

P-10.4: High Image-Content Zenithal Bistable Devices

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Abstract

Grating aligned zenithal bistable LCDs offer a low cost route to ultra-low power displays with excellent appearance. The flexibility of the grating design and embossing fabrication method allows each pixel to have several latching thresholds without extra fabrication cost. Combining this approach with a novel addressing method allows each row driver to address several lines of information. For example, this technique allows high numbers of greys to be addressed using digitally weighted spatial dither, but without the extra-cost of additional electronic drivers.

1. Introduction

Bistable displays aim to satisfy market demand for ultra-low power devices with excellent optical properties and at a low cost. Bistable LCDs have a distinct cost advantage over the emerging bistable display technologies, because they allow passive matrix addressing and fabrication within the existing infrastructure for STN LCD manufacture. However, a limitation common to all bistable displays, including bistable LCD, is achieving very high levels of greyscale and full colour operation. It is important that this limitation is overcome, before widespread adoption of bistable technologies will occur in applications such as Web browsers and Mobile Phones.

It is the objective of the current work to produce a device that overcomes this limitation, and to deliver the high image content, low cost, bistable combination that will be so powerful in the portable displays market.

The Zenithal Bistable Device [1, 2] is similar in construction to a conventional Twisted Nematic LCD, except that it incorporates a grating on one surface to impart alignment to the liquid crystal, instead of the usual rubbed polymer, figure 1. This grating surface stores the image after the field is removed, maintaining either vertical or planar alignment of the liquid crystal director.

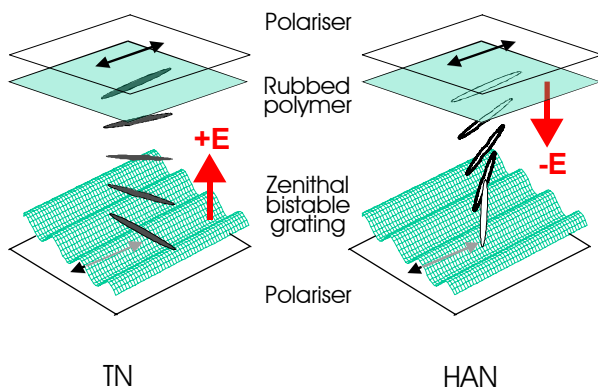


Figure 1 Schematic of the ZBD display.

As a surface effect, the stored image is retained despite severe mechanical shock and it allows bistability to be achieved with a variety of optical configurations. An example design is that shown in figure 1, in which the grating is arranged opposite a conventional rubbed polymer surface to give a TN in the low tilt state, and a Hybrid aligned nematic (HAN) in the high tilt state. This arrangement combines the excellent reflectivity of the HAN state, with the contrast and viewing angle allowed by the TN – HAN combination. The excellent appearance is achieved without the need for compensation layers, and the tolerance on the 5µm cell gap is lenient (typically ±0.25µm rather than the ±0.05µm of STN). Latching occurs for pulse magnitudes of several volts, and durations of tens of microseconds [3].

Low cost manufacture of the grating uses a simple embossing approach similar to that taken by the CD / DVD production industry. The basic approach is shown in figure 2 in which the photo-lithographically defined structure is copied, first into Nickel shims, and then into a plastic film that is supplied to the LCD manufacturer. The grating is then replicated in photo-polymer on the internal surface of the display by embossing [4].

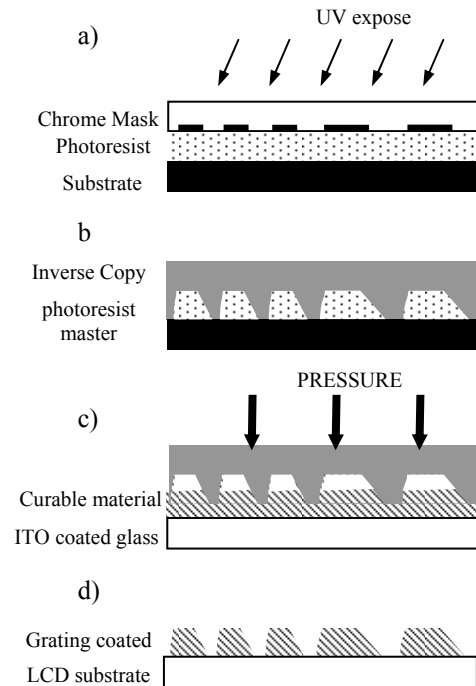


Figure 2 Fabrication method for grating on LCD substrate.

