Improvement of Contrast Ratio in QR-LPD by Four-Voltage Level Driving

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Abstract: *The image quality of Quick-Response Liquid Powder Display (QR-LPD) was improved further using the new driving method with the four-voltage levels than a conventional three-voltage level driving method. This driving method can improve the contrast ratio by 11 % in comparison with the best value given by the conventional driving method.*

Keywords: electronic paper display; driving method; non-emissive display; bistable display

Introduction

Quick-Response Liquid Powder Display (QR-LPD) shown in Fig. 1 is one of the best candidates for an ideal electronic paper display, which can be readily used like a paper and rewritten anytime and anywhere [1]. The QR-LPD is the bistable reflective display with a quick response and a high contrast ratio, achieved with newly invented high liquidity particles, so-called "electronic liquid powder." Since the QR-LPD can be driven by a passive-matrix (PM) driving method and uses no polarization effects like a LCD, the TFT array and the polarizer are not required. Therefore, low-cost productivity and display flexibility are easily obtained.

The QR-LPD has good bistability, so that the display keeps an image without the applied voltage. That is, the QR-LPD has the ability to memorize an image without the electric power. The image can be retained for several years. Unlike the emissive displays, it consumes no electric power except when the image is updated. Therefore, the power consumption of the display can be dramatically saved.

In last years, the power consumption of mobile devices such as a mobile phone and a digital audio player is increasing by adding many functions. Adopting the QR-LPD as a mobile display can be a solution for the problem.

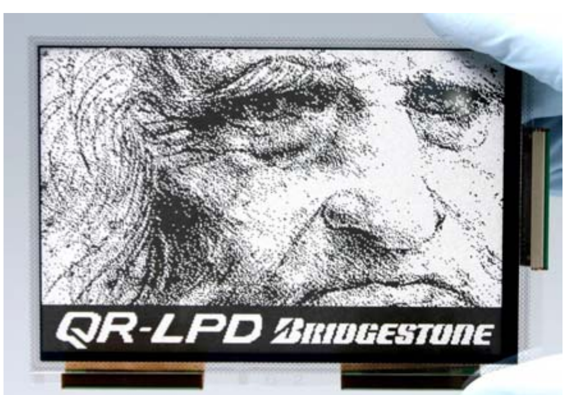

Figure 1. One Example of QR-LPD

In addition, the new applications such an electronic book, a point of purchase (POP) display, a price tag and an RF tag are possible by supplying the power with a battery or radio transmission because of the good image quality and low power consumption.

Since the QR-LPD has a wide viewing angle and a natural image with the perfect diffuse reflection, the display has the image quality just like a paper. A contrast ratio between black and white appearances is one of the image quality indexes as well as reflectance. Although the contrast ratio of QR-LPD is even equal to the contrast ratio of newspaper, higher contrast ratio is requested to realize a more natural image. The contrast ratio is affected by various kinds of factors, such as the particle materials, the applied voltages, the driving methods, the panel structures, and so on. Among these factors, the driving method is the most effective and easiest factor to improve the contrast ratio.

In this work, we have improved the contrast ratio of QR-LPD by devising the display driving method. We have employed the four-voltage level driving method that can reduce the crosstalk voltage to two-third of that in a conventional driving method.

The principle of QR-LPD

The QR-LPD has a simple structure where two ITO electrodes just sandwich the two kinds of the electronic liquid powders that consist of the polymer materials and the pigments. In case of the black/white display, one kind of powder is colored black and charged positively and the other is colored white and charged negatively. The rib formed by a dry-resist process keeps the distance between ITO electrodes 50-100μm. The rib prevents uneven distribution of powders among the pixels.

When a voltage is applied between two electrodes, the charged powders move to the electrode. When the negative voltage is applied to the upper electrode, the black negatively charged powder moves to the upper electrode and shows a black appearance. Meanwhile, when the positive voltage is applied to the upper electrode, the display shows a white appearance.

In addition, not only black and white powders but also yellow, red, blue and green are developed and the area color display can be realized [2].

The electronic liquid powder has a sharp threshold voltage. If the adequate electric field more than the threshold value is applied, the powder begins to move. In addition, the state of powder is retained even if a voltage is not applied because of the induced image and Van der Waals forces at the electrodes. That is the reason why the QR-LPD can memorize an image.

The QR-LPD can shows the same image quality like an electrophoretic display (EPD), but the response speed of QR-LPD is much faster than that of EPD since the particles of QR-LPD move in the air. The EPD usually needs a response time longer than several tens milliseconds while the QR-LPD needs only less than 0.2 millisecond.

