Temporal characteristics of electronic display screens

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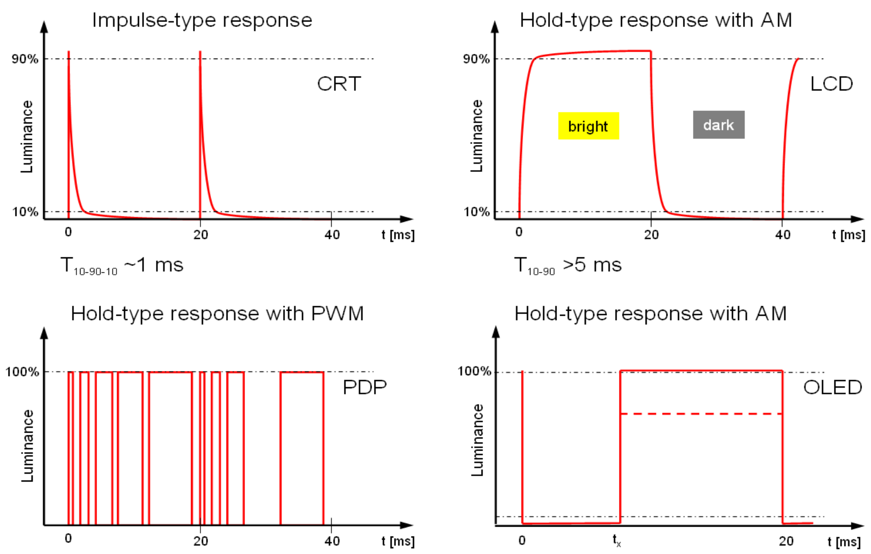
Abstract

Ever since the CRT with its impulse-type temporal response characteristics is on the retreat in most parts of the global market, manufacturers of LCD-screens have been working hard to improve the temporal performance of that display technology in order to reduce the blurring of moving images to values below visual perception thresholds. Other types of displays with faster transitions (switching) between different luminance levels (PDP, FED, SED, OLED displays) have often been described as superior with respect to the display of moving images.

This contribution compares the basic temporal performance of different types of electronic displays and explains the impact on the capability of portrayal and perception of moving images. Measurements are carried out with a variety of display devices and analyzed to explain and illustrate the impact of controlled backlight units (BLU) on the static and dynamic performance of modern TV-screens.

The paper tries to analyze and explain the actual meaning of data-sheet announcements like "Clear Motion Rate 600 Hz" or even "Perfect Motion Rate 1200 Hz".



Zusammenfassung

Seitdem sich die Kathodenstrahlbildröhre in den meisten Teilen des globalen Markts auf dem Rückzug befindet, haben die Hersteller von Flüssigkristallbildschirmen hart daran gearbeitet, das Schaltverhalten dieser Anzeigetechnik zu verbessern und das Verschleifen von bewegten Bildinhalten bis unter die Wahrnehmungsschwelle zu reduzieren. Währenddessen standen andere Anzeigetechniken (PDP, FED, SED und OLED-Anzeigen) in dem Ruf, durch ihr schnelleres Umschalten zwischen unterschiedlichen Leuchtdichtepegeln eine bessere Bewegtbilddarstellung zu bieten.

Dieser Beitrag vergleicht die grundlegenden dynamischen Eigenschaften verschiedener Anzeige-techniken und erklärt deren Einfluss auf die Darstellung und auf die Wahrnehmung von bewegten Bildinhalten. Messergebnisse, die an einer Vielzahl von Anzeigen ermittelt wurden, werden analysiert, um die Auswirkungen von zeitlich und räumlich gesteuerten Hinterleuchtungseinheiten auf die dynamischen und statischen Eigenschaften moderner Fernsehbildschirme zu erläutern.

Der Beitrag versucht die tatsächliche Bedeutung von Datenblattangaben wie "Clear Motion Rate 600 Hz" oder sogar "Perfect Motion Rate 1200 Hz" zu ermitteln.

Moving images on cathode-ray tubes (CRT) - the ideal case

The technology that made the proliferation of television across this globe possible since the 1950s has been the cathode ray tube where a controlled beam of electrons excites phosphors to emit light. In the year 1887, Ferdinand Braun realized a first version of this electro-optical transducer at the University of Karlsruhe, but Braun himself harshly rejected the idea of his assistant Max Dieckmann to use this device for television purposes ("… as much nonsense as the perpetuum mobile"). From the 1950s to about 2005 the CRT dominated the television market and then gradually has been replaced by liquid crystal display (LCD) screens.

Activation of the picture elements (pixels) of a CRT screen basically happens in a strictly time-sequential way, starting e.g. in the upper left corner of the screen, proceeding horizontally to the right, then with the intensity set to zero, jumping to the left edge of the screen and starting with the second line, etc., until the lower right corner is reached and thus, one frame is accomplished. In order to reduce the perception of flicker at a given bandwidth of the transmission channel, two half-images (frames) were interlaced with odd and even lines separated in the two frames. So 25 plus 25 frames were displayed during one second each presenting half of the lines of the image and recorded at subsequent moments in time.

