Novel Driving Method for fast Response Time in Vertical Alignment LCDs

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Key words : response time, PVA mode, DCC, DCCII, pre-tilt signal, overshoot signal

Abstract

The switching mechanism of multi-domain vertical alignment mode LCD and delayed on response time phenomenon in special conditions are investigated. A modified DCC (Dynamic Capacitance Compensation), DCCII has been developed for the fast response time performance in PVA TFT-LCD TVs. DCCII applies a pre-tilt voltage to addressed pixels during the previous frame in addition to an overshoot voltage. In result, the response time less than 8 msec, has been obtained for all moving images through the DCCII technique.

1. Introduction

Recently, the needs for TFT LCD-TVs have dramatically increased by the expansion of the digital-TV market. Compared with other FPD-TVs such as PDP and projection TVs, TFT-LCD TVs have the advantages of high resolution, light weight, slim size and low power consumption, while there are also several disadvantages, in particular, slow response time. Response time property is very important for LCD TVs performance because TV images generally consist of moving pictures. There are two problems to cause the slow response time in LCDs. One is the nematic liquid crystals' slow response itself to an external field, the other is LCD's hold display type different from peak display type such as PDP and CRT. To perfectly reproduce moving pictures in TFT-LCD TVs, two problems should be solved simultaneously. [1~2]

In this report, we focus on the way to apparently improve liquid crystals' response time using the driving method DCCII (Dynamic Capacitance Compensation II), a modified DCC. And DCCII was basically designed for the VA mode. [9]

2. Switching Mechanism in the PVA Mode: Propagation of tilting wave.

In the PVA (Patterned Vertical Alignment) mode,[3-5] there are many factors that influence the response time: material properties of liquid crystals, pixel structures and driving methods etc. Among them, the most effective way to reduce the response time is the driving method (DCC).[6-8] The DCC technique has greatly improved the response time performance of TFT-LCDs under the same LC materials and pixel structure. The DCC technique adopts overshoot voltage to improve switching speed. The role of the overshoot voltage is to accelerate the response of liquid crystals and to compensate the decreased internal filed by the increased liquid crystal capacitance during switching. However, there is still a limit to decrease the response time, particularly on time (on-response time) from black to white state. At present state, a realizable on time with DCC is about 15 msec, which is not adequate to satisfy human eye's perception.

Generally, in most of the LCDs, the higher an applied voltage is, the faster a response time is. It is because Ton (on time) is controlled by the following formula:

$$\tau_{on} \propto \frac{\gamma d^2}{\Delta\varepsilon\left(V^2 - V_0^2\right)}$$

However, it doesn't always apply in the PVA mode. In some condition, that is, an applied high voltage increases Ton in reverse.

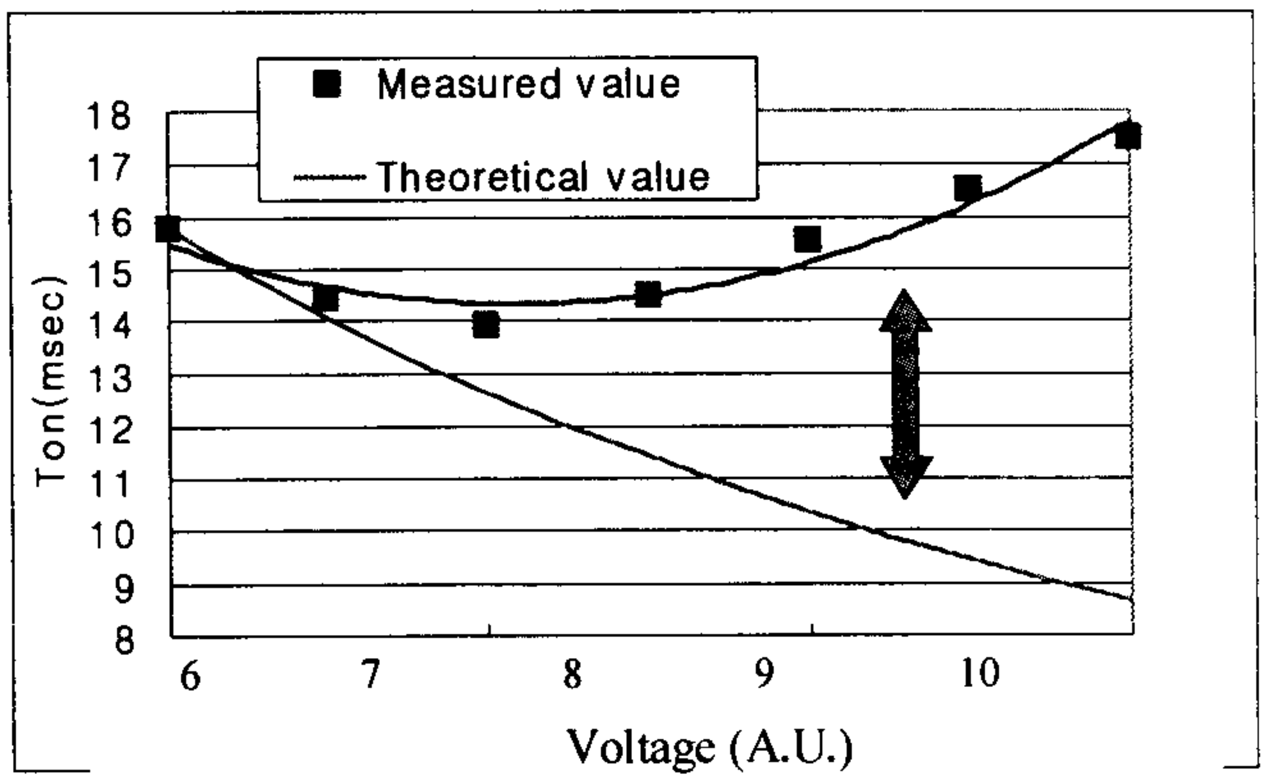


Figure 1 : Ton time according to applied voltage in multi-domain VA mode panel. (Not in common condition, but in special condition)

