A Novel Dithering Algorithm for High Color Depth and High Color Performance: Hi-FRC

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FAE Sec. 4 Vincent
Abstract

- Conventional FRC can display only 16,194,277 colors with 6-bit source D-IC’s.
- “Hi-FRC” enables full (16,777,216) color on an LCD panel.
Dimming Function

- **Dimming**
  - The CCFL brightness is varied by varying the output current, etc. using an external or other signal. Dimming methods include pulse width modulation (PWM), voltage and current dimming.

- **PWM (Pulse Width Modulation)**
  - This method uses a pulse signal to dim the lamp. The dimming range can be varied between 10 and 100%.
FRC and Dithering

- FRC is achieved by controlling on and off pixels over multiple frames. (*Temporal*)

- Static dithering regulates the number of on and off pixels in a small defined pixel group. (*Spatial*)
FRC Driving Method

<table>
<thead>
<tr>
<th>Frame</th>
<th>Visual Grayscale Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td></td>
</tr>
<tr>
<td>4th</td>
<td></td>
</tr>
</tbody>
</table>

+ + + + =
+ + + + =
+ + + + =
+ + + + =
Dithering Driving Method

Visual Grayscale Effect

(2 x 2) Unit Pixel
### FRC

<table>
<thead>
<tr>
<th>6bit</th>
<th>=&gt;</th>
<th>8bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>=&gt;</td>
<td>0</td>
</tr>
<tr>
<td>0.25</td>
<td>=&gt;</td>
<td>1</td>
</tr>
<tr>
<td>0.5</td>
<td>=&gt;</td>
<td>2</td>
</tr>
<tr>
<td>0.75</td>
<td>=&gt;</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>=&gt;</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>=&gt;</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>=&gt;</td>
<td>12</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
</tbody>
</table>

![Diagram](image)

\[
L = \frac{1}{4} (1+1+1+0) = 0.75
\]

The human eyes average the luminance and feel the brightness is the same as grayscale “0.75”

Number of color of 6bit+FRC

\[
= (256-3)^3 = (253)^3 = 16,194,277
\]
Temporal Average of FRC Algorithm

8 bits input => 6 bits output

127 \((01111111)_2\) = 31,32,32,32

126 \((01111110)_2\) = 32,31,32,31

8 bits input => 6 bits output

127 \((01111111)_2\) = 31,32,32,32

126 \((01111110)_2\) = 32,31,32,31
Spatial Average of FRC Algorithm

\[
\begin{align*}
124 + 128 + 128 + 128 &= 127 \\
\frac{124 + 128 + 128 + 128}{4} &= 127 \\
127 \ (01111111)_2 &= > 31, 32, 32, 32
\end{align*}
\]
Spatial Dithering and Temporal Averaging Pattern

- (upper 6-bit+1)x4
- (upper 6-bit)x4

<table>
<thead>
<tr>
<th>Lower 2 bit</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>01</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Time (frame)
Conventional FRC is Limited to only 253 Luminance Levels

\[
\begin{align*}
255 &= (1111111)_{2} = 252 + (11)_{2} \\
254 &= (1111110)_{2} = 252 + (10)_{2} \\
253 &= (1111101)_{2} = 252 + (01)_{2} \\
252 &= (1111100)_{2} = 252 + (00)_{2} \\
261 &= (1111011)_{2} = 248 + (11)_{2} \\
260 &= (1111010)_{2} = 248 + (10)_{2} \\
249 &= (1111001)_{2} = 248 + (01)_{2} \\
127 &= (0111111)_{2} = 124 + (11)_{2} \\
126 &= (0111110)_{2} = 124 + (10)_{2} \\
125 &= (0111101)_{2} = 124 + (01)_{2} \\
124 &= (0111100)_{2} = 124 + (00)_{2} \\
4 &= (00000100)_{2} = 4 + (00)_{2} \\
3 &= (00000110)_{2} = 0 + (11)_{2} \\
2 &= (00000110)_{2} = 0 + (10)_{2} \\
1 &= (00000010)_{2} = 0 + (01)_{2} \\
0 &= (00000000)_{2} = 0 + (00)_{2}
\end{align*}
\]

\[252 + 256 + 256 + 256 = 255 \quad \text{Ideal case}\]
\[252 + 256 + 252 + 256 = 254 \quad \text{Real case}\]
Hi-FRC Enables a Higher Number of Available Colors

8 bit → 9 bit → 6 bit

data expansion → 3-bit reduction
### An Example of Hi-FRC for Higher Color Depth

<table>
<thead>
<tr>
<th>8bit</th>
<th>9bit</th>
<th>frame</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>255</td>
<td>504 = 504+(000)_2</td>
<td>504</td>
</tr>
<tr>
<td>254</td>
<td>502 = 496+(110)_2</td>
<td>496</td>
</tr>
<tr>
<td>253</td>
<td>500 = 496+(100)_2</td>
<td>496</td>
</tr>
<tr>
<td>252</td>
<td>498 = 496+(010)_2</td>
<td>496</td>
</tr>
<tr>
<td>251</td>
<td>497 = 496+(001)_2</td>
<td>496</td>
</tr>
</tbody>
</table>

cf) 504 = (111111000)\_2 = 63x8, 496 = (111110000)\_2 = 62x8
Temporal Averaging
Concept of Hi-FRC

Time (frame)
Spatial Dithering Concept of Hi-FRC (011)
The Measured Luminance