The optical response of the CRT phosphors to the electron beam is quite fast, the transition between 10% of the amplitude up to the maximum and back to 10% takes only about 1 ms.

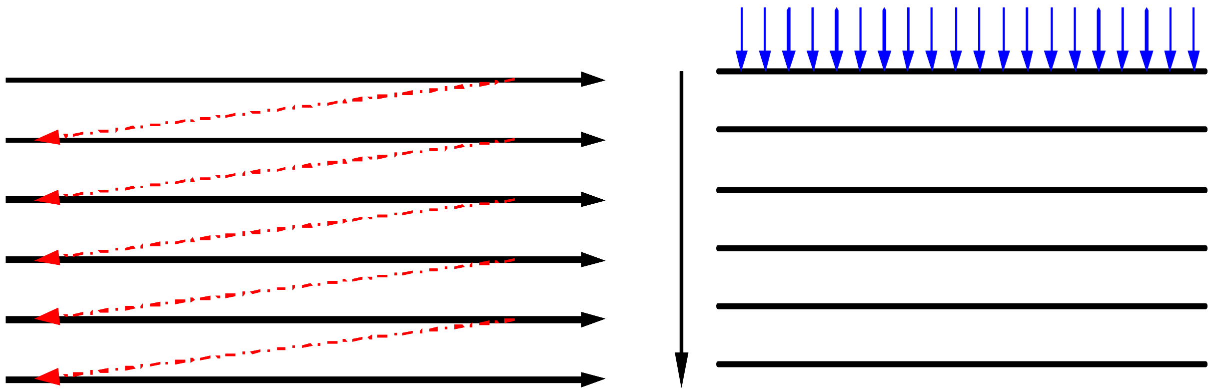


Figure 1a: Time-sequential scanning of CRT lines during one frame (half image). Two pixels are never addresses at the same moment in time.

Figure 1b: Parallel-addressing of pixels in a row and sequential scanning of rows in matrix addressed displays (e.g. LCD, PDP, OLED).

Due to this short period of time during which a moving target is presented to the observer, edge blur caused by temporal integration over one frame period during the process of *smooth pursuit eye-tracking* is very small and thus the visual quality of moving image portrayal is high [1].

In the case of LCD-screens, a certain amount of electrical charge is applied to the pixel capacitors during a charging period (~frame period / number of rows, e.g. 20 ms / 1080 ~ 18,5 µs) and the voltage resulting from that charge effects a momentum which makes the liquid crystal change its alignment and thus the optical response. In a first approximation we can assume that the charge on the pixel capacitor remains constant during a frame period, but due to the changing capacitance of the LC-capacitor the voltage across the LC-layer changes with LC-alignment. As a consequence, the voltage induced switching process in LCDs usually takes longer that one frame period. This switching can be made faster by a measure called "overdriving" or "dynamic capacitance compensation" where the driving voltage initially is increased to the maximum or reduced to the minimum for one frame period and then adapted to the target luminance level [2]. This approach requires a frame memory, since the amount of over- or undershoot is evaluated according to the starting and the end level of the luminance. This approach, if implemented well, is quite effective to reduce transition times between different levels of gray and to make transition times more uniform. Together with other measures (i.e. reduction of cell gap to about 5 µm, reduction of LC-viscosity), transition periods between different levels of gray could be reduced in state-of-the-art LCD-screens to about 5 ms as our review of a large number of technical papers revealed.

In addition to the impulse-type response of the CRT and the hold-type response of LCD-screens there is a third type of temporal response realized in plasma-display panels PDP). Since there are only two optical states available here (discharge either ON or OFF), the variation of luminance must be controlled by pulse-width modulation (PWM).

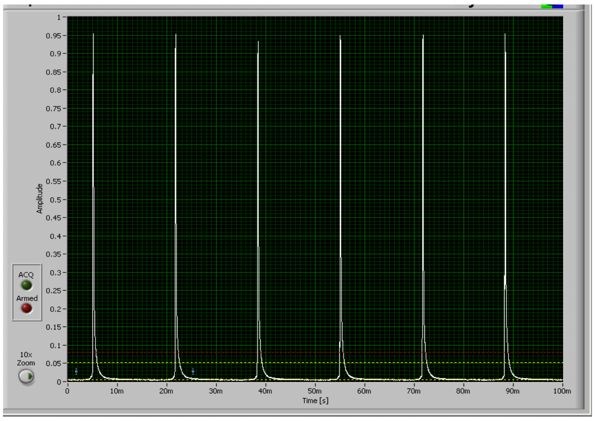


Figure 2a: Impulse-type luminance response of a CRT display. Effective luminance ~150 cd/m^2.

