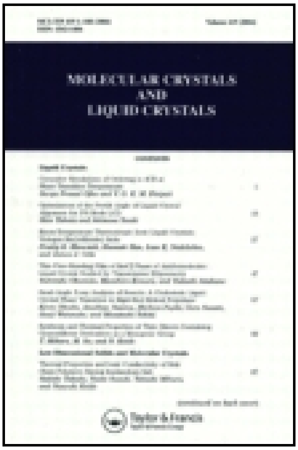

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The saturation characteristics of red, green, and blue phosphor layers were measured using 8 sub-fields in an alternative current plasma display panel (ac-PDP). It was found that the white color changed depending on the choice of the sub-field used. This variation in the white color was caused by differences in the saturation characteristics of the red, green, and blue phosphor layers.

Keywords: phosphors layers; plasma display panel; saturation characteristics

INTRODUCTION

Alternative current plasma display panels (ac-PDPs) are a promising candidate for use in large area (>40-inch) full-color wall-mounted digital High Definition Televisions (HDTVs) [1]. Ac-PDP-HDTVs are already being produced on a large scale as electronic home applications. However, despite the intensive research that has focused on developing a commercial high quality PDP device, certain issues still need to be solved, such as improving the luminance efficiency, reducing the production costs, and perfecting the picture quality [2–4]. The problems related with the color image quality in an ac-PDP are

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inherently due to the differences in the visible emissions and decay characteristics among the red, green, and blue phosphor layers. As such, various techniques, including an asymmetric barrier rib structure [5] and new driving schemes [6,7], have been suggested to solve the low intensity of the blue light emitted from the stimulation of the blue phosphor layer.

In order to display a full-color gray scale, a sub-field combination method has been employed as the driving scheme for an ac-PDP [8]. In this method, a full-color gray level is expressed based on the modulation of the total number of sustain pulses. As such, the red, green, and blue colors from an ac-PDP pixel need to be reproduced in exact proportion to the number of applied sustain pulses. In other words, if the white color is balanced to a certain value, the corresponding white colors should not change according to the gray level. If the change in the white color is even greater than the minimum perceptible white color difference ($\Delta uv < 0.004$) [9], the full color images implemented by the white colors result in degrading the color image quality of the PDP. In this sense, it is very important to adjust the white color variation within the minimum perceptible white color difference irrespective of alteration of gray levels.

In a PDP system adapting a sub-field combination method, whether the white color is balanced with 256 gray levels is determined depending on a combination of the luminance among the red, green, and blue colors. Consequently, when the sub-field varies to express the specific gray level, the correlation of the luminance among the red, green, and blue colors is a key issue for balancing the white color. According to the operation principle, the red, green, and blue colors are produced from the stimulation of red, green, and blue phosphor layers, respectively. Since the sustain pulses are shared commonly among the red, green, and blue cells, the correlation of luminance among the red, green, and blue lights in an ac-PDP depend strongly on the emission and decay characteristics of the red, green, and blue phosphor layers [10]. Accordingly, it is significant to investigate detailed changes in the decay and saturation characteristics of the red, green, and blue phosphor layers relative to the number of applied sustain pulses. Moreover, it is also vital to examine the effects of any difference in the decay and saturation characteristics of the red, green, and blue phosphor layers relative to the number of applied sustain pulses on the white color balancing of an ac-PDP.

In the current paper, the saturation characteristics of the red, green, and blue phosphor layers are measured using 8 sub-fields in an ac-PDP. The changes in the white color according to 8 sub-fields are also investigated based on the difference in the saturation characteristics of the red, green, and blue phosphor layers. Finally, the white color balancing with 8 sub-fields is discussed in view of the minimum perceptible white color difference.

