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Analysis of luminance variation with display load and display pattern in AC-plasma display panels

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ABSTRACT

The luminance variance according to the display load was found to be mainly due to a distortion of the sustain waveform. In particular, the distortion of the rising slope of the sustain waveform according to the display load was shown to affect the sustain discharge characteristics, thereby varying the luminance of the ac-PDP. Therefore, the luminance variation relative to the display load was significantly compensated by proper control of the rising slope of the sustain waveform according to the display load.

1. Introduction

The luminance of current plasma display panels (PDPs) is controlled by the number of applied sustain pulses. Theoretically, if the number of applied sustain pulses is constant, the luminance should also remain constant, regardless of the display load determined by the ratio of the displayed area to the entire panel area. However, in the case of current ac-PDPs, the luminance varies according to the display load, even when applying the same number of sustain pulses [1,2]. Furthermore, the luminance also varies according to the display pattern, even under the same display load. As a result, the gray level expression of ac-PDPs is degraded, along with the quality of dynamic and static images. Therefore, this problem needs to be solved urgently to improve the image quality of ac-PDPs. In previous experimental results, the current authors found that the luminance variation according to the display load or display pattern was strongly related to the distortion of the sustain waveform, especially the distortion of the rising slope of the sustain waveform [3], meaning that a change in the display load or display pattern causes a variation in the sustain discharge characteristics, thereby inducing different luminance levels.

Accordingly, this paper investigates the luminance variation relative to the display load and relative to the display pattern under a consistent display load (8%) in a 50-in. full-HD PDP. To identify the cause for the luminance variation with the display load or display pattern, the distortions of the sustain waveforms and related IR emission characteristics are measured relative to the display load or display pattern. In particular, the changes in the resistance and capacitance relative to the display pattern are measured and calculated to identify the cause for the distortion of the sustain waveform. Finally, the rising slopes of the sustain waveforms are properly controlled using an energy recovery circuit to compensate for the luminance variation resulting from the display load or display pattern.

2. Experiments

The pixel pitch of the 50-in. full-high definition (full-HD) ac-PDP used in this study was 576×192 µm. The discharge gas composition was a Ne + He (35%) + Xe (15%) gas mixture, and the gas pressure was 420 Torr. The 50-in. test panel included box-type barrier ribs and three electrodes: two sustain (X, Y) and one address (A). The sustain frequency was 200 kHz.

Fig. 1 shows the test patterns relative to the display load, ranging from 10% to 100%. Here, the display load means the ratio of the displayed area to the entire area of the 50-in. full-HD PDP. The number of applied sustain pulses was fixed at 100, irrespective of the display load variation. The luminance was measured using a color analyzer (CA-100 plus), and the IR emission measured using an IR detector (Photosensor Amplifier, c6386).

To analyze the sustain waveform distortion phenomenon according to the display pattern under the same display load, three types of display pattern were employed, as shown in Fig. 2. While

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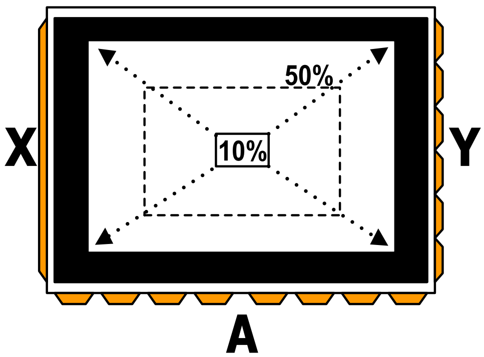
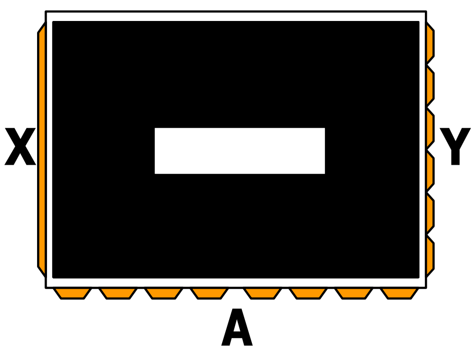
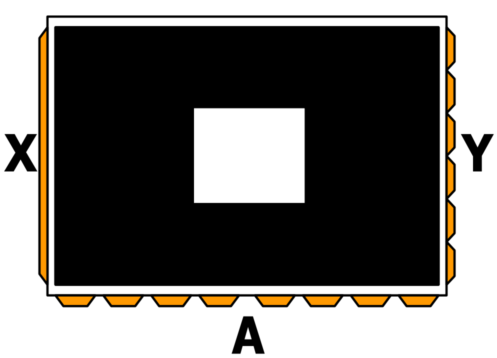


