P-42: Color-Depth Improvement using Gamma Voltage Control

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Abstract
A novel Gamma Voltage Control (GVC) technique that can increase the color depth of TFT LCD has been developed. With this method, we can use n bit data driver to provide more than n bit performance on the display. Experimental results successfully demonstrate the feasibility of this method.

1. Introduction
Liquid crystal displays have been widely used, for example, in notebook computers, monitors and televisions, for the advantages of low radiation, low power consumption, and light weight. To get better display quality, improving the color depth is one of the important trend of TFT LCD. As we know, there are two kinds of conventional structure have been applied for this purpose. One is true n-bit data driver, the other is n-bit + FRC (frame rate control). In true n-bit data driver, there are $2^n - 1$ resisters in Resistor String DAC (R-DAC). It means more color depth needs more resisters in R-DAC. In the other words, the chip size becomes larger and also means cost up. FRC uses the voltages that change of time and space to let our eyes sense more color depth. However, the n-bit data driver still keeps 2^n output voltages. Hence, different FRC algorithm reveals its FRC side effect at different particular patterns. And for the algorithm reason, FRC will lose last three gray levels for increasing 2 additional bits. To get maximum gray levels but still keep lower cost, "Gamma voltage control" is proposed to provide another choice to improve the color depth of display.

2. Gamma Voltage Control

2.1 Concept of Gamma Voltage Control
The concept of Gamma Voltage Control is based on Ohm's law. Figure 1 shows the relationship between bits (resolution) and resister quantity. Obviously, the more bits you want the more resisters you need.

According to the results of Figure 1, we can develop the "Gamma Voltage Control" technique to get the output results of Figure 1C from Figure 1A. Figure 2 shows the concept of "Gamma Voltage Control" technique where V1 and V2 are the external input supply. In Figure 2, if we applied 4 pairs of external voltages to V1 and V2, it will generate 4 pairs of outputs at node 2 and 3, respectively. So we can get 16 output voltages. The voltage results are same as Figure 1C but fewer resisters. The key point is the external voltage supply will be changed under a particular control. Because the DAC in source driver is resistor-string (R-string) structure, it also needs external voltage supply for gamma correction. The structure can be applied to Figure 2. Table 1 shows the relationship between external voltages supply (V1 and V2) and output voltages. For the case in Figure 2, we can use 2 bits decoder select the output voltages that we want. This is the concept of Gamma Voltage Control.

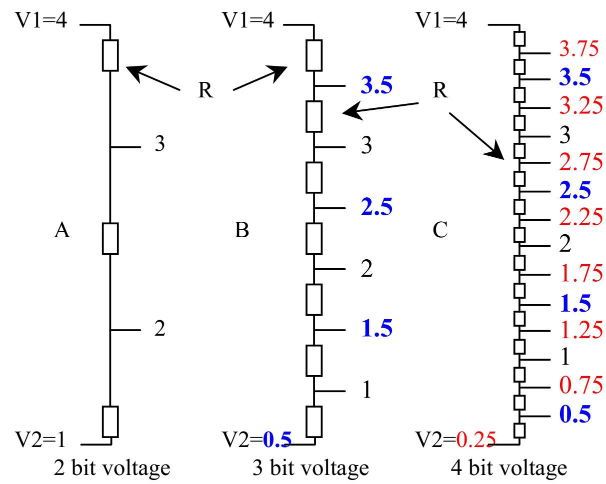

Figure 1 The relationship between bits and voltage.

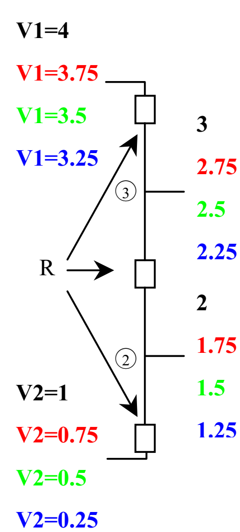

Figure 2 Concept of Gamma Voltage Control

Bit0	1	0	1	0
Bit1	1	1	0	0
V1	4	3.75	3.5	3.25
V2	1	0.75	0.5	0.25
Output	4	3.75	3.5	3.25
	3	2.75	2.5	2.25
	2	1.75	1.5	1.25
	1	0.75	0.5	0.25

Table 1 The relationship between input and output

2.2 Diagram of Driving System

Figure 3 and Figure 4 show the difference between conventional and the proposed Gamma Voltage Control (GVC) block diagram of driving system. Conventional system has only one set of reference voltage into source driver. GVC system needs more than one set of reference voltages into source driver. Two sets of reference voltages are minimum request.