EXPERIMENTAL SETUP

Figure 1 shows the optical measurement system used to investigate the optical characteristics of the red, green, and blue lights emitted from a 4-inch ac-PDP test panel. The 4-inch test panel was driven by the circuit system shown in Figure 1. The luminance, color temperature, and color chromaticity were measured using a PR-704 spectrometer. The changes in the peak intensities of the red, green, and blue lights (Blue: 448 nm, Green: 526 nm, Red: 592 nm) were measured using a PMT tube and monochromator. The 4-inch ac-PDP test panel was composed of 30×60 RGB cells (cell pitch: 1.08 mm) and filled with a Ne-Xe (4%) gas mixture with a pressure of 400 Torr. The red, green, and blue phosphors utilized under the current study were (Y, Gd) BO_3: Eu, $(Zn, Mn)_2$ SiO_4, and (Ba, Eu) $MgAl_{10}O_{17}$, respectively. Thirty six pixels with 108 red, green, and blue cells were selected in the 4-inch ac-PDP test panel to measure the optical characteristics of the red, green, and blue lights, as shown in Figure 1.

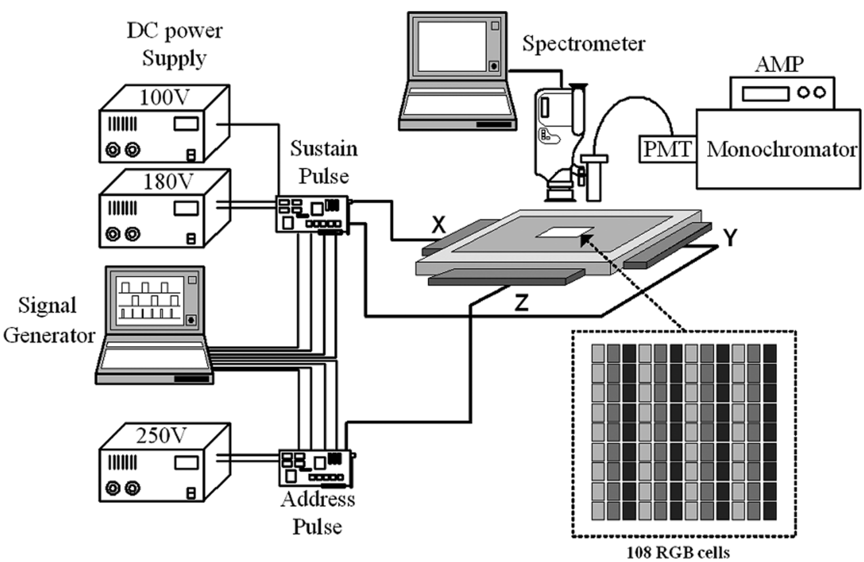
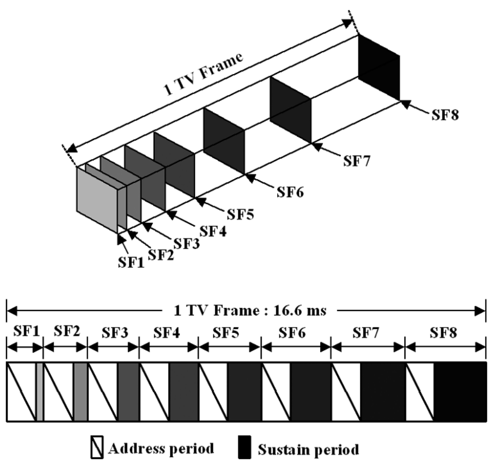
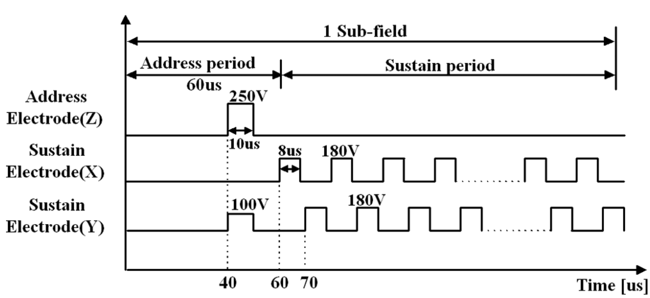


FIGURE 1 Optical measurement system.