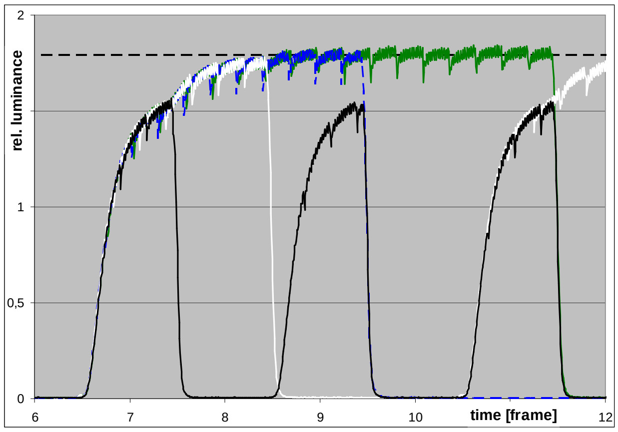


Figure 2b: Hold-type luminance responses of an LCD-screen (1, 2, 3 and 5 frame periods).

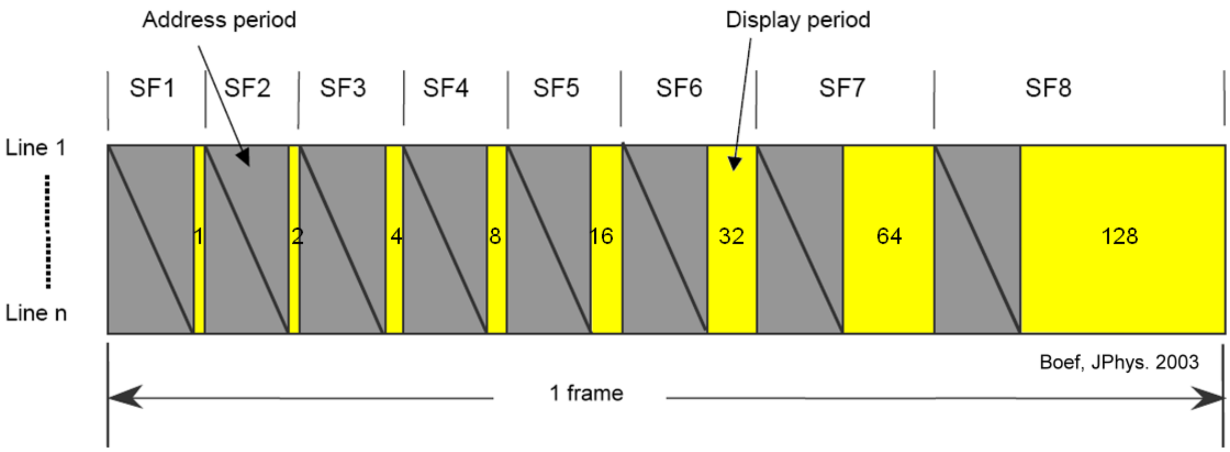


Figure 3a: Pulse-width modulation applied to plasma-display panels (PDP).

One frame period is divided into eight sub-periods, each comprising an address period (with reset and addressing), and a sustain (emission) period. Reset and address step durations are the same for all sub-fields. The durations of the emission (sustain) periods are 1, 2, 4, . . . , and 128 unit. The ratio of address-time to emission time is about 2,4 [3]. For HDTV PDP-screens operated at 50 Hz the frame period is 20 ms and thus the total emission time becomes 5,88 ms which has to be divided into 255 time-slices of 23 µs each. By adequate combination of the 8 time-slices, 255 levels of emitted luminance can theoretically be generated. In practical realizations however a limitation is given by the response time of the phosphors, of which the green and the red are slower than the blue, thus requiring spatio-temporal dithering to replace the shorter emission periods (1, 2 and 4 time-slices) [4].

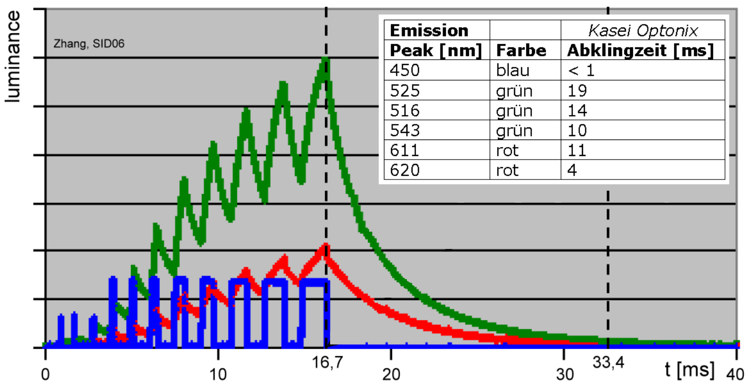


Figure 3b: Actual temporal response of PDP phosphors to UV excitation illustrating limited transition times.