Figure (1) is on response time according to applied voltage in a panel. As indicated in the figure (1), by increasing an applied voltage, on-response time actually increases. This is different from the time predicted by the theoretical formula. This is not problem in common PVA panels, but this phenomenon have been a limitation to improve Ton response time of PVA mode under 10msec.

LC molecules in the PVA mode are vertically aligned in the static state, and tilted by an applied electric field across a panel because of their negative dielectric anisotropy. Then, the tilting direction of LC molecules is determined by the fringe field generated by regular ITO patterns. Figure 2 shows the switching process by the fringe field effect in the PVA mode. Before starting the switching (0 msec), in the whole area including upper and lower ITO-open areas, all the molecules are vertically aligned (Figure 2(a)). In the early stage (first 10 msec) of the switching under a rectangular-wave electric field, the LC molecules near both ITO-open areas start falling down to the direction parallel to the electric potential lines (Figure 2(b)), but the LC molecules in the center are still vertically aligned. In figure 2(b), there happen tilting waves from ITO patterns area to center area. In the final stage (after 20 msec), the LC molecules in the center area are consecutively tilted to the same direction as others (Figure 2(c)) by the propagation of the tilting wave like dominos do. Here, the tilting wave makes an important role to switching process in PVA mode. The tilting wave transmits the information of the tilting direction. In figure 2(b), the liquid crystal molecules in center area have not information of tilting direction. Thus, if it were not for tilting wave, the molecular tilting direction in the center of two ITO-open areas is not determined.

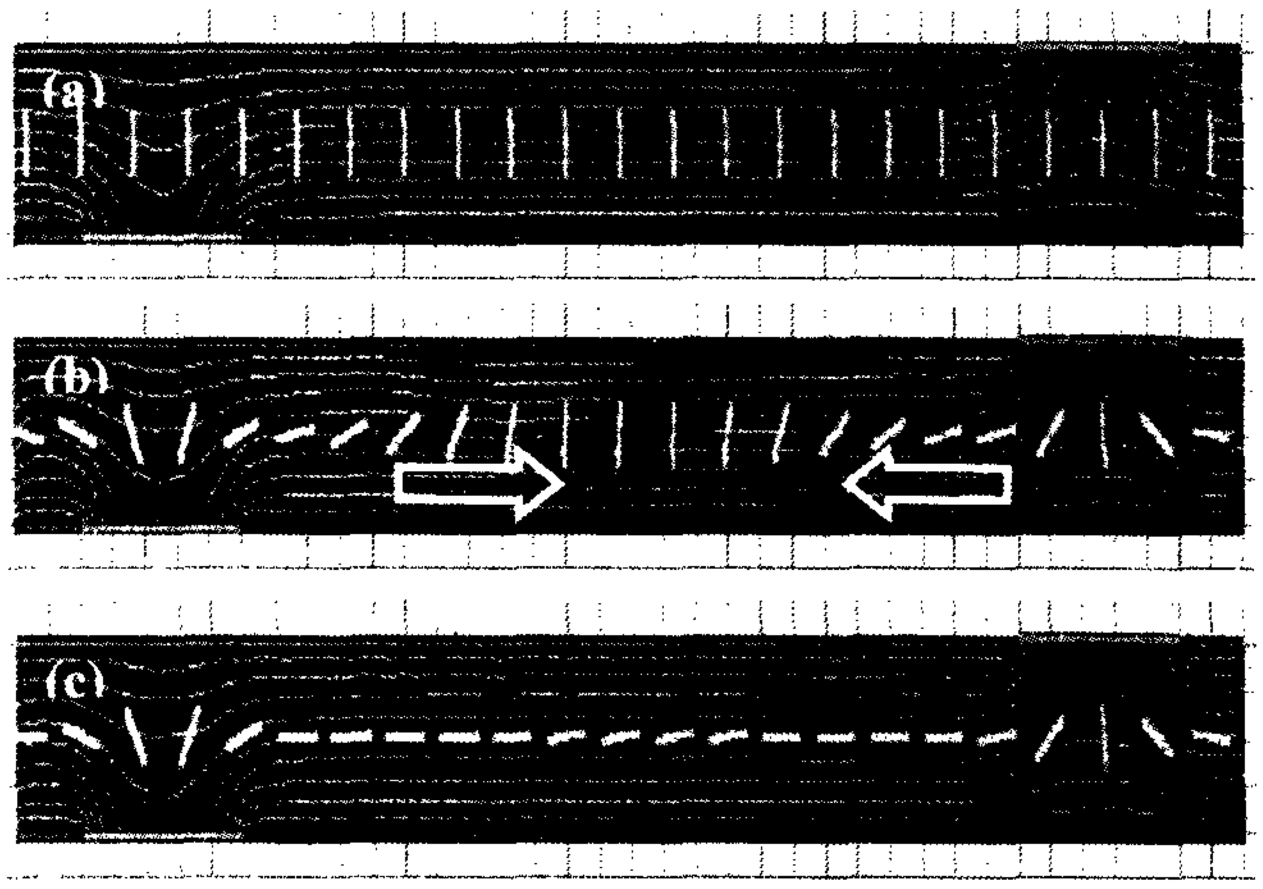
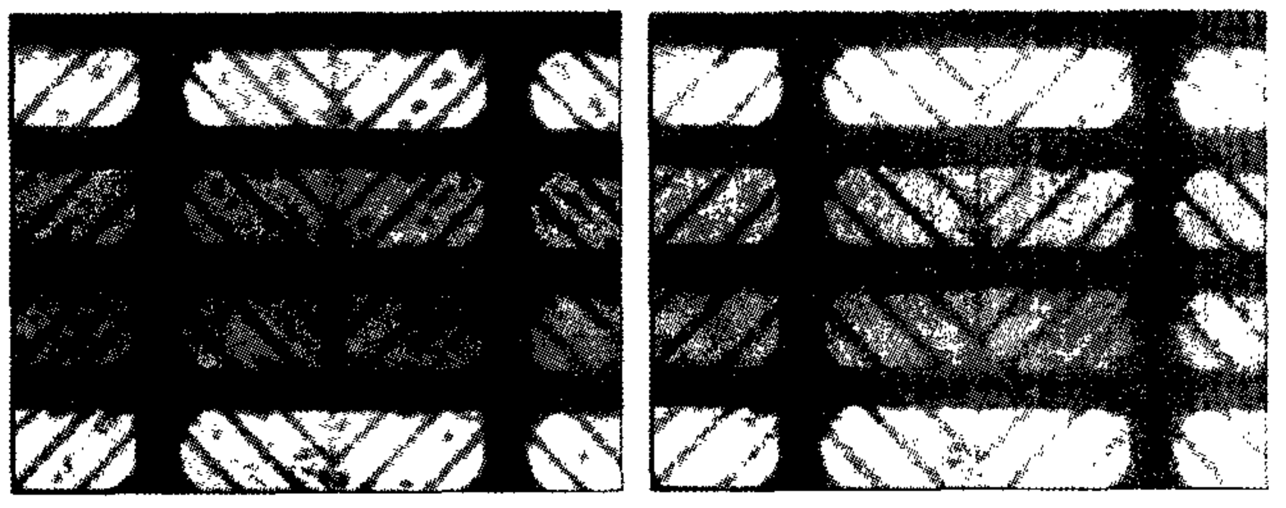