Custom driver LSI

A relatively high voltage about 70 V is necessary to drive the QR-LPD at present. Therefore, the special driver LSI, which generates high voltage signals, is necessary to drive the display. In our laboratory, the custom-made driver LSI was designed. This driver LSI has 160 outputs and three-voltage levels including a ground level. A conventional CMOS process adding the 110V LDMOS (laterally double diffused MOS) process is employed, which is the simplest process for a high voltage LSI. The driver circuit has the original level shifter, which can save the power consumption and the chip area and has the current-sink function at the middle voltage level, which can reduce the transient time and recover the power from the capacitive panel load. This three-voltage-level output driver can realize various kinds of driving methods that can efficiently improve the image quality [3]. In this work, we used the driver LSI for the four-voltage level driving by changing the different voltage level at the middle voltages of a column and row drivers.

Conventional driving method (three-voltage level driving method)

The QR-LPD has a sharp threshold voltage and a quick response, so that the display can adopt a PM driving. This fact gives tremendous advantages because the PM driving needs no high-cost TFT backplanes unlike the active-matrix (AM) driving. Therefore, we can reduce a production cost and provide the low-cost panels. In addition, elimination of high temperature process enables the use of plastic substrate. We can realize a flexible and robust display. Actually, the prototype of the flexible QR-LPD has been presented [4].

The QR-LPD panel is composed of row- and column-electrodes, which are set in a reticular pattern. A crossing point of the row and column electrodes forms a pixel and the voltage difference between the row and column electrodes is applied as the pixel voltage.

During the driving process, a previous image has to be erased at first because the QR-LPD keeps an image. The erasing high voltage is applied to all row electrodes (or all column electrodes) and a ground voltage is applied to all column electrodes (or all row electrodes). After erasing, the middle voltage is applied to the row electrodes except of the line selected sequentially, and the column electrodes are applied the high or middle voltage according to the image data. In this sequence, the voltage applied to the written pixels has to be more than a threshold voltage, and the voltages applied to unwritten pixels or unselected pixels have to be less than a threshold voltage.

The conventional driving method uses three-voltage levels, high, middle and ground voltages. In this case, the combination of column voltage (written, unwritten) and row voltage (selected, unselected) has 6 patterns as shown in Table 1.

The image quality of QR-LPD strongly depends on the driving method. This difference comes from the "crosstalk", which occurs with the unexpected voltage applied to unwritten or unselected pixels. The QR-LPD has a clear threshold voltage but a little switching happens even at less voltage than the threshold. During the driving process, the crosstalk voltage affects the unwritten pixels or unselected pixels and the contrast ratio results in deteriorating. In the three-voltages driving described above, the crosstalk voltage exists between MV and –MV levels.

Table 1. Conventional Driving Method

	Row		Column	
	Selected	Unselected	Written	Unwritten
1	GND	MV	HV	MV
2	GND	MV	HV	GND
3	GND	HV	HV	MV
4	HV	MV	GND	MV
5	HV	MV	GND	HV
6	HV	GND	GND	MV

Four-voltage level driving method

The conventional driving methods drive a panel with three-voltage levels, while the new driving method drives with four-voltage levels. For example, in the conventional driving method 1 in Table 1, both unwritten voltage of row electrode and unselected voltage of column electrode are set to the middle voltage or half of the high voltage. In the new driving method, we set the unselected voltage of row electrode to two-thirds of high voltage and the unwritten voltage of column to one-third. In the new driving methods, the crosstalk voltage can be decreased from half of the high voltage to one-third as shown in Fig. 2.

In the case of four-voltage levels, the combination of column and row voltages has 2 patterns as shown in Table 2. These are named 1' and 4' since the unwritten and unselected voltages are set to neither GND nor HV as well as the conventional driving method 1 and 4.

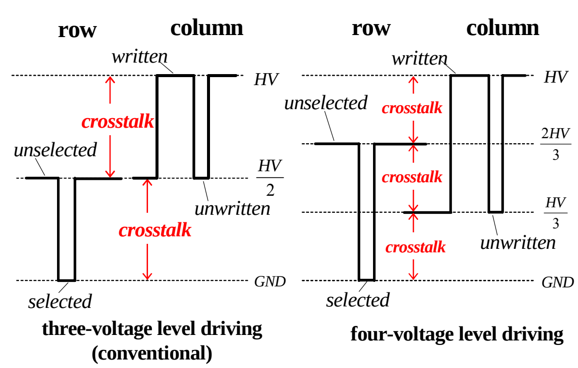

Figure 2: One Example of Three-Voltage Level Driving and Four-Voltage Level Driving

Table 2. Four-Voltage Level Driving Method

	Row		Column	
	Selected	Unselected	Written	Unwritten
1'	GND	2/3HV	HV	1/3HV
4'	HV	1/3HV	GND	2/3HV

The new driving methods could decrease the absolute value of crosstalk voltage. However, in the four-voltage level driving methods 1' and 4', the crosstalk voltage was applied in both positive and negative directions while the crosstalk voltage in the driving methods 1 and 4 was applied in just only the same direction as the writing voltage. The former factor obviously reduces the crosstalk-effect but the latter factor enhances the effect.

We have to confirm how much the image quality is improved by the new driving method, so that we drove the QR-LPD with both the conventional and new driving methods and estimated the constant ratio.

