Power-Saving Solution for AMOLED Displays Based on Cathode Segmentation

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Abstract

Currently, AMOLED is mainly manufactured using the FMM process, and the cathode of AMOLED is designed as a single piece limited by factors such as technical and cost. When displaying a frame of an image, the ELVSS driving voltage of the panel is the voltage value corresponding to the high gray level, and there is a waste of power consumption. Recently, a photolithography technology without FMM has begun to develop, which makes cathode partition possible and provides a direction for saving power consumption of AMOLED panel. This paper establishes a power consumption model for the cathode partition and calculates the power consumption of different region using signal statistical methods. The results show that the power consumption of AMOLED decreases as the number of cathode partition increases, and the power consumption can be saved by 8.68% at 64 partition. Meanwhile, the visual effects of different cathode partition schemes are simulated and verified, and the human factors experiment shows that there is no obvious loss in subjective visual effects.

Author Keywords

AMOLED; FMM free; Cathode partition; Power saving;

1. Background

AMOLED has become the standard configuration of terminal products such as high-end mobile phones, watches, laptops and TVs due to its advantages of high contrast, high luminance and high image quality. It has a very good market share in terminal products, and has begun to expand to the field of vehicle display, which has a good market prospect.

At present, multiple sets of Fine Metal Mask (FMM) are used for pixel evaporation in the manufacturing process of AMOLED panels, as shown in Figure 1. FMM needs to be customized according to the product, which has disadvantages such as high cost, long customization cycle, and low utilization rate, which has a negative impact on the product development cycle and production cost. Recently, lithography technology instead of FMM schemes has begun to develop gradually, which can solve the above-mentioned problems of FMM [1-2]. At the same time, the lithography process can pattern the cathode, making it possible to control the AMOLED cathode partition independently, which provides a direction for saving power consumption of AMOLED.

In this paper, the power consumption of R/G/B in different regions is calculated based on the model of partition power consumption and the method of signal statistics. Meanwhile, the subjective image quality effect is simulated and tested, and relatively ideal results are obtained.

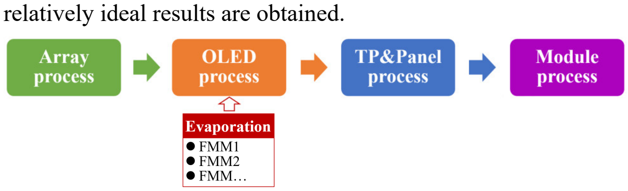

Figure 1. AMOLED production process

2. Power consumption model

2.1 Partition power consumption principle

Due to the limitations of the AMOLED process, the current cathode adopts a one-block design, so that the cathode of all pixels has the same driving voltage. In the design of the drive circuit, the voltage of the cathode is generally set to the voltage required for highlighting, and the low-light area of a frame will also be forced to use the cathode voltage of the high-light area, which is a waste of power consumption, especially for the picture of large-area dark scenes [3-6], as shown in Figure 2(a). If the cathode is designed in partitions, the cathode voltage (*Elvss*) of each partition is independently controllable, and a large cathode voltage is used in region A, while a small cathode voltage is used in region B, as shown in Figure 2(b), which will be very conducive to power consumption saving.