Figure 2 : Simulation results of the switching process in the PVA mode. (a) 0 msec (b) 10 msec (c) 20 msec

3. Switching Limitation in the PVA Mode: Two step motion.

Although tilting wave is generated, in special cases, liquid crystals fail to fall down to the same direction, specifically, in the case that the distance between ITO patterns is too long, or in case a very high voltage is applied to the cell. If the distance between ITO patterns is too long, the tilting wave does not reach the center area in time, that is, before the liquid crystals in center area fall down. A high voltage can also cause randomly tilted domains in the ITO-patterned panel, since the high voltage accelerates the falling speed of liquid crystals in the center area. Figure 3 shows the switching process from black to white state in the PVA mode, when a high voltage is applied. Before the propagation of the tilting waves by the fringe field from both sides, LC molecules in the center area start tilting randomly by a vertically applied electric field.

It is confirmed by some black spots observed in the middle of two ITO-open areas (Figure 3(a)). The lower images (Figure 3 (b)) use abnormally crossed polarizers with a very bright backlight to show more information about the dark spots. The dark spots seen in the upper pictures are seen as brighter spots in lower images. This means that liquid crystals in dark spots are not vertically aligned, but they have fallen down to the wrong direction



a) under the normal crossed polarizer (L: ~10msec, R:~30msec)

b) under the abnormal crossed polarizer (L: ~10msec, R:~30msec)

Figure 3 : Microscopic images of the switching process from black to white state in the PVA mode.

We can get that, in special condition, dark spots appear between ITO patterns, and those dark spots gradually become smaller. This actually causes the delay of response time.

Consequently, some LCs experience two-step motions. In first step, LCs fall down and falling direction is not controlled, that is, the direction may be affected by defects or tiny asymmetry of alignment layer. The first step motion happens in a short time compared to the second step. In the second step, the LCs rotate azimuthally by elastic force among disordered LCs. The response curve (Figure 4) shows the speed of each step. The first motion, polar rotation, happens in a half frame or in about 8msec. However, the second motion takes over 100msec. Therefore, the existence of any second step azimuthal motion could be fatal to on time performance. Consequently, to remove the second step motion is the most important condition for fast on response time in multi-domain vertical alignment modes.