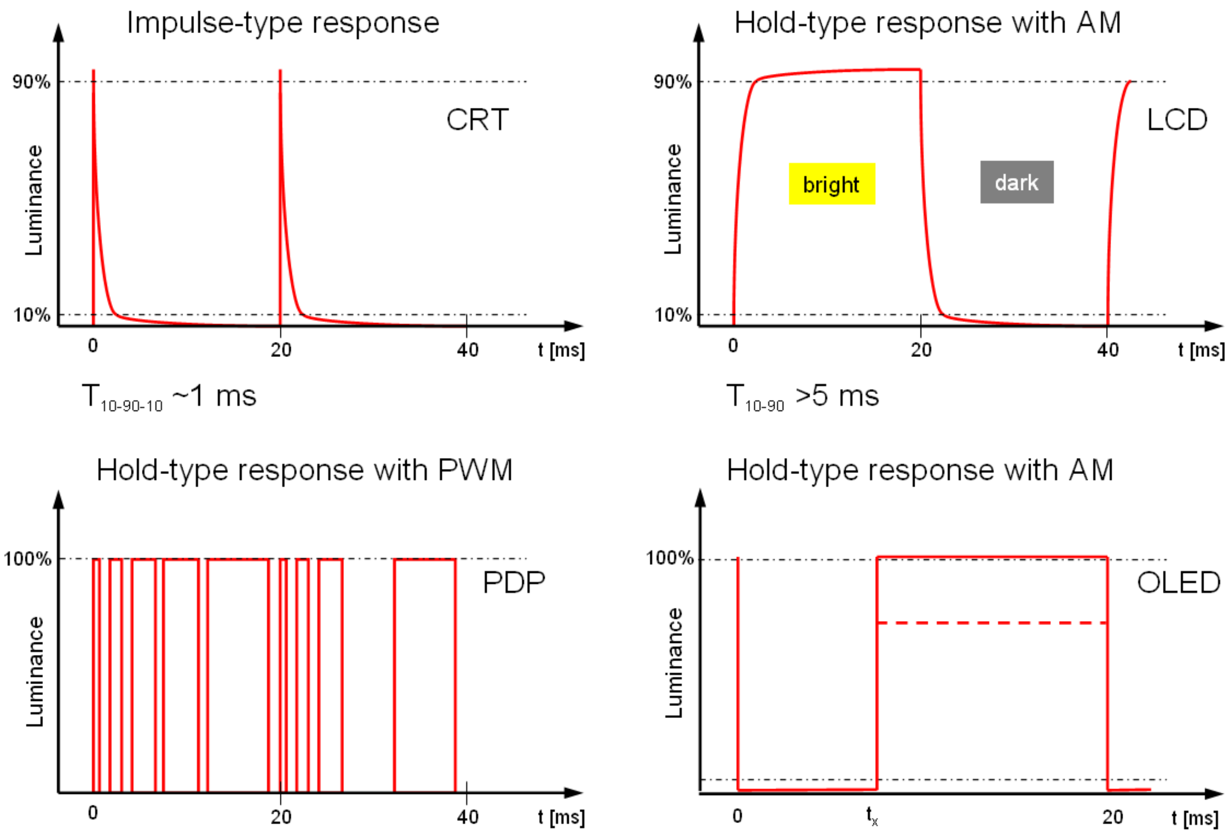


Figure 4: Idealized temporal response characteristics of CRT, LCD, PDP and OLED-screens.

Improvements by backlight control

In order to further improve the quality of motion picture display of LCD screens, and in order to reduce power consumption of LCD-TV-sets, the backlight unit (BLU) can be controlled in several ways. If the emission of the BLU is controlled over time as a function of the gray-level histogram of the images to be displayed, that in the case of darker images the BLU intensity is reduced (and thus power consumption) and the LCD transmittance is increased, the total luminance range of the display can be expanded by this approach called "global BLU dimming". Artefacts may be generated when fast changes occur between dark and bright image sequences.

When the light emitting area of the BLU is divided into sections that can be controlled individually with respect to the emitted luminance, such a division may be realized with horizontal segments that are switched ON and OFF in a sequence and synchronized with the refresh of the screen. This measure called "scanning backlight"can effectively reduce motion blur effects during the display of moving images.

When the horizontal segments of the BLU are further divided into tiles that can be controlled individually, the backlight becomes a kind of active (light emitting) vertically scanned display with a low resolution (large picture elements). The emitted luminance of these tiles can be controlled according to the actual image content in such a way, that instead of absorbing excess light from the BLU in the LCD, the BLU emission is reduced in darker parts of the image. In order to synchronize local BLU emission and LCD transmittance over the area of the display and over time, quite some amount of calculations are required. When this approach is successfully implemented (i.e. without introduction of new artefacts like double edges, color splitting and perception of flicker), display of moving images can be improved, the contrast of the display can be enhanced and at the same time, the power required for the BLU can be reduced [5, 6].

According to the results of Langendijk, et al. [7], the reduction of power required for the BLU in the global dimming mode goes up to 15%, and in the case of local dimming, power reduction is depending on the number of tiles: up to 50% is possible for 100 tiles, up to 75% for 1000 tiles.

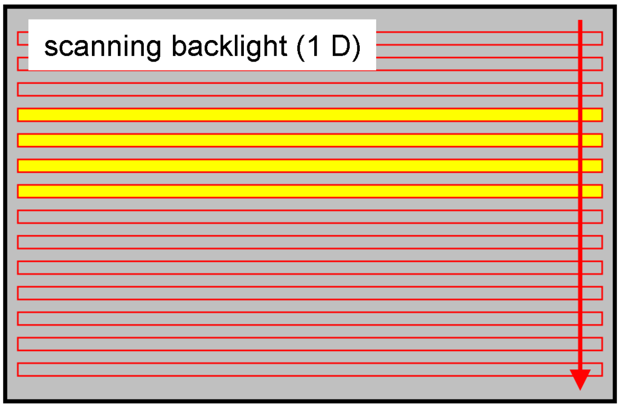


Figure 5a: The emission of horizontal regions of the BLU can be controlled individually and synchronized with the screen refresh timing (vertical scanning).