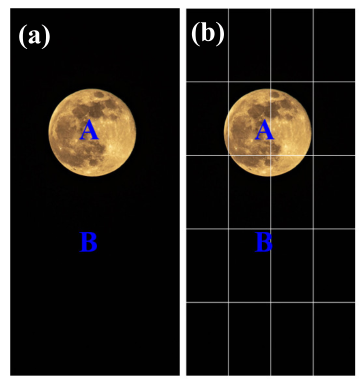

Figure 2. Schematic diagram of AMOLED cathode partition

In order to maintain the stable and controllable luminous state of AMOLED, the Driver TFT (DTFT) in the pixel circuit needs to work in the saturation region. According to the device characteristics of the MOSFET, the voltage difference between the source (S) and the drain (D) is greater than the voltage difference between the gate (G) and the source, i.e., $V_{DS} > |V_{GS}|$. As can be seen from the simplified pixel circuit in Figure 3(a): $V_{DS} = |(Elvss - Elvdd) - V_{oled}| > |V_{GS}|$. It is only necessary to ensure that the *Elvss* voltage of DTFT is in the saturation region. On this basis, the *Elvss* voltage of different partitions can be optimized. Consequently, the purpose of reducing power consumption can be achieved. Figure 3(b) shows the cathode drive voltage setting of the current AMOLED, which sets the cathode voltage *Elvss* at the highest display scenario, and then modify the cathode voltage to *Elvss*' according to the *Elvdd* Drop. Instead of metal masks, lithography can not only save power consumption of region A through cathode partition, but also reduce the voltage drop of *Elvdd* line, thereby saving power consumption of region B. In this paper, only the power consumption saving in region A is studied under different cathode partitions, and the power saving research in region B will be expanded in the future.

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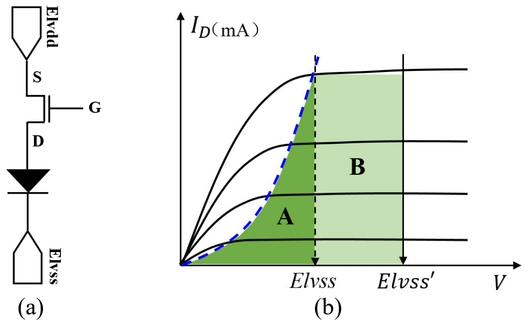


Figure 3. AMOLED pixel driver circuit

2.2 Partition signal statistics

The dynamic adjustment of cathode voltage under different partitions can be realized by the lithography process based on the display content. For a frame, only one cathode voltage can be set for a partition. If the cathode voltage is set based on the highest gray scale in the partition, the display quality will not be affected, but the power consumption savings are not significant enough. If the cathode voltage is set based on a certain gray scale, it will improve the power consumption saving, but it may affect the image quality effect of the AMOLED. Therefore, it is necessary to carry out statistical and mapping analysis of the display content in each partition to find the most suitable cathode voltage, so as to achieve the purpose of reducing power consumption while ensuring that the image quality has no subjective visual loss. There are many ways of signal statistics: maximum statistics, minimum statistics, mean statistics, and weight statistics. In this paper, two kinds of weight statistical methods are used to calculate the statistics and mapping of gray scale signals.

a) Gray scale weight statistics

The gray scale weight statistics will count the gray scale of the current partition and calculate the target gray scale of the partition according to the weight value. Consequently, the cathode voltage corresponding to the current partition can be obtained. Then, we can map all gray scales according to the gray scale mapping curve to save the power consumption of the partition. The weight value statistical method is used to count and calculate the signals of different partitions, which can obtain the target gray scale of the current partition. The target gray scale of each partition is calculated as follows:

$$\begin{aligned} tar_{Rn} &= ratio_{Rn} \times max_{Rn} + (1 - ratio_{Rn}) \times ave_{Rn} \\ tar_{Gn} &= ratio_{Gn} \times max_{Gn} + (1 - ratio_{Gn}) \times ave_{Gn} \\ tar_{Bn} &= ratio_{Bn} \times max_{Bn} + (1 - ratio_{Bn}) \times ave_{Bn} \end{aligned} \quad (1)$$

Where, n is the nth partition of panel. tar_{Rn} , $ratio_{Rn}$, max_{Rn} and ave_{Rn} are the target gray scale, weight value, maximum gray scale, and average gray scale of partition n, respectively.

After obtaining the target gray scale, all gray scales in the current partition need to be mapped to make the gray scale transition smooth, so as to avoid AMOLED working in the linear region and affecting the image quality. Figure 4 shows the gray scale mapping curve, where tar_{gray} is the target gray scale of the current partition and inf_{gray} is the gray scale at the inflection point. It can be seen that the gray scale mapping line is divided into two segments, the first segment is a straight line, the second segment is a curve, and the two have a smooth transition. When the gray scale is greater than gray scale at the inflection point, the gray scale mapping is required, and vice versa. The inflection point of the mapping curve dynamically adjusts with the display content to reduce image quality sacrifice.

