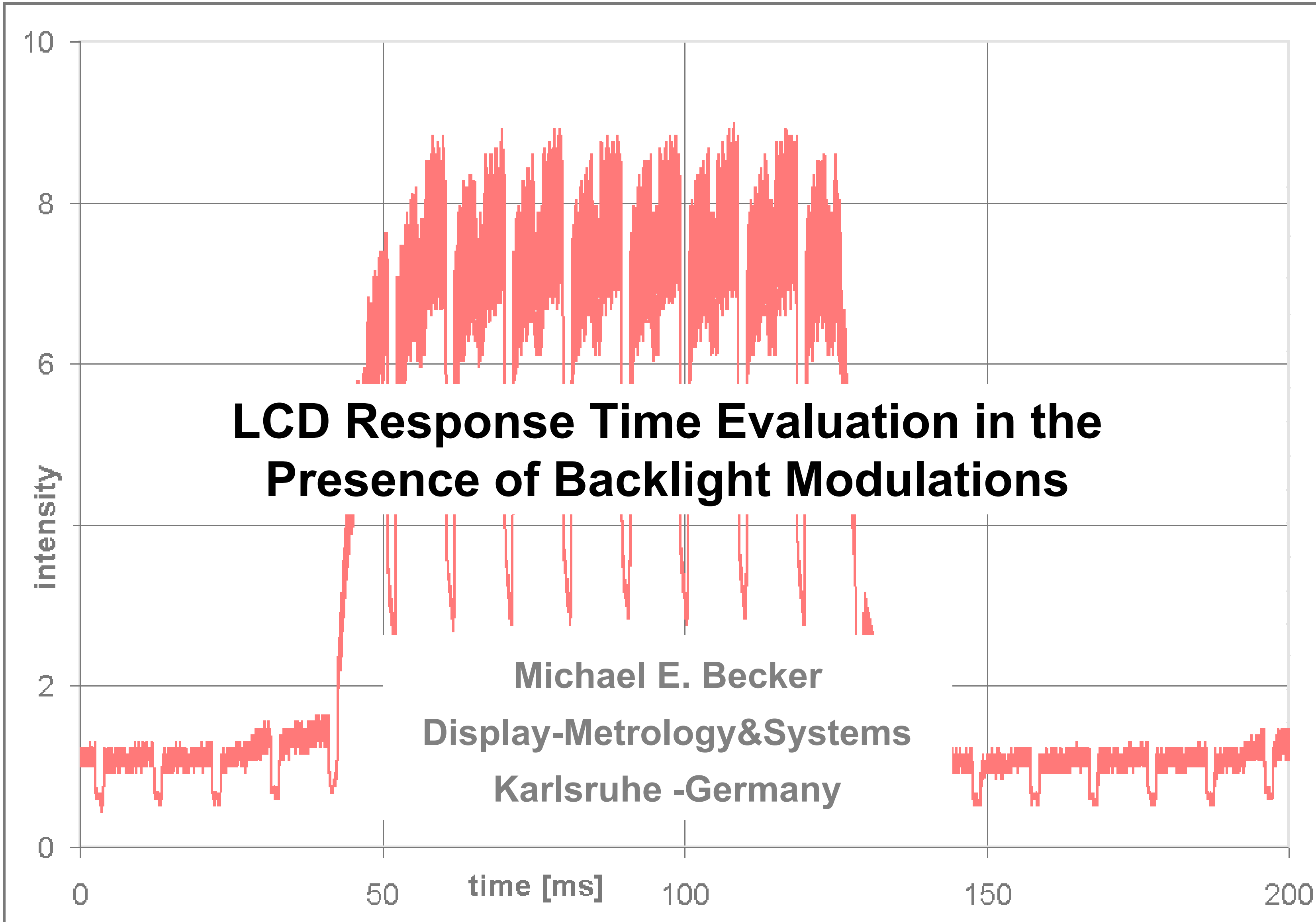
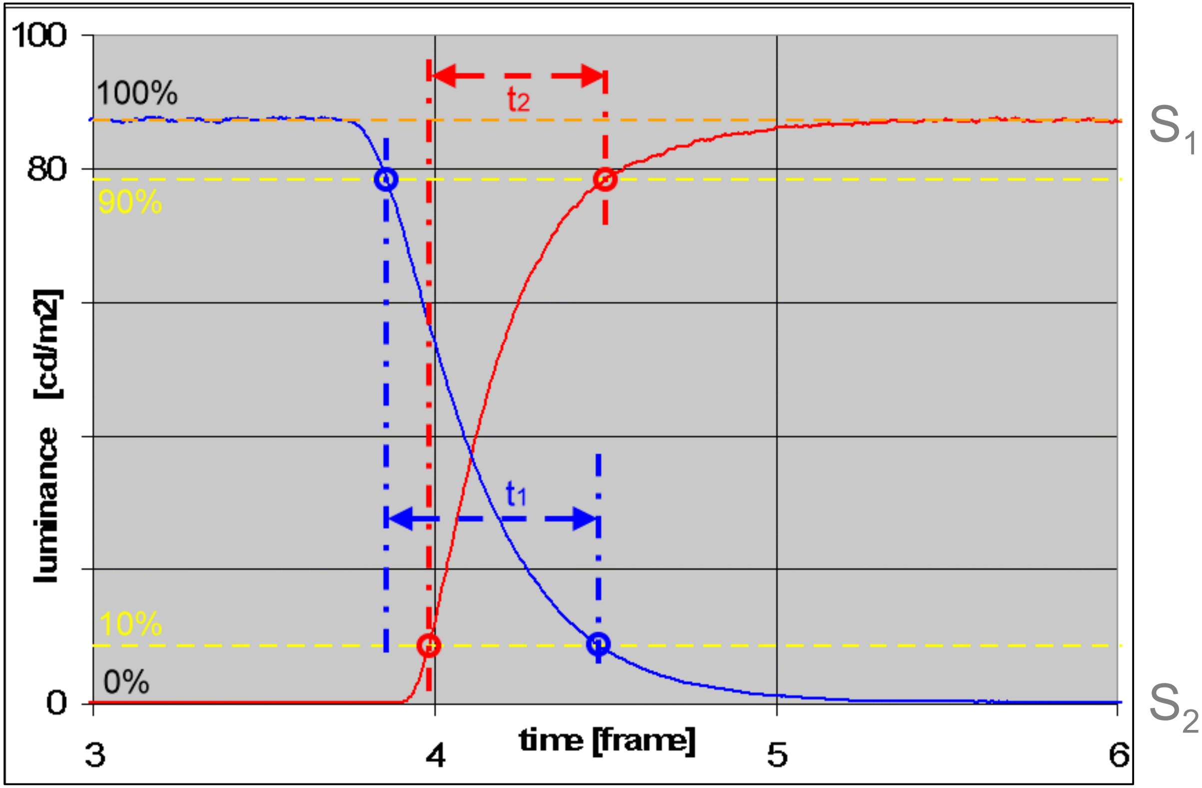