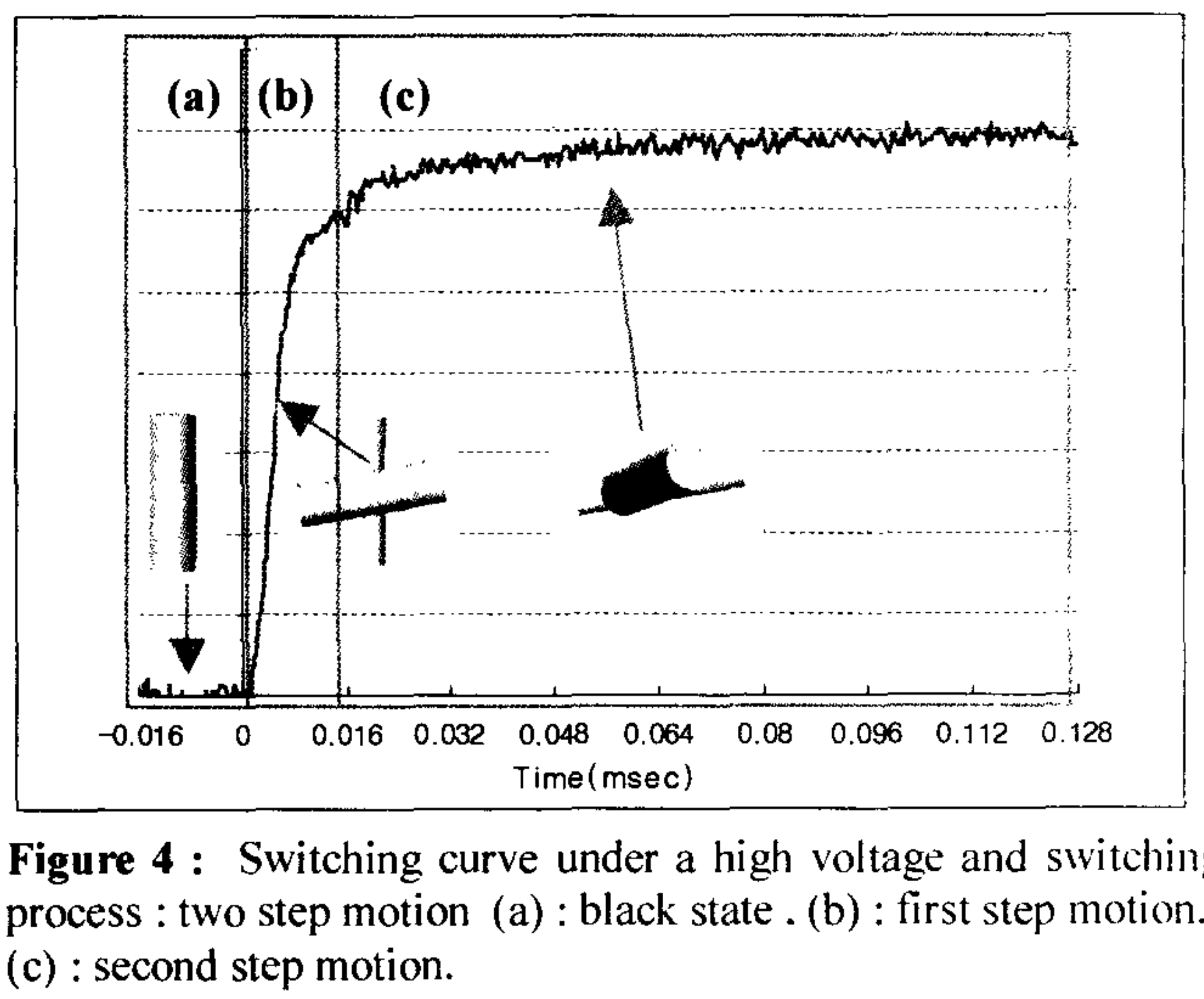


Figure 4 : Switching curve under a high voltage and switching process : two step motion (a) : black state , (b) : first step motion, (c) : second step motion.

Based on the explained mechanism of delayed on time, we can conceive several methods to reduce the second type of motion. First, if the distance between ITO patterns is decreased, the tilting wave will reach the center area more rapidly, and consequently the second type of slow LC motion disappears. However, to decrease the distance, the number of domains has to be increased, thereby decreasing the aperture ratio of the pixel. Considering the loss of luminance, this method is not useful. Secondly, if the cell has a pre-tilt angle at the black level, the LCs fall down to the pre-tilted direction. Of course, the pre-tilting direction must differ according to domains, which is very difficult to apply. One can see that it is difficult to overcome the second type of motion with sustaining other impacts.