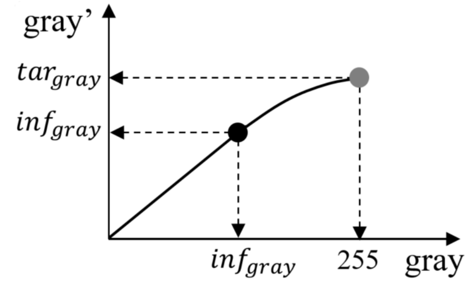


Figure 4. Gray scale mapping curve

b) YUV weight statistics

The YUV weight statistics is to transfer the RGB signal of the source to the YUV space, then map the converted Y curve, after that the YUV weight statistics convert the mapped YUV to the corresponding RGB gray scale, then find the cathode voltage corresponding to the maximum RGB value in the current partition to achieve the purpose of power saving. The conversion formula of RGB to YUV space is as follows:

$$\begin{aligned} Y &= 0.299 \times R + 0.587 \times G + 0.114 \times B \\ U &= -0.1687 \times R - 0.3313 \times G + 0.5 \times B \\ V &= 0.5 \times R - 0.4187 \times G - 0.0813 \times B \end{aligned} \quad (2)$$

The converted Y is mapped and the mapping curve is shown in Figure 5, where tar_{ratio} is the target luminance ratio, inf_Y is the luminance inflection point, and Lv_{255} is the luminance corresponding to the gray scale 255. It can be seen that the mapping curve is also a combination of straight lines and curves, so that the luminance Y of all pixels is mapped smoothly. When the converted luminance Y is greater than inf_Y , the curve mapping of Y is required, and vice versa. The inflection point of the mapping curve is dynamically adjusted with the display content. The target luminance ratio can be set separately or dynamically adjusted with the display content.

The luminance $Y_{1,2,3\dots}$ of all pixels in the current partition is mapped and calculated through the luminance mapping curve to obtain the corresponding mapped luminance $Y'_{1,2,3\dots}$, and the Y'UV values of all pixels are converted into the corresponding R'G'B' values, and then the mapping and calculation of the partition signal are completed. The cathode voltage under the current partition is the voltage corresponding to the maximum gray scale after conversion.

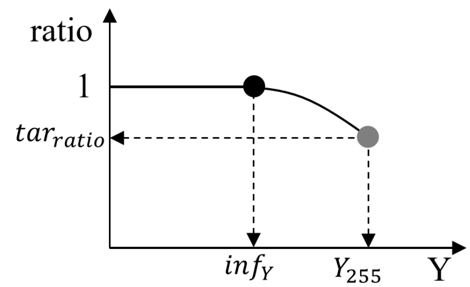


Figure 5. Luminance mapping curve

2.3 Image quality evaluation

Both the gray scale weight statistics and the YUV weight statistics will have a negative impact on the display effect of AMOLED, so it is necessary to evaluate the display effect subjectively and objectively. Some representative images are used for verification, and two signal statistical methods are used for simulation calculation. The loss of image quality by using the two signal statistical methods above was evaluated by subjective visual comparison with the original image. Figure 6 shows a comparison of the two signal statistical methods. It can be seen that there is no obvious visual difference between the images obtained by two signal statistical methods and the original images. Also, there is no obvious visual difference between the two methods. Therefore, it can be shown that no visual loss is found in the images obtained by gray scale weight statistics and YUV weight statistics.

