# A new metric for LCD temporal response: Dynamic gamma

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## Abstract

*In this paper, we propose a new metric called "dynamic gamma" to quantitatively evaluate the dynamic temporal response of an LC display device. The widely-used response time and corresponding 3-D bar graphs cannot fully describe the dynamic characteristics of an LC panel [1], and using response time to compare different LC panels and assessing the dynamic features of LC panels is difficult. On the other hand, the new metric MPRT mixes an LC panel's slow temporal response with its hold-type display effect. The proposed new metric, dynamic gamma, and corresponding 2-D plots, are arguably more suitable for quantitatively characterizing the dynamic characteristics of an LC panel, so comparing two LC panels becomes easy. Furthermore, dynamic gamma has the unique property that it can be used to quantify the limitations/capabilities and to assess the effectiveness of an overdrive mechanism for a particular LCD. In the paper, two LC panels using different technology are analyzed and compared using this new metric.*

## 1. Introduction

With its advantage on size, weight, style, power consumption and MTF, LC TV is penetrating the TV market with accelerating speed. Compared with traditional CRT TV and other flat-panel TV such as plasma TV, however, LC TV has the shortcoming of motion blur. One of the reasons that cause motion blur on an LC panel is its slow temporal response. Many efforts have been made to accelerate LC panel's temporal response, and one of them is overdrive technology [1-6]. A metric is urgently needed that can quantitatively describe and compare the dynamic characteristic of LC panels and quantify the improvements due to overdrive. The widely-used metric, response time, cannot serve this purpose well.

Response time is defined as the arrival time at 90% of the difference between the starting luminance and the targeted luminance [1]. The concept of response time was coined in the old days of on-off, black-white LC panels. To describe LC panels with gray-level capability, a set of response times (typically 9x9) that sample and cover the range of driving values are measured and usually represented by 3-D bar graphs. In [1], the authors point out that the definition of response time unfairly gives larger error tolerance to the transitions with larger difference between starting and targeted luminance. For example, response time from 0 to 255 is measured at the time when the actual luminance reaches 229.5, while response time from 200 to 255 is measured at the time when the actual luminance reaches 249.5. Although the two transitions seemingly share the same target luminance, the actual response times are actually measured at different ending luminance values (249.5 and 229.5 respectively). Furthermore, it is not efficient to use so many response time data as a quantitative description, especially when comparing two similar LC panels where some response time data of one panel are faster than the other panel and some are slower.

Recently, a new metric, moving picture response time (MPRT), has been proposed by an industrial working group [7][8]. MPRT is based on measuring blurred width of camera-captured moving sharp edges on the screen of a display device. The camera imitates the human visual system (HVS) with smooth pursuit and integration effects. Therefore, MPRT can be used not only to describe LC panels, but also to perform comparisons with PDP and CRT as well.

Nevertheless, MPRT is not a desirable metric for quantitatively describing the temporal response of an LC panel. Most importantly, MPRT mixes together the two blurring factors of an LC panel: its hold-type display and its slow temporal response. Besides, an MPRT measurement system is too complicated. The system needs to mimic the two effects in human visual system, namely, smooth pursuit and integration [9]. While integration only requires properly setting the camera's exposure time, smooth pursuit requires that the camera chases the motion of sharp edges. Due to implementation difficulty of smooth pursuit, as many as four different methods have been developed [8]. Two of them make the camera lens physically pursue the moving object. Because the camera pursuit is too expensive, the other two simpler methods calculate the results from still camera lens plus mathematical models of pursuit and integration effects.

In this paper, we propose a new metric: dynamic gamma, which is more suitable for quantitatively describing the temporal response of an LC panel than response time and MPRT. Dynamic gamma and its 2-D graphical representation have unique properties that are important to overdrive design and assessment. They reveal the fundamental limitation to overdrive, and provide a simple method for quantifying the effectiveness of an overdrive mechanism for a particular LC panel. Dynamic gamma also makes quantitative comparison between two LC panels easy. In addition, the measurement of dynamic gamma is relatively simple. All the above aspects will be discussed in detail in the following sections.