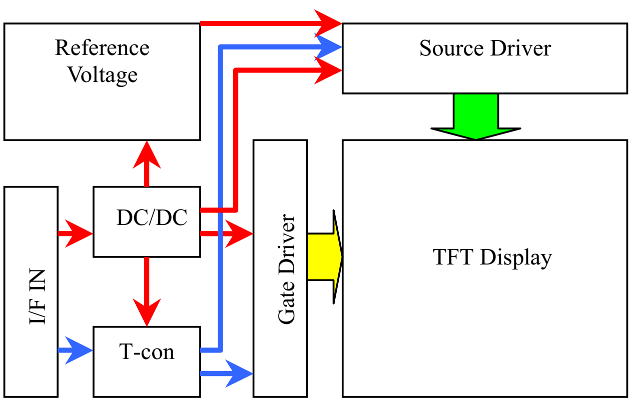

Figure 3 The conventional block diagram of driving system.

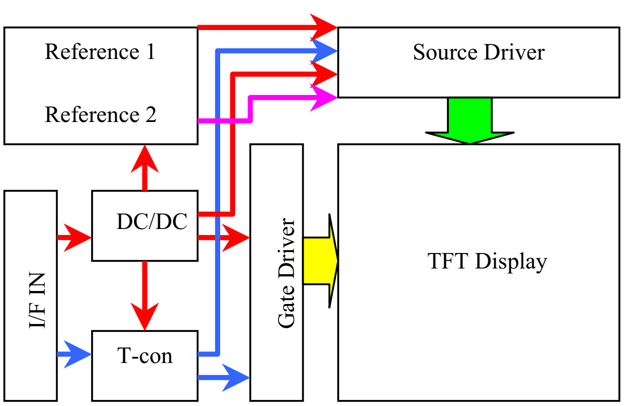

Figure 4 The proposed GVC block diagram of driving system.

2.3 Diagram of Source Driver

Figure 5 and Figure 6 show the difference between conventional and the proposed GVC block diagram of source driver. In addition to the different reference voltage sets, GVC source driver also needs a selector. Generally speaking, one set of reference voltage including 10 to 18 voltages for gamma correction. The selector is controlled by the Least-Significant Bit (LSB) of Data to decide which reference voltage will be selected. Figure 7 shows the schematic of selector with LSB controlling case.

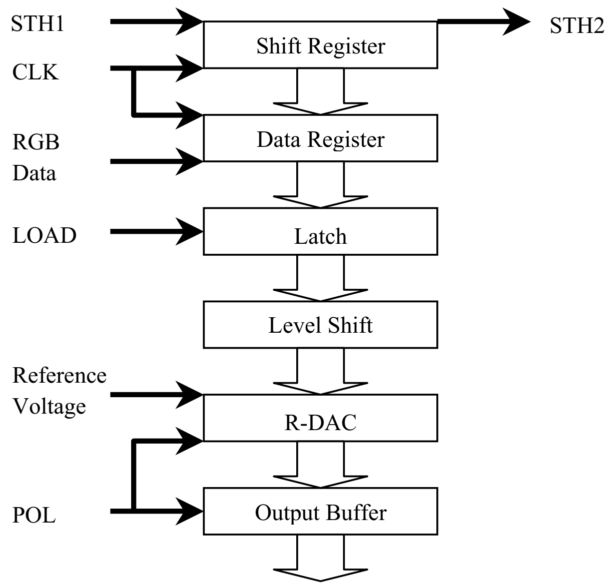

Figure 5 Conventional block diagram of source driver.

