

# A Mura Optimization Scheme Based on AMOLED DC Dimming

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## Abstract

The current OLED panel usually adopts hybrid dimming, DC dimming is used in the high-light part to improve human eye comfort and save power consumption, and PWM dimming is used in the low-light part to improve the uniformity of the picture and improve the MURA problem introduced by the poor consistency of the driver TFT. However, for some consumers who are sensitive to flicker, it is still required that OLED panels can also use DC dimming in low-brightness bands to improve eye comfort. The realization of full DC dimming has become the direction that the industry needs to improve. In this paper, MURA optimization of low brightness display under full DC is realized based on VREFN2 (OLED anode reset voltage) and ELVSS (OLED cathode voltage) voltage difference setting optimization and De-MURA scheme optimization. It is proved that the new scheme can improve the gray scale MURA of low brightness Band under full DC condition to be equivalent to PWM dimming.

## Author Keywords

AMOLED; Full DC; VREFN2-ELVSS voltage difference

## 1. DC dimming and PWM dimming comparison, and full DC dimming advantages and disadvantages.

DC dimming is a dimming method that changes the luminous intensity of OLED by adjusting the current varies flowing through the OLED. Specifically, control the current through the OLED by writes different voltages to the gate of the driver TFT in the OLED pixel circuit, so as to achieve light control, so it is also called Gamma dimming, and the voltage written to the gate is called Gamma voltage.

PWM dimming refers to the adjustment of OLED brightness by changing the width of the pulse. Which is, Change the OLED on and off time ratio to achieve the adjustment of OLED brightness. In a certain period of time, if the OLED is turned on for a longer time, the total light emitting time of the OLED will be longer, resulting in higher brightness; On the other hand, if the OLED is turned off for a longer time, the total luminous time of the OLED will be reduced, and the brightness will be lower. When the OLED panel is in low brightness Band and low gray level display, its driving TFT consistency is poor, resulting in poor display effect; In order to avoid this problem, the working characteristic interval of TFT is changed indirectly by EM insertion black, so as to effectively avoid the serious phenomenon of low gray MURA caused by poor consistency of TFT. Earlier, the IC only supported a small number of pulse (2, 4, etc.), due to the concept of "eye protection", the IC slowly upgraded to support 16, 32, 64 and other pulse, that is, the so-called 3840Hz high-frequency PWM dimming (120Hz\*32).

At present, OLED panels usually use hybrid dimming, that is, the two dimming methods are combined; DC dimming is used in the highlighted part to improve human eye comfort while saving power. Low-light parts use PWM dimming to improve picture uniformity

and reduce MURA problems introduced by poor consistency of drive TFT. However, for some consumers who are sensitive to flicker, it is still required that OLED panels can also use DC dimming in low-brightness bands to improve eye comfort.

Advantages of full DC dimming: (a)By changing the dimming mode of the low-light Band from PWM to DC dimming, the power consumption required for the output of high-frequency EM pulse can be saved, and the power consumption of the mobile phone OLED panel can be saved 50~80mW (Table 1). (b)Compared with PWM dimming (by quickly lighting and extinguishing pixels to adjust the brightness), DC dimming can reduce stroboscopic stimulation to the eyes, ensuring greater eye comfort during use. (c) Full DC dimming, because each Band EM Duty is the same, Tuning Band target brightness can be optimized or some bands use linear interpolation copy; As a result, the number of Gamma tuning bands was reduced from the original 10 bands to 7 (Table 2), thus reducing the Gamma tuning time by 30%.

**Table 1.** Logic power consumption comparison of PWM dimming and DC dimming for NOR8 (2nit Band)

Pattern	120Hz (mW)	120Hz_DC (mW)	Power saving (mW)
W255	321.11	262.26	58.85
W0	302.40	225.35	77.05
Red	348.86	273.26	75.61
Green	348.31	291.49	56.82
Blue	347.77	288.99	58.78
Smile	355.84	304.68	51.16

**Table 2.** Dimming scheme comparison

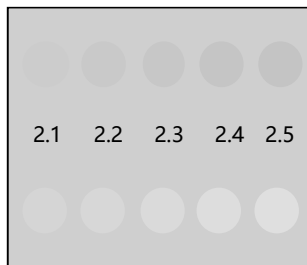
Band	Hybrid dimming			Full DC dimming		
	Lv(nit)	EM Pulse	EM Duty	Lv(nit)	EM Pulse	EM Duty
APL	2500	1	99.06%	2500	1	99.06%
HBM	1200	1	99.06%	/	/	/
Nor1	600	1	99.06%	600	1	99.06%
Nor2	380	1	99.06%	212	1	99.06%
Nor3	150	1	99.06%	/	/	/
Nor4	90	1	99.06%	90	1	99.06%
Nor5	89.8	32	90.47%	/	/	/
Nor6	30	32	32.19%	50	1	99.06%
Nor7	7	32	10.31%	7	1	99.06%
Nor8	2	32	10.31%	2	1	99.06%

