What is needed in LCD panels to achieve CRT-like motion portrayal?

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Abstract — In LCD panels, motion portrayal as well as panel-addressing speed and response time are critical. They need to be balanced carefully, in particular for HDTV. It will be shown which combination of technologies, such as response-time improvement, black-frame insertion, double frame rate, and scanning backlight, can achieve CRT-like motion portrayal without demanding extreme response speeds from the panel.

Keywords — *Motion blur, motion fidelity, response time, hold time, frame rate, scanning backlight.*

1 Introduction

One of the shortcomings of present-day LCD TVs is the representation of moving images; they lose their sharpness. In this paper, what is needed to achieve CRT-like motion performance on LCDs is addressed. The two main contributors to this are the response speed of the LCD panels and the so-called "hold effect" of the LCD. Let us take as an example an object that moves across the screen with a speed of 0.5 picture widths per seconds (pw/sec), which for a 60-Hz frame rate is equivalent to 1/120th picture width per frame (pw/fr). When the "hold time" is equal to the full-frame period time, then the image is blurred over 1/120th of the screen width, or 16 pixels of a full-HD panel with a 1920 pixels/picture width. So, in order to avoid the resolution loss in this example, the hold time must be reduced, ideally to 1 msec.

The motion effects manifest themselves as a loss of spatial resolution for moving images and can also be measured as such. However, the underlying cause is a temporal one, and this temporal effect can also be measured directly, as explained in Ref. 1.

In particular, to determine the motion properties of CRT displays it is worthwhile to skip the intermediate step of measuring the spatial resolution of moving images, because CRTs make use of electron spots, spots that are larger than the pixel sizes of LCD panels. As a result, moving edges can be intrinsically vague, not because of movement. This unintended mixture of mechanisms can be avoided by looking directly at the temporal response of the display. The temporal response of LCDs includes the so-called "hold effect" and in CRT displays the phosphor time decay.

At this moment, there is not yet an agreed to measure to characterize the motion performance of a display basically because it is difficult to capture a complete response into one number. For the time being, we will use, in this paper, the so-called blurred edge time[2,3] (BET) as a measure of the temporal response.

The temporal response can be translated into the BET as follows.

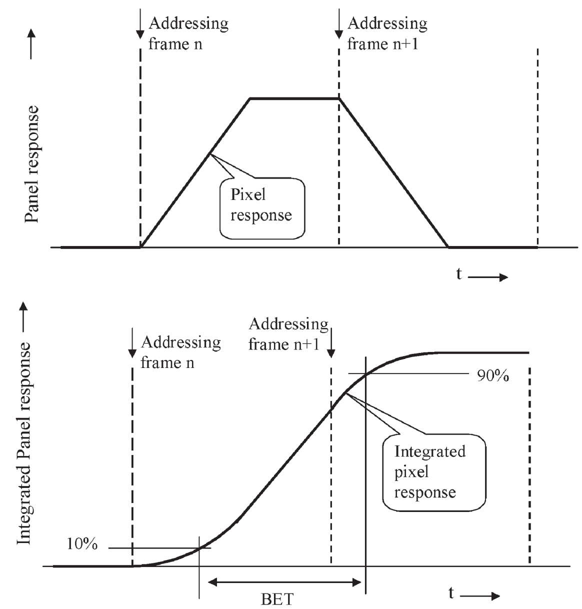

FIGURE 1 — The temporal response of a panel (top) and the integrated response (bottom) from which the BET can be derived.

Measure the luminance pulse that arises when the panel is set from one level to another level at one frame, and immediately back at the next frame. By integrating the luminance pulse, one obtains a luminance jump, in which we can determine the 10% and 90% levels and the time between them. This time is equivalent to the normalized BET. This approach automatically includes the "hold effect" of the display (To make it equivalent to the extended BET, it needs to be multiplied by 1.25, but that is not being used here.).