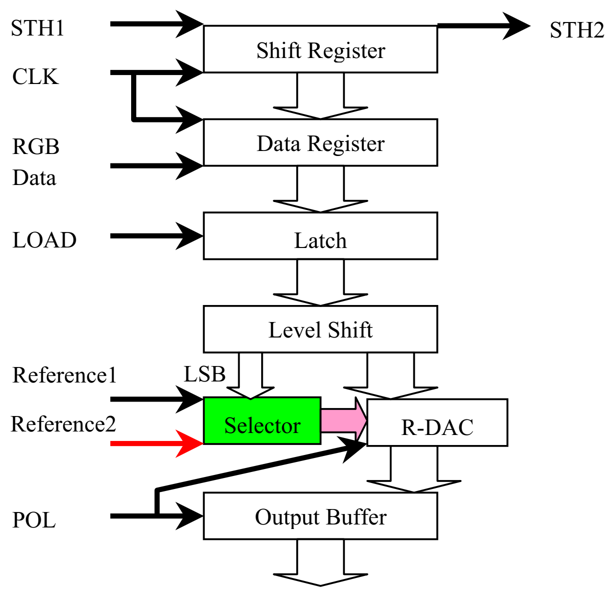

Figure 6 Proposed GVC block diagram of data driver.

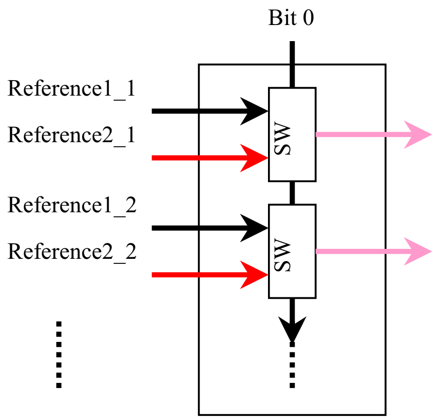

Figure 7 Proposed schematic of selector.

The switch (SW) consists of several transmission gates. Therefore, GVC can keep the source driver size and get two times of output voltages with the same R-string.

If we provide one set of reference voltage into n-bit data driver. According to the Ohm's law, we can have 2^n voltages in R-DAC. If we provide another set of reference voltage, we can have another 2^n voltages in R-DAC. Thus, we can have 2^{n+1} voltages with only one 2^n R-DAC. Because the number of resisters in R-DAC has been reduced, compared with the same color depth of data driver, we can have the cost advantage on the data driver. In GVC system, LSB is for reference voltage selection, the other bits are for R-DAC. For example, if 2 bits for reference voltage select, only 2^{n-2} resisters are needed in R-DAC. And we can keep 2^n kind of output voltages. Besides, if combined with FRC, the FRC side effect will be reduced, too. As we know, FRC uses the voltages that change in time and space to gain more gray scale. In 6bit+FRC application, we can gain the color depth from 262144 (64 x 64 x 64) to 16194277 (253 x 253 x 253). Unfortunately, we can observe FRC noise (such as flicker, line noise…) in some patterns. However, GVC technique provides less voltage change, so the goal of less FRC side effect can be achieved. For example, if we use GVC gain one bit, FRC gain another one bit. In 6bit+GVC+FRC application, we can gain the color depth from 262144 (64 x 64 x 64) to 16581375 (255 x 255 x 255). More than pure FRC application and more close pure 8bit system (16777216 = 256 x 256 x 256). It's another advantage of Gamma Voltage Control.

3. Experiment Results

To verify the feasibility of the proposed "Gamma voltage control" technique, an experiment using a 6 bit source driver with two sets of 7x2 external gamma voltages (0, 1, 16, 32, 48, 62, 63) has been set. The measured 128 negative-polarity output voltages of data driver are listed in Table 2. The results demonstrate that 1-bit has been successfully increased using the proposed GVC technique.

The yellow blocks are the gamma compensation points (we use the source driver with 14 gamma compensation). The data in blue are the source output voltages with the reference voltage 1. The data in red are the source output voltages with the reference voltage 2. Base on Table 1, the data in blue and red are interlaced by each other. This shows the GVC is worked well for improving the color-depth. Figure 8 shows the curve of Table 1.