## 2. Dynamic gamma

Our proposed metric borrows a well-known term in color science: gamma. The gamma of a display describes the nonlinear relationship between the input digital-counts (0-255 if 8-bit) and the output luminance of a display [9]. For example, the nonlinear relationship of a CRT display is a power function with exponent of approximately 2.2. The native static gamma of an LC panel is sigmoid, and a gamma correction circuitry is often used to make an LC panel to have a gamma that is similar to that of a CRT. To distinguish from the "dynamic gamma" that we will introduce later, we referred this gamma as "*static gamma.*"

Unlike CRT that has instant transitions from one level of luminance to another level, LCD has gradual and often slow transition. The nonlinear relationship between the input digital-counts and the output luminance of LCD keeps changing during a transition.

To describe dynamic input-output relationship of an LC panel during transition times, a new concept, "*dynamic gamma,*" is proposed. A dynamic gamma value is the actual luminance at a fix time point after a transition starts. The fix time point is chosen to be one frame time after a transition starts. More specifically, *a dynamic gamma value is defined as the actual display luminance value at one frame time after a new driving value is applied.*

To eliminate the influence of disparity of different LC panels, the measured actual display luminance of an LC panel is normalized by its static gamma. More specifically, the measured data are mapped back through the inverse static gamma curve to the digit-count domain (0-255 if LC panel is 8-bit).

Transition time describes dynamic input-output relationship of an LC panel during transition times in a different way, as illustrated in **Figure 1**. Response time measures *the transition time required* for a pixel to transit from a starting value and to reach a value pre-set by the starting luminance and the targeted luminance. On the contrary, dynamic gamma measures *the actual luminance after one frame* to transit from a starting luminance and to reach a targeted luminance. In summary, the former measures the time when a fixed luminance is reached, while the latter measures the actual luminance when a fixed time is reached.

Same as response time, dynamic gamma has two input valuables: starting luminance and targeted luminance. Dynamic gamma also sparsely samples the range (for example, 9x9) of the two input valuables to cover all possible transitions.

Different from response time that is typically represented by 3-D bar graphs, dynamic gamma is best shown as a set of 2-D curves, such as **Figure 2**. We call these curves dynamic gamma curves. Each curve describes the relationship between the actual display luminance and the driving value with the same starting luminance value, and different curves represent different starting values. For the purpose of convenience, dynamic curves are indexed by their starting values. For example, curve 0 represents the curve starting with luminance value 0.

## 3. The properties of dynamic gamma

**Figure 2** (a) and (b) show two 2-D plots of dynamic gamma curves measured from two LC panels (LCD A & B) that are built with different technology. Graphically showing 9x9 measured data, **Figure 2** (a) and (b) reveal four important properties of dynamic gamma:

(1) **Figure 2** shows a pattern that every curve is monotonically increasing, and the curves with higher starting luminance are above the curves with lower starting luminance in the plots. This pattern reflects the fact of LC panels that (i) the luminance of a transition is always higher than the luminance of another transition starting from the same starting luminance but with lower driving value, and (ii) the luminance of a transition is higher than the luminance of another transition with same driving value but starting from the same starting luminance, as illustrated in **Figure 3**.

(2) The curves in **Figure 2** are scattered. The scattering is caused by slow response of LC panels, and the area that the curves cover reflects the degree of slowness of an LC panel's temporal response. Faster an LC panel is, smaller the scattered area is. An ideal LC panel with instantaneous response has the dynamic gamma curves converged to one curve. Because the input-output dynamic gamma relationships are normalized to digit-count vs. digit-count domains, the converged curve is a linear line with identical input and output.

(3) The nine dynamic gamma curves in **Figure 2** can be directly used to derive a 9x9 overdrive lookup table. Given current targeted value and previous frame value, we first find the curve that is corresponding to the previous frame value. Then we find the driving value on this curve that make the targeted value, and the driving value is the overdriving value. For example, for LCD A with dynamic gamma curves shown in **Figure 2** (a), if we want to have 50 at the current frame and the previous frame is 0, we first find the curve 0; then we find 120 on this curve as the overdrive value that can make output to be 50.