Figure 2(a) shows the combination of the sub-fields within a single TV frame, which consist of 8 sub-fields (SF1–SF8) with a time duration of 16.67 ms. Each sub-field is divided into two regions; the first region was the address-period for writing the data, while the other is the sustain-period for displaying the data, as shown in Figure 2(a). In general, the addressing time for each sub-field is fixed as about 1.5 ms, so that the total time needed in addressing for a single TV frame (16.67 ms) is about 12 ms. Hence, the total sustaining time for one frame is 4.67 ms. Thus, 256 full-color gray levels for one frame is realized for 16.67 ms by a proper combination of the 8 sub-fields. The luminance for each sub-field depends on the number of plasma discharge on-times determined by the number of applied sustain



(a)



(b)

FIGURE 2 Sub-fields in single TV field (a) and timing diagram of voltage pulse waveforms (b) applied to three electrodes in one sub-field.

pulses, which in turn is determined according to the type of the sub-field. For a high color quality ac-PDP driven by a digital driving scheme, the luminance of the red, green, and blue colors should increase linearly according to the number of applied sustain pulses. In particular, the correlation of the luminance among the red, green, and blue lights needs to remain constant in order to balance the white color irrespective of the number of applied sustain pulses. However, since an ac-PDP utilizes the visible light emitted from the stimulation of the red, green, and blue phosphor laysers, the white color balancing determined by the ratios of the red, green, and blue luminance levels, depends strongly on the optical characteristics, such as the saturation characteristics of the red, green, and blue phosphor layers. Therefore, in this paper, the saturation characteristic of the red, green, and blue phosphor layers were carefully examined by varying the sub-field (i.e., the number of applied sustain pulses). In addition, the variations in the white colors with each sub-field were investigated and the effects of the saturation characteristics on the white color balancing were also discussed.

Figure 2(b) shows a timing diagram of the voltage pulse waveforms applied to the three electrodes, X, Y, and Z, in a sub-field. The period for all sub-fields (SF1–SF8) employed under the current study consisted of an address-period and sustain-period. For all sub-fields, only one address pulse was applied during the address-period, which was fixed as 60 μs. The number of applied sustain pulses during the sustain-period was given according to the particular sub-field. The amplitude and width of the address voltage pulse were 250 V and 10 μs, respectively, whereas those of the sustain voltage pulse were 180 V and 8 μs, respectively. The time duration until the next sustain pulse was 10 μs. A voltage pulse of 100 V, as shown in Figure 2(b), was applied to the sustain electrode Y to prevent any plasma discharge from being produced between the sustain electrode Y and the address electrode Z during the address-period.

Figure 3 shows the number and time duration of the voltage pulses as the sub-field was varied from SF1 to SF8 over 16.67 ms. For a single TV frame, only one addressing pulse was applied for 60 μs, irrespective of the sub-field type, and the sustain pulses were then applied for the remaining time of the TV frame. Eight different sub-fields were used to implement the 256 luminance levels, and voltage pulses with a pulse width of 8 μs were applied to the sustain electrodes X and Y. The pulse numbers of sub-field SF1, SF2, SF3, SF4, SF5, SF6, SF7, and SF8 were 2, 4, 8, 16, 32, 64, 128, and 256, respectively. Since the time duration per sustain pulse was 10 μs, the total time duration for SF1 to SF8 ranged from 20 μs to 2,560 μs (i.e., 2.56 ms), as shown in

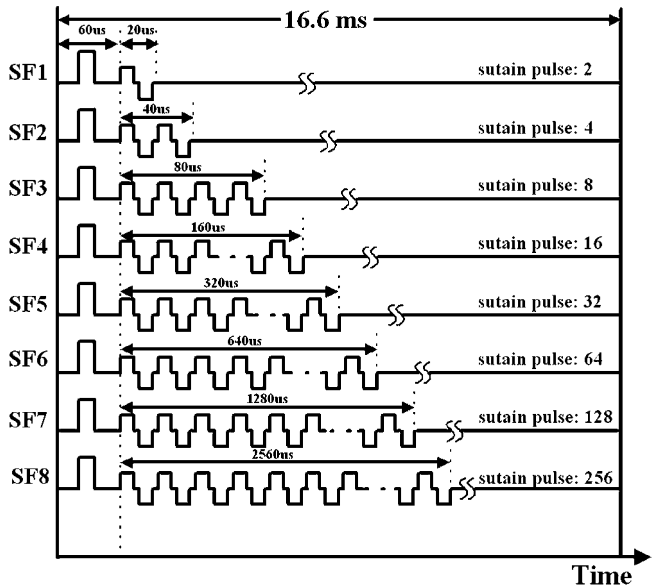


FIGURE 3 Number and time duration of voltage pulses with variation in sub-fields from SF1 to SF8.