Disadvantages of full DC dimming: The existing hybrid dimming scheme, low brightness Band EM Duty ranges from 10% to 90%. The EM Duty of the low-brightness Band with the full DC dimming

scheme uniformly increases to 99%. The EM duty increases, the DTFT leakage current increases, the OLED uniformity deteriorates, and the display uniformity of the low-light Band with low gray level decreases.

## 2. Improvement scheme of low gray level MURA for low brightness Band with full DC dimming

In order to describe the improvement of MURA, two indexes JND and E5 are introduced to evaluate the uniformity of screen display quality. JND, the minimum perceptible difference, is a quantitative unit to measure the degree of psychological difference between two senses. The MURA degree is gradually transformed from the traditional standard (light, medium and heavy) statistical method to the JND degree statistical method. It is easy to distinguish the quality level of each stage of the panel, and is a commonly used tool to determine the quality of the panel. Figure 1 corresponds to standards 2.1 to 2.5 from left to right.



- JND2.1: The defect is not visible when viewed straight on, but it can be seen slightly when viewed at an oblique angle.
- JND2.2: The defect is visible when viewed straight on, but the phenomenon is mild.
- JND2.3: The defect is visible when viewed straight on, but the shape and size of the defect are not very three-dimensional.
- JND2.4: The defect is clearly visible when viewed straight on, and the shape and color difference have formed.
- JND2.5: The defect has a noticeable shape and color difference, and the perspective has a sense of three-dimensionality.

Figure 1. Examples of MURA levels

E5, Feedback 2nit Band 32 gray level picture uniformity, the smaller this data is, the better. The specific test method is to measure the brightness and chrominance of 135 points (Figure 2) uniformly distributed within the visible area of the OLED panel; then the brightness and chrominance of each point are compared with the brightness and chrominance of the center point to calculate the result; the maximum value of the calculation result is taken as the E5 parameter of this sample.

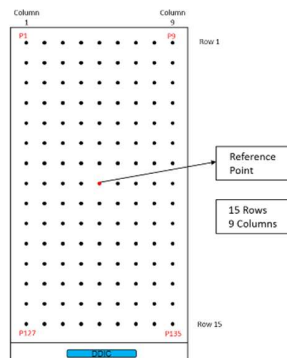


Figure 2. E5 test position

### 1.VREFN2-ELVSS voltage difference increase scheme:

The OLED pixel circuit is shown below. The OLED light-emitting current consists of two parts (Figure 3). The current which pre-charged by OLED anode reset voltage VREFN2 during anode reset and the current flowing through the DTFT. When VREFN2 is negatively adjusted or ELVSS is positively adjusted, the voltage difference between VREFN2 and ELVSS becomes smaller, thus reducing the VREFN2 pre-charge flow and increasing the proportion of current flowing through DTFT. At this time, the impact of DTFT current difference on the display is greater, and the lower the brightness, the more obvious the phenomenon is. When this principle is applied to De-MURA, the lens can recognize the texture state of MURA more clearly and the compensation space is larger. On the other hand, VREFN2 is adjusted positively, and increasing the VREFN2-ELVSS voltage difference can reduce MURA at low brightness. The low-brightness MURA difference is caused by the difference of current flowing through DTFT. Increasing the VREFN2-ELVSS voltage difference to increase the proportion of VREFN2 pre-charge flow can reduce the proportion of current flowing through DTFT, thus reducing the influence of current difference flowing through DTFT in each pixel circuit. The specific effect of MURA reduction scheme with increased VREFN2-ELVSS Voltage difference is shown in Figure 4.