LCD Response Time Evaluation in the Presence of Backlight Modulations

Michael E. Becker
Display-Metrology&Systems
Karlsruhe -Germany

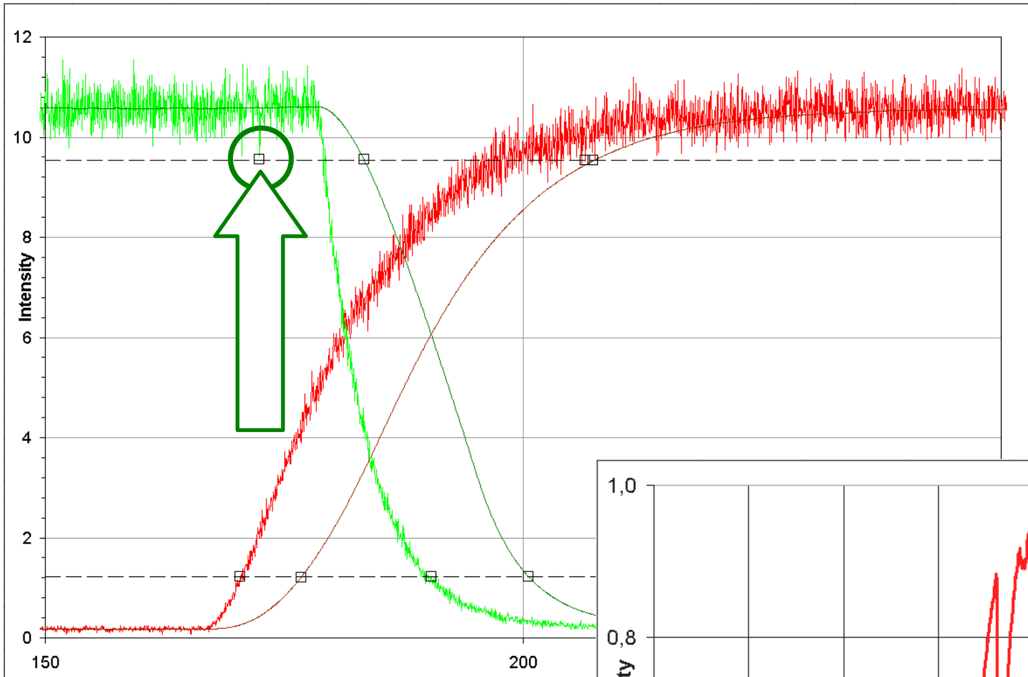
Transitions of Step Responses



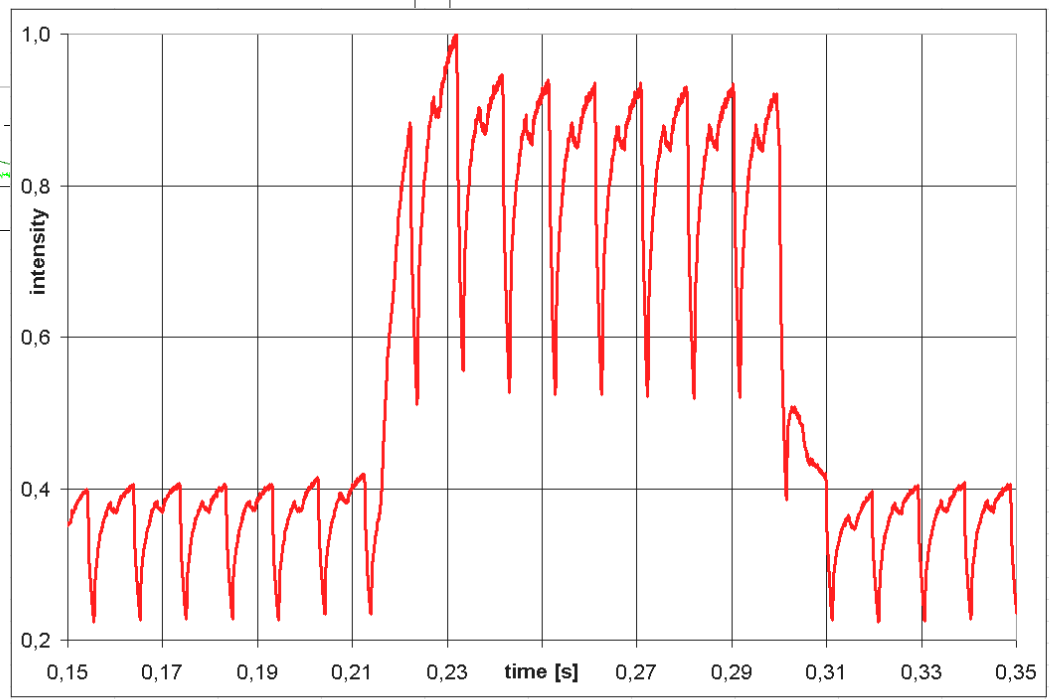
Luminance versus time: two well conditioned monotonous transitions between two optical states, S_1, S_2,without artefacts, e.g. fluctuations, modulations, overshoot or undershoot.

Transitions characterized by response-time period (t_{90} - t_{10})

Modulations

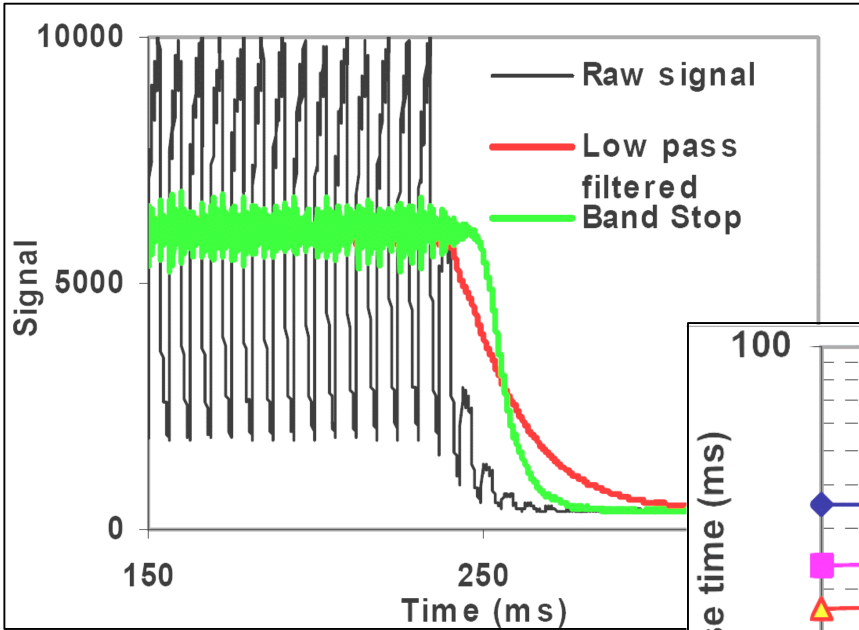


LCD transitions recorded with PMT based receiver, corruption of transition characteristics (t_{90} - t_{10}) by noise.



LCD transitions in the presence of backlight modulations, slope characteristics (t_{90} - t_{10}) ???

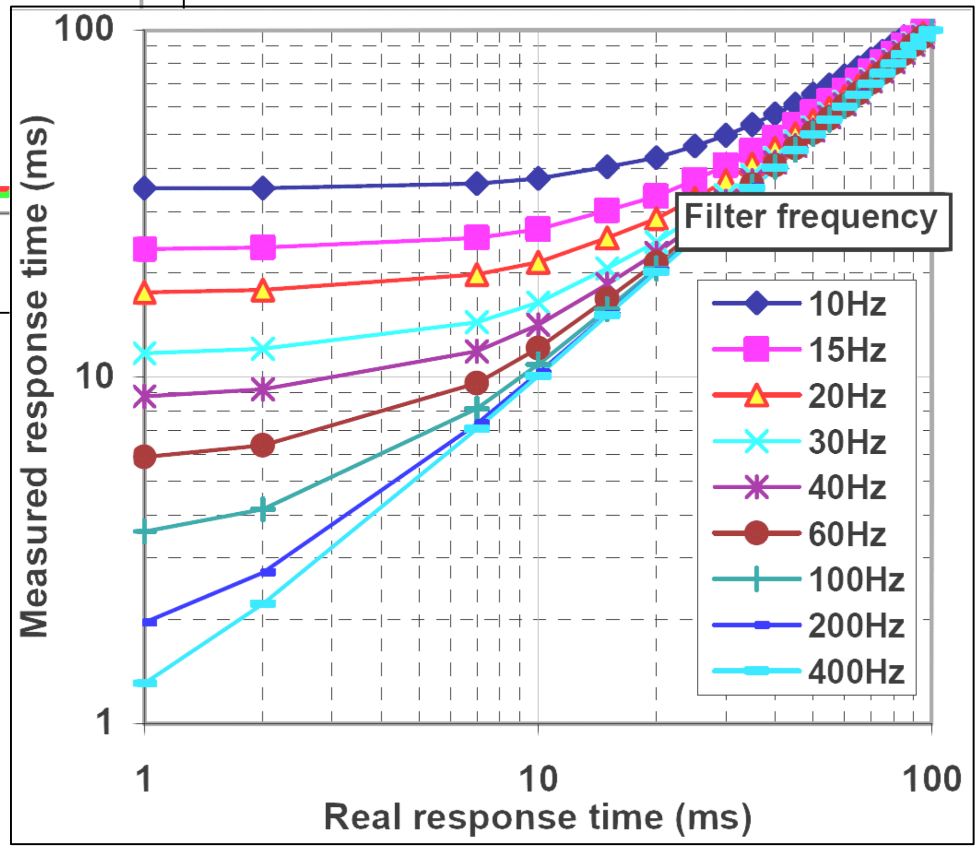
Filtering



Electronic filtering:

- low-pass, various kinds & orders,
- band-stop (notch filter), etc. ...

not easy to match to specific task.