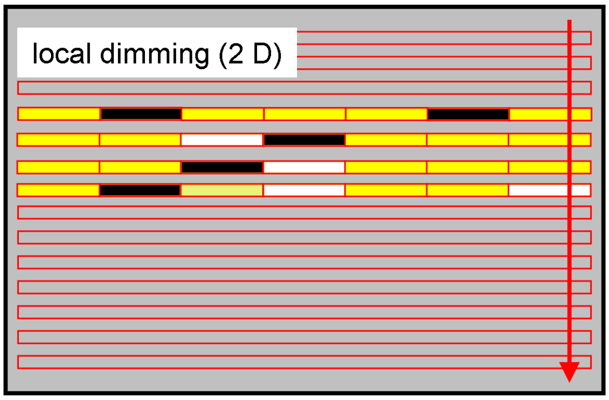


Figure 5b: Segmentation of the BLU lines into tiles of which the emitted luminance can be controlled individually across the display area and over time.

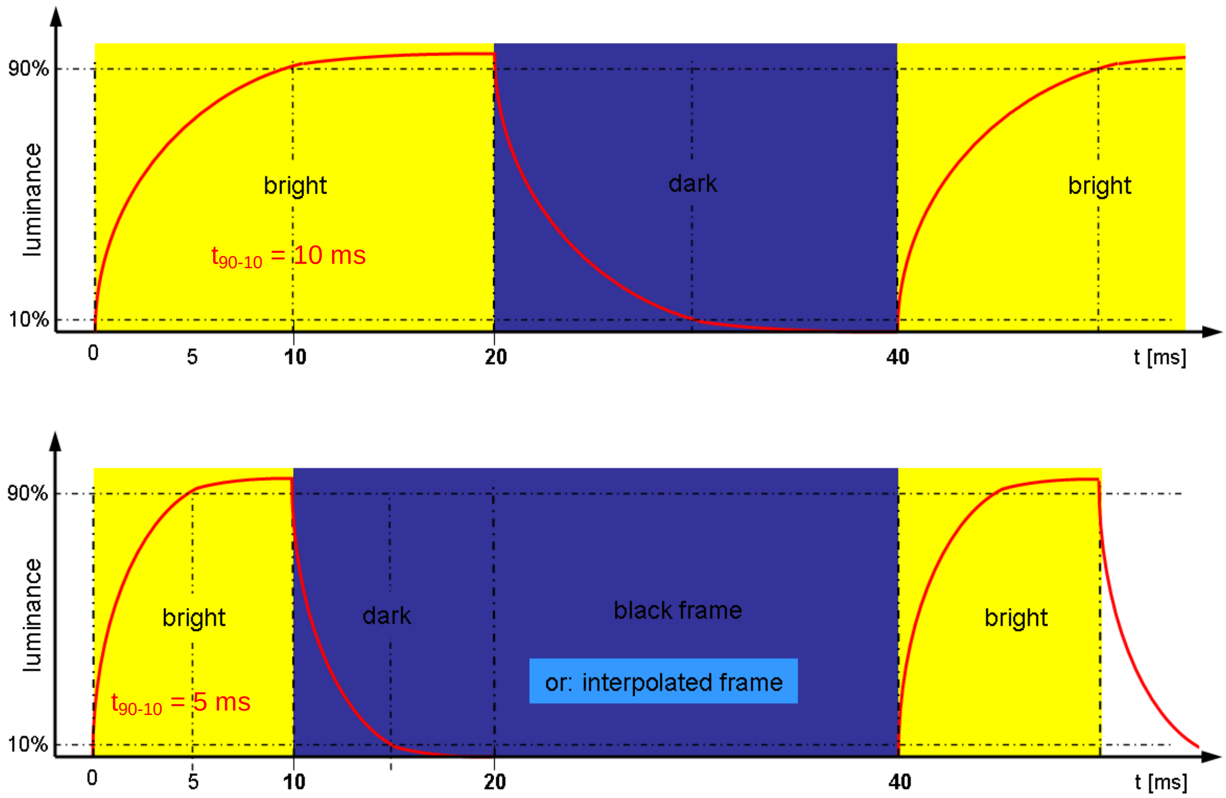


Figure 6: Approximation of the impulse response of the CRT in order to improve moving image display by e.g. doubling of frame rate (e.g. 50 Hz -> 100 Hz) with black frames inserted (risk of flicker and reduction of perceived luminance) or with additional interpolated images.

