A Dithering Algorithm for Full-Color (16,777,216-Color) Support in an LCD with 6-bit Driver ICs

Seung-Woo Lee*, Sang-Soo Kim

Advanced R & D Group, R & D Center, LCD Business, Samsung Electronics Co.

* +82-31-209-7579, e-mail: swlee00@samsung.com

Abstract

A new dithering algorithm, "Hi-FRC", to enable full (16,777,216) color display on LCD panel with 6-bit source D-IC's is presented. The conventional FRC can display only 16,194,277 colors. In addition, The LCD panel with Hi-FRC can meet the color grayscale linearity of TCO '03 because it can improve the color shift problem.

1. Introduction

Thin film transistor liquid crystal displays (TFT-LCD) have been replacing cathode ray tubes (CRTs) over 50% in monitor applications [1]. The current main models in the monitor applications are 15" XGA and 17" SXGA, and 19" SXGA panel is growing very fast [1]. Most LCD panels over 80% of monitor panels adopt 6-bit source driver IC. Thus, a dithering algorithm is applied because the input image source is 8-bit. The dithering algorithm is also called as FRC (Frame Rate Control), because the algorithm uses temporal averaging by changing data frame by frame. The conventional FRC cannot show 16.7M colors but 16.2M colors due to the limitation of the dithering algorithm. This paper propose a novel dithering algorithm which can show full color image on the LCD panel with 6-bit driver IC's. In addition of higher color depth, it can improve color performance.

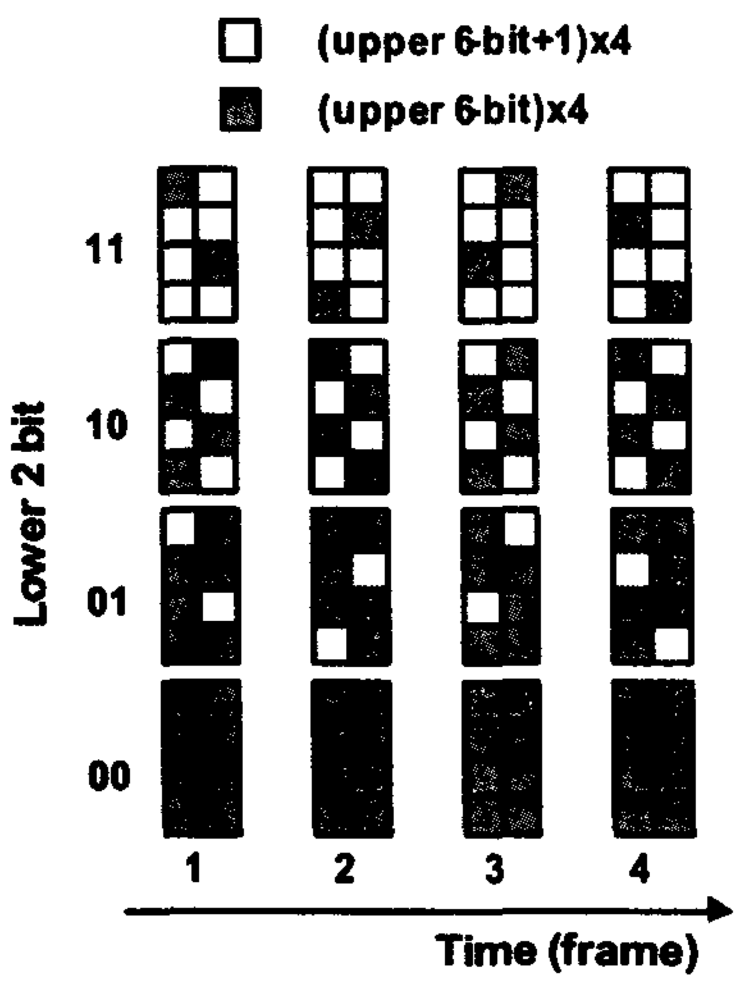


Figure. 1 Spatial dithering and temporal averaging pattern of conventional FRC.

2. Conventional Dithering Algorithm

6-bit driver IC can generate only 64 analog levels because the input data is 6-bit. Input 6-bit data ranges from 0 to 63, that is, from 0 to 252 (=63x4) in 8-bit expression. Fig. 1 shows a spatial dithering and temporal averaging pattern of a conventional dithering algorithm. According to the lower 2-bit of 8-bit input data, a spatial and temporal averaging of 6-bit data is determined as shown in Fig. 1.