2 The CRT performance

When applying this to a CRT, the results will be dependent on the time decay of the phosphors. Figure 2 shows the phosphor decay for a typical (green) CRT phosphor. As can be seen, the luminance decreases to less than 10% in a fraction of a millisecond, but after the initial very fast decay there is a tail that decays not as fast. Figure 3 shows the

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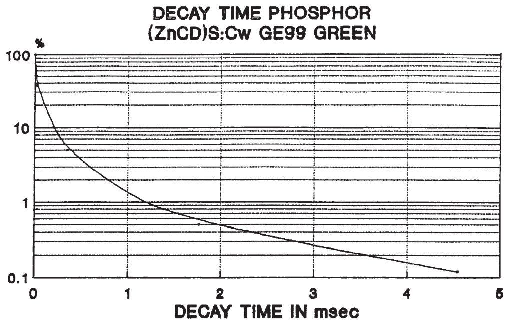

FIGURE 2 — The decay of a typical green CRT phosphor.

integrated response of the phosphor decay, leading to a BET of 1.6 msec, well below 2 msec.

The measurement of the CRT response with a pursuit camera[4] may give larger values because such a measurement measures more lines simultaneously and because of the size of the electron spot. So, if the temporal response of the CRT has to be approached by an LCD, a BET time of 1.6 msec would be the final goal.

3 The BET in LCDs as a function of decay/rise time, with a continuous backlight

Let us first look at the influence of the rise and decay time (the times mentioned here include the possibility of overdrive) for a given frame rate. Assume that the 10–90% rise time (LC-RT) is 80% of the frame time. Outside the 10–90% range, the panel response is extrapolated linearly for the sake of transparency. For this example, it does not matter if the response speed of the panel is intrinsic or achieved *via* overdrive.

The resulting BET will be 1.1 times the frame time, as is illustrated in Fig. 4.

For an infinitely fast panel, the luminance profile would be block shaped, and the resulting BET would be 0.8 times the frame time, as shown by Fig. 5.

So once the rise/decay time of the panel is shorter than 80% of the frame time, the maximum that could be gained by just reducing the response time even to zero is 27%. Figure 6 shows the BET as a function of the LC-RT (for three different frame rates).

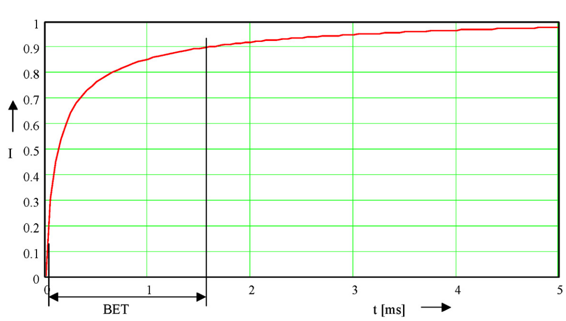

FIGURE 3 — The integrated time decay of a green CRT phosphor, leading to a BET of 1.6 msec.

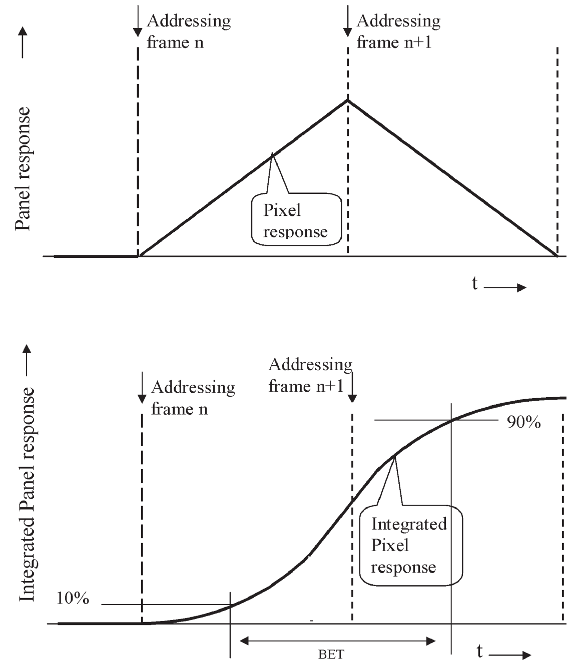

FIGURE 4 — The temporal response (top) and integrated response (bottom) of a panel with a 10–90% rise/decay time of 80% of the frame time, leading to a BET of 1.1 times the frame time.