Again, Figure 8 shows two groups of output data can be interlaced by each other. It means GVC create 128 different voltages with 6 bit DAC correctly. When the 128 different voltages have been provided into TFT LCD, we can get 128 gray levels on the display. In other words, we use GVC to improve the output resolution of source driver and achieve the goal of improving the color-depth through GVC technique.

	Ref 1	Ref 2		Ref 1	Ref 2		Ref 1	Ref 2		Ref 1	Ref 2
0	0.211	0.707	16	2.960	2.973	32	3.567	3.580	48	4.072	4.085
1	1.161	1.173	17	3.026	3.039	33	3.599	3.612	49	4.120	4.133
2	1.348	1.361	18	3.081	3.094	34	3.631	3.644	50	4.168	4.180
3	1.522	1.535	19	3.136	3.149	35	3.662	3.676	51	4.215	4.227
4	1.684	1.697	20	3.191	3.205	36	3.694	3.707	52	4.262	4.275
5	1.833	1.846	21	3.237	3.249	37	3.726	3.739	53	4.309	4.322
6	1.970	1.983	22	3.280	3.293	38	3.757	3.770	54	4.379	4.392
7	2.107	2.119	23	3.324	3.337	39	3.789	3.801	55	4.450	4.462
8	2.232	2.244	24	3.357	3.369	40	3.820	3.833	56	4.520	4.532
9	2.355	2.367	25	3.390	3.402	41	3.851	3.864	57	4.613	4.626
10	2.453	2.466	26	3.423	3.435	42	3.883	3.895	58	4.707	4.720
11	2.552	2.565	27	3.456	3.469	43	3.914	3.927	59	4.824	4.836
12	2.638	2.651	28	3.478	3.491	44	3.946	3.958	60	4.940	4.953
13	2.724	2.737	29	3.500	3.513	45	3.977	3.990	61	5.080	5.093
14	2.811	2.824	30	3.523	3.535	46	4.009	4.021	62	5.315	5.328
15	2.885	2.898	31	3.545	3.557	47	4.040	4.053	63	5.956	6.953

Table 2 The list of measured output voltages of data driver with GVC technique.

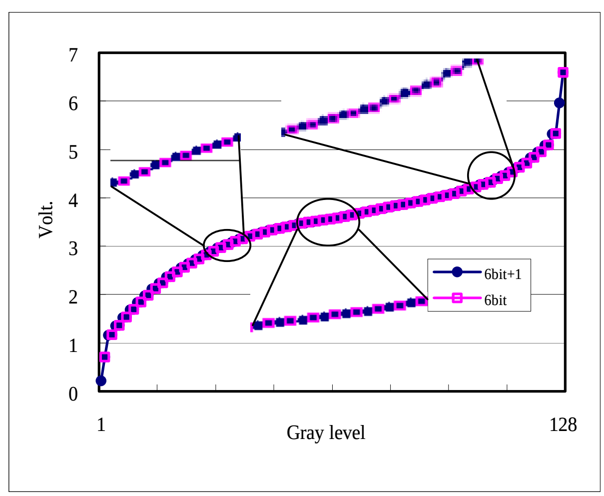

Figure 8 Curve of Table 1.

4. Conclusion

A novel gamma voltage control has been developed that can increase the color depth of TFT LCD. With this method, we can use n bit data driver to provide more than n bit performance on the display. Because the number of resisters in R-DAC has been reduced, compared with the same color depth of data driver, we can have the cost advantage on the data driver. In addition, if combined with FRC, the FRC side effect will be reduced and gain more color depth than pure FRC application, too. Experimental results successfully demonstrate the feasibility of this method.

5. References

[1] C. H. Hsu, C. C. Chen, N. K. Lu, M.L. Lee, "Driving circuit and method for increasing effective bits of source drivers", US patent pending.

[2] Kazuo Sekiya, Tokyo; Yuichi Shiraishi, Yamato, US patent 5059962, "Display system".