Temporal Averaging: Let's assume the input is 127 gray with full page. The lower 2 bits are $(11)_2$. Fig. 2 shows the explanation of the temporal averaging for the upper left pixel. The sequence of the upper left pixel data is 124 => 128 =>

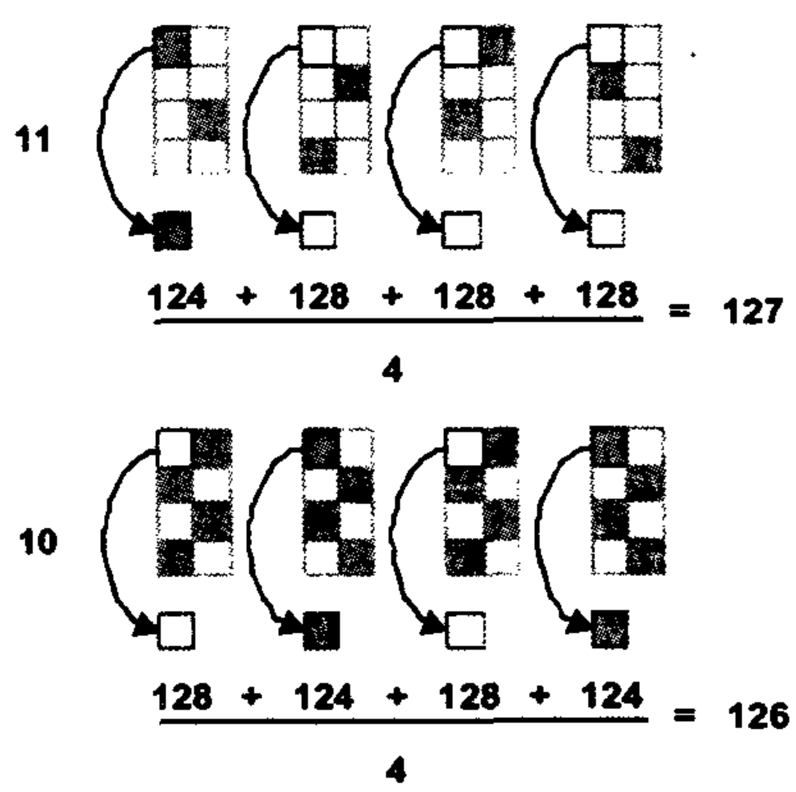


Figure. 2 Temporal average of FRC algorithm to display luminance of 127 and 126 gray.

128 => 128 => 124... Thus, the temporal average value is (124+128+128+128)/4 = 127. The other pixels have different data sequences, but have the same average value of 127. In the same reason, the upper left pixel in the full page pattern of 126 gray shows the sequence of 128, 124, 128, and 124. Thus, all pixels have the same temporal averaging value of 126.

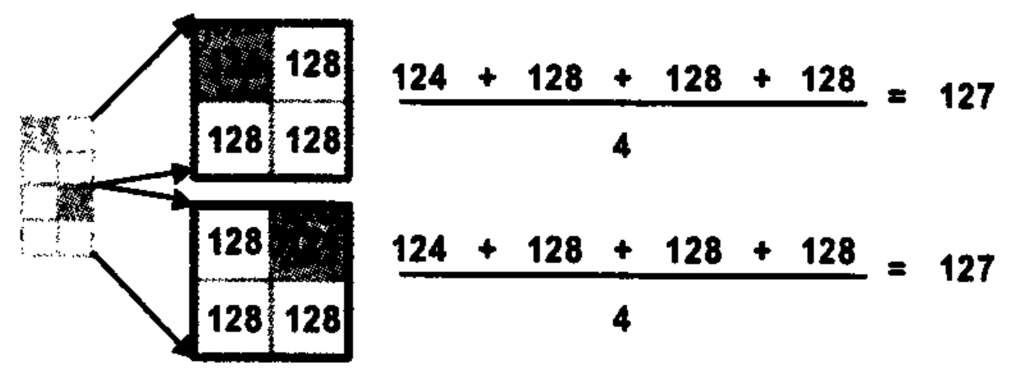


Figure. 3 Spatial average of FRC algorithm to display luminance of 127 gray.

Spatial Averaging: Fig. 3 shows two units of 4 pixels. The two units, however, have the same average value of 127. The total spatial average is also 127. Through all frames, the spatial averaging of the two units of 4-pixels shown in Fig. 1 is maintained as 127.