4 Approaches for reducing BET

A step in the response can be made by reducing the frame time. For the reduced frame time, similar relationships exist between the rise/decay time and BET. This is illustrated in the next figure in which the BET is given as a function of the

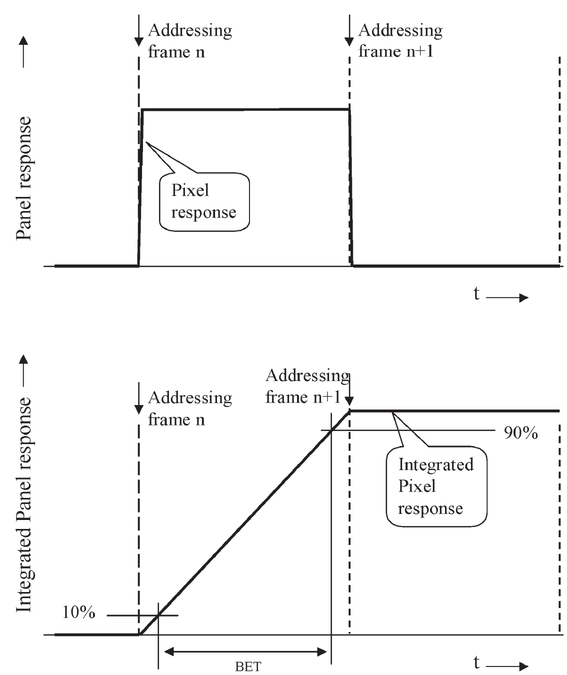

FIGURE 5 — The temporal response (top) and integrated response (bottom) of an infinitely fast panel, leading to a BET of 0.8 times the frame time.

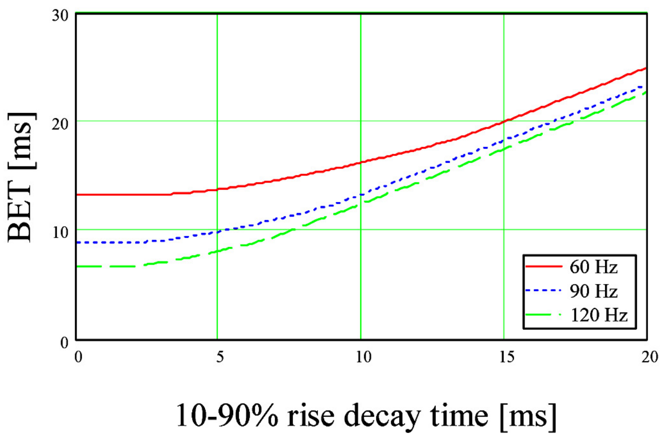

FIGURE 6 — BET as a function of the 10–90% rise/decay time of the panel, for three different frame rates.

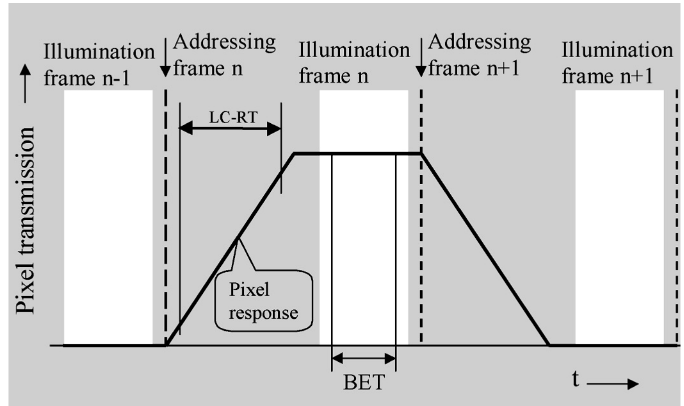

FIGURE 8 — Timing in an ideal scanning backlight with a block-shaped luminance profile. The LC-RT is allowed to have a value between zero and a maximum value that is determined by the illumination time. The shorter the illumination time becomes, the longer the response time of the panel can be.

10–90% response time, for frame rates of 60, 90, and 120 Hz (see also Ref. 1).

For a 90-Hz frame rate, motion-compensated frame-rate conversion has to be used, which is not trivial.

At 120 Hz, one can also use motion-compensated frame-rate conversion, or just insert a black frame between two original 60-Hz frames. This is also known as black frame/field insertion (BFI). This can be achieved without frame-rate conversion, but if used just on its own, it leads to reduced brightness or reduced contrast. One can also decide to apply the BFI only at the low intensity segments of the image and use both frames without motion compensation for the high intensity segments of the image. This approach is also known as gray-field insertion (GFI), but has the disadvantage that motion improvement is not achieved for the higher intensity segments of the image.