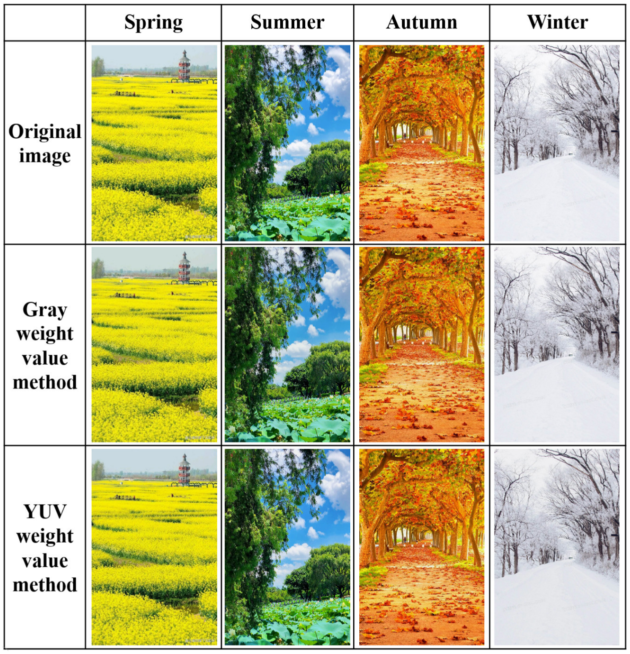


Figure 6. Comparison of two signal statistical methods

In addition, the PSNR of the images obtained by the two methods is calculated, and the image quality of the two methods is further evaluated. The results are shown in Table 1. The PSNR values of gray scale weight statistics and YUV weight statistics are both higher, and the former is slightly better than the latter. The results show that the image loss after processing by the two methods is relatively small. Next, we conduct signal statistics for each partition based on gray scale weight method to obtain the target cathode voltage corresponding to the target gray scale of each partition, and then evaluate the power saving of AMOLED cathode partitions.

Table 1. PSNR processed by the two methods

PSNR	Spring	Summer	Autumn	Winter
Gray weight value method	40.44	39.47	43.01	40.8
YUV weight value method	38.06	43.27	44.13	32.97

3. Power consumption evaluation

As we know that power is related to voltage and current, the calculation formula is as follows:

$$P = U \times I \quad (3)$$

For AMOLED, U in the equation is the voltage difference between Elvdd and *Elvss*, and I is the current passing through the OLED. The power consumption of the DOE module under different cathode partitions is evaluated.

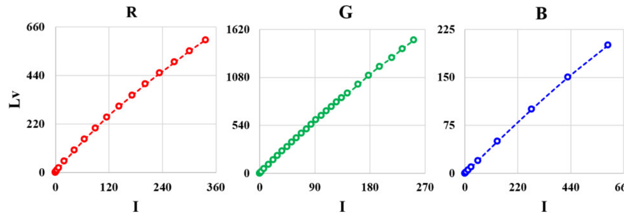


Figure 7. R/G/B Luminance vs. current curve

The variation curve of R/G/B luminance with current is shown in Figure 7. As the current increases, the luminance of the module increases approximately linearly. The luminance of the module is exponentially related to the gray scale change, so the current I corresponding to different gray scales can be obtained through the luminance and current curve. Figure 8 illustrates the relationship between R/G/B cathode voltage *Elvss* and luminance at different gray scales, and identifies the inflection points of saturation region and linear region at each gray scale. The *Elvss* voltage corresponding to different gray scales can be obtained by the relation curve between luminance and *Elvss*. Based on the above analysis, the power consumption of different display states can be calculated through the relation curve between luminance and current and the relation curve between luminance and *Elvss*, and then the power consumption savings of AMOLED by different cathode partitions can be evaluated.