4. Novel DCCII method

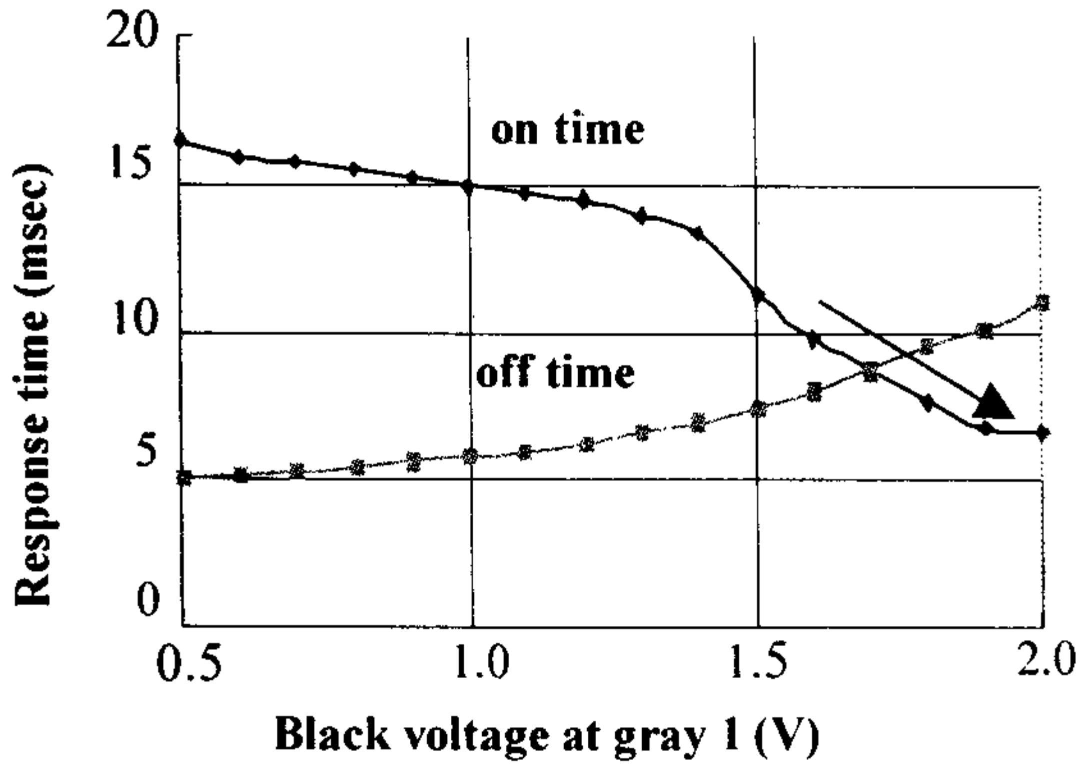


Figure 5 : Black voltage dependence of the response time at gray 1.

As indicated in Figure 5, the on time depends on the black voltage. In this graph, the X-axis is black voltage and Y axis is response time. This experiment is conducted with test cells having ITO patterns. This graph shows that on time decreases as the black voltage increases. This is because a higher black voltage causes the LCs to tilt slightly. We can take advantage of this pre-tilting to effectively remove the second step motion..

However, the high black voltage can cause deterioration in the quality of the LCD panel performance such as viewing angle, contrast ratio and off time. The pre-tilted liquid crystals make residual retardation in the black state, which generates the light leakage at the side and the diagonal, resulting in the deterioration of the viewing angle performance of the contrast ratio. Moreover, a high black voltage increases the off time as indicated in Figure 5. Therefore, it is not feasible to simply increase the black voltage level. Instead, we can overcome these problems by adopting DCCII technology as illustrated in Figure6. The DCCII technology is designed for improving the on time without any deterioration of other performances.

As illustrated in Figure 6, new driving scheme includes both a pre-tilt and an overshoot signals on the rising edge. Before changing the black to the white state, the pre-tilt signal is applied to the addressed pixels. The pre-tilt signal acts as a high black voltage, so the liquid crystals get pre-tilted before the white signal comes. Therefore, all the liquid crystals are ready for falling