The conventional FRC algorithm shows a very effective method to simulate 8bit-like display only using 6-bit driver IC's. However, it is not a perfect scheme for a full-color display. The FRC algorithm cannot display distinguishable 256 luminance levels of each red, green and blue. Fig. 4 shows the measured data and the reason why the FRC algorithm cannot display full 256 luminance levels. To display 255 gray, the FRC algorithm should ideally generate a data sequence of 252=>256=>256=>256. 252 is 63x4 and 256 is 64x4. However, the value of 256 (64x4) is out of the range of 6-bit driver IC which has from 0 (000000_2) to 63 (111111_2). By this reason, upper 3 input data (255, 254, 253) have the same luminance level of 252. Thus, only 253 luminance levels are available in the conventional algorithm. Even though the input image data have full color (256x256x256 = 16,777,216 ~ 16.7 M), the total number of

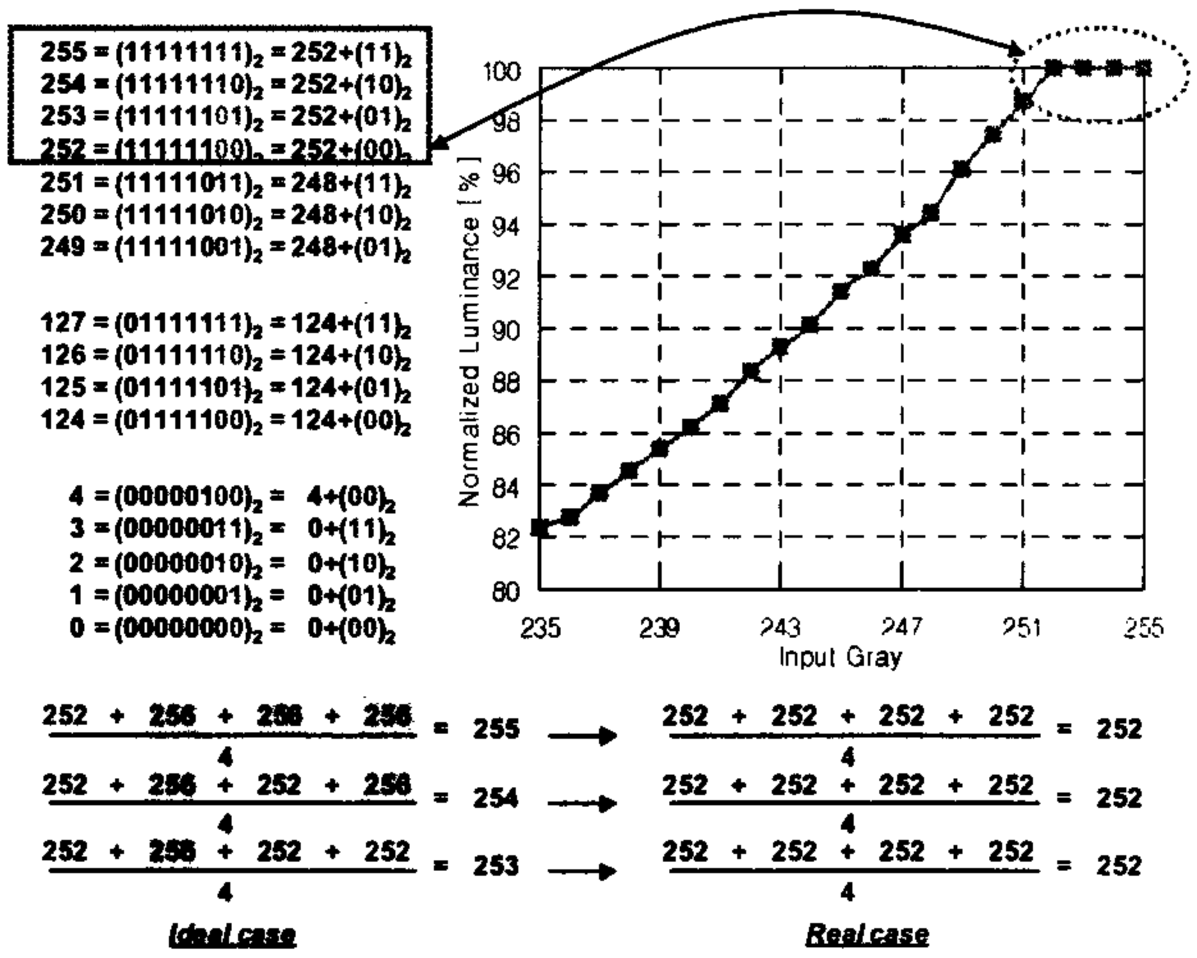


Figure. 4 The explanation why the conventional FRC shows only 253 luminance even though the input levels are 256.

available colors in a 6-bit LCD are 253x253x253 = 16,194,277 (~ 16.2 M colors).