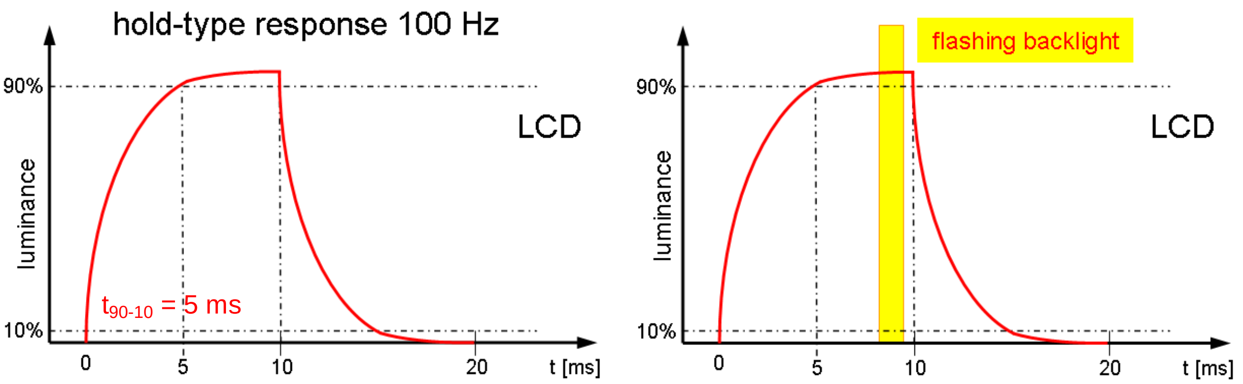


Figure 7: Masking of slow LCD-transitions by flashing of the BLU at the risk of perception of flicker and at the cost of strongly reduced perceived luminance.

Emission control in the case of OLED-display screens

OLED display screens have long been announced in the media as the ultimate solution to all motion artefacts due to the fast switching from one luminance level to another (in the range of tenths of milliseconds). However, it is known that not only the transition period ("switching speed"), but most of all the hold-period (persistence of the displayed image) that determines the amount of motion blur experienced by an observer under the condition of smooth pursuit eye-tracking with integration.

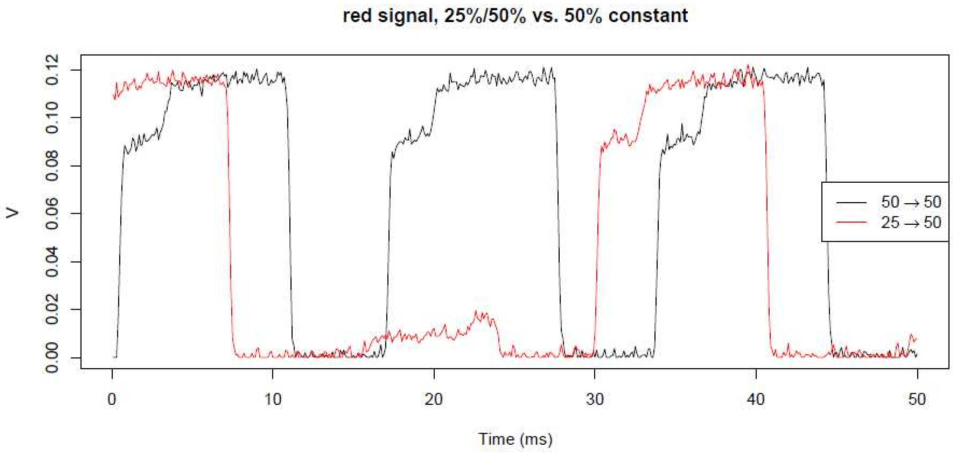


Figure 8: Measured temporal luminance variations of an OLED medical monitor for transitions between input signals RGB = 25 and 50, compared to the steady state of RGB = 50 @ 60 Hz frame refresh frequency. Transitions times are between 0,15 and 0,3 ms depending on output luminance swing and color. Tobias Elze (March 18, 2012), private communication.

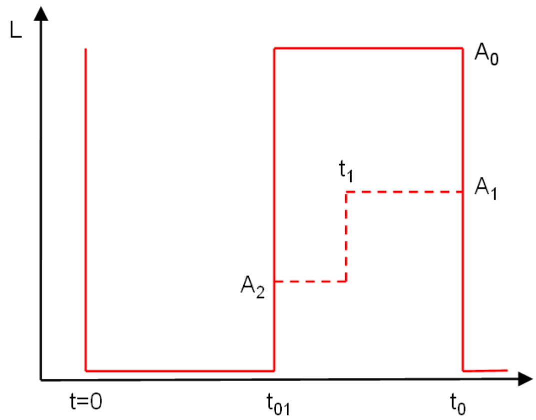


Figure 9a: Idealized structure of the mixed pulse-width and amplitude modulation of the OLED monitor of Fig.8. With the ratio $(t_0\text{-}t_{01})/t_0$ fixed to about 2/3, the parameters A_0, A_1, A_2 and $(t_0\text{-}t_1)$ can be controlled to adjust the emitted luminance.