Estimation

We compared the contrast ratios of the QR-LPD driven by the conventional driving methods 1 and 4 and the new driving methods 1' and 4'. After driving with each method, we measured the optical density at the white and black parts on the driven panel with optical densitometer and calculated the contrast ratio.

In all driving methods, the writing voltage (high voltage, HV) was set to 70V. Hence, the middle voltage (MV) for the three-voltage levels driving was set to 35V, and one third of the high voltage (1/3 HV) and two-thirds (2/3HV) were set to 23V and 46V, respectively. In case of driving methods 3 and 6, the iteration of row select pulse was effective to increase the contrast ratio. Oppositely, in case of driving methods 1 and 4, the highest value of contrast ratio was obtained when the iteration number of row select pulses was just one [3]. Therefore, the number of row select pulses was chosen to be one and the period of selecting pulse was 600 μsec. This condition leads the best value of contact ratio for the driving method 1 and 4.

The square area with 20×20 pixels were written in a checker flag pattern on the QR-LPD panel. The measured QR-LPD panel was the B/W monochrome panel with a 160×160 array of pixels. The pixel size was 300μm×300μm and the glass substrate was employed. The optical density was measure at the center of written square region in several points and several times. The written pattern was reversed and measured again in the same manner to consider the sticking image effect. After all measurements, the average numbers of black and white optical densities are used to calculate the constant ratio.

The black and white optical densities of the QR-LPD panel written by each driving method are shown in Fig. 3. The optical density D is defined as the following equation;

$$D = -\log_{10} R, \tag{1}$$

where R is the reflectance.

Higher the black density and lower white density give higher contrast ratio. In cases of the driving methods 1 and 1', the panel is written with black color on the base of white color, but the crosstalk voltages are applied in the direction to write the black color for the driving method 1 and in both directions for driving method 1'. Therefore, the optical densities of black and white colors in driving method 1 are higher than that of method 1'. Oppositely, in cases of driving methods 4 and 4', the optical densities of driving method 4 are lower than that of driving method 4'.

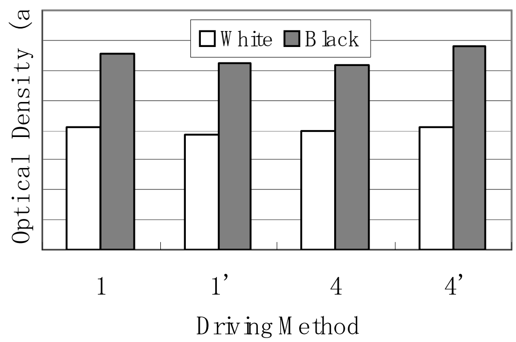

Figure 3. Black and White Optical Densities

Assuming that the optical densities of black and white regions are D_{black} and D_{whithe}, respectively, the contrast ratio C is calculated from the following equation;

$$C = 10^{D_{black} - D_{white}}. \tag{2}$$

The contrast ratio of each driving method are shown in Fig. 4. The highest contrast ratio is obtained in driving method 4', which uses four voltage values. The contrast ratio of 4' is improved by 26% compared with the value of driving method 4 and improved by 11% compared with the driving method 1 that is the best of the conventional driving methods. The contrast ratio of 1' was not improved from the value of driving method 1.

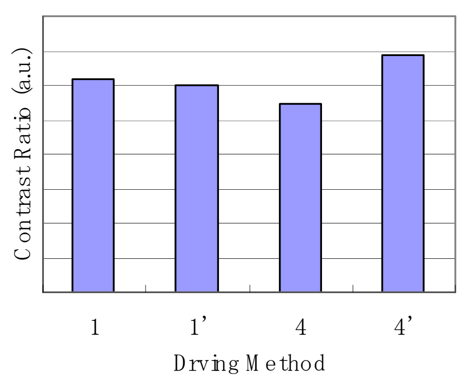

Figure 4. Contrast Ratio

In the four-voltage level driving methods, the crosstalk effect of the written pixels is enhanced because the polarity of the crosstalk voltage is opposite to that of the written voltage. On the other hand, the crosstalk effect of the retained pixels is reduced because the absolute value of crosstalk voltage is reduced by one-third in the new driving method.

In case of driving method 1', since the black color is written to the base white color, the optical density of the written black parts is decreased and the optical density of the retained white parts is decreased. Oppositely, in case of driving method 4', both optical densities of written and retained parts are increased because the written color is white.

The contrast ratio is very sensitive to the optical density of black parts comparing with that of white parts because the reflectivity of black parts is calculated as a denominator in a contrast ratio. Therefore, the contrast ratio of the driving method 1' is not improved because the optical density of black parts is deteriorated by the crosstalk voltage. On the other hand, the contrast ratio of driving method 4' can be improved by the improvement of the black color quality.

Summary

We could improve the image quality by the driving method investigated in this work. The improvement by 26% in the contrast ratio from the conventional three-voltage level driving method was obtained in case that the white color is written to the black base color. Comparing with the best value obtained by the conventional method, the contrast ratio is improved by 11%.

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