Figure 3. To measure the saturation characteristics of the red, green, and blue phosphor layers, the corresponding voltage pulses according to the sub-field were applied for 16.67 ms to the three electrodes X, Y, and Z, as shown in Figure 3.

RESULTS AND DISCUSSION

The measured peak intensities of the red, green, and blue lights emitted from the stimulation of the red, green, and blue phosphor layers were plotted in Figure 4 in the case of employing 128 sustain pulses in sub-field SF7. The red, green, and blue lights showed the different saturation characteristics due to the different decay times among the red, green, and blue phosphor layers. In a previous study the current authors measured the decay time of the red, green, and blue phosphor layers, including the Ne Plasma emission, in a surface type ac-PDP [10]. As a result, the blue light had the shortest decay time of 0.4 ms, whereas the red and green lights showed longer decay times of 10 ms and 13 ms, respectively, thereby leading to faster saturation characteristics for blue light compared to red and green lights. Since the time duration is 10 μs per one sustain pulse, the time required to

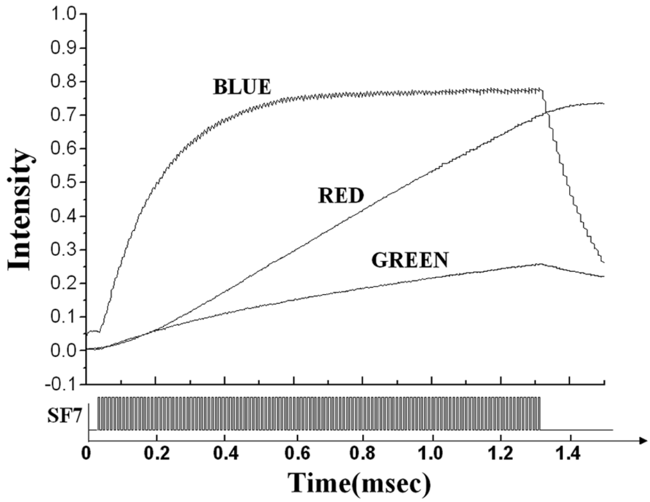


FIGURE 4 Saturation characteristics of red, green, and blue lights in sub-field SF7.

apply one sustain pulse was much shorter than the decay times of the red, green, and blue phosphor layers.

Since the red, green, and blue lights were again emitted by the next sustain pulse before complete extinction of the lights produced by the previous sustain pulse, the red, green, and blue phosphor layers, the red, green, and blue lights from successive sustain pulses were superimposed to accumulate the respective emission intensities. In the current study, the blue light tended to exhibit saturation characteristics at about 0.4 ms, whereas the intensities of the red and green lights continued to increase without being saturated, as shown in Figure 4.

Figures 5(a) and (b) illustrate the saturation characteristics of the red light (592 nm) emitted from the stimulation of the red phosphor layers by varying the sub-field from SF1 to SF8 during a TV field. Figure 5(b) shows the sustain voltage pulses applied to either the sustain electrode X or Y according to the sub-field. The intensity of the red light in Figure 5(a) did not become saturated until the sub-field was varied from SF1 to SF8. In other words, the intensity of the red light increased for 2.56 ms as the number of the sustain pulses increased. This phenomenon can be explained as follows. A plasma discharge is produced once per sustain pulse, thereby generating ultraviolet (VUV) that stimulates the red phosphor layer to emit red light. Since the decay time of the red phosphor layer is much longer than the pulse width of the sustain pulse, the intensity of the emitted red light