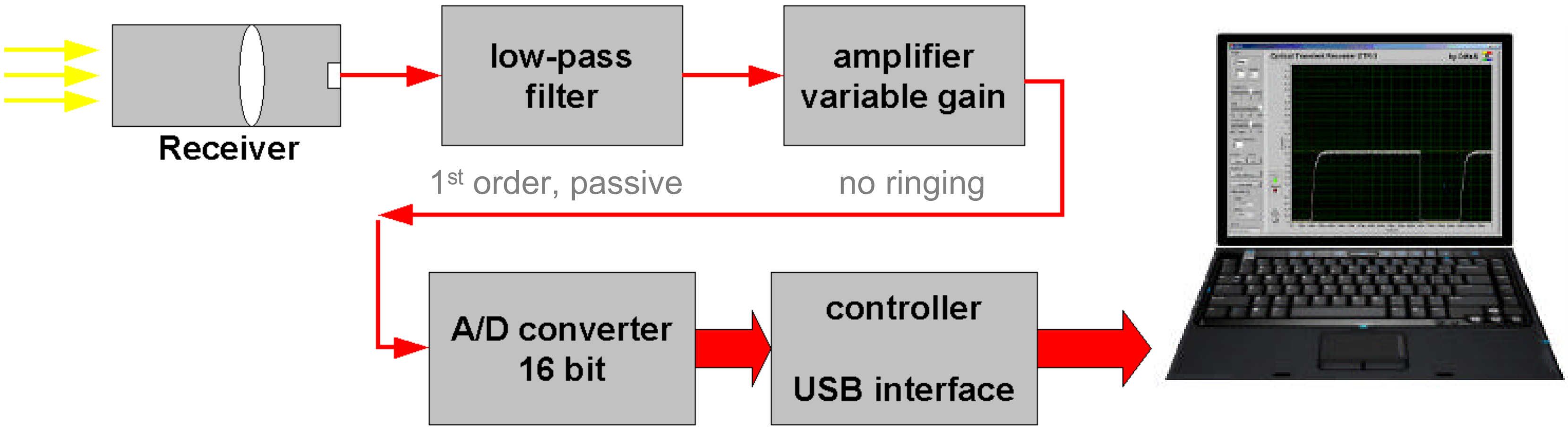


Electronic filtering:

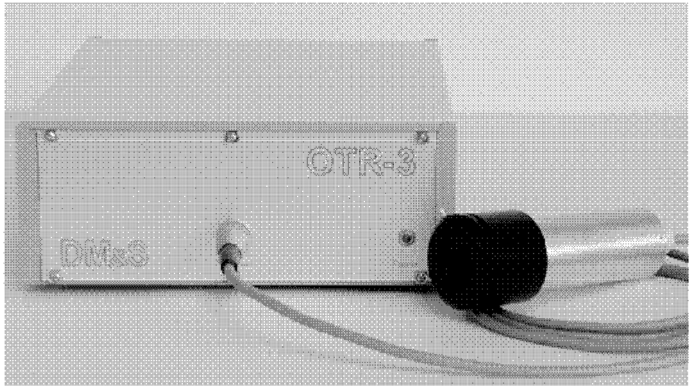
System specific corrections can be integrated in instruments.

D. Glinel, et al., *Precise response time measurement and analysis of liquid crystal displays*, IMID/IDMC'06 Digest

Optical Transient Recorder



Recording of optical transients:

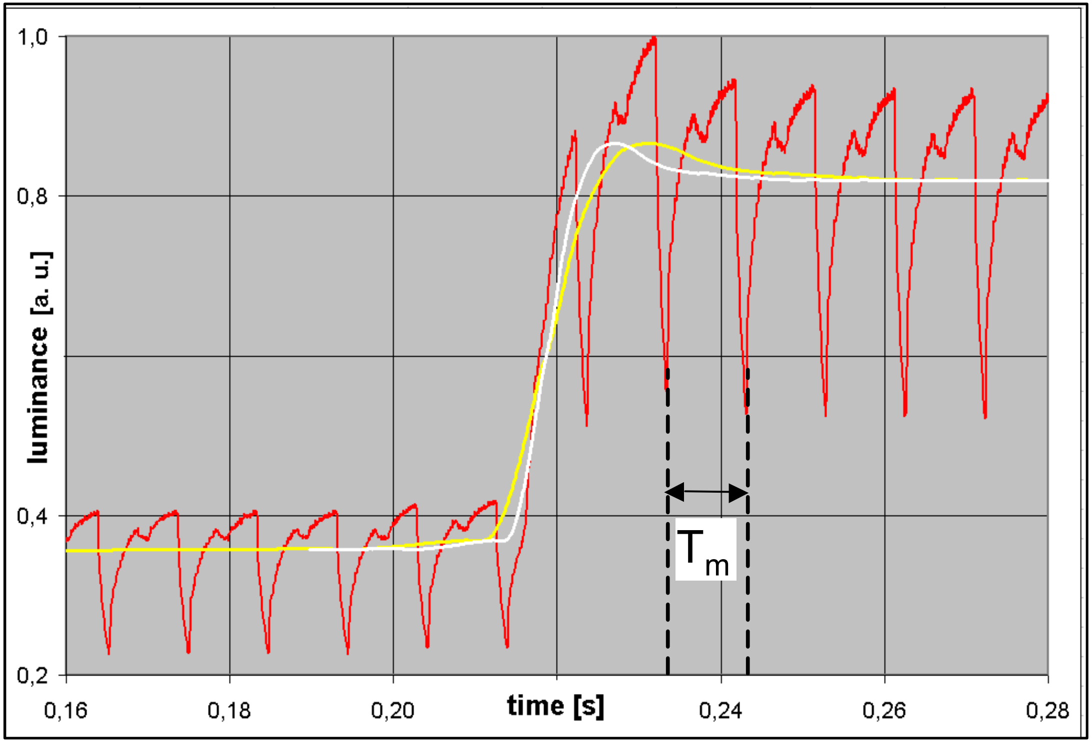


- bandwidth control,
  avoid ringing, clipping, latch-up,
- oversampling (10k samples per set),
- matched timing of DUT driving + luminance sampling,
- numerical data processing (filtering) in computer.

Moving Window Averaging

Moving Window Averaging (Convolution):

- effective,
- precisely matched to target frequency (e.g. modulation),
- easy to implement.

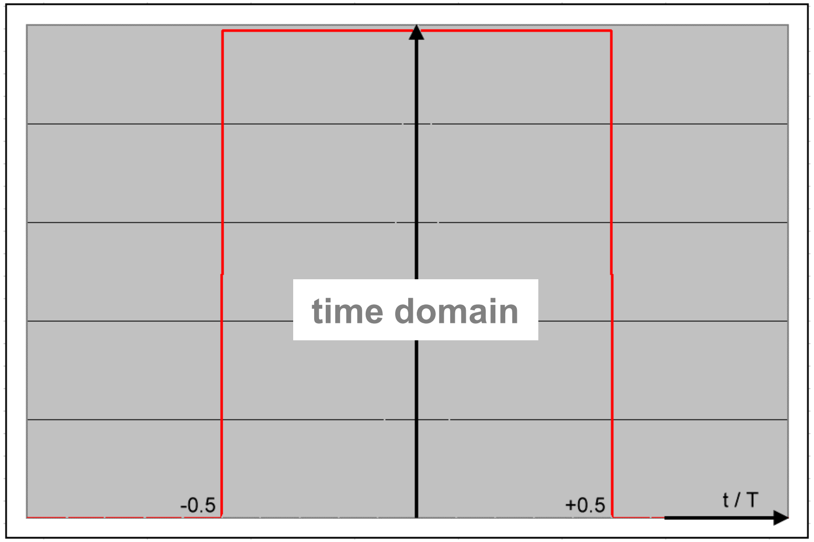


Determine modulation period, T_m or modulation frequency, $1/T_m$,

- assign average value to center of window,
- advance window,
- continue to end.