(4) **Figure 2** shows that, for any starting luminance, there is certain luminance that can never be reached after one frame. As an example, one can see in **Figure 2** that if the starting luminance is white (255), both LCD A and B cannot reach black (0) within one frame cycle; if the starting luminance is black (0), both panels cannot reach white (255).

## 4. Characterization and comparison of LC panels with dynamic gamma

The measured dynamic gamma values quantitatively describe the dynamic characteristics of an LC panel. Unlike transition time in which smaller values for better temporal response, dynamic gamma features the values closer to targeted values for better temporal response. In 2-D plots, better temporal response has more converged dynamic curves.

The above quantitative characterization of an LC panel's temporal response requires all the dynamic gamma values. Nevertheless, the number of values used to serve this purpose can be greatly reduced. Specifically, it is *the size of the area that a set of dynamic gamma curves scatter* that quantitatively describes the dynamic characteristics of an LC panel. Despite of so many curves, the size of the area is actually determined only by two dynamic gamma curves: the top one (starting luminance 255 if 8-bit) and the bottom one (starting luminance 0). The rest curves must fall between the two curves according to the first property discussed in the last section. Therefore, for a 9x9 measured dynamic gamma values, only 2x9 values that correspond two sets of transitions starting from 0 and 255, respectively. In contrast, transition time has to keep all its 9x9 measured values because all of them are equally important. As an example, the size of this area of LCD B in Figure 2 (b) is much larger than the ones of LCD A in Figure 2 (a), indicating that LCD B has much slower temporal response.

## 5. Assessment of overdrive performance with dynamic gamma

Dynamic gamma curves of a particular LC panel can be used to assess the quality of overdrive. More importantly, they reveal the capability and the limitation of overdrive applied to the panel.

Overdrive applies a driving value that is based on the previous frame and current frame to accelerate the transition. As discussed in the previous section, the ideal fast panel has a set of dynamic gamma curves that converge to one straight line. Therefore, a good overdriven panel should converge to one straight line.

Nevertheless, overdrive is never perfect. **Figure 4** measured dynamic gammas of two LC panels (LCD A & B) that overdrive technology has been applied to. The dynamic gamma curves in both **Figure 4** (a) and (b) almost converge to one single line except the two ends. The two triangular "dead zones" at the two ends, as we will discuss later, are not due to 'bad' overdrive, but due to the fundamental limitation of overdrive technology.

The imperfection of overdrive comes from the fact that for any starting luminance, certain luminance may not be reached after one frame because the input driving values have to be with the range from 0 to 255. Therefore overdrive does not 100% solve the slow response problem of an LC panel.

The quantitative description of the imperfection of overdrive can be provided by dynamic gamma. From **Figure 4**, one can see that two critical points determine the size of dead zones. The lower critical point represents the transition from 255 to 0, and the higher critical point represents the transition from 0 to 255.

In summary, two particular dynamic gamma curves, 0 and 255, among all the curves, are most important. The area that the two curves cover reflects the temporal response of an LC panel. Each curve possesses a critical point that sets the limitation/capabilities for the overdrive performance.

Because the on-off characteristics of LCD B are also much worse than that of LCD A, even with overdrive, LCD B still cannot catch up with LCD A. In **Figure 4** (a) and (b), the overdrive dead zones of LCD B are much bigger than LCD A. In fact, LCD B cannot reach the desired level for most values within one frame period. Such an LC panel, compared with LCD A, is not a good candidate for LCD TV applications.

## 6. Measurement of dynamic gamma

The measurement system for dynamic gamma is simple. A driving input is illustrated in **Figure 5**. Before frame 0, the driving value $z_{n-1}$ is applied for several cycles to make the pixel into equilibrium state. Then in the frame 0, different driving value $z_n$, covering the driving range (from 0 to 255 for 8-bit LC panel), is applied, and the corresponding luminance is measured exactly at the end of frame 0.