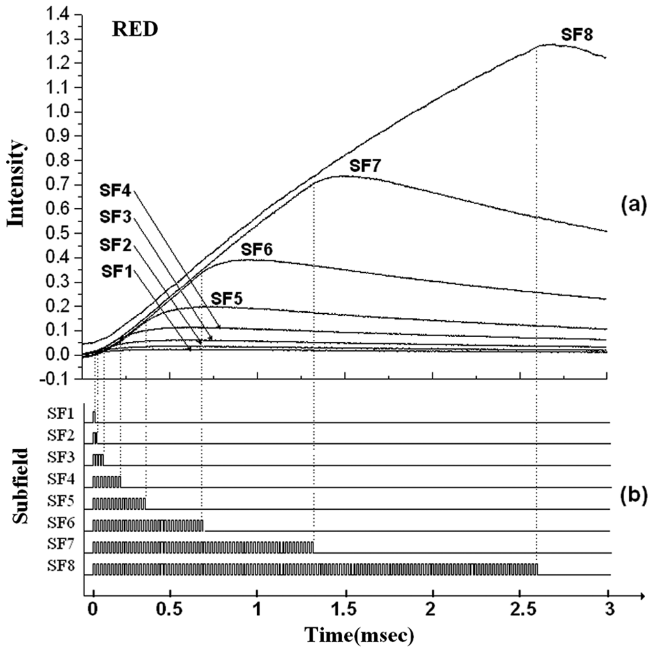


FIGURE 5 Saturation characteristics of red light with sub-fields SF1 to SF8, (a) change in intensity of red light; (b) sustain pulses applied for each sub-field.

decreases very slowly. When another sustain pulse is applied before the complete extinction of the red light emitted by the previous sustain pulse, the red phosphor layer is re-excited. Resultantly, the red lights emitted by the successive application of the sustain pulses are superimposed so that the intensity of the total red light increases linearly, as vividly shown in Figure 5(a).

Similarly, Figures 6(a) and (b) illustrate the saturation characteristics of the green light (526 nm) emitted from the stimulation of the green phosphor layers by varying the sub-field from SF1 to SF8 during a TV field. Since the green phosphor layer has the longest decay time of 14 ms, the intensity of the green light was not saturated for all the sub-fields from SF1 to SF8, yet rather increased for 2.56 ms with an increase in the number of sustain pulses applied, as shown in Figure 6.

The saturation characteristics of the blue light (448 nm) emitted from the stimulation of the blue phosphor layers were also shown in Figures 7(a) and (b). Since the blue phosphor layer has the short decay time of about 0.4 ms, the blue light emitted by the first sustain pulse disappears after about 0.4 ms. Consequently, the intensity of the blue

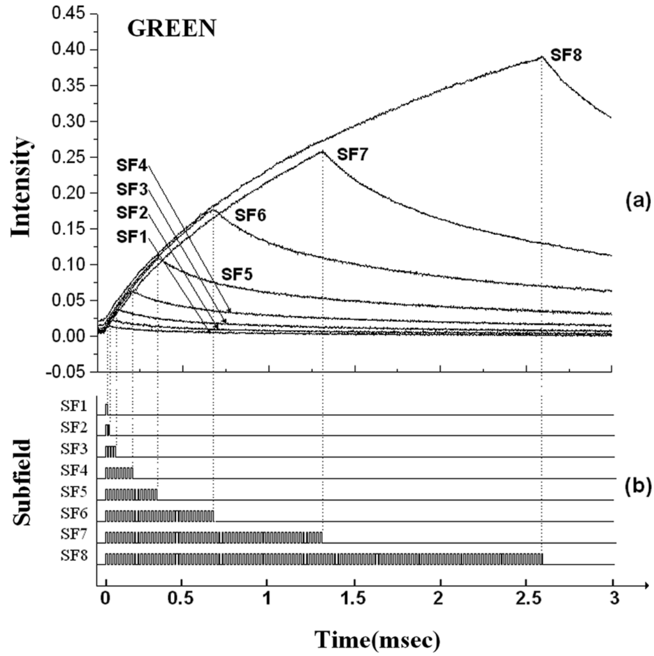


FIGURE 6 Saturation characteristics of green light with sub-fields SF1 to SF8, (a) change in intensity of green light; (b) sustain pulses applied for each sub-field.

light began to be saturated after about 0.5 ms between sub-fields SF5 and SF6. Above sub-field SF6 the intensity of the blue light became saturated completely and increased no longer, as shown in Figure 7(a).