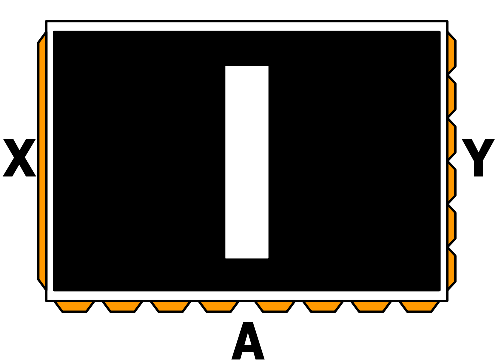
Fig. 1. Test patterns according to different display loads of 10%, 50%, and 100%, where display load means ratio of displayed area to entire area of 50-in. full-HD PDP.



(a) Horizontal bar pattern (Type 1)



(b) Box pattern (Type 2)



(c) Vertical bar pattern (Type 3)

Fig. 2. Three types of display pattern with identical display load (8%): (a) horizontal bar pattern with horizontally aligned cells (type 1), (b) box pattern with mixture of horizontally and vertically aligned cells (type 2), and (c) vertical bar pattern with vertically aligned cells (type 3).

the display load was exactly the same for all three display patterns, i.e., 8%, meaning that the total number of turned-on pixels was exactly the same for the three display patterns, the pattern shapes, i.e., the configurations of the turned-on cells, were different, where type 1 was a horizontal bar pattern, type 2 was a box pattern, and type 3 was a vertical bar pattern. A total of 256 sustain pulses was applied to display each display pattern in Fig. 2.

3. Results and discussion

3.1. Luminance variation according to display load

Fig. 3 shows the changes in the luminance relative to the display load. In this study, the number of applied sustain pulses was fixed at 256, regardless of the variations in the display load. As shown in Fig. 3, the luminance decreased with an increase in the display load. In particular, when the display load was increased from 30% to 70%, which is typical when displaying a dynamic image, the corresponding luminance was decreased by about 43%, representing a severe degradation of the gray level expression.

Meanwhile, Fig. 4 shows the distortion of the sustain waveforms and corresponding IR emission waveforms measured under various display loads of 10%, 50%, and 100%. As shown, when the display load was increased, the sustain waveform was severely distorted and the resultant IR emission intensities reduced, resulting in a luminance variation according to the display load. In particular, the distortion to the rising slope of the sustain waveform according to the display load affected the sustain discharge characteristics. Consequently, to minimize the luminance variation with a change in the display load, the rising slope of the sustain waveform needs to be properly controlled according to the display load. In a conventional PDP, the rising slope of the sustain waveform can be adjusted by controlling the timing sequence of the energy recovery circuit (ERC) [3,4].

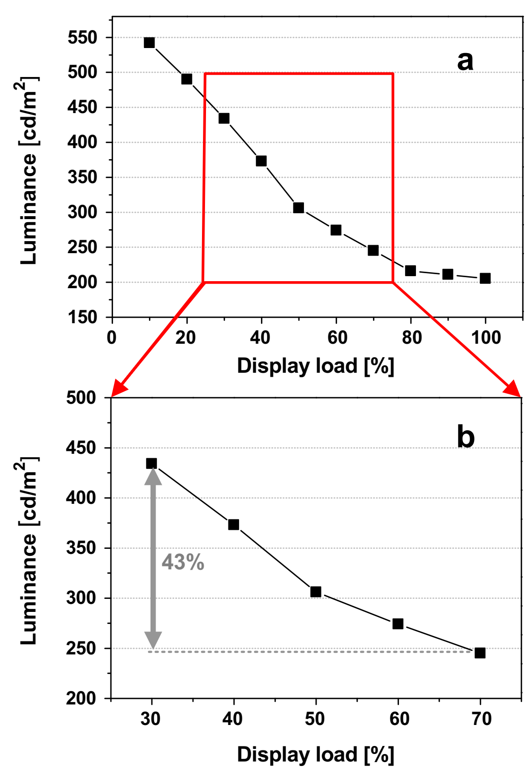


Fig. 3. Luminance variation according to changes in display load: (a) from 10% to 100% and (b) from 30% to 70%.