3. Hi-FRC for Higher Color Depth

A novel FRC algorithm which enables to display higher than 16.2 M colors, "Hi-FRC", is presented hereafter. A schematic diagram of Hi-FRC is shown in Fig. 5. The conventional FRC reduces 2 bits from 8-bit input. Hi-FRC reduces 3 bits from a 9-bit expanded data as shown in Fig. 5. 9-bit data can have more than 500 levels. The key idea of Hi-FRC to display higher color depth is to select different 256 levels among more than 500 levels.

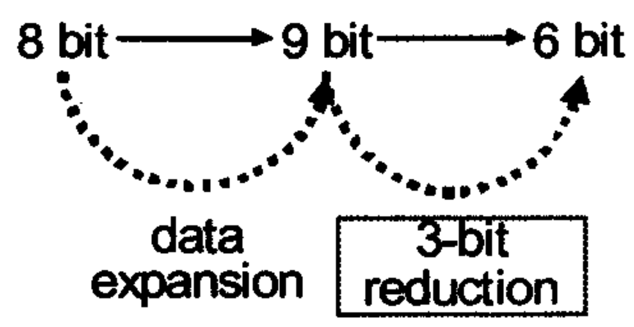


Figure. 5 Schematic diagram of Hi-FRC to enhance the number of available colors in spite of 6-bit driver IC.

Concept: Table 1 shows an example of Hi-FRC for full color depth. Input 255 gray is transformed to 504. Through the 8 frames, input data of source driver IC is maintained 504 (63x8) as shown in Table 1. Input 254 gray has an expanded data of 502. Input data sequence comprises 496 (62x8) through 2 frames and 504 during the other 6 frames. The temporal average is (496x2 + 504x6)/8 = 502. In this way, all 256 input data have distinguishable 256 luminance levels.

Table 1. An example of Hi-FRC for a high color depth.

8bit	9bit	frame							
		1	2	3	4	5	6	7	8
255	$504 = 504+(000)_2$	504	504	504	504	504	504	504	504
254	$502 = 496+(110)_2$	496	496	504	504	504	504	504	504
253	$500 = 496+(100)_2$	496	496	496	496	504	504	504	504
252	$498 = 496+(010)_2$	496	496	496	496	496	496	504	504
251	$496 = 496+(000)_2$	496	496	496	496	496	496	496	496

cf) $504 = (111111000)_2 = 63x8$, $496 = (111110000)_2 = 62x8$

Temporal Averaging: Lower 3-bit data are 000, 001, 010, ..., 101, 110, 111. For data with 0 least significant bit (LSB) such as 000, 010, 100, and 110, there is no difference from the conventional FRC of 00, 01, 10, 11, conceptually. Thus, we will present the temporal averaging of the data with 1 LSB such as 001, 011, 101, and 111. Through the 8 frames, for 001 data, the data sequence of 000 during 4 frames and 010 during 4 frames can make a temporal average through 8 frames to be 001 as shown in Fig.6. Conceptually, 000 has same FRC pattern with 00 of the conventional FRC.

