A New Design of AMOLED Screen with Multi-Frequency-Display and Compensation Methods

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Abstract

In this paper, we designed a new circuit and verified the driving method of MFD (Multi-Frequency-Display), which can support different refresh rates in different parts of the display panel (later described as zonal refreshing). The boundary of different parts can be freely customized, and the refresh rates range from 1 to 120Hz. At the same time, to improve the issues of flicker in the low-refresh-rate area and brightness differences between high and low refresh rate areas after zonal refreshing, we optimized the performance of MFD through voltage compensation. The final compensated effect shows no visible flicker in the low-refresh-rate area, and the boundaries between high-refresh-rate and low-refresh-rate areas are almost invisible to the naked eye. Meanwhile, we also tested the objective values of flicker after compensation and the power consumption benefits under different zoning modes. We believe that in the future, refresh rates could be flexibly adjusted according to the content, enabling longer battery life but also ensuring good display quality.

Author Keywords

Multi-frequency-display; LTPO; Compensation; Flicker; Power Consumption

1. Introduction

In recent years, the demand for low-power-consumption screens has become increasingly urgent. Mobile phone manufacturers aspire to achieve extreme low power consumption while ensuring display quality at the same time. LTPO (low-temperature-polysilicon-oxide) technology emerged in response to this need, utilizing the low leakage current characteristics of IGZO (In-Ga-Zn-Oxide) devices to achieve a wide operation range of 1-120Hz. This allows for effective power savings by reducing the drive frequency when displaying static images, eliminating the need for frequent data refreshes.

However, considering that split-screen display scenarios are quite common, such as two typical situations: 1. Part of the screen displays dynamic videos or games, while other areas show static text or image information; 2. When watching videos or playing games, if the display ratio does not perfectly match with the screen ratio, there will be black stripes on both sides which don't need to be refreshed. Using traditional driving methods, because the dynamic area requires high-frequency refresh, and the entire screen can only be set at one refresh rate at the same time, every frame's refreshing involves not only writing the dynamic area's new data but also repeating the static area's old data. This leads to waste of power, especially in static areas.

If the drive circuit can be redesigned to allow the screen to display at different frequencies in different areas simultaneously, then only the data in the dynamic area would be refreshed, and the data in the static area would no longer be refreshed, so that power consumption can be significantly cut down.

2. Circuit Design and Driving Sequence

As shown in Figure1, in common LTPO pixel circuits, the two oxide TFTs (thin film transistors) are driven by SN (S1N and S2N signals, respectively). The corresponding signals are output by the SN (Scan circuit of N type) VSR (Vertical Shifting Registers). During full-screen low-frequency operation, S1N and S2N no longer refresh (set to low potential), so that two oxide TFTs in Pixel circuit are cut off, preventing new data from being written to the gate of the driver transistor. The gate of the driver transistor maintains its previous voltage, and the light-emitting current of the driver transistor remains the same. This is the principle of traditional low-frequency driving.

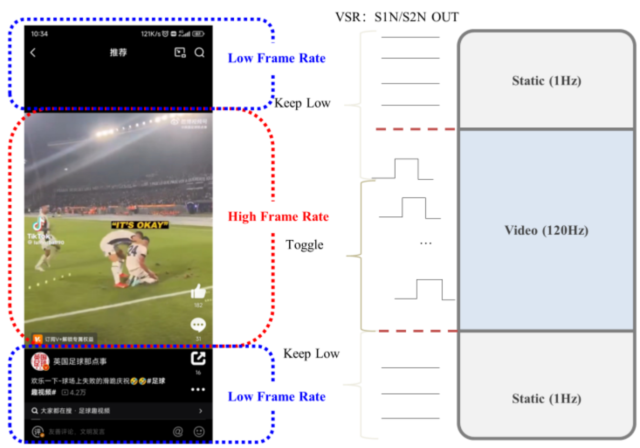

Figure 1. Concept of MFD

To achieve multi-frequency refreshing, the two SN signals should normally scan in the dynamic area but remain as constant low potential in the static area. Considering the current SN circuits, if the SN output of a certain level is set to low, the transmission of subsequent levels (that is, the level shifting) will be interrupted. Therefore, the low-frequency display area cannot be located above the high-frequency display area. To achieve zonal refreshing at any position and any frequency, a new SN circuit must be redesigned to separate its level shifting from the output, enabling different SN outputs at different positions within the panel.