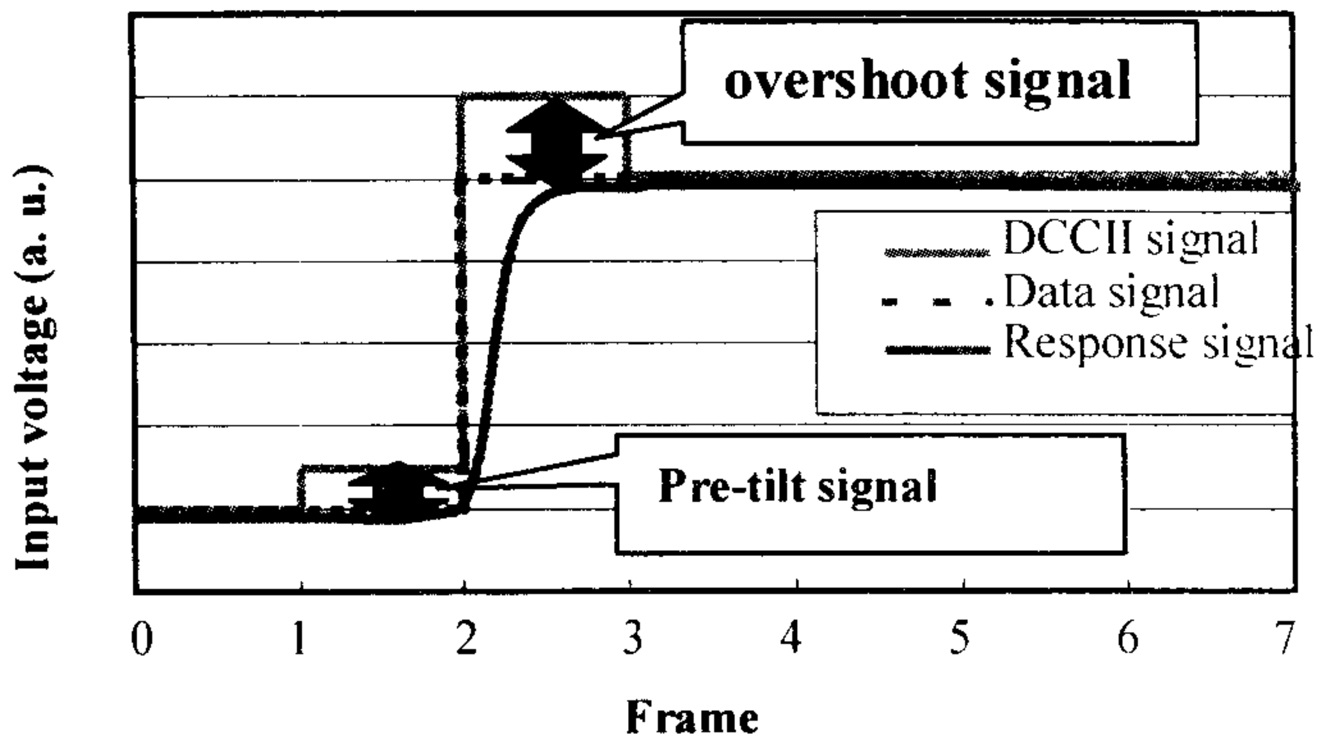


Figure 6 : Schematic diagram for the explanation of DCCII technique. A pre-tilt voltage is applied during previous frame in addition to a DCC voltage.

down on the same direction. The following overshoot signal decreases the response time additionally. In this process, the high black voltage for the pre-tilt is applied only during the previous frame, so the deterioration of the image quality doesn't occur, since the liquid crystals keep almost perfect vertical alignment in the black state.