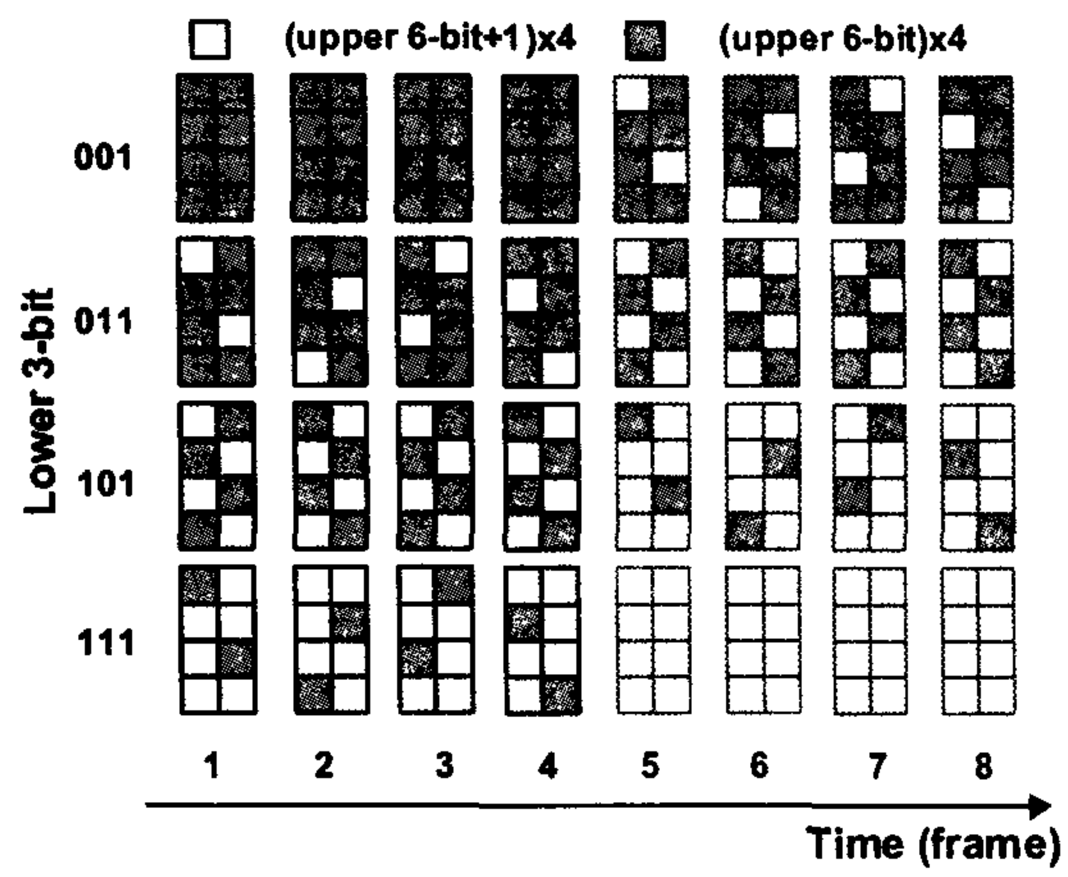


Fig. 6 Temporal averaging concept of Hi-FRC.

Spatial Averaging: Fig. 7 shows the example of a spatial dithering concept. For the case of 011, Hi-FRC needs 64 pixels (8x8) for spatial averaging. 32 pixels on upper left and under right have 010, but 32 pixels on upper right and under left have 100. By this reason, the spatial average is 011.

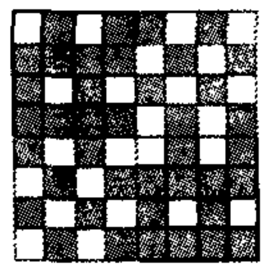


Fig. 7 Spatial dithering concept of Hi-FRC (011).

Experimental Results: Fig. 8 shows the measured data of a 6-bit LCD panel with an application of Hi-FRC. As shown in Fig. 8, the measured results say that Hi-FRC can generate 256 luminance levels. Thus, a 6-bit LCD panel with Hi-FRC technology can display full colors (16.7 M colors).