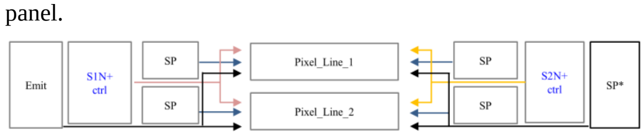

Figure 2. Driving Architecture of MFD

As shown in Figure 2, to implement MFD, changes are required based on the original SN circuit. An additional CTRL signal (control signal) is added to control the output of the SN. The entire SN circuit is divided into two parts: one part performs normal level shifting, while the other part determines whether to output the SN of the current level normally or to directly set it to low potential (that is, off state of oxide TFT) through logical

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operations of the CTRL signal. Figure 3 shows a specific example of the SN circuit, with the left side being the normal level shifting part and the right side containing the CTRL part for MFD control. It should be noted that there can be various designs to achieve this function. This paper only describes and verifies one of them.

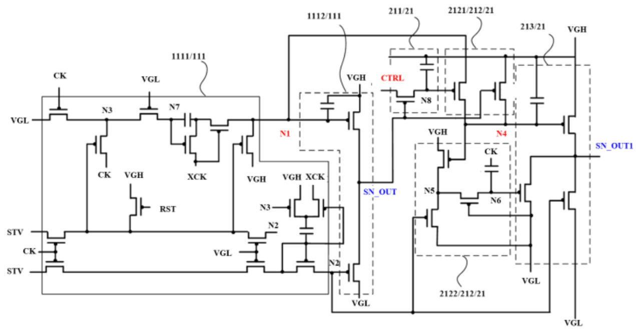


Figure 3. SN Circuit of MFD

Figure 4 illustrates the basic driving logic of the circuit. SN_OUT is the normal level shifting signal. The CTRL signal determines whether nodes N1 and N4 in the circuit of Figure 3 would be connected. When CTRL is at low potential, N4 = N1, so the output of SN_OUT1 is the same as SN_OUT, corresponding to a high refresh rate. When CTRL is at high potential, the voltage of N1 cannot be transmitted to N4, and N4 is kept at its previous high potential, thus keeping SN_OUT1 low, corresponding to a low refresh rate.

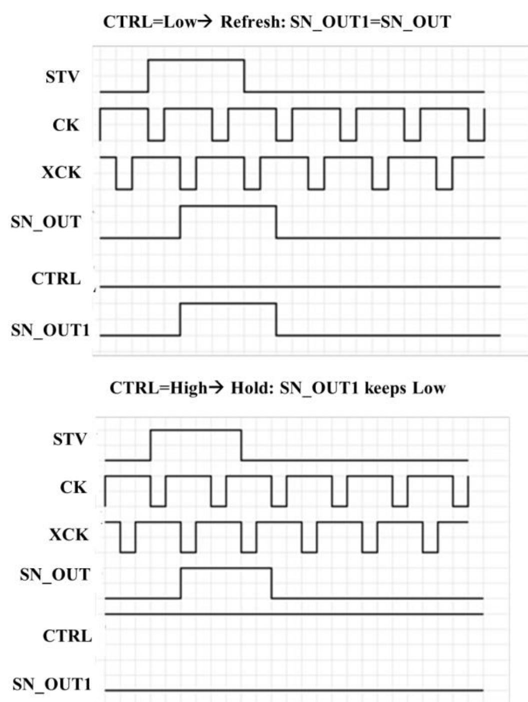
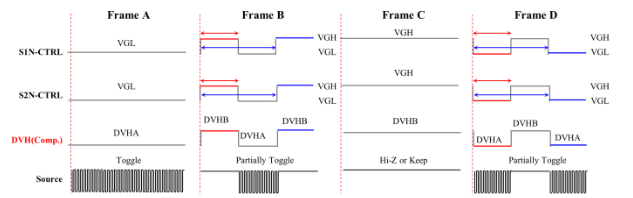


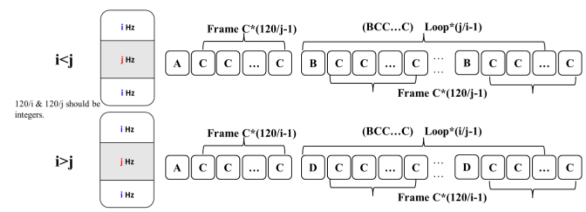
Figure 4. Driving Logic of MFD

Therefore, through the high-low transition of CTRL within a frame, some areas of the panel can have a high refresh rate, while others can have a low refresh rate. In the low-refresh-rate area, signals such as Source do not need to be refreshed, thus effectively saves the power consumption of IC (integrated circuits).