For BFI, the loss of luminance and contrast can be overcome by combining BFI with a scanning backlight.[5] However, a scanning backlight also gives favorable results on its own,[6,7] GFI is difficult to combine successfully with a scanning backlight.

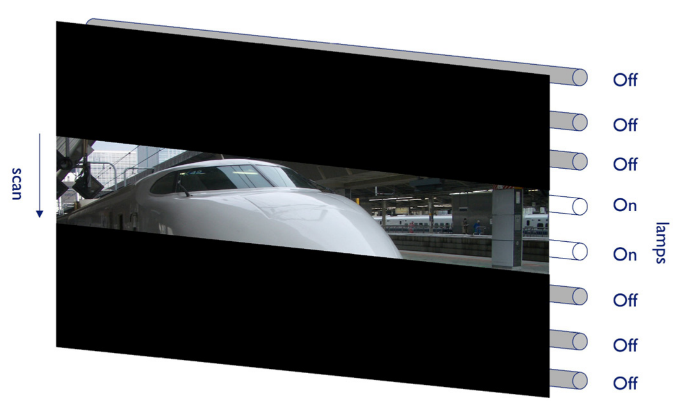

FIGURE 7 — A scanning backlight is a direct-lit backlight, in which the light sources emit light only for a short fraction of the frame-period time, and in which the light sources are ignited one after the other.

5 Use of a scanning backlight

The "hold effect" in an LCD can be reduced via its backlight. By illuminating each area on the screen only for a short period of time, the "hold effect" is reduced and motion fidelity is improved. A scanning backlight (see Fig. 7) is a direct-lit backlight, in which the illumination timing of each of the light sources varies from top to bottom according to the writing of video content into the panel.

Figure 8 shows an example of timing in an idealized scanning backlight with an ideal block-shaped luminance profile. With a scanning backlight there is, to some extent, a de-coupling between the panel response time (LC-RT) and the BET of the display.

In a practical scanning backlight, however, the luminance profile will not look exactly like a block. This is caused by the fact that, for reasons of overall luminance uniformity, there must be some overlap of the regions on the screen that are illuminated by the successive light sources. This is called optical crosstalk. It is, in fact, the combination of the optical crosstalk and the difference in illumination timing between the successive light sources that causes this broadening of the luminance profile on the screen. The broadening of the illumination pulse therefore becomes, expressed in milliseconds, less when the backlight is used for a higher frame rate.

Figure 9 shows a simulated luminance pulse based on measurements on the window of a sample backlight, at a point near the center of the window. This sample backlight has, from a timing point of view, 10 different light sources. The point where the light is measured is close to a light source, and the timing of that source is used as a reference. The luminance of that light source is defined as 100%. The light of neighboring light sources, at that same point, each give a luminance contribution of 27%, and their neighboring sources give a contribution of 7%. The on-time of the light source in Fig. 9 is 1.67 msec, 10% of the frame time of a 60-Hz display.

Integrating the luminance pulse leads to a BET in a similar manner as in Figs. 1 and 4 for the panel response.

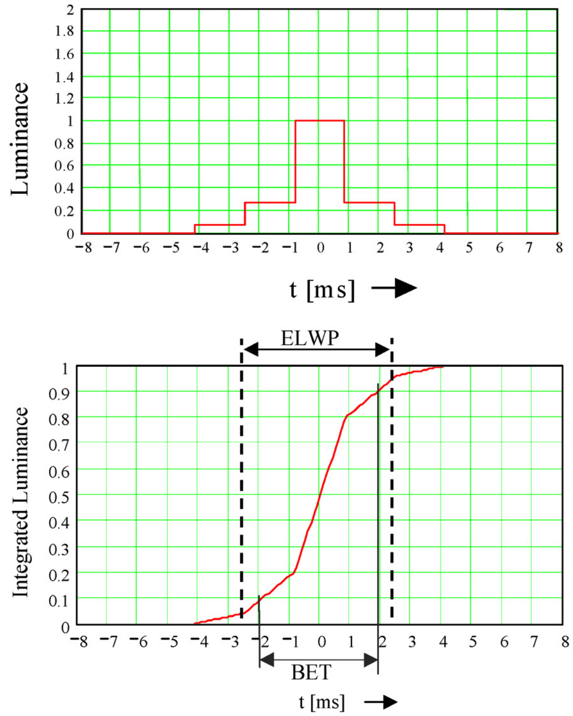

FIGURE 9 — The luminance (top) and integrated luminance (bottom) from which the BET is calculated, including optical crosstalk. In this backlight, there are 10 (timing) different light sources, and their illumination duty cycle is 10% at a 60-Hz frame rate. The ELWP indicates the timing of a block-shaped luminance profile with the same BET.