➲ yellow curve: modulations removed, transition slowed down.

Moving Window Averaging



luminance = f(t)

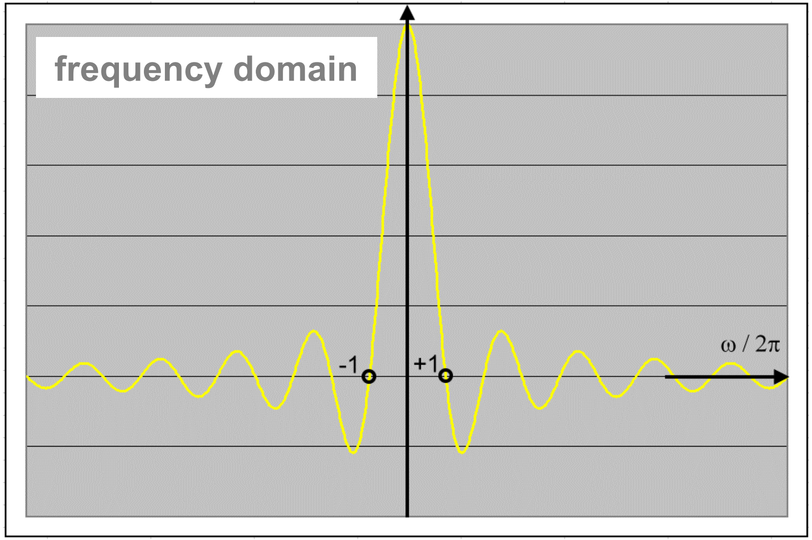
$$f(t) \otimes Rect(T_m) = F(\omega) \cdot \frac{\sin \omega}{\omega}$$

$$\omega = 2\pi / T_m$$

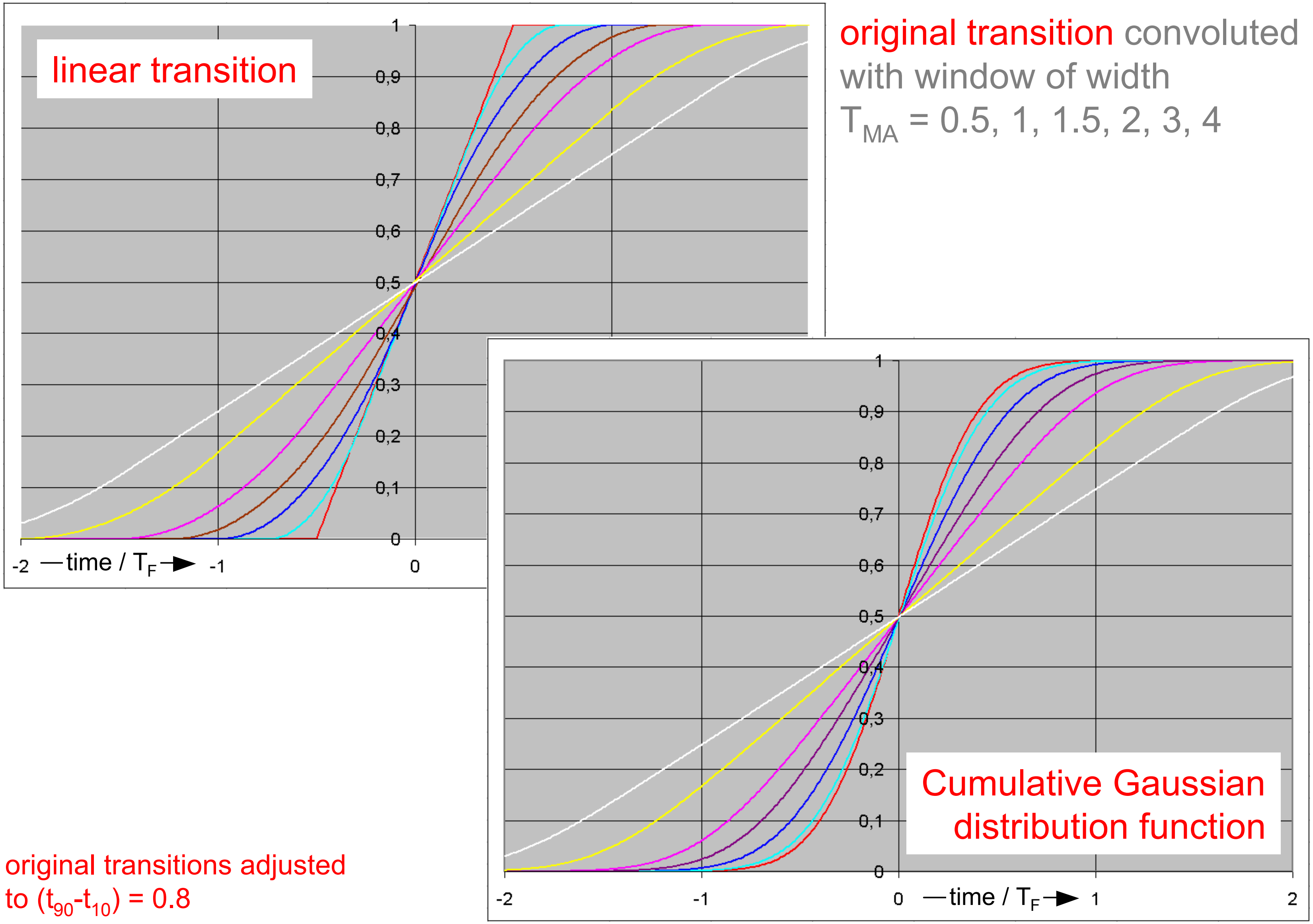
convolution of f(t) with rectangular window $Rect(T_m)$ = multiplication of Fourier spectrum of f(t) = F(ω) with sinc(ω):