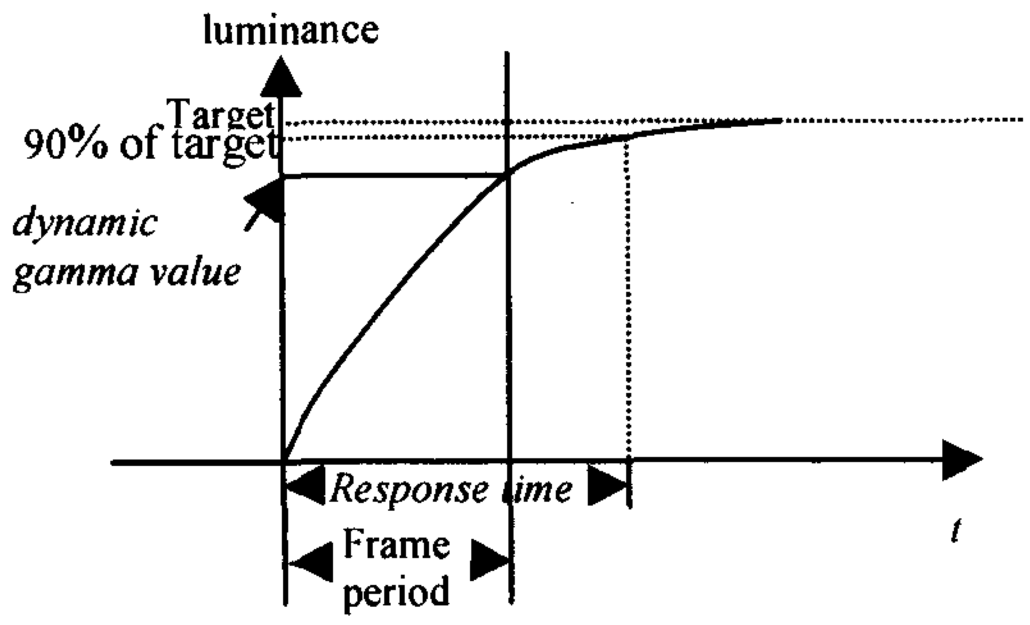
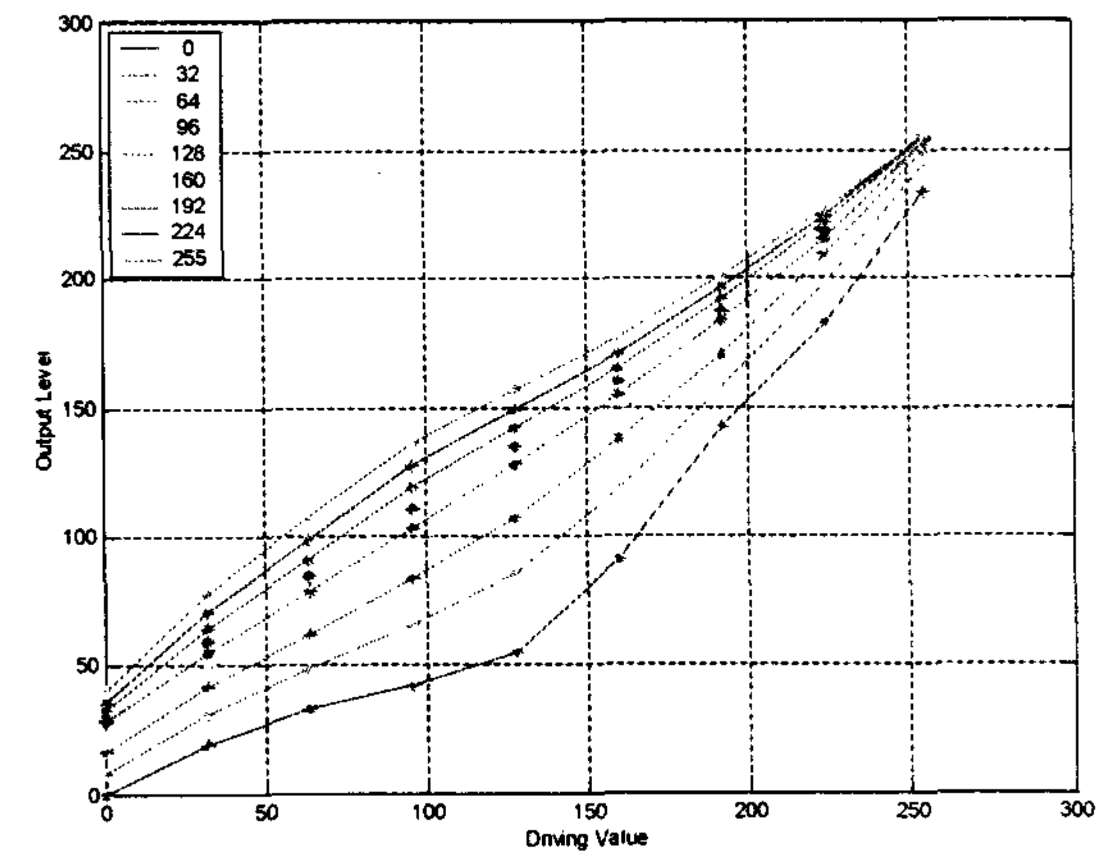