The different saturation characteristics of the red, green, and blue phosphor layers result in the different increasing tendency in the luminance among the red, green, and blue lights emitted from the PDP cells. When the sustain pulses increase from 2 to 256 with the 8 sub-fields, the increasing tendency in the luminance for the red, green, and blue lights is illustrated in Figure 8. The pulse number in Figure 8 represents the number of sustain pulses applied to the two sustain electrodes X and Y. For the green and red lights, the luminance deviated from linear tendency above sub-field SF7. However, for the blue light, the luminance increased linearly until sub-field SF8. The increasing rates of luminance between SFi and SF$i+1$ ($i = 1$ to 7) are detailed in Table 1. In the case of the red and blue lights, the increasing rate of luminance between successive sub-fields was found to be increasing continuously when the sub-field changed from SF1 to

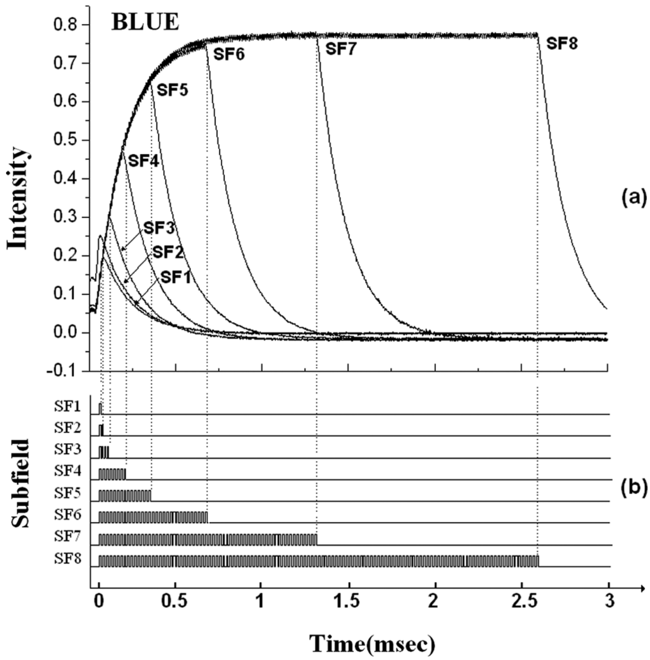


FIGURE 7 Saturation characteristics of blue light with sub-field SF1 to SF8, (a) change in intensity of blue light; (b) sustain pulses applied for each sub-field.

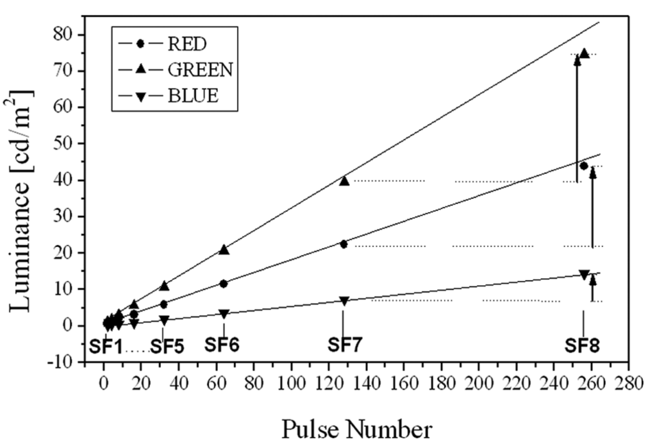


FIGURE 8 Luminance of red, green, and blue lights with 8 sub-fields.

TABLE 1 Increasing Rates of Luminance for Red, Green, and Blue Lights Between Successive Sub-Fields

		Subfield							
Phosphor		SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8
RED	Luminance [cd/m^2]	0.77	1.09	1.77	3.14	5.90	11.50	22.40	43.80
	Luminance-increasing rate between SFi and SFi + 1 [%]		41	62	78	88	94	95	96
GREEN	Luminance [cd/m^2]	1.20	1.84	3.13	5.70	10.70	20.70	39.60	74.60
	Luminance-increasing rate between SFi and SFi + 1 [%]		53	70	82	89	92	92	88
BLUE	Luminance [cd/m^2]	0.24	0.34	0.57	1.00	1.89	3.67	7.24	14.40
	Luminance-increasing rate between SFi and SFi + 1 [%]		45	69	77	86	94	97	99

SF8. For the green light, the increasing rate became greater until SF6. In addition, the increasing rate of the green light was higher than those of the red and blue lights within the range of SF1 to SF5. This means that the luminance of the red, green, and blue lights did not increase at the same rate as the sub-field changed, thereby inducing a resultant change in the white color quality. Since the 256 gray levels for a full color image are realized through the proper combination of the 8 sub-fields, the discrepancy in the luminance correlation at the specific gray level can cause the severe disturbance of the white color balancing.