From the calculated BET, the equivalent light width pulse (ELWP) is derived as 1/0.8 times BET. The ELWP is used later on to calculate the maximum allowed LC-RT of the panel.

Figure 10 shows, for a given optical crosstalk, the relationship between the light-source duty cycle and the BET.

As can be seen from Fig. 10, the influence of the optical crosstalk becomes less for larger BET values. Ultimately, the BET is 80% of the illumination time of one light source. It is also clear that for a given optical crosstalk it will be difficult to achieve BET values smaller than 0.23 times the frame time. This limit will be taken into account when calculating the maximum panel response times later on.

6 Design rules for a scanning backlight

For maximum improvement in the motion fidelity, the lamps must be able to give sufficient light in spite of a small duty cycle. This can be achieved by increasing the number of light sources, or by increasing their peak light output. Using the HCFL light sources allows for a drastic increase in the lamp current.

A further requirement is that there is sufficient optical isolation between the areas on the screen that are illuminated by successive light sources. This has to be accomplished without sacrificing the overall luminance uniformity of the backlight.

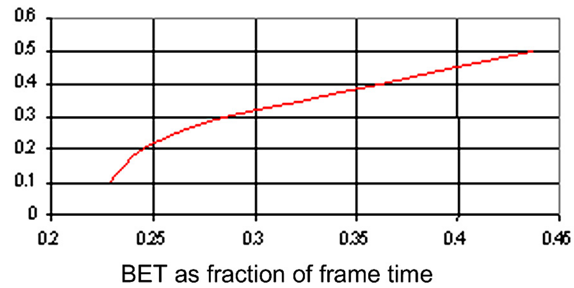

FIGURE 10 — The required lamp duty cycle as a function of a desired BET, in a specific case of optical crosstalk.

Besides reducing the optical crosstalk, it is also important that the illumination timing of succeeding light sources is minimized. One could even chose to give all of the light sources the same timing, thus eliminating the effect of optical crosstalk. However, this can only be applied when there is only one region on the screen that needs to have good motion fidelity.

It will also be clear that increasing the frame rate results in an improvement because then the timing difference between the light sources reduce proportionally with the frame-period time.

7 Maximum panel response time when a scanning backlight is used.

To calculate the allowed rise and decay time, we assume a square luminance distribution, given by the ELWP and being equal to BET/0.8 msec. Depending on the optical crosstalk, the luminance duty cycle of the light sources has to be smaller. Furthermore, there is a minimum BET value that can be achieved, depending on the frame-period time, optical crosstalk, and maximum peak output of the light sources. For the example given in this paper, the minimum achievable BET value is 23% of the frame-period time (see Fig. 10).

So, the BET is determined by the scanning backlight, and for that BET value the LC-RT can have a value between zero and a maximum value. This maximum value is at its largest when the illumination time, and thus the BET, is smallest. This is shown in Fig. 11.

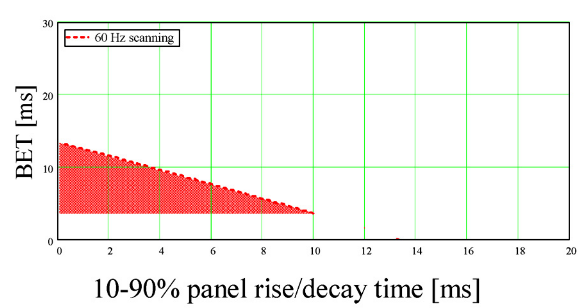

FIGURE 11 — The possible combinations of BET with a scanning backlight, and the rise/decay time LC-RT of the panel.

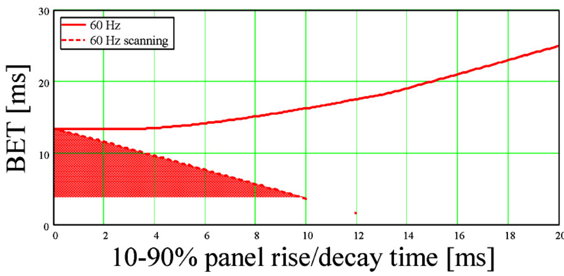

FIGURE 12 — The obtainable BET as a function of the panel rise/decay time (LC-RT) for a scanning backlight and a non scanning backlight, at a 60-Hz frame rate.