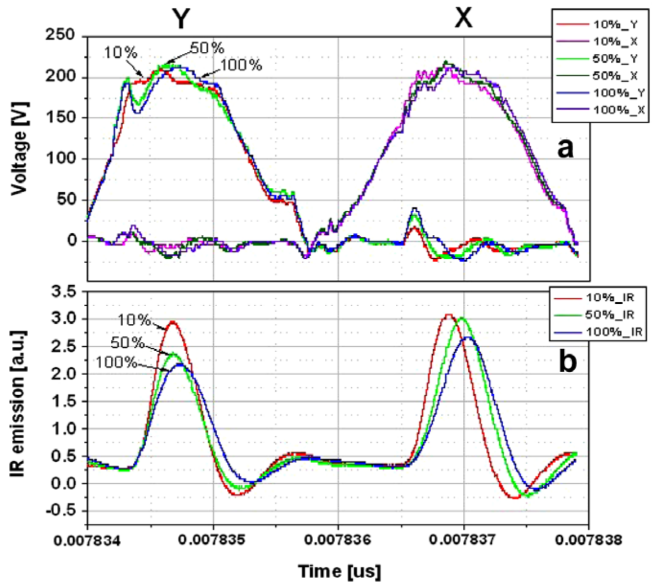


Fig. 4. (a) Sustain waveforms and (b) related IR emission waveforms with different display loads of 10%, 50%, and 100%.

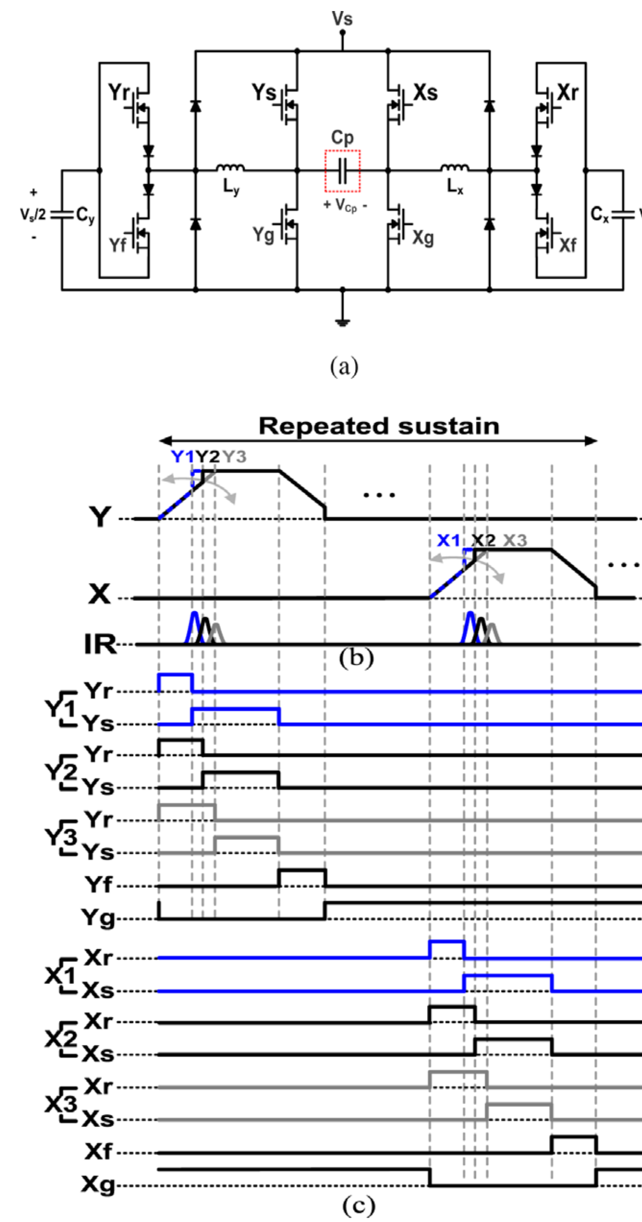


Fig. 5. (a) Conventional sustain driving circuit with energy recovery circuits, (b) variations in rising slopes of Y and X sustain waveforms, and (c) switch timing table for varying rising slopes (Y1, Y2, and Y3) of Y sustain waveform and rising slopes (X1, X2, and X3) of X sustain waveform.