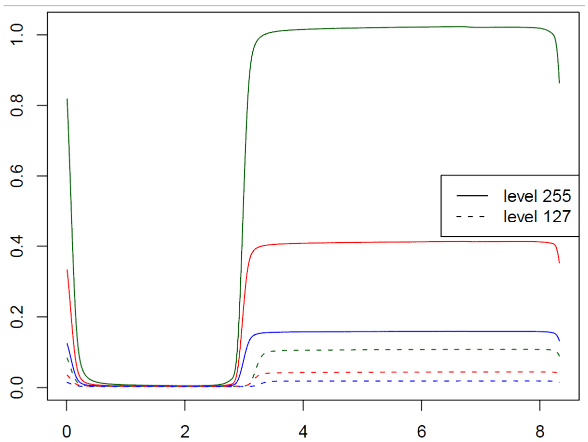


Figure 9b: Alternative emission control of an OLED monitor by temporal luminance amplitude modulation. The frame time of 16,7 ms is divided into two identical sub-fields. Tobias Elze (May 28, 2012), private communication.

The shorter the interval $(t_0\text{-}t_{01})$ is chosen, the more the impulse type response of the CRT is reproduced and motion artefacts should eventually be sufficiently reduced or eliminated. However, with decreasing time period $(t_0\text{-}t_{01})$ the amplitude of emission must be increased to maintain an acceptable perceived luminance (integral over one frame period). Such emission peaks require high currents through the OLED pixel and the resulting stress may reduce the lifetime of the organic emitters.

Figure 9b shows an alternative way for emission control in the case of an OLED monitor via amplitude modulation, here applied to reduce perceived flicker by doubling of the frame frequency. This approach improves motion portrayal only when additional images are computed (interpolated) or made available by the program source.

A look at the LCD-TV market

We had a closer look at two LCD TV-screens, both with controlled backlight units, the smaller one (47 inch screen diagonal) with 6 vertically stacked segments (scanning BLU) and the larger one (72 inch screen diagonal) with 32 horizontal segments arranged in 15 vertical groups (480 tiles) for local dimming. The MCI (Motion Clarity Index, undefined meaning) is specified as 800 Hz and 1000 Hz respectively. The LCD of both devices is specified as "normally black", no further technical data is available.

We measured the variation of luminance with time to evaluate the transition periods of the LCD and to obtain information about the luminance control of the BLU.

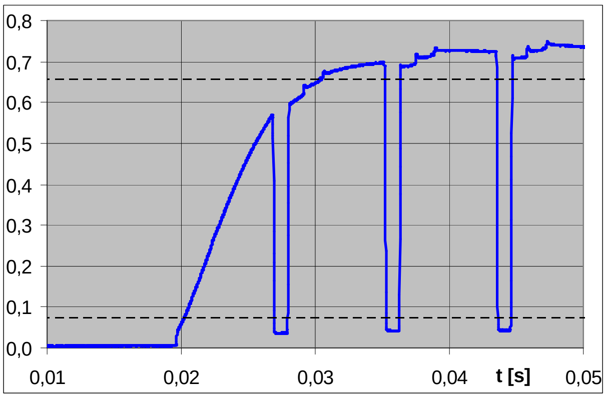


Figure 10a: Luminance transition from black (0,0,0) to white (255,255,255) of the LG47LM860V (MCI 800 Hz). Transition time t_{90-10} = 10 ms, 100% BLU @ switching frequency of 120 Hz.

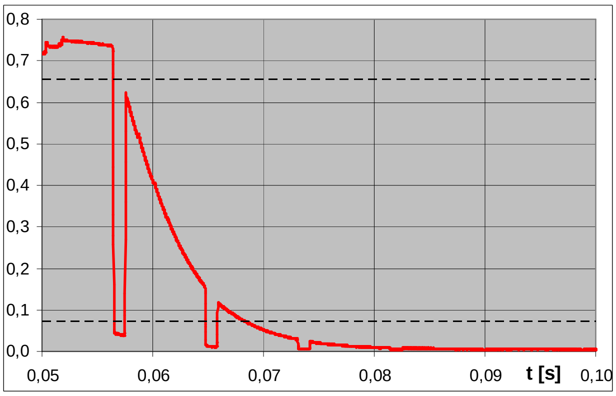


Figure 10b: Luminance transition from white (255,255,255) to black (0,0,0) of the LG47LM860V (MCI 800 Hz). Transition time t_{90-10} = 11 ms, 100% BLU @ switching frequency of 120 Hz.

With the response times of the 47-inch TV-screen being close to 10 ms, we can examine the limits of its dynamic performance with the schematic of Fig. 6. At a frame refresh frequency of 50 Hz the luminance response is quite well settled at the end of the frame period (20 ms). At a frame refresh frequency of 100 Hz however, the luminance step response is not as well settled yet. So this LCD could be used for presentation of images at a maximum frame rate of 100 Hz without major artefacts. Further increase of applicable frame frequency is not possible, since the transition from white to black (relaxation of the LC) cannot be made faster by e.g. overdriving.