2. Multiple Thresholds and Greyscale

As well as providing a low cost and reliable method for grating fabrication, this technique has the distinct advantage that the embossed features can also be changed across the panel without

extra manufacturing cost because the increased complexity is in the formation of the original master grating only, and not the film. For example, the orientation of the grating, and correspondingly the liquid crystal alignment direction, may be changed to improve the viewing angle. The example of figure 2 shows two areas of different grating pitch designed to provide different electro-optic latching thresholds. This approach has previously been used to fabricate a greyscale ZBD display [5], wherein areas of different grating pitch and mark-to-space across each pixel gave several different latching thresholds and hence produced multiple pixel transmission (*i.e.* grey) levels.

Unlike other routes to producing greyscale in bistable displays, the embossing technique provides a greyscale fabrication method without extra manufacturing cost. If the thresholds are designed to have sufficiently different voltages then each grey will have a range of operating conditions that produce the desired transmission level tolerant to temperature and panel variations. In this sense, the greys bestowed may be described as error-free [5].

This is illustrated in figure 3. ZBD latching is polar and depends on the magnitude and duration of the electrical pulse that results at the pixel due to the difference between row and column voltage at a given pixel. Latching from black to white (BW) will occur for a high positive pulse (τV) but the pixel remain unchanged for pulses below the threshold, or for any negative pulse. Patterning the grating to provide two areas with different thresholds leads to addressing windows where both areas of the pixel change state, neither area changes, and one area only changes.

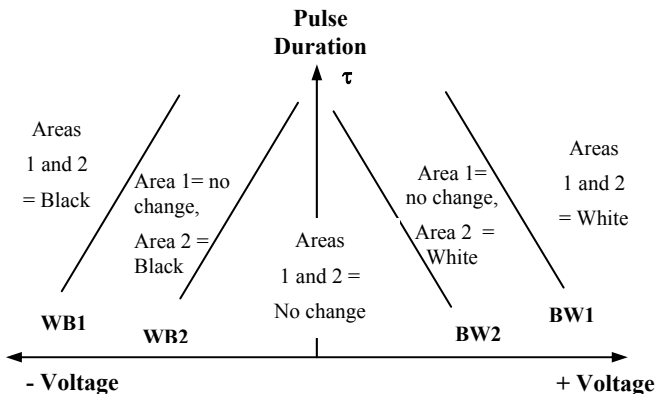


Figure 3 Schematic of the electro-optic latching response for a bistable device with two separately defined areas each with different thresholds.

A matrix device is addressed a line at a time, with the resultant voltage at a given pixel equal to the difference between the row and column voltages. A voltage at or close to the threshold is applied to the row, and the data on the column either causes the resultant to be above the threshold (change) or below it (no change). With a greyscale device, different data waveforms are used to modulate the resultant waveform and latch *all* areas with thresholds below the resultant voltage, and none above.

Producing any bistable display with more than sixteen levels of error-containing analogue greyscale is a challenge due to variations across the display [6]. Even with the error-free greyscale offered by ZBD the data voltage limits the number of greys: 64 greys spaced by 0.2V require a data voltage of over

$\pm 6V$. Such a high data voltage significantly impairs the power advantage of the bistable display. In practice, higher numbers of greys have been produced using weighted spatial dither [5]. This involves additional cost, since the number of column electrodes and drivers is increased.