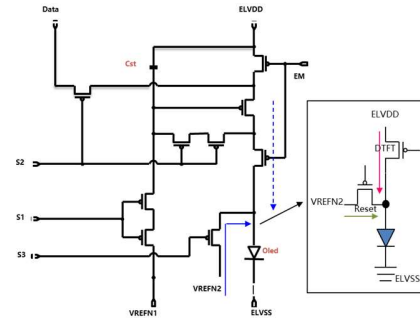


Figure 3. Pixel circuit & OLED light-emitting current



Figure 4. MURA compare between VREFN2-ELVSS 0.7V and VREFN2-ELVSS 1.2V

As shown in Table 3: Compared with the visual effect of full DC and EM dimming 2nit L32, the MURA of the full DC scheme deteriorates by 0.15-0.2JND. When the voltage difference of VREFN2-ELVSS is increased from 0.7V to 1.2V, the visual effect of 2nit 32 gray level is significantly improved by 0.05~ 0.1JND. Therefore, for low brightness Band, we can reduce MURA in low brightness display of full DC scheme by setting VREFN2 to dynamically change with ELVSS and maintaining the VREFN2-ELVSS Voltage difference to 1.2V.

**Table 3. Dimming scheme comparison**

NO.	Snowflake MURA			Source MURA			Color Uneven		
	2nit	EM	DC-0.7V DC-1.2V	EM	DC-0.7V DC-1.2V	EM	DC-0.7V DC-1.2V	EM	DC-0.7V DC-1.2V
1#	2.4	2.55	2.45	2.3	2.5	2.4	2.3	2.5	2.4
2#	2.3	2.5	2.4	2.3	2.45	2.4	2.2	2.4	2.35

**II. De-MURA scheme optimization:**

De-MURA compensation algorithm principle: The sampled gray scale data representing MURA status of the module is obtained by optical equipment, and MURA compensation data of different regions of the benchmark gray scale is obtained by De-MURA algorithm. Then, different brightness and gray level compensation data are mapped by the preset node gain under different DBV and gray level, so as to enhance or weaken the compensation effect. Based on this, the closer the MURA characteristics of the sampled gray scale data are to the MURA state under different brightness and gray level, the better the compensation effect will be.

The existing conventional solution is to take photos at 16/32/64/128/192/224 gray level under Nor1 (such as 800nit) or other high DBV Band brightness (such as 600nit) to obtain the brightness data of the OLED panel under each screen; The brightness data obtained by the 16/64/192 gray level photography is used as the compensation data base for gray scale compensation data mapping in other bands. This can take into account the photographing time, and at the same time make appropriate compensation for MURA under other bands; However, MURA cannot be effectively eliminated in the case of low brightness and low gray level, especially the low brightness and low gray level MURA of the full DC scheme is heavier than that of the PWM scheme. The usual practice is to add the photography of low brightness and low gray level images, so that the MURA characteristics of the collected gray scale data are close to the MURA state under the low gray level of the low brightness Band. For example, adding 32/64 gray level photography under 5nit, the collected data is used as the compensation basis of 16 or 64 gray level, which can improve the compensation effect of low-light Band low gray level MURA, but the low-brightness photo time will increase by 30 to 60%.

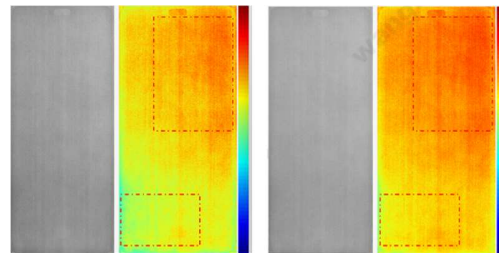
Compared with the conventional scheme, the additional shooting part of the optimization scheme adopts the additional shooting of the 16/32/64 gray level under the NOR1 when voltage deviation. The voltage deviation refers to the negative adjustment of VREFN2 or the positive adjustment of ELVSS, so that the VREFN2-ELVSS voltage difference becomes smaller, so that the current flowing through the DTFT increases, and the influence of the DTFT difference becomes prominent. The additional shooting part is completed in NOR1, because the NOR1's brightness is higher than 5nit, so the shooting time is shorter. At the same time, because of the voltage deviation, the MURA shape of 16/32/64 gray level is consistent with the MURA shape of low brightness Band, thus improving the MURA of low brightness Band and low gray level. The specific photo scheme is shown in Table 4. By setting the algorithm, the additional shooting data of the voltage deviation is used as the benchmark for low-brightness Band MURA compensation, and the data of the conventional NOR1 photo is used as the benchmark for high-light Band MURA compensation, which

can avoid the overcompensating problem that may be caused by the additional shooting data in the high-light Band.