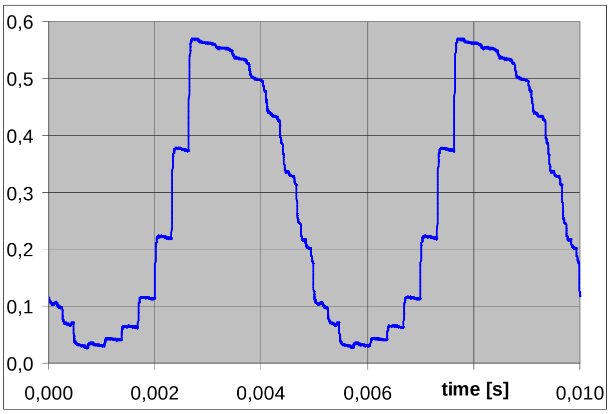


Figure 11a: Luminance vs. time for a constant gray level. The modulation period is 5 ms (200 Hz) for the LG72LM950V with local dimming BLU (MCI 1000 Hz).

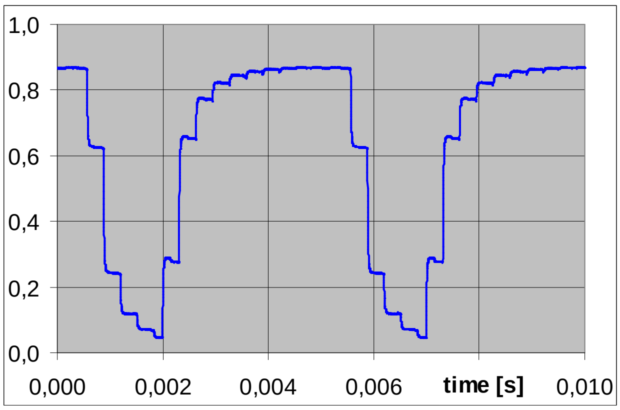


Figure 11b: Luminance vs. time for a constant white level. The modulation period is 5 ms (200 Hz) for the LG72LM950V with local dimming BLU (MCI 1000 Hz).

The temporal luminance variation of the 72-inch TV-screen at two luminance levels of the BLU is shown in Figs. 11. The base frequency for BLU switching is 200 Hz, the shorter modulation intervals of which the steps can be seen in Figs. 11 are at a frequency of 3125 Hz. The full-swing transition periods of the LCD-panel of this TV-screen are 10,5 ms and 7,5 ms for black to white and white to black respectively, but nevertheless, the "Motion Clarity Index" is specified with 1000 Hz.

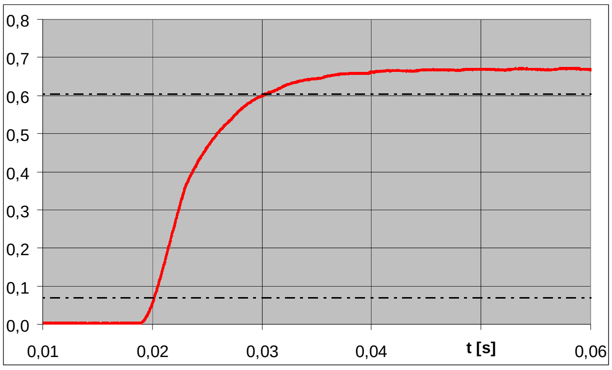


Figure 12a: Luminance transition from black (0,0,0) to white (255,255,255) of the LG72LM950V (MCI 1000 Hz). Transition time t_{90-10} = 10,5 ms, 100% BLU

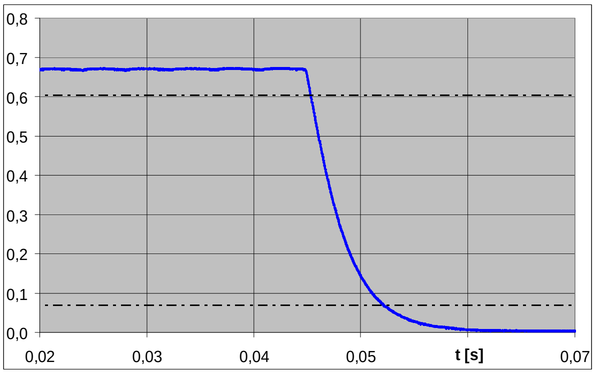


Figure 12b: Luminance transition from white (255,255,255) to black (0,0,0) of the LG72LM950V (MCI 1000 Hz). Transition time t_{90-10} = 7,5 ms, 100% BLU

Since we could not establish a relation between the specified "motion clarity indices" and the measured timing characteristics (similar to [7]), we assessed the quality of motion portrayal by visual observation of a vertical bar (black on white or vice versa) moving across the area of the 72 inch screen with a constant velocity of 10 pixel/frame period. The moving bar did not only exhibit edge blurring, it revealed distinct pronounced artefacts like zig-zag edges and judder. The same (horrible) results became visible with e.g. a moving pendulum test target supplied from a blue-ray disk.

Conclusion

Temporal and spatial control of the luminance of backlight units with LEDs, if properly implemented, provides the potential for improving moving image portrayal, contrast and energy efficiency. For the LCD TV-sets that we have measured we could not establish a relation between the specified values for the undefined "motion clarity index" and the timing of display and BLU control. In line with the actual reduction of electro-optical performance specifications in the product data-sheets, the "motion clarity tags" seem to be rather a feat of the marketing division than a technical performance specification. The customer thus is advised to check the motion portrayal performance of the display of interest by visual inspection with suitable test patterns.

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