The variation in the white color with respect to the 8 sub-fields was measured and shown in Figure 9. The color chromaticity of the white color changed from $x = 0.3502$, and $y = 0.3673$ at SF1 to $x = 0.3484$, and $y = 0.3684$ at SF4. This was due to the high increasing rate of luminance of the green light in contrast to those of the red and blue lights when the sub-field was varied from SF1 to SF4. However, above sub-field SF5, the color chromaticity of the white color changed from $x = 0.348$, and $y = 0.3666$ at SF5 to $x = 0.3457$, and $y = 0.3512$ at SF8 due to the high increasing rate of luminance of the blue light in contrast to those of the red and green lights, as explained in Figure 8. Consequently, the white color changed from 4,872 K at SF1 to 4,976 K at SF8, with a change rate of about 2.13%, which was due to the different increasing rates of luminance between the green and blue lights with the varying sub-field.

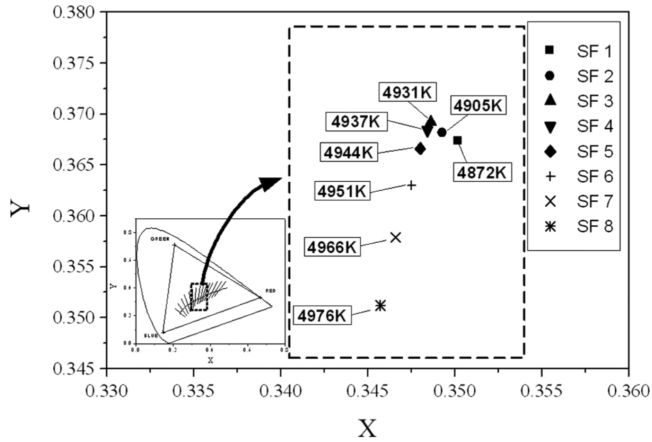


FIGURE 9 Variation in color temperature with 8 sub-fields.

The variation in the white color much greater than the minimum perceptible white color difference ($\Delta uv < 0.004$) means the disturbance of the white color balancing necessary for a good color image quality in an ac-PDP. Thus, in order to check the white color difference from SF1 to SF8, the x and y coordinates of the white colors are transformed into the u and v coordinates by using the following equations;

$$u = \frac{4x}{-2x + 12y + 3} \tag{1}$$

$$v = \frac{6y}{-2x + 12y + 3} \tag{2}$$

$$\Delta uv = \sqrt{(u_1 - u_2)^2 + (v_1 - v_2)^2} \tag{3}$$

where Δuv is the distance between (u1, v1) and (u2, v2).

In this case, the uv coordinate at SF1 is (0.2088, 0.3286), whereas the uv coordinate at SF8 is (0.2119, 0.3230). Therefore, the Δuv between SF1 and SF8 is shown to be much greater than the minimum perceptible white color difference (($\Delta uv < 0.004$), implying that the white color balancing is required to display the high quality color image. This significant difference in the white color is basically due to the different saturation characteristics of the red, green and blue phosphor layers, as the 8 sub-fields vary from SF1 to SF8, such that the disturbance of the white color balancing in an ac-PDP is unavoidable. The further study is needed to solve the white color disturbance problem with a variation of 256 gray levels.

CONCLUSIONS

This paper measured the saturation characteristics of the red, green, and blue phosphor layers using 8 sub-fields in a 4-inch ac-PDP test panel. The changes in the white color relative to the 8 sub-fields were also investigated based on the saturation characteristics of the red, green, and blue phosphor layers. It was found that the white color changed from 4,872 K at SF1 to 4,976 K at SF8 (a change rate of about 2.13%) when the sub-field was varied from SF1 to SF8.

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