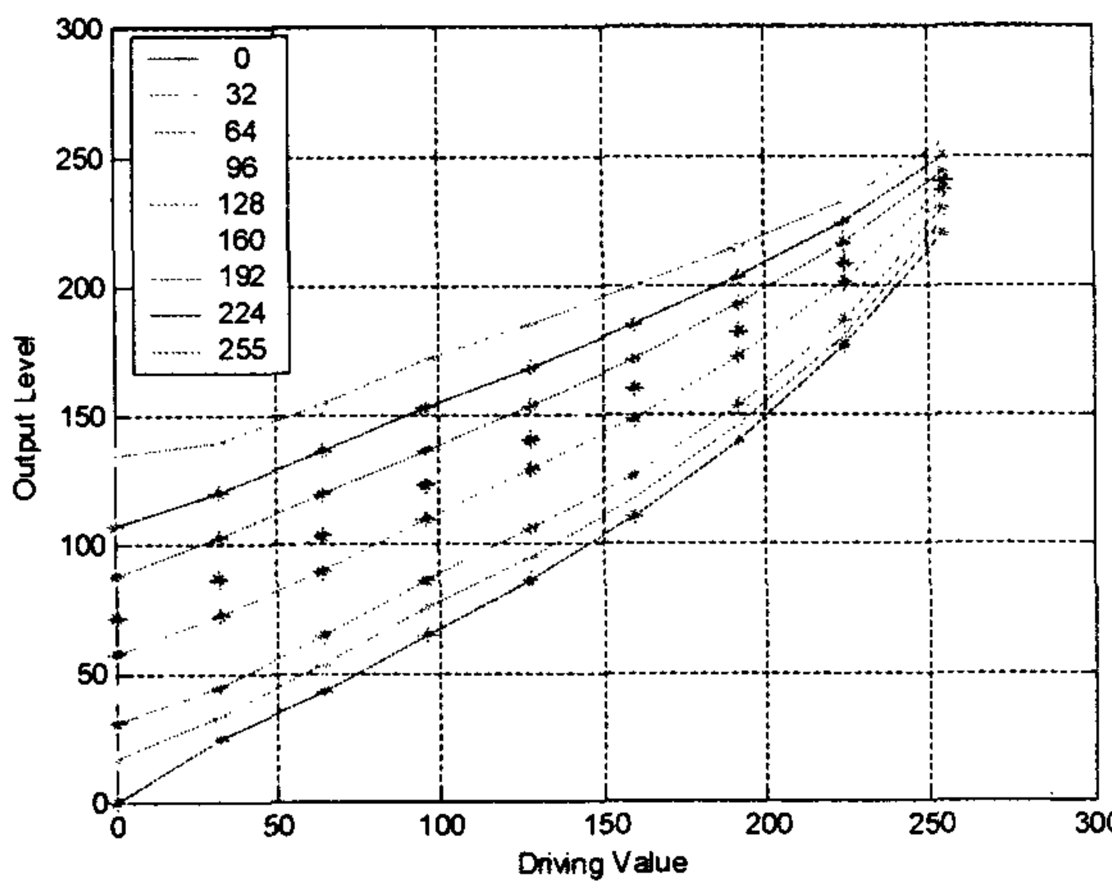