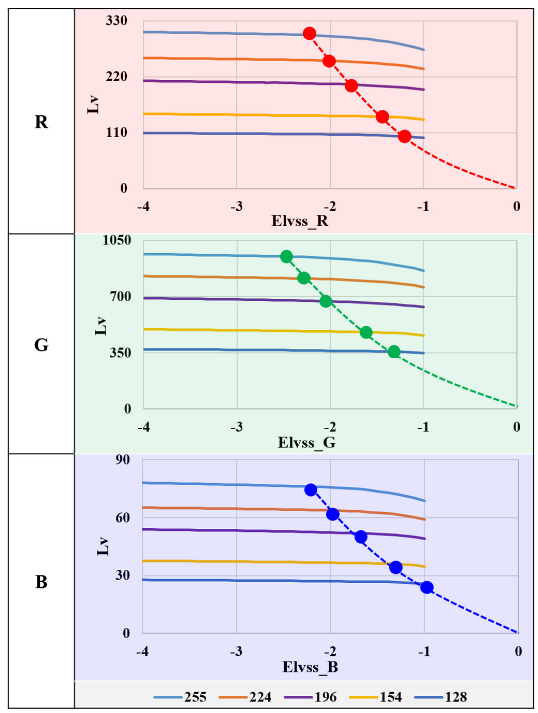


Figure 8. R/G/B Luminance vs. *Elvss* curve at different gray scales

The cathode partition is set to 1/8/16/32/64, and the power consumption is evaluated based on the stellar map, as shown in Figure 9. The gray scale weight statistics method is used to count the gray scale of each partition, and the target gray scale of each partition and the mapping gray scale of all sub-pixels are obtained. The target gray scale is converted to the target luminance according to gamma curve, and then the *Elvss* voltage corresponding to each partition is obtained by the luminance and *Elvss* voltage relationship curve. The mapping gray scale is converted to the mapping luminance according to gamma curve, and the corresponding current of each sub-pixel is obtained through the relationship between luminance and current curve. According to formula (3), the power consumption of each partition can be calculated, and then the power consumption savings of each partition can be evaluated: 4.25% for 1 partition and 8.68% for 64 partitions. The more partitions, the more power savings.

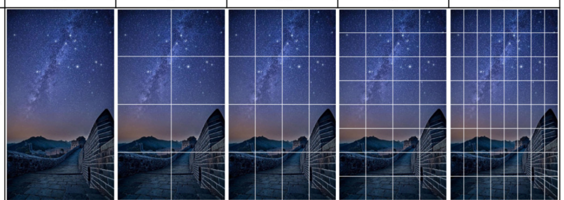
Partition number	1	8	16	32	64
Partition type					
Power saving	4.25%	6.42%	6.76%	7.91%	8.68%

Figure 9. Power savings for different cathode partitions

The power saving under 1-1000 partitions are calculated to further analyze the power saving under different partitions, as shown in Figure 10. With the increase of the number of partitions, the proportion of power saving increases sharply at first and then slows down gradually. Since the number of partitions is positively correlated with cost, the more partitions, the greater the cost. It is necessary to balance the number of partitions with the cost to save power consumption and improve the cost-effectiveness of the module. The point where the curve is tangent to the line with slope 45 is defined as the optimal partition, as shown by the red dashed line in Figure 10. The optimal partition is 100 and the power saving is 9.6%.

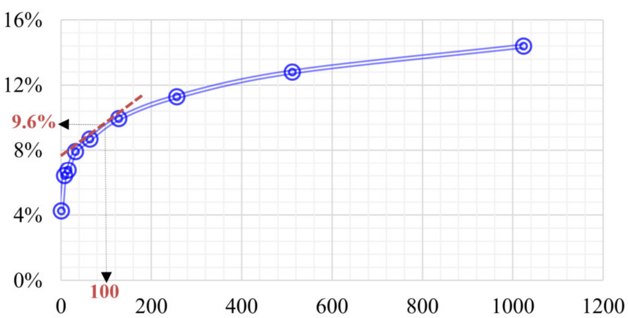


Figure 10. The number of partitions vs. power saving

4. Conclusion

With the development of display technology, the AMOLED production process is gradually becoming mature, and how to reduce power consumption has become a special concern of end customers. The FMM process limits the cathode to a single block design, which increases unnecessary power consumption. The lithography without FMM meets the needs of multi-partition design of the cathode, which provides the conditions for further reducing power consumption. In this paper, the power consumption model is established based on the cathode multi-partition scheme, and the power saving is calculated and analyzed by using DOE module. The results show that the power saving is positively related to the number of partitions, and the power saving is 8.68% for 64 partitions and 9.6% for 100 partitions. In addition, two signal statistical methods are also studied and analyzed to evaluate the impact of cathode multi-partition on the subjective image quality. Subjective experiments show that the signal statistical methods based on gray scale weight and YUV weight can achieve visual lossless effect, and the PSNR of both methods is at a high level. It shows that the risk of cathode multi-partition image quality is low, which proves the feasibility of cathode multi-partition productization. In the following work, we will further study the power consumption and partition image quality of partitions.

5. References

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