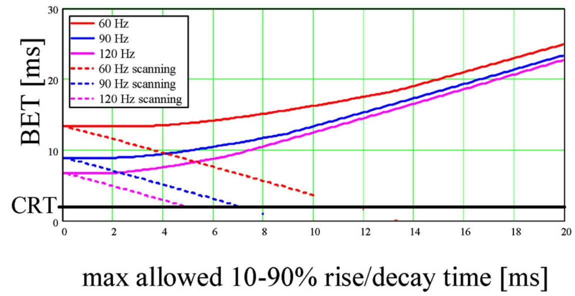

FIGURE 14 — The maximum allowed rise/decay times (LC-RT) for a required BET, for 60-, 90-, and 120-Hz frame rates, with and without a scanning backlight, and a CRT BET value of 1.6 msec.

Figure 12 shows, for a 60-Hz frame rate, the relationship between the BET and the panels LC-RT for both a scanning and a non-scanning backlight.

As can be seen clearly from Fig. 12, there is for a non-scanning backlight a lower-limit value for the BET, no matter how short the LC-RT has been made. This conclusion was also drawn in Ref. 1 and could be derived from Refs. 2 and 8. Applying the scanning backlight enables an reduction of the BET and even allows larger LC-RT values.

To create an overview for different frame rates in one figure, Figs. 11 and 12 could be simplified. By renaming the horizontal axis of those figures into the “maximum allowed 10–90% rise/decay time (msec),” the triangular surface can be represented by just the border line of that surface. This is applied in Fig. 13, where the maximum allowed rise/decay times (LC-RT) for a required BET, for 60-, 90-, and 120-Hz frame rates, are given for a display with and without a scanning backlight.

The next step, and the purpose of this paper, is to introduce the BET value for a CRT that was derived earlier in this paper. This is shown in Fig. 14.

Figure 14 shows, first of all, that just by increasing the frame rate, even to 120 Hz, will not bring the LCD BET value to the level of a CRT. Furthermore, Fig. 14 shows that at any frame rate and any rise/decay time, a scanning backlight reduces the BET. So, from a motion portrayal point of view, the scanning backlight eliminates the need to go to higher frame rates. Furthermore, it eases the requirements on panel rise/decay times. This can be of particular interest for HDTV systems. One might argue that up-conversion to higher frame rates is needed to avoid flicker. However, it could also be argued that the 60-Hz frame rate is already high enough for TV application. If one nevertheless decides that frame-rate up-conversion is needed, this can be kept as small as is practically possible because this eases the response-speed requirements of the LCD panels

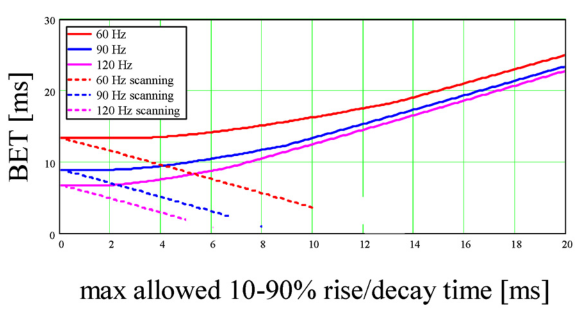

FIGURE 13 — The maximum allowed rise/decay times (LC-RT) for a required BET, for 60-, 90-, and 120-Hz frame rates, with and without a scanning backlight.

8 Conclusion

The starting point of the investigation is the need to give an LCD the same motion portrayal as a CRT, and how this, in view of HDTV, can be achieved without having requirements that are too extreme on panel response times.

It was found that

- The BET of a CRT is shorter than 2 msec.
- The motion fidelity of a CRT cannot be achieved in an LCD panel by just increasing the frame rate to 120 Hz and increasing the response speed of the panel.
- The largest allowable panel response time for a required BET can be obtained by using a scanning backlight.
- Then, frame frequency does not have to be chosen any higher than needed from the field flicker point of view.
- When BFI is used, it is best combined with a scanning backlight.

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