**Table 4. Photo scheme**

Scheme	Voltage setting	VREFN2_-1.9V						VREFN2_-2.6V			
	Brightness & Gray level	16	32	64	128	192	224	16	32	64	128
Conventional scheme	5nit	/	/	/	/	/	/	/	/	/	/
	Nor1(800nit)	√	√	√	√	√	√	/	/	/	/
Overshot the low-light band	5nit	/	√	√	/	/	/	/	/	/	/
	Nor1(800nit)	√	√	√	√	√	√	/	/	/	/
Optimization scheme	5nit	/	/	/	/	/	/	/	/	/	/
	Nor1(800nit)	√	√	√	√	√	√	√	√	√	/

Compared with the simulation image generated by taking photos with 16 gray level images under NOR1 Band in the conventional scheme, the texture degree of Source Mura and the bright/dark Mura in the upper right and lower left regions of the optimized scheme is clearer, which is actually closer to the characteristics of full DC dimming display under low brightness and low gray level (Figure 5).



**Figure 5. Conventional scheme (left), Optimization scheme (right)**

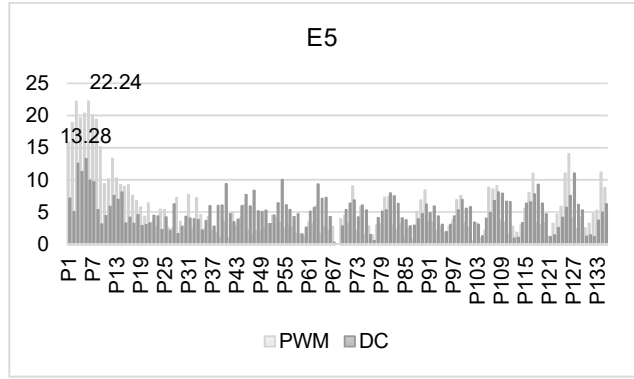
**III. Scheme verification:**

Based on the additional shooting De-mura optimization scheme, combined with the VREFN2 and ELVSS voltage difference schemes of 1.2V, the JND results before and after the improvement of low brightness and low gray level in full DC mode are shown in Table 5. The initial state in the table refers to the initial MURA state of the front panel of De-MRUA. The conventional scheme is the existing scheme of high-light BAND DC dimming and low-light BAND PWM dimming. The optimized scheme refers to the use of DC dimming for both high and low brightness bands, but the addition of NOR1 low gray level additional shooting scheme in the case of negative VREFN2 distortion in De-MURA and VREFN2-ELVSS voltage differential is set to 1.2V. The data pairs of E5 are shown in Figure6. From the E5 data of 32 gray level under 2nit band, the E5 data distribution is consistent with the overall trend of adopting low-brightness band PWM dimming scheme by using the optimized scheme, and the maximum E5 value is 13.28, the result is better.

According to the data, the JND and E5 data of full DC dimming using VREFN2 and ELVSS voltage differential increase combined with optimized shooting strategy are equivalent to the De-MURA scheme of conventional low-brightness PWM dimming. The optimization scheme can be used to optimize the full DC low brightness Band low gray level MURA to the level of the existing low brightness Band PWM dimming scheme.

**Table 5.** Comparison between conventional scheme and optimized scheme (JND)

JND	L32@2nit			L64@2nit		
	initial status	Conventional scheme	Optimization scheme	initial status	Conventional scheme	Optimization scheme
Snowflake MURA	2.45	2.35	2.35	2.3	2.2	2.2
Source MURA	2.4	2.2	2.1	2.3	2.1	2
Color Uneven	2.4	2.35	2.25	2.3	2.2	2.15
JND	L32@800nit			L128@800nit		
	initial status	Conventional scheme	Optimization scheme	initial status	Conventional scheme	Optimization scheme
Snowflake MURA	2.3	2.2	2.1	2.1	2	2
Source MURA	2.3	2.1	2.1	2.1	2	2
Color Uneven	2.2	2.1	2.1	2.1	2	2



**Figure 6.** Comparison between conventional scheme and optimized scheme (E5)

### 3. Conclusion

By setting the voltage difference between VREFN2 and ELVSS to a larger value (1.2V in this paper), the proportion of the current flowing through DTFT in the OLED luminescence current can be reduced, and the MURA JND level can be increased by 0.1-0.15. By adjusting the VREFN2 or ELVSS voltage, the voltage difference between VREFN2 and ELVSS is reduced, and the MURA form of NOR1 16/32/64 gray level Photo data is close to the MURA form of low brightness Band under full DC dimming. The effect of De-MURA is better by using the additional shot data as the benchmark for compensation. The optimization scheme combines the above two schemes. After the implementation of the optimization scheme, the MURA compensation effect of the low brightness band low gray level display with full DC dimming is comparable to that of the PWM scheme.

### 4. Acknowledgements

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