$$f(t) \otimes Rect(T_m) = F(\omega) \cdot sinc(\omega)$$

⇨ removal of all harmonics of $1/T_m$



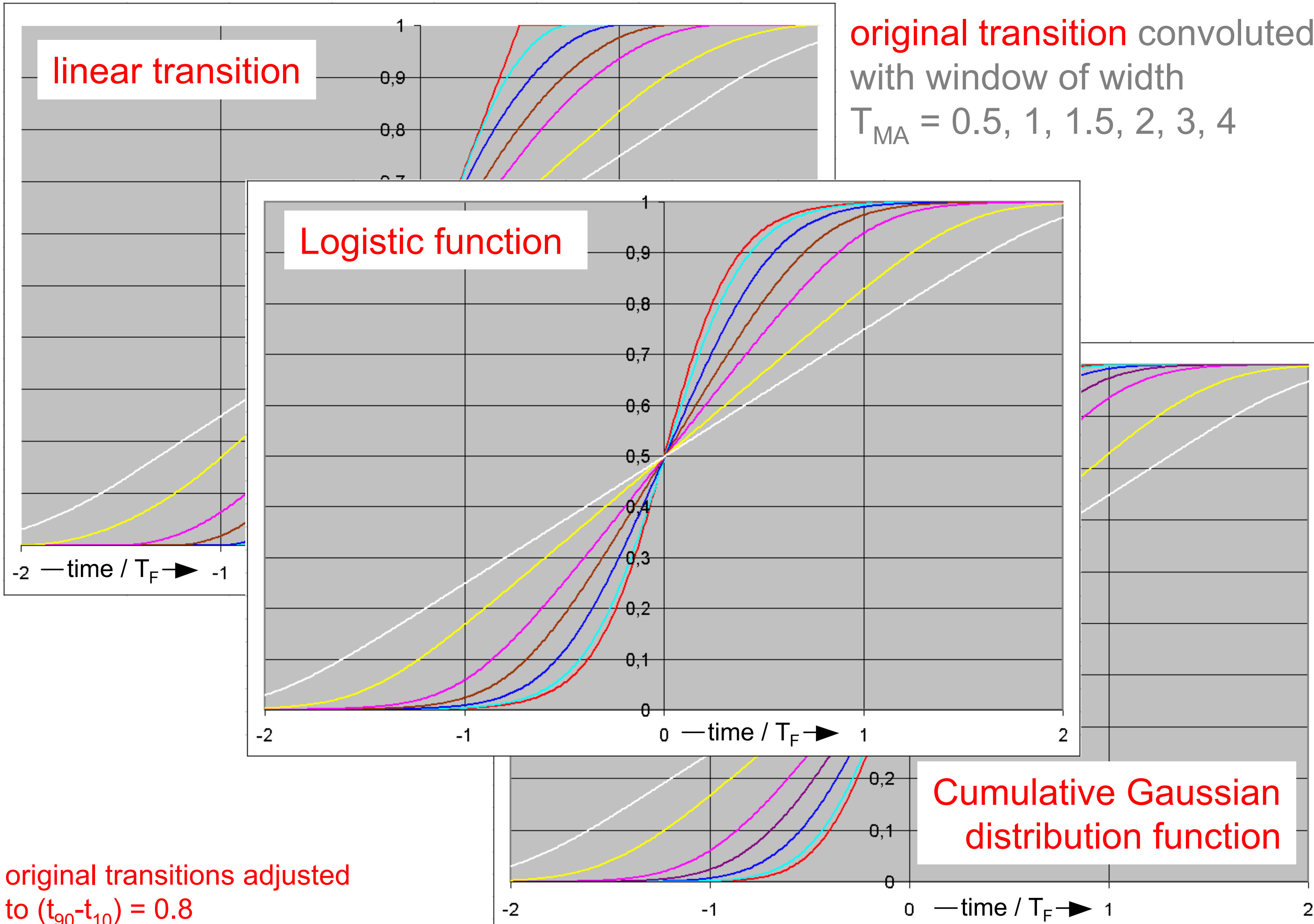
Model Functions for Transitions



original transition convoluted with window of width T_{MA} = 0.5, 1, 1.5, 2, 3, 4

original transitions adjusted to $(t_{90}-t_{10})$ = 0.8

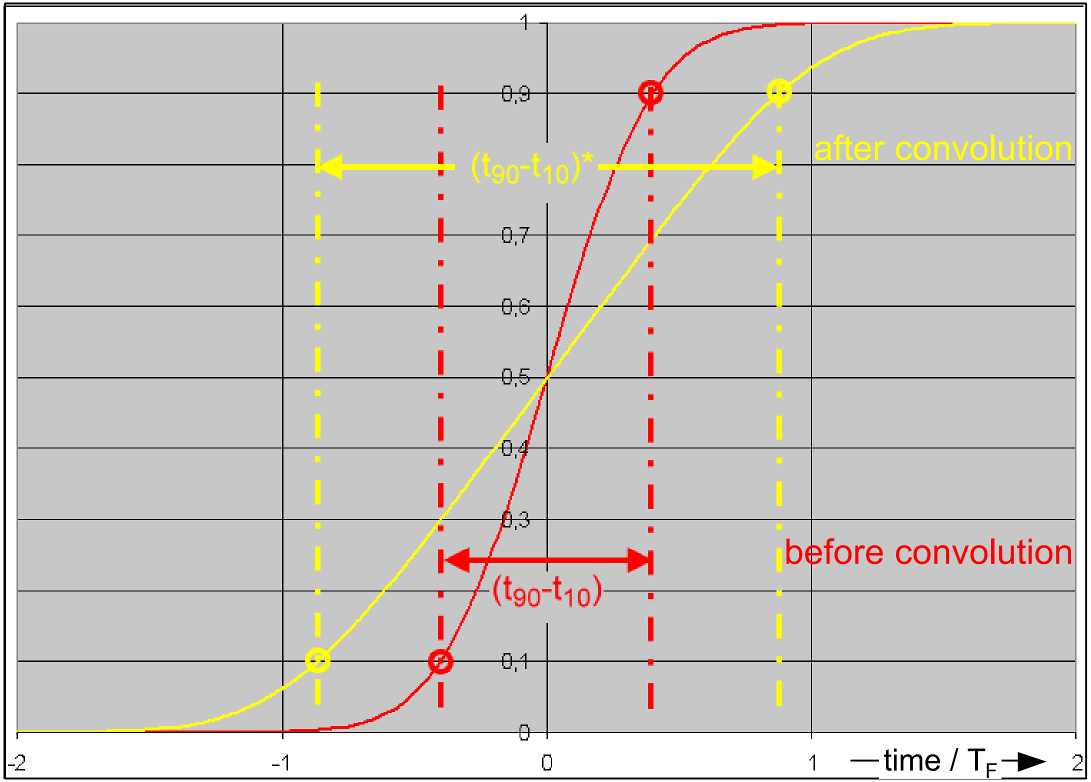
Model Functions for Transitions



original transition convoluted with window of width T_{MA} = 0.5, 1, 1.5, 2, 3, 4