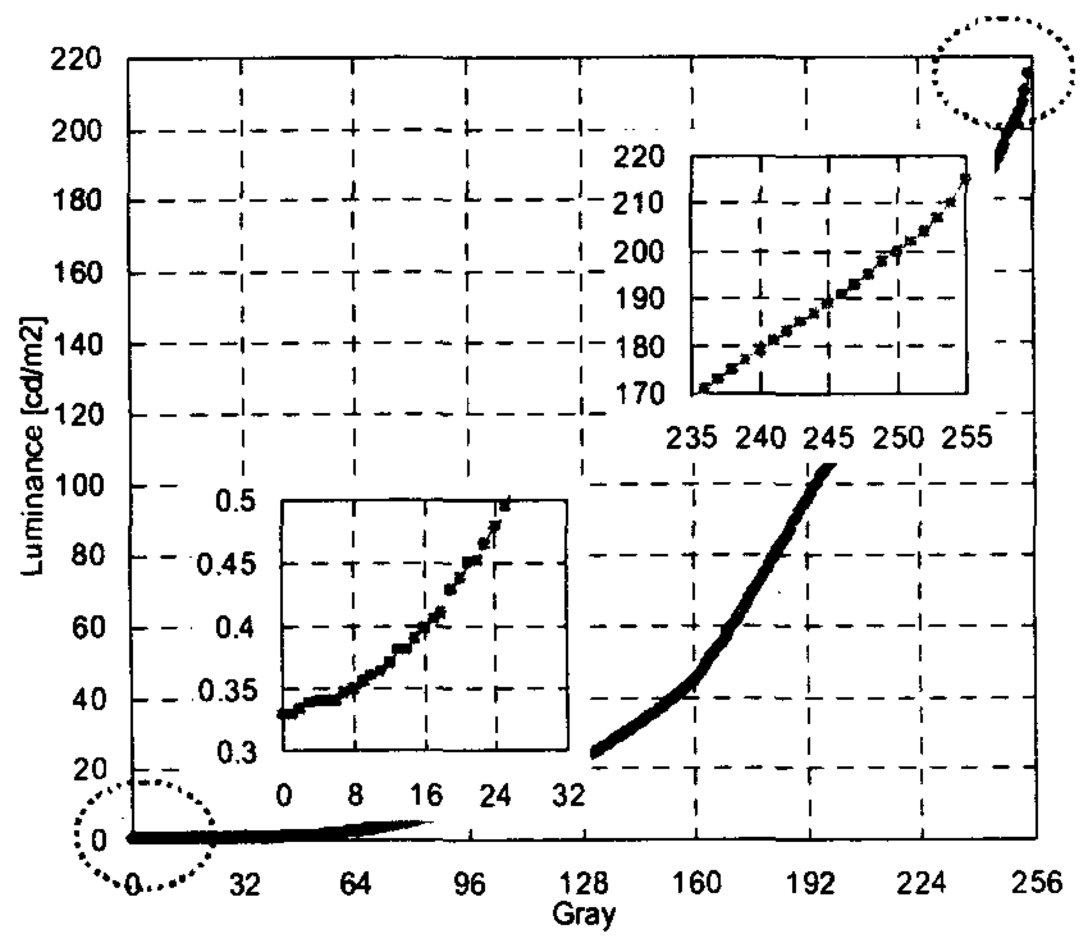
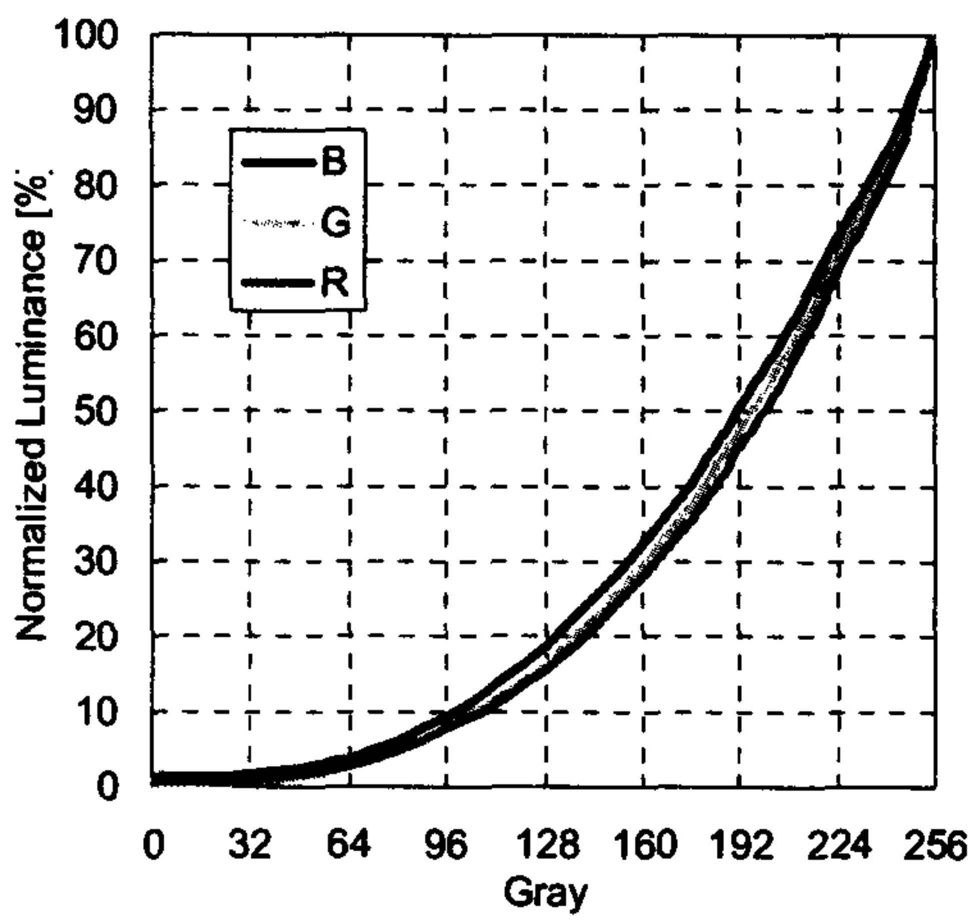