Following similar logic, complex zoning displays can be achieved. As shown in Figure 5(a), the first frame is the refresh frame (Frame A), represented by CTRL being at a low level, with all SNs having output, resulting in a full-screen data refresh once. Subsequent frames are holding frames (Frame B/C/D). By adjusting the timing of CTRL, setting it high or low respectively, and different positions of SN can be refreshed or set to low. That is, the content can refresh or not refresh. Adjusting the order and repetition cycle of holding frames can realize different frequencies (Figure 5(b)).



(a)



(b)

Figure 5. (a) CTRL, Source & Compensation settings in refresh and holding frames, (b) Driving Logic of MFD for Complex Zoning

In actual driving, considering the timing differences of different zones and the changes of characteristics of the driver TFT after long-time operation, there will inevitably be some brightness differences between the low-refresh-rate area and the high-refresh-rate area. Traditional LTPO is either full-screen high refresh rate or full-screen low refresh rate; the brightness difference between the two manifests as flickering during frequency switching, which is relatively less noticeable. However, when displaying in MFD mode, the brightness difference between the two areas will directly cause the screen to appear segmented, with obvious boundaries. Additionally, human eyes are more sensitive to low refresh rates and can more easily perceive flicker caused by brightness changes. Therefore, it is necessary to make compensation through timing or voltage settings in the circuit.

As shown in Figure 5(a), voltages in the circuit, such as DVH or VREF, can be set to different values in the high-refresh-rate area and the low-refresh-rate area to compensate for the brightness differences and improve display quality.

Among them, DVH is the voltage used in the pixel circuit to apply stress to the driver TFT. Typically, DVH voltage is periodically written into the source of the driver TFT. Different DVH voltages result in different stress effects on the driver TFT, leading to variations in the light-emitting current of the driver TFT under the same gate voltage. VREF voltage serves as the initial voltage of the OLED anode, and slight differences in the initial voltage may result in slight variations in brightness even when the driver TFT's current is the same. Adjustments to the brightness at low grayscale levels can be made through changes in VREF. In practice, the IC output signals such as DVH/VREF can be set as AC (alternating current) signals, writing DVHA into the high-refresh-rate zones and DVHB into the low-refresh-rate zones. Thus, the subtle differences in brightness can be compensated for through voltage offsets, thereby improving the display quality of MFD.

3. Performance

3.1 Display Quality

Based on the aforementioned circuit and driving logic, we devised a display screen supporting MFD mode using LTPO backplane technology and verified its optical performance. The final sample can achieve display partitioning into any number of zones—be it two, three, or more—through timing adjustments of CTRL. The boundaries of these partitions can be adjusted arbitrarily, and the frequency of each partition can also be customized, supporting free adjustment from 1-120Hz.

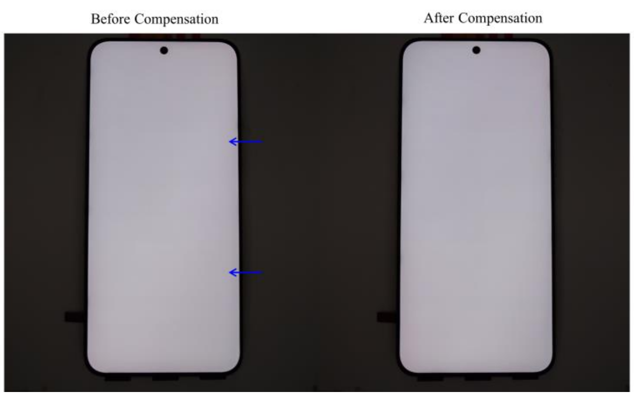


Figure 6. The sample displays in uniform gray level on 1-120-1Hz MFD mode, before and after voltage compensation (the arrows show the boundaries of different zones. The luminance difference of different zones is slightly visible in human eyes, although less noticeable in photos)