3. The Multi-Scan Addressing Technique

In the present work, a novel method is presented for dramatically increasing the image content of bistable displays without the additional cost associated with spatial dither. The method also provides a route for increasing the number of lines, or increasing the resolution of a display with no extra driver cost.

The basic principle is shown in Figure 4. Each pixel is arranged to

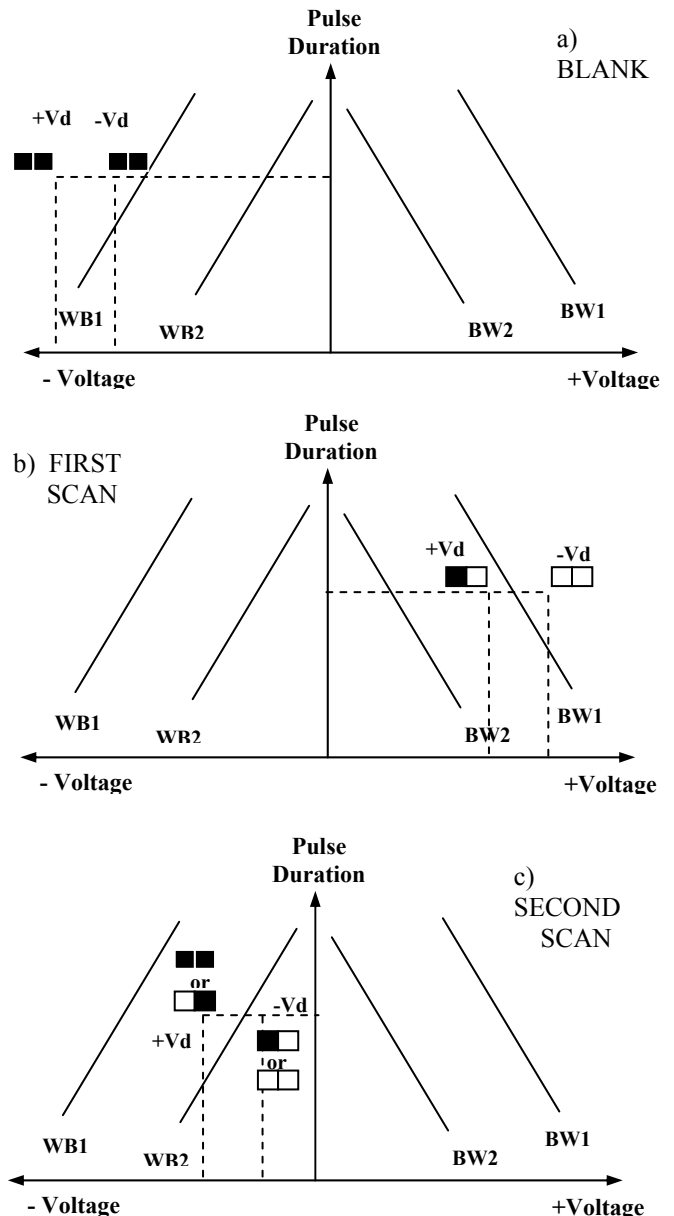


Figure 4 Principle of Multi-scan operation. The data voltages and selected states are shown after a) the blanking pulse, b) first row scan and c) second row scan.

have two or more widely separated latching thresholds that are addressed in separate scans of the row electrode. A row or several rows are initially blanked using a pulse that sets the whole of each pixel on the row into one or other of the states. In figure 4, a high negative pulse is used to blank the pixel Black. The rows are then scanned in sequence a number of times equal to the number of latching thresholds. Each row scan is designed to address one of the sub-pixel areas selectively, according to the data voltage synchronously applied to the column. The order in which the sub-pixel areas are addressed is fundamental to the method. Each successive scan acts to select the state for the highest remaining threshold. Either the voltage or the duration of the row signal may be reduced between successive scans.