Figure 1 Dynamic gamma vs. response time.




(A) LCD A




(B) LCD B

Figure 2 Dynamic gamma curves before overdrive. Different curves represent different starting luminance (the actual values are shown in the legend).

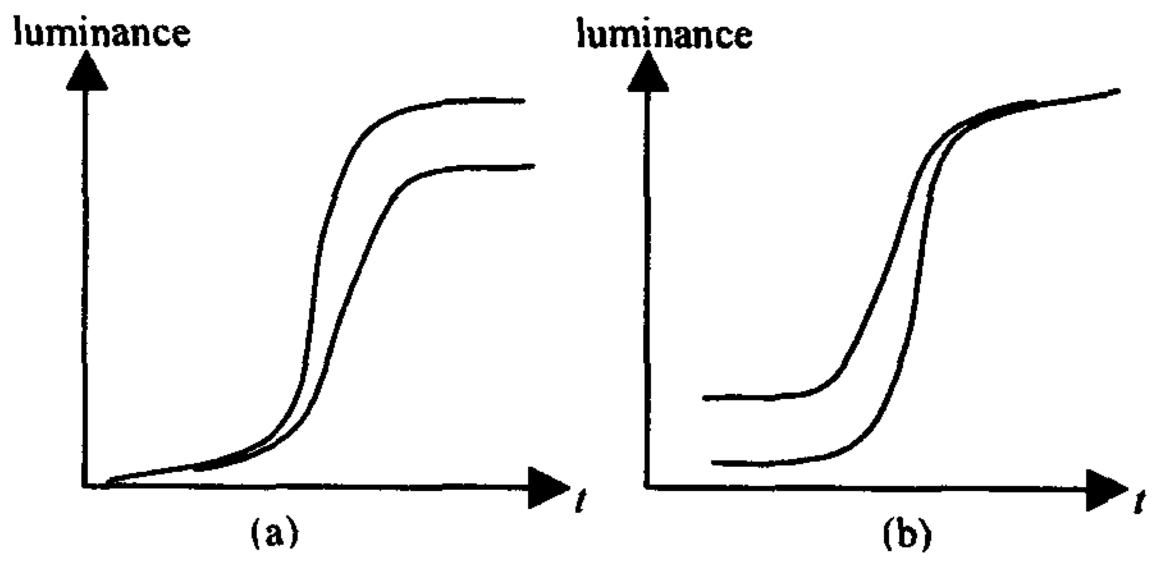
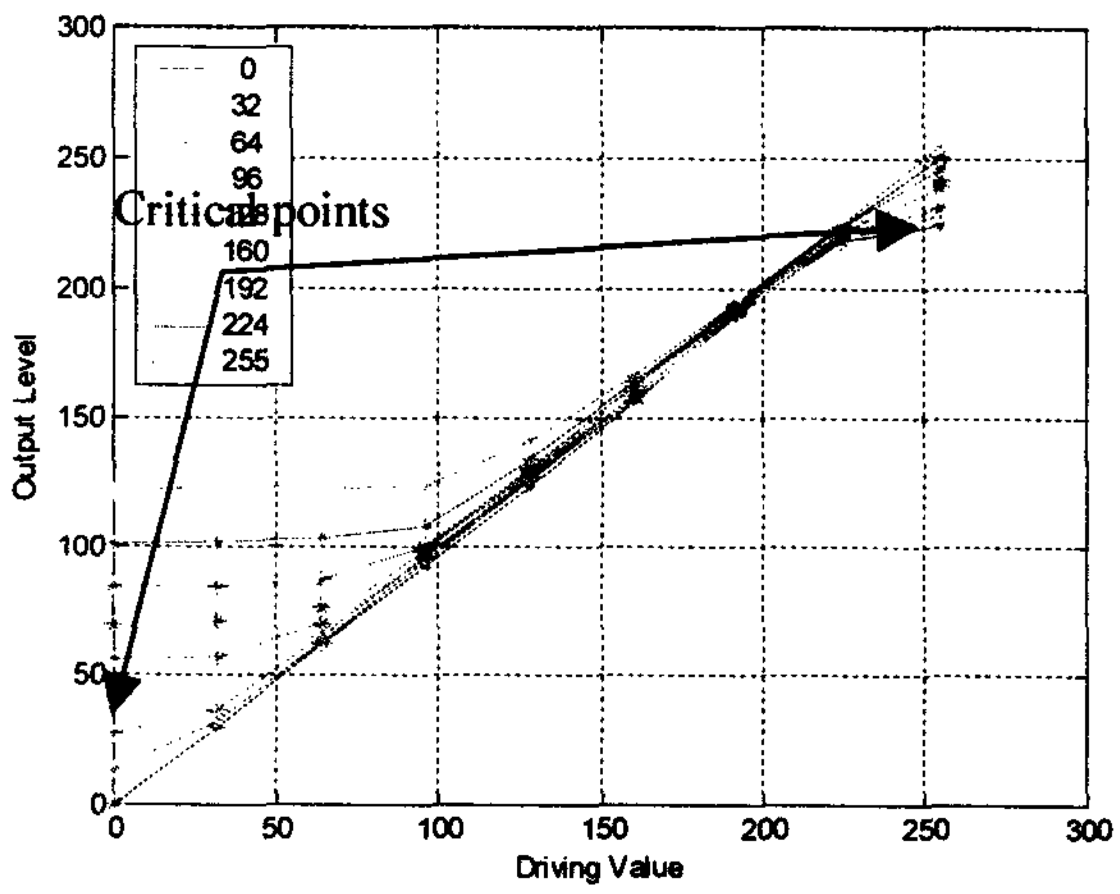
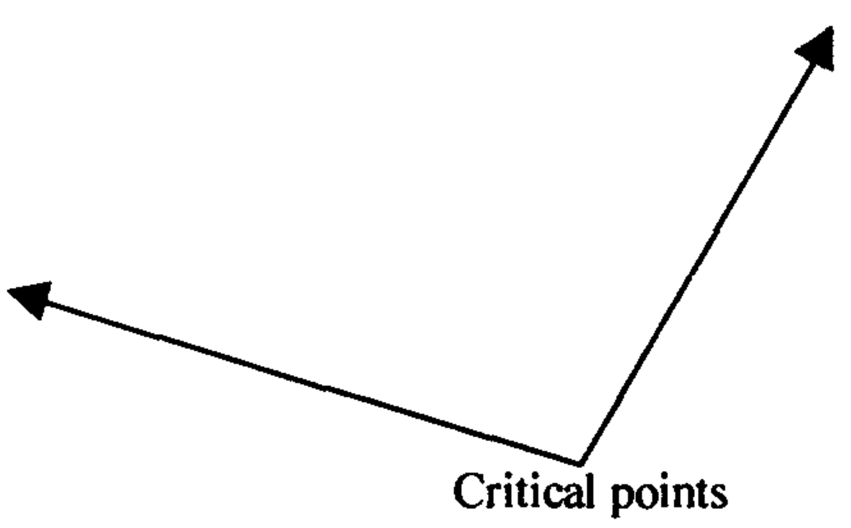



Figure 3 (a) Two transition curves starting from the same luminance but with different driving value. The luminance of the transition with higher driving value is higher; (b) Two transition curves starting from different luminance but with the same driving value. The luminance of the transition starting from higher luminance is higher.