We paid particular attention to the boundaries and flicker conditions when displaying locally at low refresh rates and locally at high refresh rates. For example, when the screen is divided into three partitions at 1-120-1Hz, as shown in Figure 6, under uniform low grayscale on the panel, without compensation, there would be a slight brightness difference between the 1Hz and 120Hz regions. However, through timing optimization and the previously mentioned voltage compensation, the boundaries between different partitions are almost invisible, thus achieving imperceptible frequency switching.

In practical application scenarios, the situation is closer to what is shown in Figure 7, where different partitions display different content. In this case, there are inherent brightness differences and natural boundaries between different partitions. Here, the focus is on the flicker condition in the low refresh rate region.

Considering that human eyes are extremely sensitive to brightness changes in low refresh rates, the flicker in low refresh rate area may be still perceivable without compensation, and the situation may get even worse when the low refresh zone is as low as 1Hz. By compensating with DVH & VREF, applying different voltages in refresh and holding zones, the brightness change over time in the low refresh rate region can be effectively reduced, resulting in visually flicker-free performance.

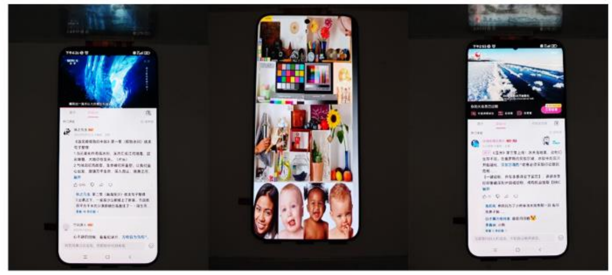
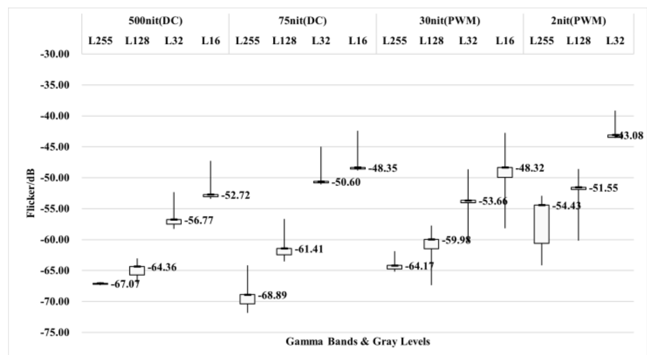


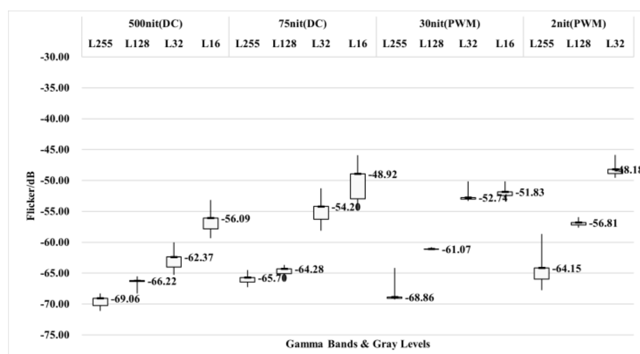
Figure 7. The performance when the sample displays different content in different partitions.

3.2 Flicker

Figure 8A-8B shows the flicker performance of the 1Hz region before and after voltage compensation. It can be seen that the objective flicker in low gray levels such as L32 L16 is improved to some extent.