original transitions adjusted to $(t_{90}-t_{10})$ = 0.8

Modification of Transitions

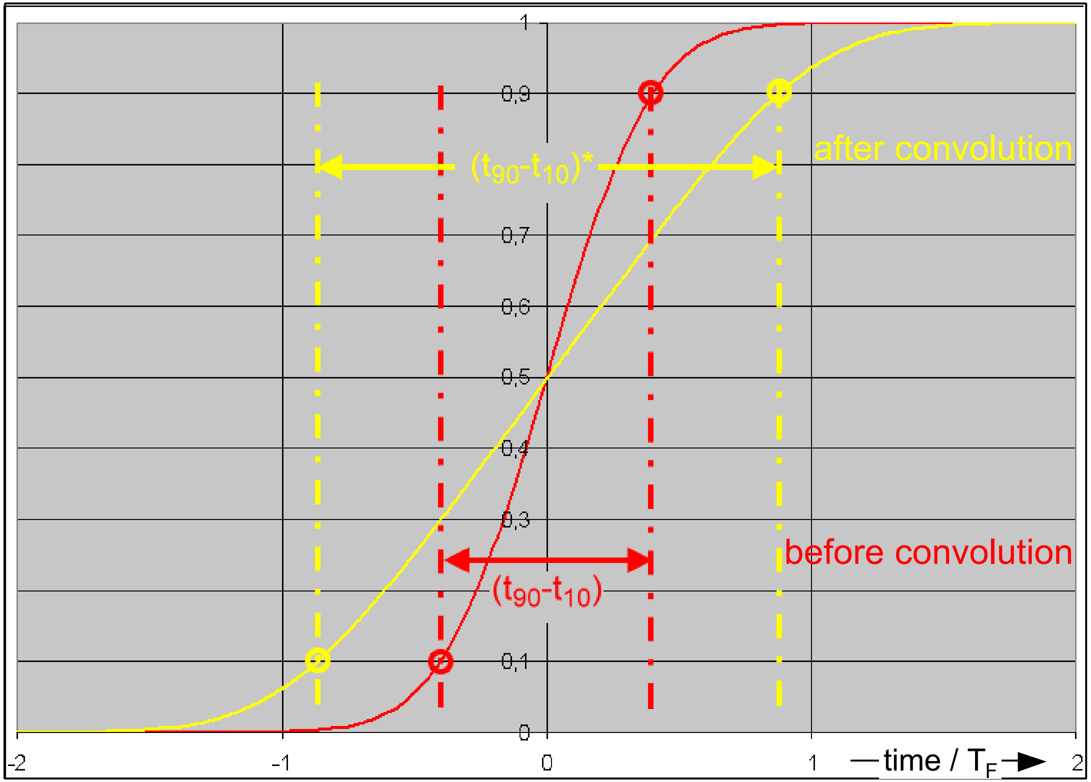


corruption factor, f_c

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

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

Modification of Transitions



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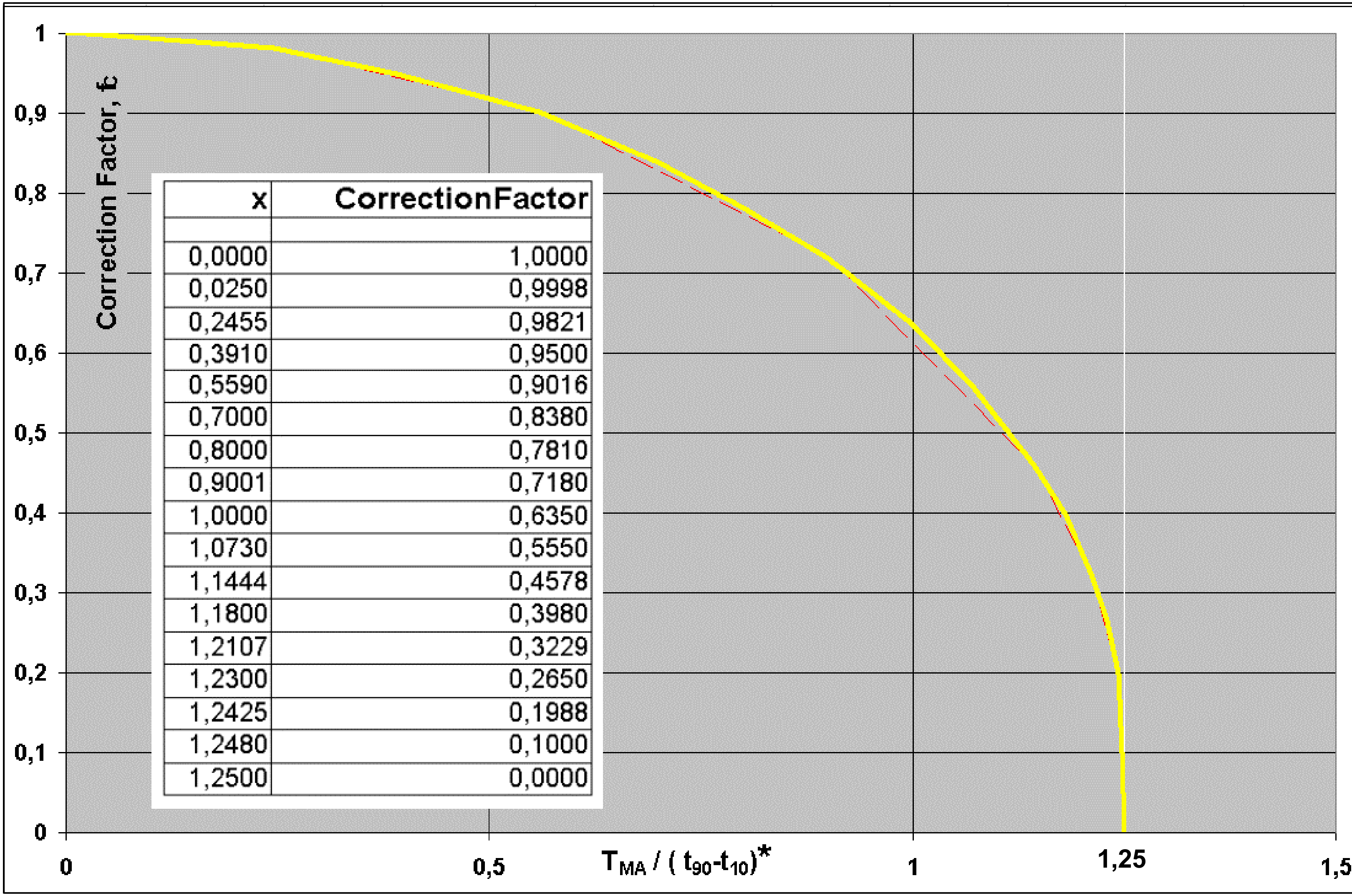
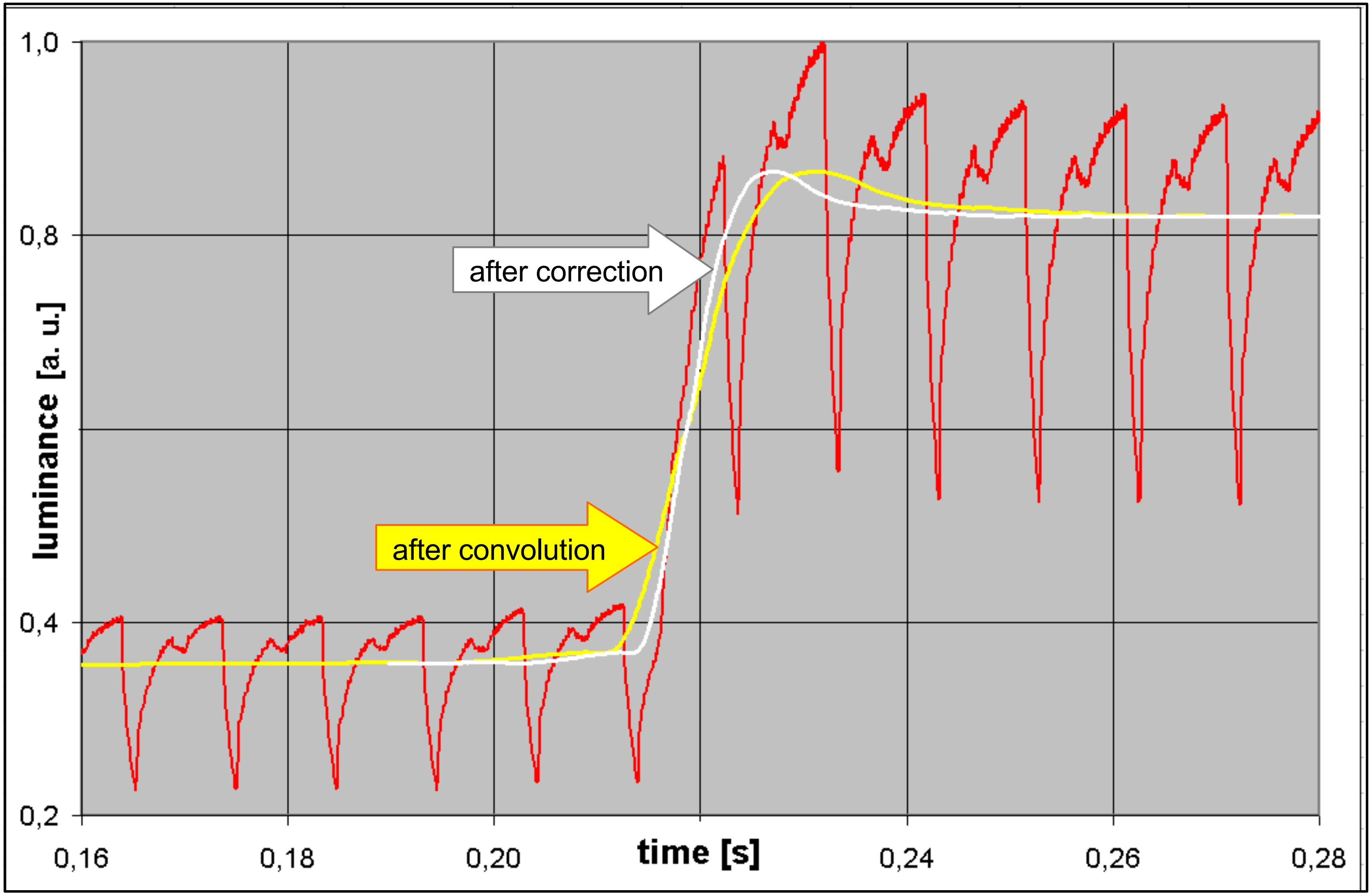
Correction Factor from Logistic Function