In the case of Weber's ERC shown in Fig. 5a, the panel capacitor and resonant inductor form a series resonant network with a voltage source that is charged to 1/2 Vs. With 1/2 Vs of resonant energy, the panel voltage then changes to Vs from its initial level, thereby explaining the description of Weber's ERC as a 3-level-type ERC (−Vs to zero to +Vs). Weber's ERC also facilitates many topology variations, plus the driving sequence can be easily and independently changed for each driving board (X and Y) [4]. Fig. 5b shows the various rising slopes (Y1, Y2, and Y3/X1, X2, and X3) for the Y and X sustain waveforms when adopting Y2 and X2 as the reference rising slopes for the sustain waveforms, irrespective of variations in the display load. Meanwhile, Fig. 5c shows the switch timing table for varying the rising slopes of the conventional (Y2 and X2) and compensated (Y1 or Y3/X1 or X3) sustains waveforms. The circuit response in the sustain circuit, including the ERC, is entirely determined by the initial energy stored in the capacitor [5]. The rising slopes of the applied Y and X sustain pulses are determined by combining the time intervals between the rising and sustaining switches (Yr and Ys for a Y sustain pulse, and Xr and Xs for an X sustain pulse), as shown in Fig. 5c. In Fig. 5b, the Y1 and X1 rising slopes of the sustain waveforms are faster than the reference rising slopes (Y2 and X2) of the conventional sustain waveform, whereas the Y3 and X3 rising slopes of the sustain waveforms are slower than the reference rising slopes (Y2 and X2) of the conventional sustain waveform. Thus, since the sustain discharge depends strongly on the rising slope of the sustain waveform, the resultant luminance levels are also inevitably affected by changes in the rising slopes of the sustain waveforms according to the display load. For a display load of less than 50%, three different types of rising slope were adopted: Y2 and X2 for the reference, Y2 and X3 for case 1, and Y3 and X3 for case 2, as shown in Table 1. Meanwhile, for a display load over 50%, Y2 and X2 were adopted as the rising slopes of the sustain waveforms for all three cases.

Fig. 6 shows the variations in the luminance when varying the display load from 30% to 70%. As shown, there was no compensation for the luminance variation with a display load over 50%, as the rising slopes of the sustain waveforms were all the same. However, when the display load was below 50%, the luminance variation was compensated by controlling the rising slopes of the sustain waveforms, meaning that the luminance variation with a display load below 50% could be compensated by adopting slower rising slopes for the sustain waveforms.

Table 1
Various rising slopes for X and Y sustain waveforms under display load ranging from 1% to 50%.

	Rising slope of sustain waveform	
	Display load [1–50%]	Display load [50–100%]
Reference	Y2, X2	Y2, X2
Case1	Y2, X3	Y2, X2
Case2	Y3, X3	Y2, X2

As shown in Table 2, for a display load over 50%, three different types of rising slope were adopted: Y2 and X2 for the reference, Y2 and X1 for case 3, and Y1 and X1 for case 4. Meanwhile, for a

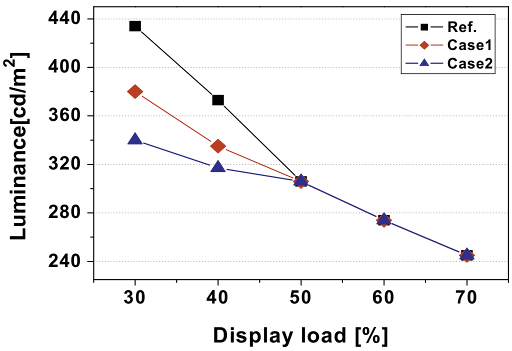


Fig. 6. Variations in luminance according to changes in rising slopes of sustain waveforms when varying display load from 30% to 50%.

Table 2
Various rising slopes for X and Y sustain waveforms under display load ranging from 50% to 100%.

	Rising slope of sustain waveform	
	Display load [1–50%]	Display load [50–100%]
Reference	Y2, X2	Y2, X2
Case 3	Y2, X2	Y2, X1
Case 4	Y2, X2	Y1, X1

display load of less than 50%, Y2 and X2 were adopted as the rising slopes of the sustain waveforms for all three cases.