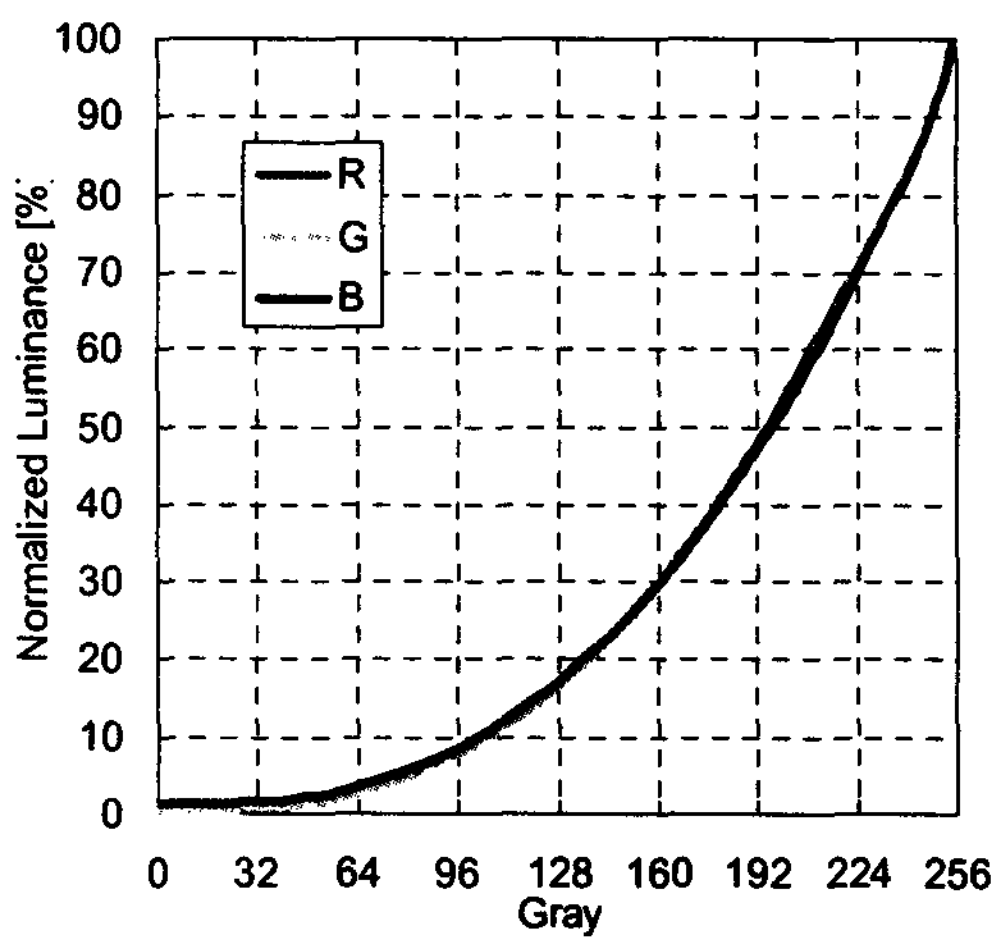
Fig. 8 The measured luminance according to 256 input gray when Hi-FRC is applied.

5. Hi-FRC for High Color Performance

The color shift phenomenon of TN mode can be improved by the Hi-FRC. Hi-FRC uses the data expansion to 9-bit from 8-bit. If there are differences between the expanded data of red, green, and blue, color shift phenomenon can be improved as presented in SID '03 [2]. Then, the monitor with Hi-FRC function can meet the color gray scale linearity item in TCO '03 [3] even in TN mode. Fig. 9 shows the application results of Hi-FRC. If the expanded RGB data are same, the blue gamma curve is located over green and red curves. But, different RGB data can make same RGB curves. Then, the color shift (ΔCCT: correlated color temperature) can be improved to 1500K from 3000K at 64 gray. The Δu'v' which is defined in TCO '03 is reduced from 0.23 to 0.15. As shown in the figure, Hi-FRC technology can make TN mode to meet the color grayscale linearity (Δu'v' < 0.02).