(a)

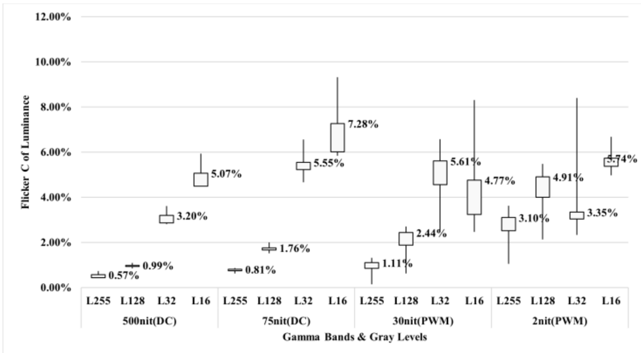


(b)

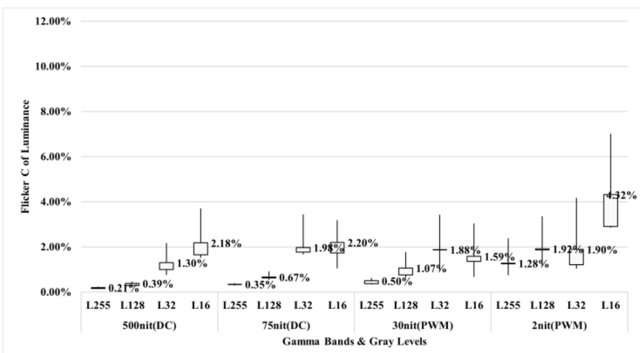
Figure 8. (a) 1Hz flicker before compensation (b) 1Hz flicker after compensation

What is more important, the luminance differences between the 120Hz and 1Hz regions when the screen is displaying at 1-120-1Hz are greatly reduced after our compensation (figure 9A-9B).

It can be concluded that under the MFD operation method, by appropriately selecting timing and voltage compensation, there is significant improvement in both the flicker value of the low refresh rate area and the brightness difference between the high and low refresh rate areas. Ultimately, there is no flicker or noticeable brightness difference between the high and low refresh rate areas, allowing for an imperceptible switch between high and low refresh rates.



(a)



(b)

Figure 9. (a) 120-1Hz flicker C before compensation (b) 120-1Hz flicker C after compensation

3.3 Power Consumption Benefits

We measured the power consumption benefits under different driving modes. When only part of the area requires a high refresh rate (e.g., 120Hz), since the Data (the source signal of the driver IC) in the low-refresh-rate area need not to be refreshed, it effectively saves the power consumption of the IC.

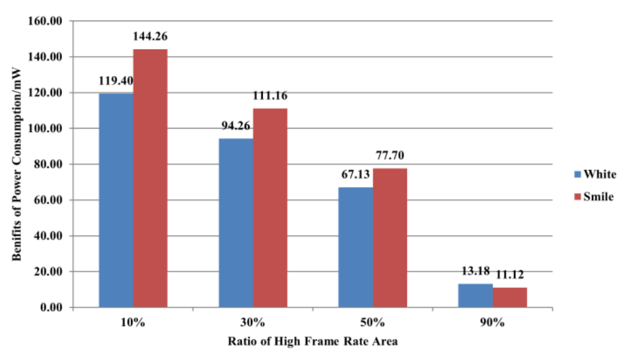


Figure 10. Power Consumption Benefits

Compared to the traditional whole-screen 120Hz high refresh rate, as shown in Figure 10, under the driving mode of 1-120-1Hz MFD, the lower the proportion of the 120Hz area, the greater the power consumption benefits. When the 120Hz area is about 30% of the whole panel, the IC power consumption can be reduced by 100mW in white or smile scenes. The power consumption benefit is related to the specific display scene, the proportion of the zones, and the frequency. When applied to the entire device, considering the low-refresh-rate part, it can also effectively save chip computing power, potentially offering even greater power consumption benefits, thereby achieving longer battery life.

4. Conclusion

In summary, we proposed a new MFD driving mode based on LTPO technology and provided a specific circuit implementation method to achieve flexible zonal and frequency-separated display. Under MFD mode with different proportions of high-refresh-rate areas, the results indicate that the smaller the proportion of the high-refresh-rate area, the higher the power consumption benefits, which benefits from the new circuit. Specifically, under 1-120-1Hz, when the high-refresh-rate area accounts for about 30%, the power consumption benefit is approximately 100mW according to the corresponding sample performances we tested. Additionally, the low-refresh-rate area has no visible flicker, and the boundaries between high and low refresh rate areas are almost invisible, achieving imperceptible zonal and frequency switching. On account of above results, we believe that in the future MFD mode may be widely used in display devices, and the battery life can be revolutionarily improved.

5. References

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