For a two-area device shown in figure 4, the first scan causes selective addressing to the higher threshold sub-pixel area 1, whilst blanking the lower threshold area 2. The row waveform is chosen to be close to the threshold BW1, such that area 1 latches white for a high resultant voltage $+V_{row} - (-V_d)$, but remains black for the lower resultant voltage with the opposite data $+V_{row} - (+V_d)$. If the device is designed correctly, both of these resultants are sufficient to latch the lower threshold sub-pixel area 2 to white.

The second scan selectively addresses the lower threshold areas whilst leaving the higher threshold areas unchanged, and in the state written during the first scan. The row waveform is inverted and set close to the threshold WB2. Area 2, blanked white during the first scan now latches black for the resultant voltage $-V_{row} - (+V_d)$, and remains white with the opposite data $+V_{row} - (-V_d)$. Again, correct design ensures that neither resultant disturbs the state of the sub-pixel area 1 written during the first scan.

In this example, it is the voltage that is decreased on successive scans, but alternatively the duration of the pulse may be modulated instead, to allow conventional STN drivers to be employed. A complete frame may be written either using two scan fields, or with two scans for each line sequentially. Photomicrographs of a ZBD device with two areas following application of a multi-scan waveform to the rows and columns are shown in figure 5.

The multi-scan technique allows multiple lines of information to be written but with only a single row and a single column electrode and associated driver. Image complexity has effectively been increased, with the only cost being the increased time to update the complete image. However, it should be noted that the frame time taken is not necessarily increased as an integer multiple of the number of scans. A ZBD device is conventionally addressed using a bi-polar pulse to ensure DC balance on each line and achieve high addressing speeds [3]. Since the row waveform is inverted after successive scans, the overall frame rate for a double scan is unchanged (with DC balancing maintained through an appropriate change to the blanking pulse). The frame rate is only doubled for four scans.

4. Obtaining Full Greyscale

Figure 6 compares two approaches for achieving greyscale from a bistable device with multiple thresholds. In the conventional error-free approach used previously [3], a pixel divided into n areas give a total number of greys $N = n+1$ greys when addressed with $n+1$ appropriate data waveforms. However, far greater numbers of greys are possible if the pixel is divided into areas

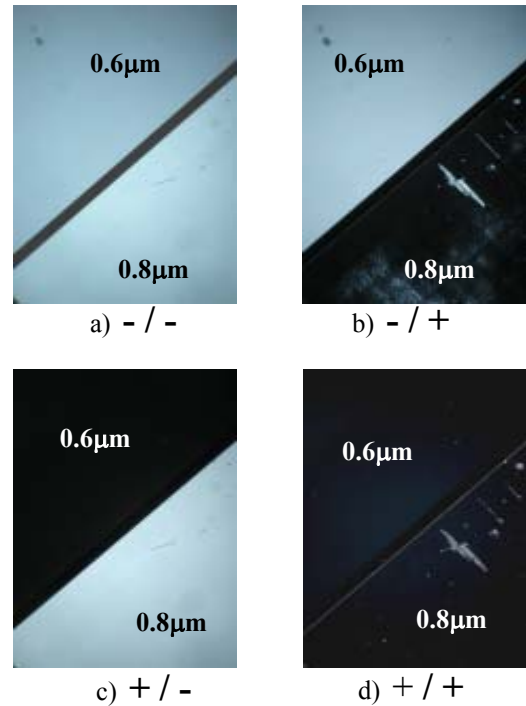


Figure 5 Photomicrographs of the four optical states achieved in the same pixel, addressed using a double scan. The upper area is aligned using $0.6\mu\text{m}$ and the lower a $0.8\mu\text{m}$ grating pitch. In this example, the threshold for the $0.6\mu\text{m}$ pitch sub-pixel area was $4V$ higher than that of the $0.8\mu\text{m}$ pitch.

with digital weighting and addressed using the new Multi-scan technique described here. Using m addressing scans then allows a total of $N = 2^m$ greys to be addressed. This is enabled by multi-scan, since all of the possible combinations of the area states can be addressed. Conventional analogue grey methods only discriminate between increasing (or decreasing) threshold levels. In the example of figure 6, the three areas are weighted in the ratio $1 : 2 : 4$ to yield a total of 8 greys from a pixel from a single row and column. Higher numbers of greys may be produced with more thresholds and correspondingly more scans: for example, 64 greys can be produced using eight thresholds from eight scans.