(a) Same expanded RGB data



(b) Different expanded RGB data

Fig. 9 Comparison of RGB gamma curves

6. Conclusion

We proposed a new dithering algorithm, "Hi-FRC", to enable full (16,777,216) color display on LCD panel with 6-bit source D-IC's. The conventional FRC can display only 16,194,277 colors. Thus, Hi-FRC can generate a higher performance LCD panel without any cost up. In addition to higher color depth, Hi-FRC gives a better color performance to LCD panel. Conventional TN mode cannot meet the color grayscale linearity of TCO '03. As shown in experimental results, Hi-FRC can make TN mode to meet the TCO '03.

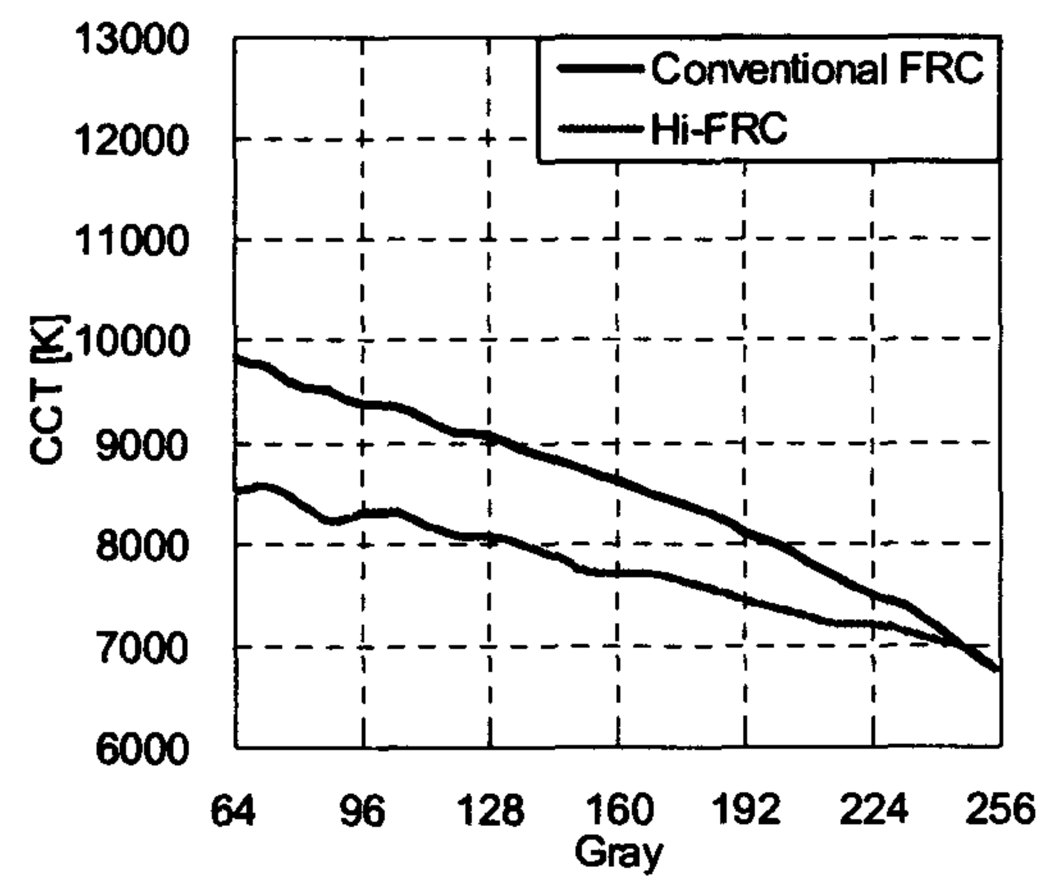


Fig. 10 Comparison of correlated color temperature

References

[1] Display Research, Q4 2003.

[2] S. -W. Lee, et al, "Driving scheme for improving color performance of LCD's: ACC", SID '03.

[3] TCO '03 Displays, Flat Panel Displays, TCOD1024 Ver 1.1, 200