Fig. 7 shows the variations in the luminance when varying the display load from 30% to 70%. As shown, there was no compensation for the luminance variation when the display load was below 50%, as the rising slopes of the sustain waveforms were all the same. However, when the display load was over 50%, the luminance variation was compensated by controlling the rising slopes of the sustain waveforms, meaning that the luminance variation with a display load of over 50% could be compensated by adopting faster rising slopes for the sustain waveforms.

Fig. 8 shows the luminance variations relative to the display load when applying sustain waveforms with the reference and compensated rising slopes. To lower the high luminance with a display load below 50%, the rising slope of the sustain waveform should be slower, as shown by case 2 in Fig. 6. Conversely, to increase the low luminance with a display load over 50%, the rising slope of the sustain waveform should be faster, as shown by case 4 in Fig. 7. Thus, when adopting slower or faster rising slopes for the sustain waveforms according to the display load, the luminance variation relative to the display load was reduced from 43% to 20%, as shown in Fig. 8.

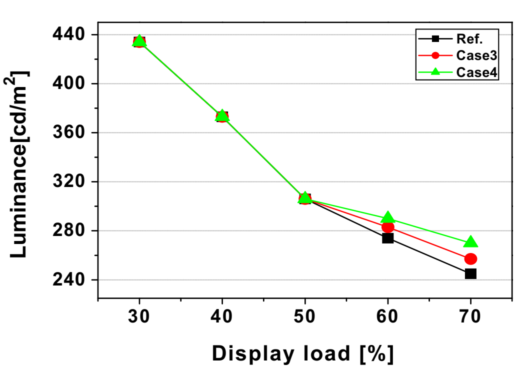


Fig. 7. Variations in luminance according to changes in rising slopes of sustain waveforms when varying display load from 50% to 70%.

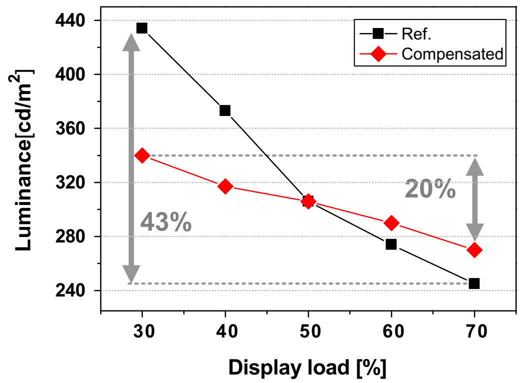


Fig. 8. Variations in luminance according to changes in rising slopes of sustain waveforms when varying display load from 30% to 70%.

3.2. Luminance variation relative to various display patterns under identical display load

3.2.1. Luminance variation due to distortion of sustain waveform

Fig. 9a shows the variations in the luminance and power consumption relative to the various display patterns (types 1–3 in Fig. 2) under the same display load (8%), while Fig. 9b shows the changes in the corresponding luminous efficiencies. Under the same display load (8%), the power consumption remained constant, regardless of the display pattern, whereas the luminance varied depending on the display pattern, as shown in Fig. 9a. Consequently, the luminous efficiency changed according to the display pattern, even with the same display load, as shown in Fig. 9b. As with the display load variation, this phenomenon was also found to be essentially linked to the distortion of the sustain waveform according to the display pattern, as shown in Fig. 10.