(A) LCD A




(B) LCD B

Figure 4 Dynamic gamma curves after overdrive.

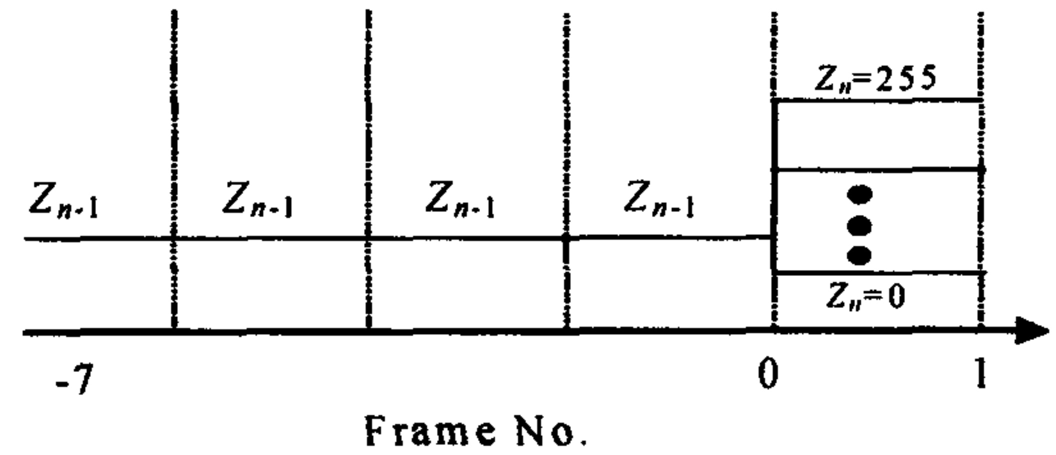



Figure 5 The input driving sequences for measurement of dynamic gamma.

## 7. Summary

In this paper, we define and propose a new metric to quantitatively characterize the temporal response quality of LC panels. The widely-used response time fixes the target level, and measures the time to reach the target level. Dynamic gamma, on the other hand, fixes the time sampling point (after one frame), and measures the actual display level that the LCD pixel reaches. The new dynamic gamma provides many capabilities that the old response time does not provide. Dynamic gamma can directly derive overdrive values; dynamic gamma shows the two dead zones after overdrive; dynamic gamma makes easier the comparison between different LC panels and assessment of improvement.

## 8. Reference

[1] K. Sekiya and H. Nakamura , "Overdrive Method for TN-mode LCDs -Recursive System with Capacitance Prediction," SID'01, pp114-117.

[2] H. Nakamura and K. Sekiya, "Overdrive Method for Reducing Response Times of Liquid Crystal Displays," SID'01, pp.1256-1259.

[3] K. Kawabe, T. Furuhashi, and Y. Tanaka, "New TFT-LCD Driving Method for Improved Moving Picture Quality," SID'01, pp 998-1001.

[4] B. Rho, B.K. Yang, S.S. Lee, and J.S. Kim, "A New Driving Method for Faster Response of TFT LCD on the Basis of Equilibrium Charge Injection," IDW'00, pp1155-1156.

[5] H. Okumura, M. Baba, K. Taira, and A. Kinno, "Advanced Level Adaptive Overdrive (ALAO) Method Applicable to Full HD-LCTVs " SID'02.

[6] B-W Lee et al, "Reducing Gray-Level Response to One Frame: Dynamic Capacitance Compensation," SID'01.

[7] Y. Igarashi and et al., "Proposal of the Perceptive Parameter Motion Picture Response Time (MPRT)", SID'03, pp 1039-1041.

[8] Y. Igarashi and et al., "Summary of moving picture response time (MPRT) measurement system," SID'04, pp 1262-1265.

[9] K. Oka and Y. Enami, "Moving picture response time (MPRT) measurement system," SID'04, pp 1266-1269.

[10] C. Poynton, "Digital Video and HDTV: Algorithms and Interfaces," Morgan Kaufmann, 2003.