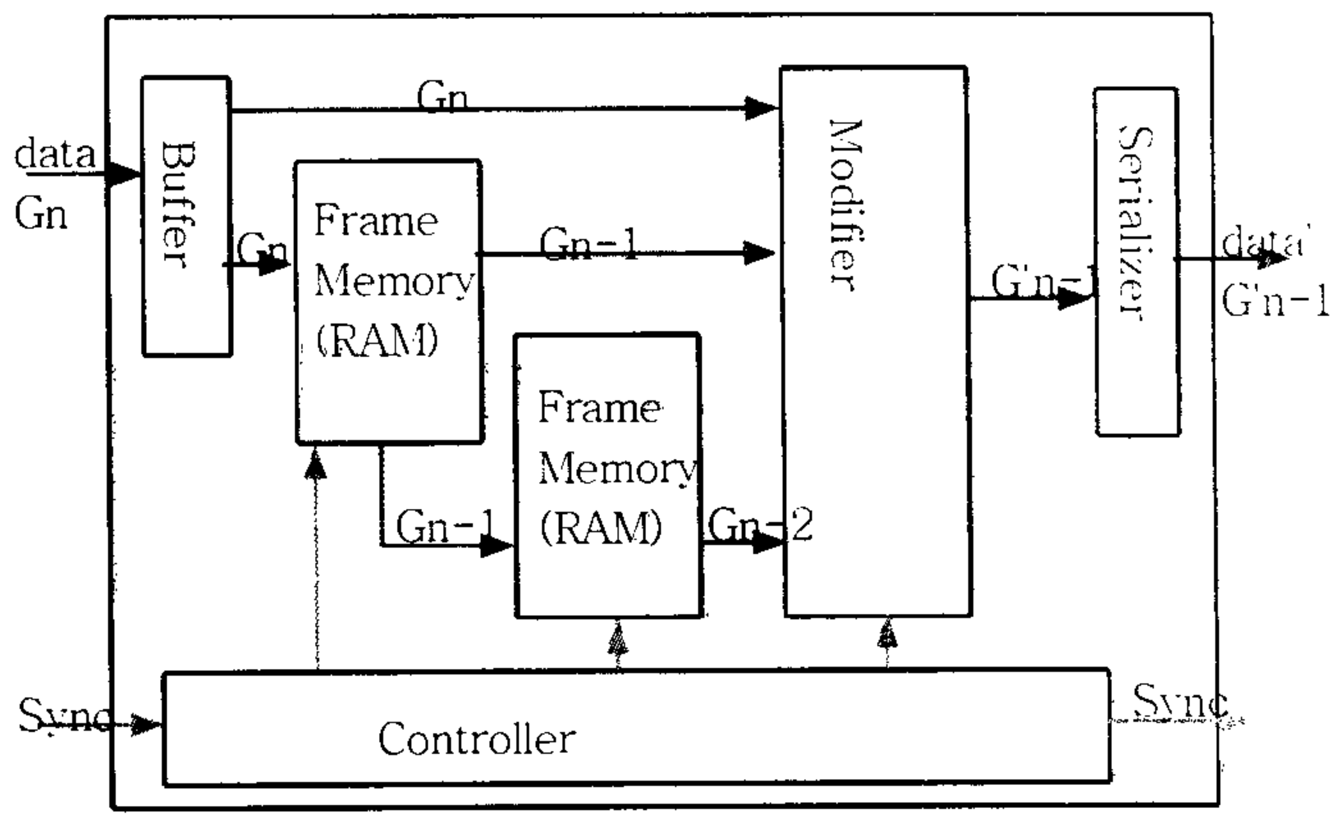


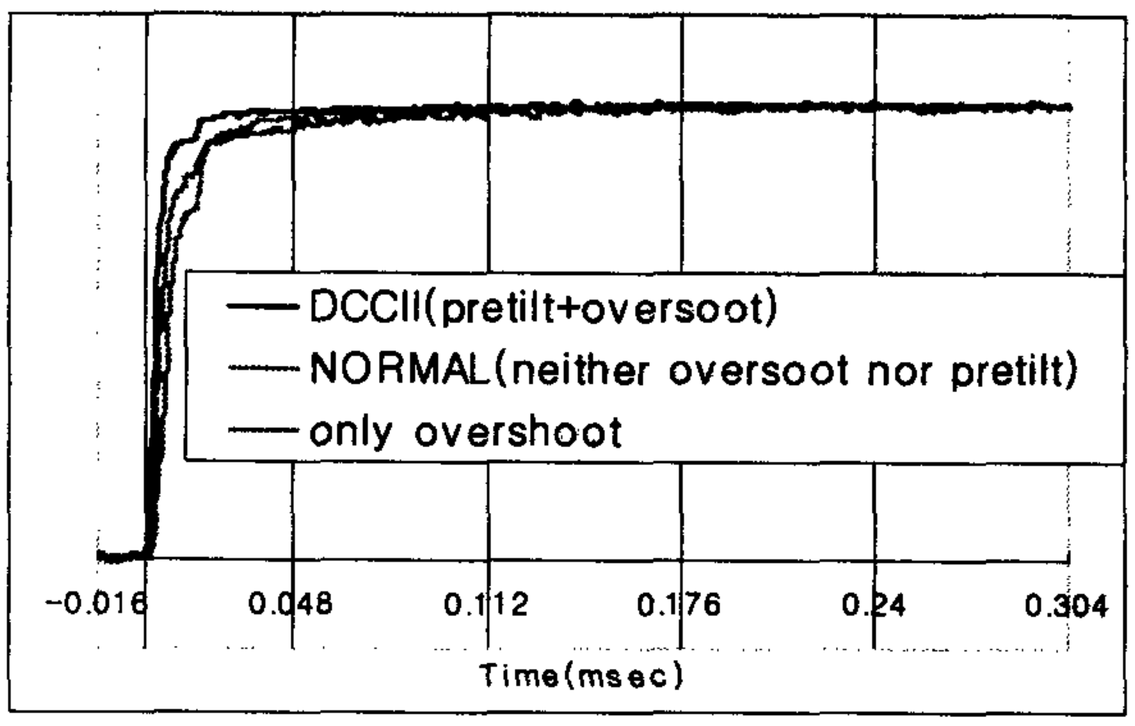
Figure 7 : Basic driving scheme of DCC II.

Meanwhile, the way to embody the pre-tilt during the previous frame is shown in Figure 7. First, images are stored in the frame memories. And the Gn-1 image is compared with the previous and the next images. When the Gn-1 and Gn images are the black and the white state, respectively, the modifier in Figure 7 changes the Gn-1 signal to a pre-tilt signal with a high black voltage. Additionally, after comparing Gn-1 with Gn-2, the modifier adds the appropriate overshoot voltage to the Gn-1 signal. The black voltage is also applied to gray-to-gray close to the black and the white state in addition to black-to-white. By expanding the black voltage application into several gray-to-gray responses, all the response times have been obtained less than 10 msec. Timing controller can contain all these functions, or frame memories can be separately positioned as a memory chip.

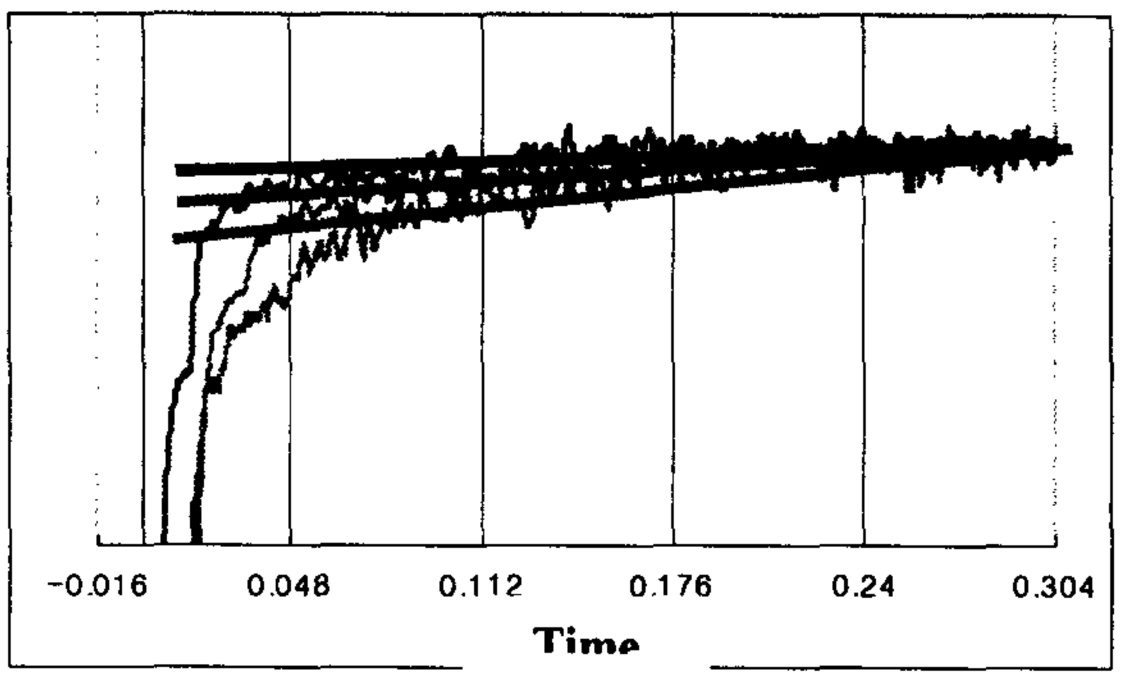
5. Experimental Result

Figure 8(a) shows response curve of a PVA panel. We experimented with different driving conditions. The red line shows the normal case, where neither an overshoot signal nor a pre-tilt signal is applied. This green line is the response graph in the case that only an overshoot signal is applied. And, the dark blue line is when DCCII technology is applied, that is, both a pre-tilt signal and then an overshoot signal are applied. Figure 8(b), which is a luminance-expanded graph, clearly shows the impact of the two-step motion. When there is only an overshoot signal, the two-step motion is made worse. However, use of the pre-tilt signal removes the second step motion, and so, the dark blue line has a flatter shape than other curves. This result proves the benefit of the pre-tilt signal.