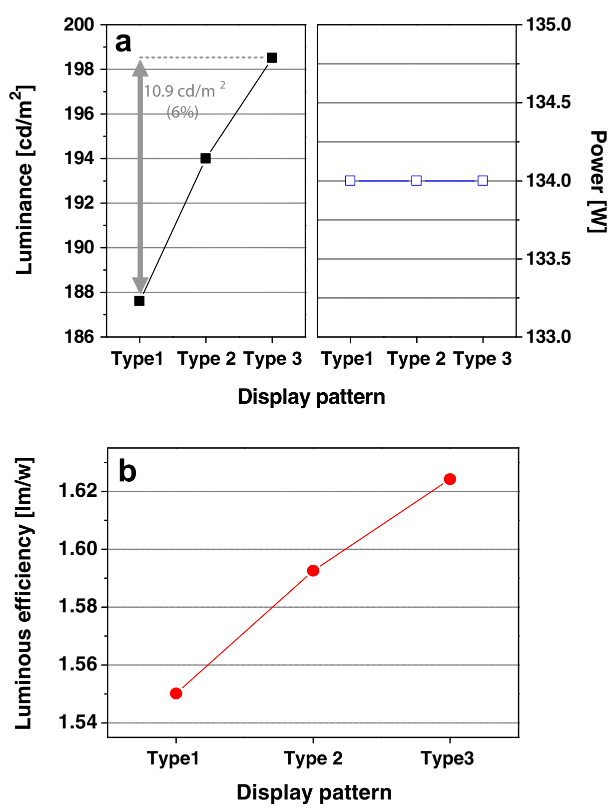


Fig. 9. (a) Luminance and power consumption according to display pattern types 1–3 under identical display load (8%) and (b) corresponding luminous efficiencies.

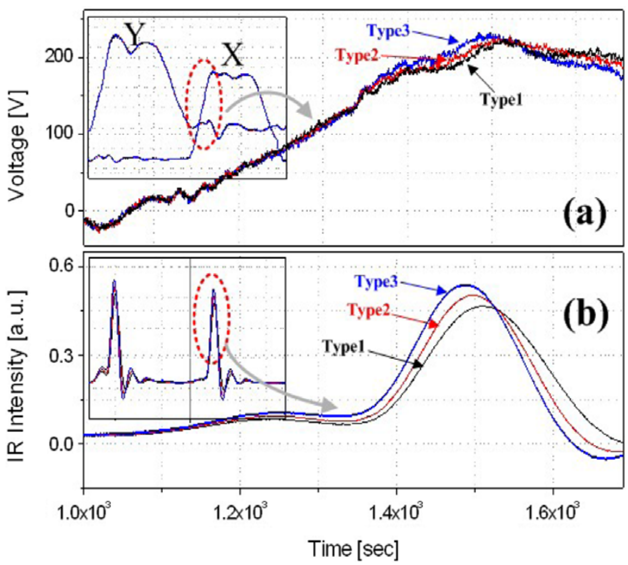


Fig. 10. (a) Distortion of sustain waveforms and (b) changes in IR emission waveforms when different display patterns (types 1–3) are displayed under display load of 8%.

Fig. 10a and b shows the distortion of the sustain waveforms and changes in the corresponding IR emission waveforms when displaying the three types of display pattern under the same display load of 8%, respectively. Even under the same display load conditions, the sustain waveforms were distorted when the displayed pattern was changed, as shown in Fig. 10a. This distortion of the sustain waveform then caused different sustain discharge characteristics, as shown by the IR emission waveforms in Fig. 10b, resulting in a luminance variation according to the display pattern even under the same display load.

3.2.2. Analysis of sustain waveform distortion

Table 3 shows the horizontal and vertical electrode lines and the total pixel number for the three types of display pattern shown in Fig. 2. For the three display patterns, the displayed area was exactly the same, meaning that the total number of pixels was exactly the same each of the three display patterns. However, the current paths during the sustain discharge differed for the three display patterns, as they each had a different cell configuration. Thus, for the on-cells in the three display patterns, the capacitance and Indium–Tin–Oxide (ITO) resistance were measured to examine their electrical properties, and the results are given in Table 4. As shown, while the capacitances were exactly the same for the three display patterns, the ITO resistances were different.

Fig. 11 shows the equivalent circuit model for the three types of display pattern, where (a) is the circuital configuration of the three display patterns in the 50-in. PDP cells, (b) is the horizontal bar pattern (type 1), (c) is the box pattern (type 2), and (d) is the vertical bar pattern (type 3). Each on-cell in the three display patterns can be represented by an electrical equivalent model using a combination of the capacitance C and resistance R. In Fig. 11, the values for R and C were assumed as follows: $R_1 = R_2 = R_3 = R_4 = \cdots = R_8 = 4\ \Omega$, $C_1 = C_2 = C_3 = C_4 = 0.2$ nF. Thus, for type 1, the total resistance, R_{Total} (=R_{Y1}) was 8 Ω, where R_1 and R_2 were series connected. For type 2, the total resistance, R_{Total}, determined by the parallel connection of R_{Y1} and R_{Y2}, was 4 Ω, where R_1 and R_2 were series connected by R_{Y1}, and R_3 and R_4 were series connected by R_{Y2}. Similar to type 2, the total resistance of type 3, determined by the parallel connection

Table 3
Electrode line number and total number of pixels for three display patterns in Fig. 2.