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

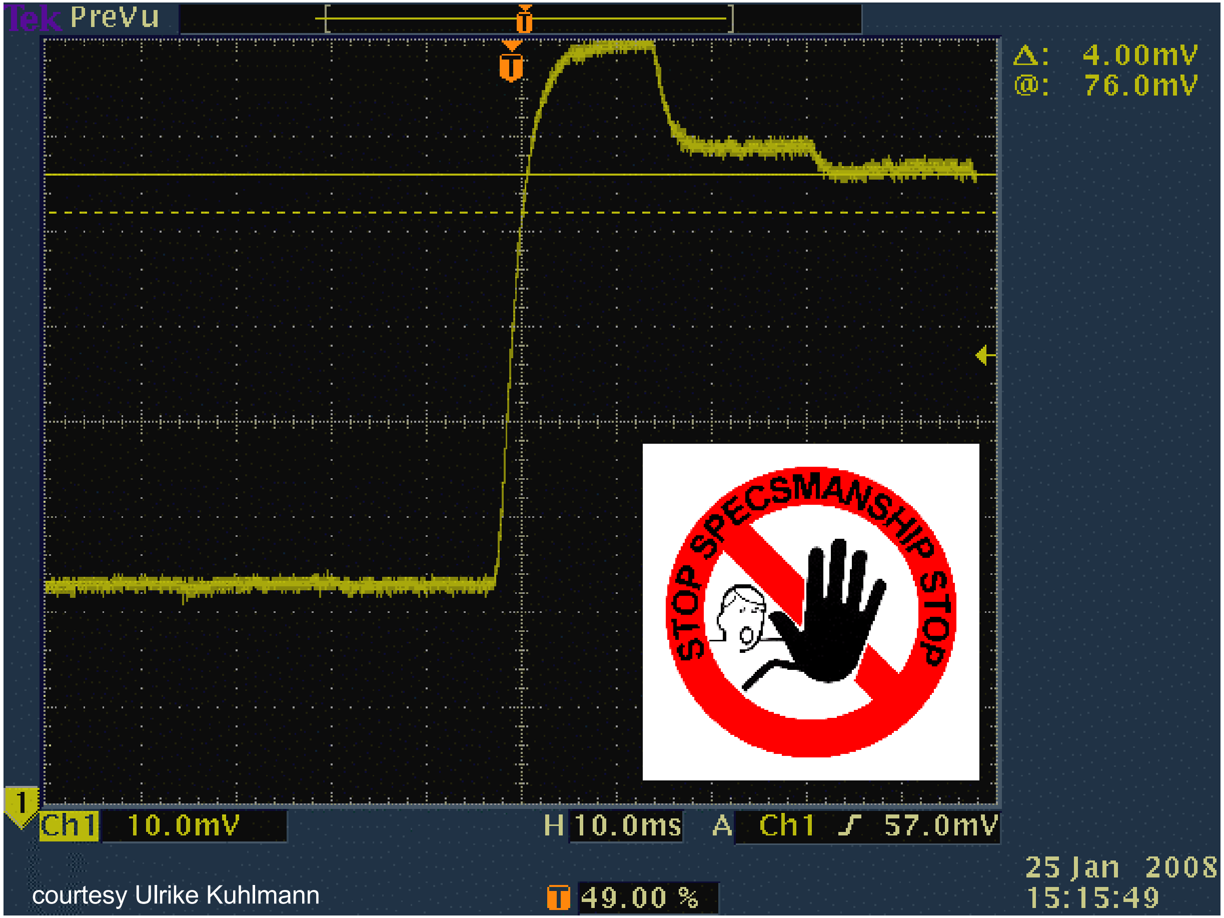
Example



104 Hz backlight modulation, transition period $(t_{90}–t_{10})^*$ of 9.7 ms,

$T_{MA}/(t_{90}–t_{10})^* = 0.9897$ ➔ **corr. factor ~0.63** (i.e. 6.1ms instead of 9.7ms).

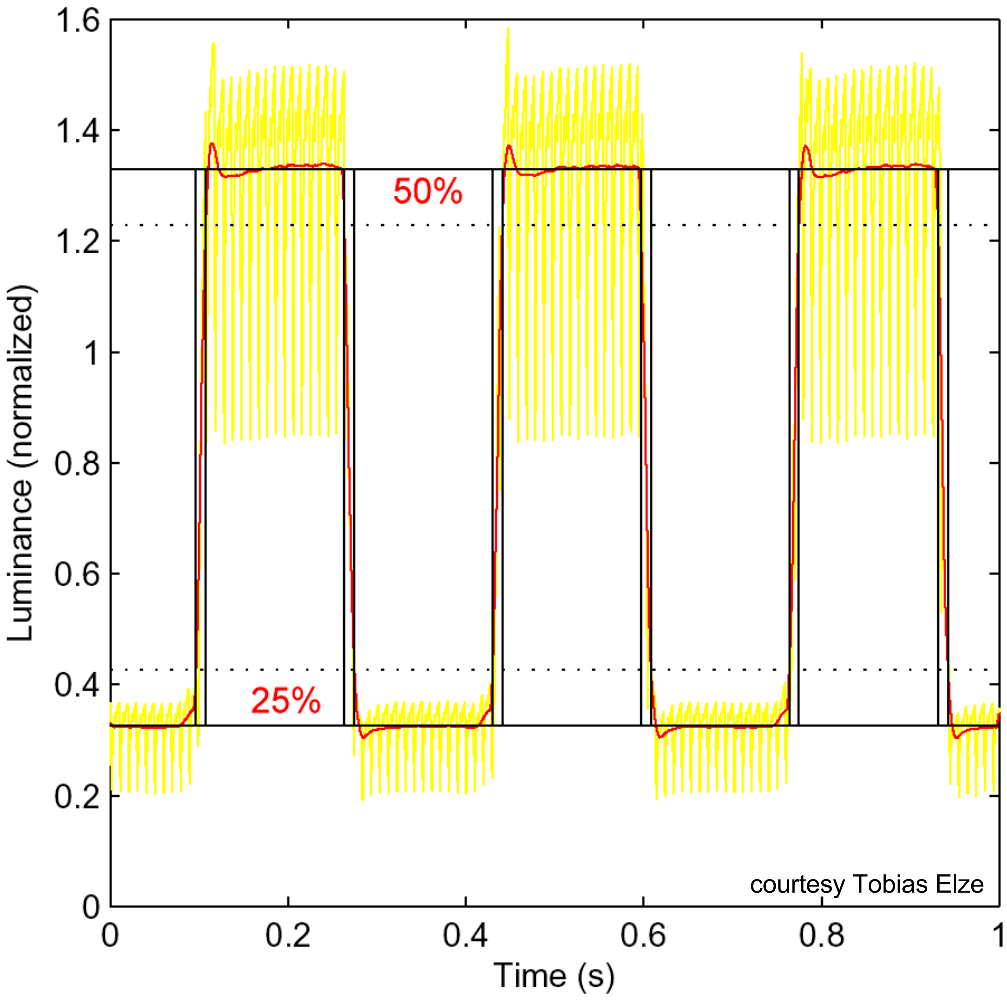
Overdriven Overdrive



courtesy Ulrike Kuhlmann

Transition model functions are monotonous

Overdriven Overdrive



Transition model functions are monotonous

Extended Approach

Transition $\tau(t)$ obscured by backlight modulation, b(t) and noise, $\nu(t)$.

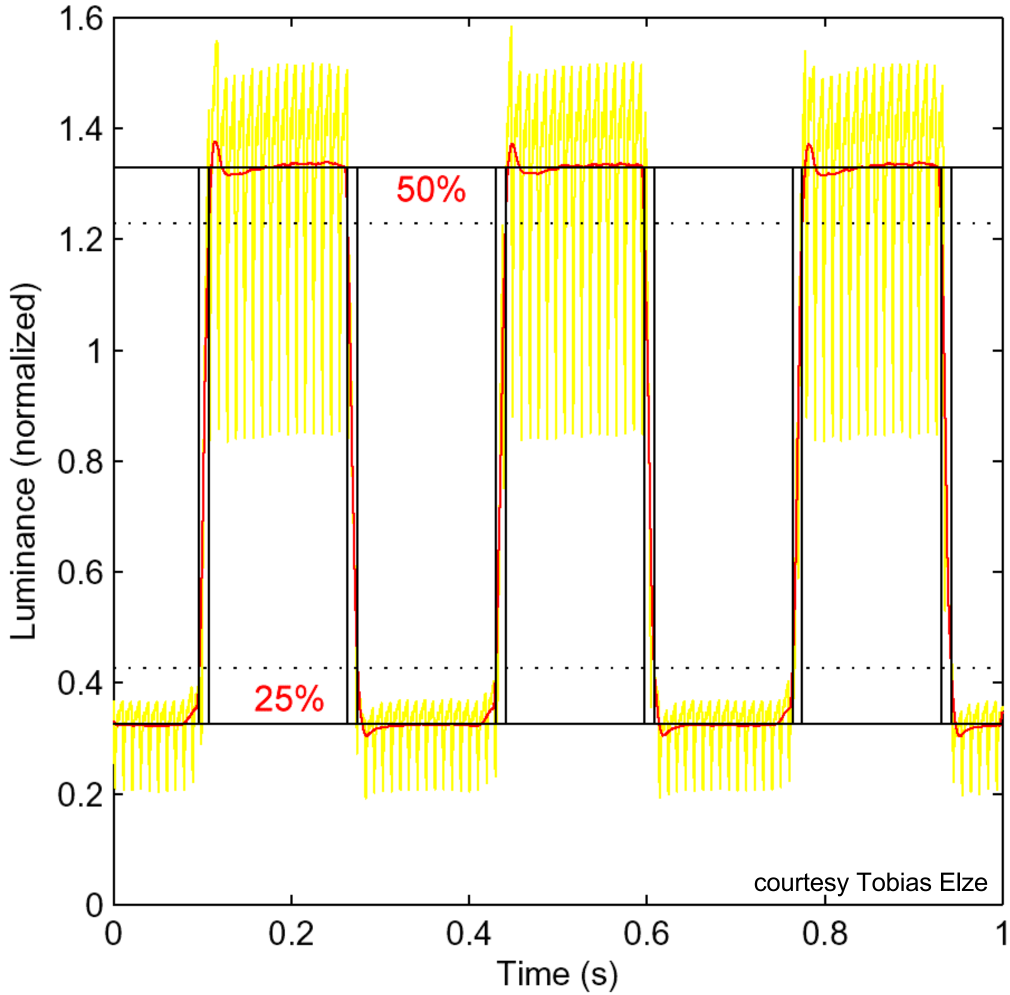
$$\tau(t) = \frac{y(t)}{b(t) + \nu(t)}$$