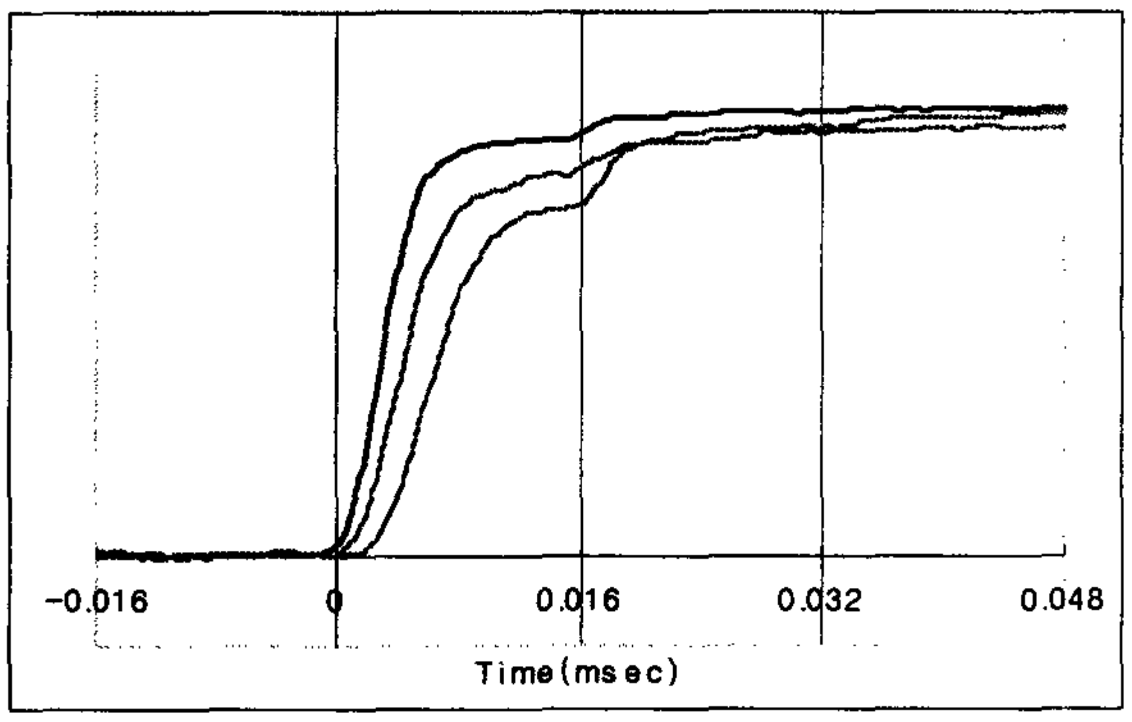
Figure8(c) is the same graph, with an expanded time scale. This graph shows the speed of the first step. If we compare the red and green lines, which represent no DCC and DCC I with overshoot only, we see the overshoot signal accelerates the transition and also raises the cusp position. The cusp position is generated by LC capacitance increase. The main purpose of DCC I technology is to raise this cusp position. Next, when comparing the green and blue lines, that is, DCCI and DCC II, we can confirm that pre-tilt signal also accelerates the initial transition. The pre-tilt signal has two roles, both to remove the second step motion and to accelerate the moving speed. We need to give attention to the starting time of the graph as well as the inclination. When we measure response time using 10 to 90% luminance criteria, only the slope is important. However, in the real world, the starting time of increasing luminance is also important, as a delayed response can create problems with specific moving pictures, as in the case of a moving narrow width black line. The pre-tilt signal makes it possible to respond promptly to all input signals.



(a) Switching curve in each driving condition



(b) Same curve as (a) with expanded time Luminance scale



(c) Same curve as (a) with expanded time scale

Figure 8 : Response time before and after applying DCCII in the PVA mode. The on time of ~ 7.5 msec has been obtained using DCC II driving technique.

We can see that the pre-tilt signal controls the undesired second step motion, accelerates the LC molecule falling speed, and induces a prompt response to input signals.

By applying DCCII technology, we have obtained response times of less than 8msec for all gray to gray transitions.

6. Conclusion

We have explained the mechanism of the switching process of multi-domain vertical alignment mode LCDs, and also effectively explained the delayed on response phenomenon by adopting two-step motion model.

The pre-tilt by the high black voltage has been introduced in the DCCII technique. DCCII accelerate the response time to less than 8 msec for all moving images. The high black voltage is applied only during the previous frame, so the image quality deterioration doesn't occur.

We believe, at present state, that the DCCII technique is the best way to reproduce moving images in TFT-LCD TVs.

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