Display pattern	Type 1	Type 2	Type 3
Horizontal line	1408	704	352
Vertical line	352	704	1408
Total pixel number	495,616	495,616	495,616

Table 4
Electrical properties of three display patterns displayed on 50-in. test panel.

Display pattern	Full-white (box 100%)		
Panel capacitance	700 nF		
ERC inductance	0.1 μH		
ITO resistance	100 Ω		
	Type 1	Type 2	Type 3
ITO resistance (Ω)	8	4	2
Panel capacitance (nF)	0.8	0.8	0.8

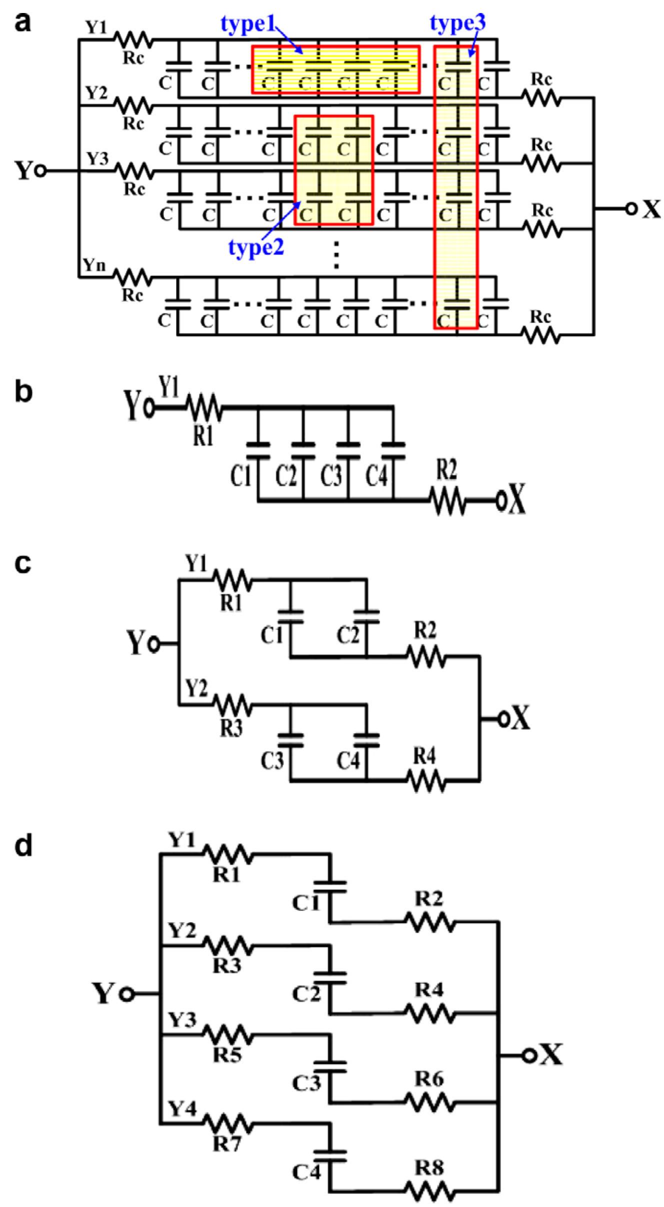


Fig. 11. Equivalent circuit models for three display patterns: (a) circuital configuration for three types of display pattern in 50-in. PDP cells, (b) horizontal bar pattern (type 1), (c) box pattern (type 2), and (d) vertical bar pattern (type 3).

Table 5
Total resistance, capacitance, and impedance (Z) calculated for three types of display pattern.

Display pattern	Electrical property
Type 1	$R_{Total} = R_1 + R_2 = 8\ \Omega$ $C_{Total} = C_1 + C_2 + C_3 + C_4 = 0.8$ nF $Z = R_{Total} + 1/j\omega\ C_{Total} = 8 + 1.25/j\omega$
Type 2	$R_{Total} = R_{Y1}//R_{Y2} = 4\ \Omega$ $R_{Y1} = R_1 + R_2 = 8\ \Omega$, $R_{Y2} = R_3 + R_4 = 8\ \Omega$ $Z = R_{Total} + 1/j\omega\ C_{Total} = 4 + 1.25/j\omega$
Type 3	$R_{Total} = R_{Y1}//R_{Y2}//R_{Y3}//R_{Y4} = 2\ \Omega$ $R_{Y1} = R_1 + R_2 = 8\ \Omega$, $R_{Y2} = R_3 + R_4 = 8\ \Omega$ $R_{Y3} = R_5 + R_6 = 8\ \Omega$, $R_{Y4} = R_7 + R_8 = 8\ \Omega$ $Z = R_{Total} + 1/j\omega\ C_{Total} = 2 + 1.25/j\omega$