The backlight modulation function b(t) can be obtained

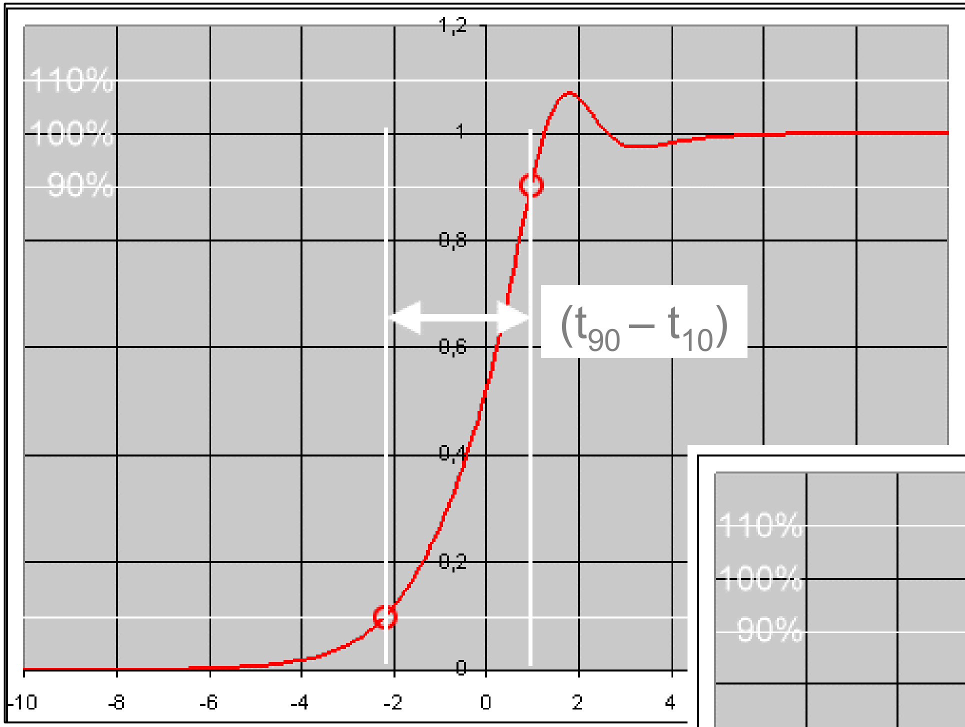
- from plateaus ($t \rightarrow \infty$) where $\tau(t)$ has settled,
- from separate measurements of the constant state.

Details of this approach, e.g. how to determine the correct **phase** of the function b(t) will be described in a forthcoming publication by Tobias Elze.

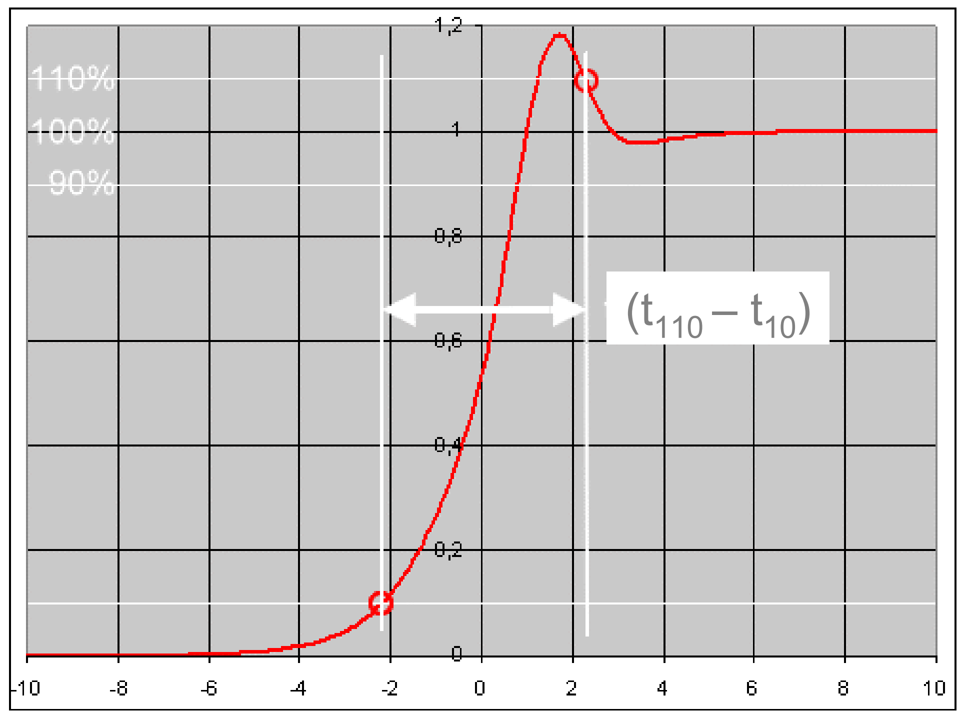
Extended Approach Applied



Overdrive Adjusted



Transition time (t_{90}–t_{10}) when overshoot remains below 10%.



Extended transition time (t_{110}–t_{10}) when overshoot exceeds 10%.

Limitations

- For infinitely fast transitions (e.g. step functions) and when b(t) adds a steep gradient to the transition $\tau(t)$,

  $(t_{90}-t_{10})^* \rightarrow 0.8 \cdot T_{MA}$ and thus
  $T_{MA} / (t_{90}-t_{10})^* \rightarrow 1.25$,

  depending on the **phase of b(t)**.

➲ For values close to 1.25 it becomes increasingly difficult to accurately determine the correction factor because of the steepness of the curve.

- **Overshoot** not (yet) considered by model functions.

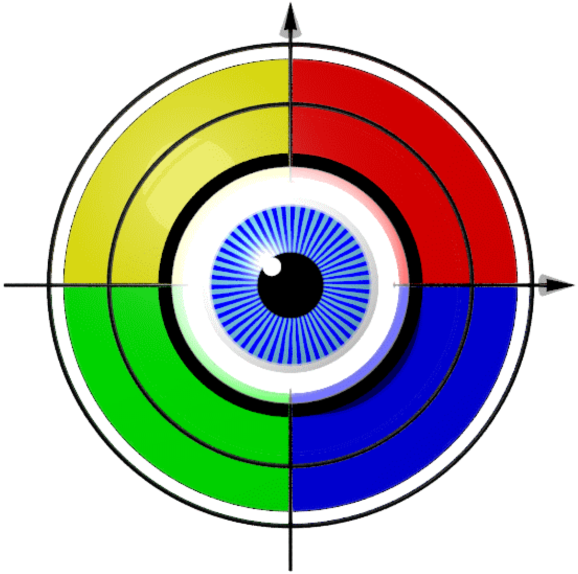
LCD response time evaluation in the presence of luminance modulations.

- The method is simple and easy to implement,
- it considerably improves the accuracy of evaluation of transition times in typical practical cases and thus the data specifying LCD-dynamics.

- A second method that overcomes the limitations of the first approach has been outlined additionally.

➲ Both methods together are a solid basis for realistic evaluation and specification of the dynamics of LCDs.

Thank you very much for your attention



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