Alternatively, high numbers of greys are achieved by combining the multi-scan method with analogue greyscale (whether error-free or not). The total number of greys is then $N = (n+1)^m$ levels. If separate thresholds are used to provide the analogue levels, then the total number required for different grating types with separate thresholds is $n + m$. For example, 64 greys result from nine thresholds using three scans ($=4^3$). A selection of routes to achieving 4, 8, 64 and 256 greys is listed in Table 1. It is clear that there is a trade-off between achieving the frame rate and the number of distinct thresholds that is required. The choice made may vary depending on the application requirement.

5. Conclusions

Multi-scan provides a powerful technique for reducing the driver cost of any bistable display technology that has a well-defined latching threshold, and that is readily fabricated with regions of different thresholds. The method is particularly effective when

used with the ZBD device, since several well-separated thresholds are readily fabricated without extra fabrication costs when copied

from the original grating master. In this fashion, high numbers of bistable greys become feasible for the first time.

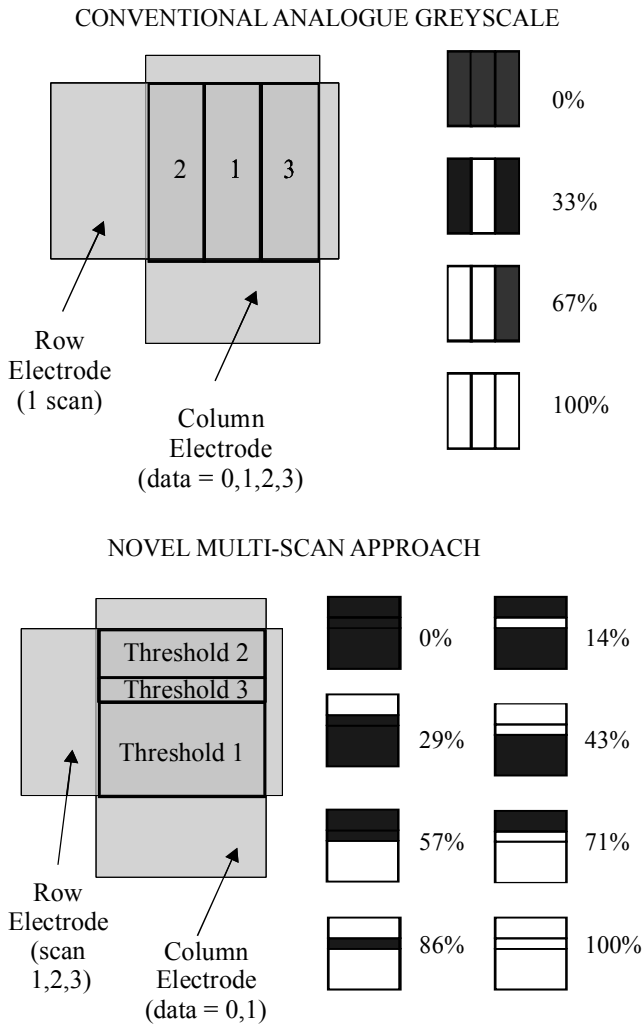


Figure 6 Comparison of the conventional approach to greyscale from multiple thresholds (top) and the Multiscan approach (bottom)

Table 1 Obtaining full greyscale by combining analogue greyscale and multi-scan.

Number of analogue levels, n+1	Number of scans, m	Total number of separate thresholds (n x m)	Relative Frame Rate	Total Greys, N n ^m
4	1	3	1	4
2	3	3	1.5	8
4	2	6	1	16
4	3	9	1.5	64
8	2	14	1	64
2	8	8	4	256
4	4	12	2	256

6. References

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