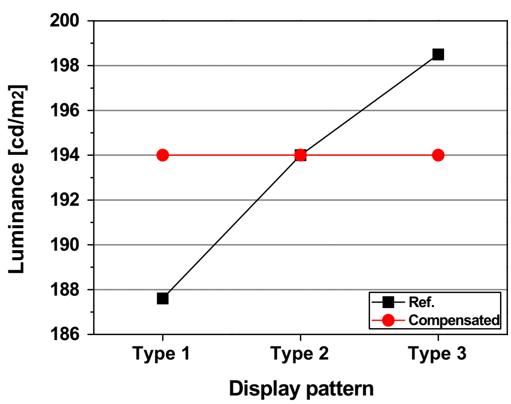


Fig. 12. Compensation of luminance variation using compensated rising slope for sustain waveform according to display pattern.

Table 6
Various rising slopes of X and Y sustain waveforms for three types of display pattern.

	Type 1	Type 2	Type 3
Reference		Y2, X2	
Compensated	Y1, X1	Y2, X2	Y3, X3

of R_{Y1}, R_{Y2}, R_{Y3}, and R_{Y4}, was 2 Ω, where R_1 and R_2 (R_3 and R_4) were series connected by R_{Y1} (R_{Y2}), while R_5 and R_6 (R_7 and R_8) were series connected by R_{Y3} (R_{Y4}). The total resistance, capacitance, and impedance for the three types of display pattern are given in Table 5. While the horizontal bar pattern (type 1) exhibited a series resistance, the vertical bar pattern (type 3) exhibited parallel resistances. Thus, when the display pattern was changed from a horizontal bar to a vertical bar, the corresponding equivalent resistance was decreased. Meanwhile, the box pattern (type 2) exhibited an intermediate resistance value between the resistance values for the horizontal and vertical patterns. Therefore, the differences in the resistance between the three display patterns caused different voltage drops for the sustain waveforms. Thus, the sustain waveform with the horizontal bar pattern (type 1) experienced the maximal voltage drop, implying that the resistance variation increased in proportion when increasing the discharged cells horizontally. For the three types of display pattern, all the equivalent capacitors were parallelly connected, so the total capacitance was equal to 0.8 nF for all three display patterns, meaning that when the number of on-cells is identical, the total capacitance remains the same. Consequently, for the different display patterns under the same display load, the resistance variation was the main factor inducing distortion of the sustain waveform, and the maximal distortion was with the horizontal bar pattern (type 1).

Fig. 12 shows the complete compensation of the luminance variation for the three types of display pattern under a display load of 8% based on adopting compensated rising slopes for the sustain waveform according to the display pattern. As shown, the luminance difference among the three display patterns was completely eliminated by adjusting the rising slope of the sustain waveform according the display pattern. In Fig. 12, with the luminance for type 2 as the reference, the lower luminance for type 1 could be compensated by adopting a faster rising slope for the sustain waveform, whereas the higher luminance for type 3 could be compensated by adopting a slower rising slope for the sustain waveform. The optimal rising slopes for the sustain waveforms relative to the display pattern are given in Table 6.

4. Conclusion

When increasing the display load, the sustain waveform, especially the rising slope of the sustain waveform, was severely distorted and the resultant IR emission intensities reduced, resulting in luminance variation according to the display load. Thus, the higher luminance with a display load below 50% could be significantly compensated by adopting a sustain waveform with a slower rising slope, whereas the lower luminance with a display load above 50% could be significantly compensated by adopting a sustain waveform with a faster rising slope. Meanwhile, despite the same display load, the sustain waveforms were also distorted according to display patterns with different cell configurations, thereby varying the luminance and luminous efficiency. In this case, the resistance variation was the main cause inducing distortion of the sustain waveform. However, similar to the display load variation, the higher and lower luminance could be effectively compensated by adopting a sustain waveform with slower and faster rising slopes, respectively.

Acknowledgement

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